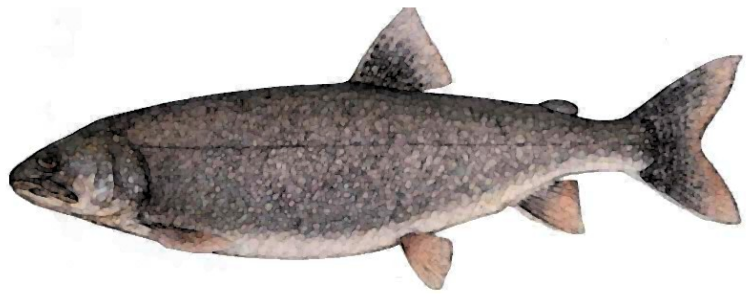
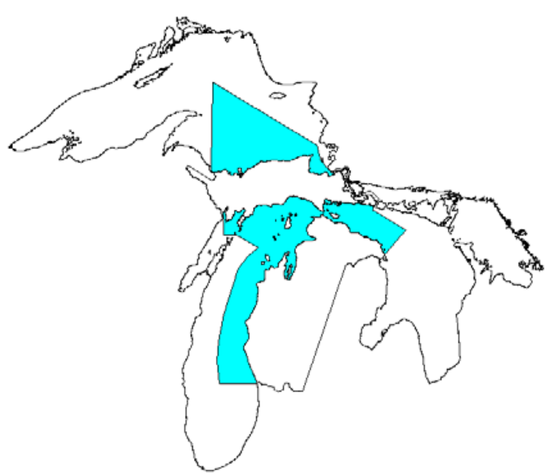
Statistical catch-at-age models used to describe the status of lean lake trout populations in the 1836-Treaty ceded waters of lakes Michigan, Huron, and Superior at the inception of the 2000 Consent Decree



A Report Completed by the Modeling Subcommittee for the
Technical Fisheries Committee, Parties to the 2000 Consent Decree, and the Amici Curiae

D.C. Caroffino (Michigan Department of Natural Resources),
S.J. Lenart (Little Traverse Bay Bands of Odawa Indians),

Editors



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Editors' Note

The information contained in this report was generated over a period of years and represents the work of multiple authors and reviewers. Every attempt was made to standardize the way information was presented among the individual lakes, but this was not always possible. While the general structure of the following chapters is similar, the authors developed the specific content at their discretion. The original intent of all involved in the Consent Decree process was to complete this report soon after the Decree was signed, and in fact drafts of most of this report were prepared during the first several years after signing. Personnel changes and competing job priorities, however, prevented previous editors from completing this document in the original timeframe established. In 2010, the co-chairs of the Modeling Subcommittee served as editors and compiled and completed this report for publication.

Introduction

On August 8, 2000, the United States District Court for the Western District of Michigan entered a Consent Decree (Decree) that was negotiated and ratified by the seven governments that are party to *U.S. v Michigan*, including the State of Michigan, Bay Mills Indian Community, Sault Ste. Marie Tribe of Chippewa Indians, Grand Traverse Band of Ottawa and Chippewa Indians, Little River Band of Ottawa Indians, Little Traverse Bay Bands of Odawa Indians, and the United States of America. The Decree governs the management, allocation, and regulation of fish stocks and fisheries that occur within the 1836 Treaty-ceded waters of lakes Superior, Michigan, and Huron through the year 2020. The Decree established a Technical Fisheries Committee (TFC), comprised of biologists and managers from each signatory party, to be the primary body for consultation and collaboration on biological issues relating to the Decree. A separate Modeling Subcommittee (MSC) was also established to serve as the principal technical body charged with establishing and updating population models to be used for setting harvest limits under the provisions of the Decree.

Lake trout are a primary focus of the Decree, which outlines a management and regulatory framework to simultaneously allow harvest and promote rehabilitation. To achieve both of those goals the Decree establishes annual harvest limits for each lake trout management unit based on a maximum annual mortality rate but also specifies lake trout refuges where harvest is prohibited. A specific allocation of the harvest limit to tribal and non-tribal fisheries in each management unit is specified by the Decree. The annual harvest limits are calculated by the MSC using statistical catch-at-age (SCAA) models. These models use information gained from commercial and recreational fisheries and independent surveys to estimate vital population statistics including growth, mortality, recruitment, and numbers at age in each management unit each year. These model-generated harvest limits are reviewed and approved through consensus by the TFC and submitted to the parties. The parties can invoke dispute resolution if they disagree with the final lake trout harvest limits.

The purpose of this document is to provide the technical details of the original SCAA models that were used to calculate harvest limits for lake trout under the terms of the 2000 Consent Decree. In addition, this document provides the status of the lake trout populations in each management unit at the inception of the 2000 Consent Decree. Subsequent reports that document the status of the populations have been published annually by the MSC. These "Status of the Stocks" reports are available, as is the text of the 2000 Consent Decree, on the Michigan Department of Natural Resources website at: http://www.michigan.gov/greatlakesconsentdecree.

Stock Assessment Models

James Bence, Shawn Sitar, and Mark Ebener

Overview

We used age-structured population models in two ways. The first was as a means to generate estimates of lake trout abundance and mortality rates and describe how these have changed over time. A critical element is to estimate the portion of mortality that is due to each fishery component being allocated a share of the yield. The second was to project yield, harvest amounts and associated effort for 2001 that met criteria established as part of the 2000 Consent Decree. The first of these tasks was accomplished through applying statistical catch-at-age analysis (SCAA) as a means of estimating parameters determining fish abundance and mortality. These catch-at-age models operated with annual time steps and age-specific abundances, and mortality rates were estimated for each year, through the last year for which data were available. Models were developed for stocks in each defined management area where the data could support the approach.

The second task built from the first, by projecting the estimated fish population forward through the 2001 fishing season, accounting for fishing and expected natural mortality and projecting the associated harvest and yield. The fishing mortality rates were adjusted in these projections to match upper bounds on fishing effort, fishery harvest, or total mortality while satisfying state and tribal allocation as defined in the Consent Decree.

Statistical Catch-At-Age Analysis

Statistical catch-at-age analysis (SCAA) is widely viewed as a state-of-the-art assessment approach (e.g., Hilborn and Walters 1992, National Research Council 1998, and Quinn and Deriso 1999). A catch-age model is fit to available data. These models generally consist of two submodels, one describing the population dynamics of the stock and a second that predicts observed data, given the estimated population each year (Fournier and Archibald 1982, Methot 1990, 2000). Following general procedures promoted by Fournier and Archibald (1982) and Methot (1990, 2000) we have adopted a likelihood based approach. The agreement between the model predictions and observed data is measured by statistical likelihood. Both the population and observation submodels include adjustable parameters. Any given set of these parameters corresponds to a specific sequence of stock abundances, mortality rates, and predicted data. The set of such parameters (and associated stock dynamics and mortality rates) that maximizes the likelihood (the maximum likelihood estimates) is taken as the best estimate. Our estimation approach includes implicit and explicit Bayesian elements (e.g., McCallister and Ianelli 1997, Sitar et al. 1999), so we are maximizing the posterior likelihood of the parameters, given the data. In such a Bayesian approach prior distributions are specified for parameters, and model fits that deviate from the most likely prior values are penalized. Thus, the likelihood being maximized is the Bayesian posterior density.

Population Sub-model

The basic population model is quite simple. Except for the first year and age, abundance-at-age at the start of each year is calculated recursively as the proportion of the cohort surviving from the start of the previous year:

$$N_{a+1,y+1} = N_{a,y} P_{a,y} \quad (1)$$

The proportion surviving is modeled as

$$P_{a,y} = e^{-Z_{a,y}} \quad (2)$$

Where $Z_{a,y}$ is the instantaneous mortality rate for age-*a* and year-*y*. Total annual mortality (*A*=1-*P*) increases with increasing Z, but asymptotes at 1.0 (Ricker 1975). Mortality targets are usually expressed in terms of *A*, but could be expressed in terms of the equivalent instantaneous rate, *Z*.

A primary challenge in developing the stock assessment models is to break the total instantaneous mortality rate into components of interest that can be calculated from a suite of parameters, which can be estimated from available data. All the models include fishing mortality (*F*) and background natural mortality (*M*). All lake trout models include sea-lamprey induced mortality (*ML*). In addition, fishing mortality is usually broken into two subcomponents. Thus:

$$Z_{a,y} = F(1)_{a,y} + F(2)_{a,y} + M_a + ML_{a,y} \quad (3)$$

Where *F*(1) and *F*(2) represent two fishery components (e.g., sport and commercial). It is not possible to estimate all these rates as independent age and year specific components. To reduce the number of parameters, for each fishery component, the age and year specific fishing mortality rates are products of age-specific "selectivity" and year-specific "fishing intensity". In a purely separable model, selectivity is constant and thus each fishing mortality component is the product of an age (*S*) and year (*f*) effect:

$$F(i)_{a,y} = S(i)_a f(i)_y \quad (4)$$

In our assessment models we have relaxed the separability assumption, to account for changing selectivity resulting from changes in size-at-age and fishery behavior or from other causes. To do this we modeled the relationship between selectivity and age with a four parameter double logistic function. The formulation used for lake trout models was:

$$num(i)_{a,y} = \left[\frac{1}{1+\exp(-\alpha_1(i)(a-\beta_{1,y}(i)))}\right]\left[1-\left[\frac{1}{1+\exp(-\alpha_2(i)(a-\beta_2(i)))}\right]\right] \quad (5a)$$

$$S(i)_{a,y} = num(i)_{a,y} / num(i)_{r,y} \quad (5b)$$

Where the α's and β's are estimated during model fitting. The output from the first part of this equation was divided by the output for reference age-r, so that selectivity was set to 1.0 for the reference age. Generally this reference age was selected because it was believed to be fully selected, and this formulation assumes that the expected catchability of the reference age is constant, and the vulnerability of other ages change over time relative to that reference age. A slightly different procedure was used for the lake whitefish models. For those models:

$$S(i)_{a,y} = num(i)_{a,y} / num(i)_{r,y_0} \quad (6)$$

replaced equation 5b. By normalizing selectivity in every year based on the "numerator" of the selectivity function applied to the reference age in the first year, this allows selectivity for the reference age to vary from 1.0 in other years for the whitefish models.

The α's determine the slope at the inflection point and were estimated on a log scale, assuring positive values. The β's are the inflection points, and usually bounds were imposed to ensure that the first component (increasing logistic) applied to young fish and the second component (decreasing complement to logistic) applied to older fish. This function provides a flexible dome-shaped relationship between selectivity and age, and includes asymptotic increases with age as a special case. Note that β_1 is explicitly year specific. To allow time-varying selectivity, β_1 was modeled as a quadratic function in time:

$$\beta_{1,y}(i) = \beta_0(i) + \gamma_1(i) \cdot (y - y_0) + \gamma_2(i) \cdot (y - y_0)^2 \quad (7)$$

Where the β_0's and γ's were estimated parameters and y_0 is the first year included in the model. Thus, selectivity patterns over time were described by the three parameters of the quadratic function and the three other parameters of the logistic function. In some models this parameterization was simplified. For some, $\beta_{1,y}$ was made a linear function of time (i.e., γ_2 was fixed to zero) or even made constant (both γ_1 and γ_2 fixed to zero). In other cases α_2 and β_2 were fixed (not estimated) at values that ensured an asymptotic (logistic pattern). These simplifications usually were made when age composition data were limited and the simpler model appeared plausible.

Fishing intensity is the fishing mortality rate for ages that have a selectivity of 1.0. Fishing intensities were not estimated freely, but instead were assumed to be proportional to effort, up to a multiplicative deviation:

$$f(i) = q(i)E(i)_y \zeta(i)_y \quad (8)$$

where q is catchability (the proportionality constant), E is observed effort, and ζ is the deviation. The quantity $q(i)E(i)$ should be viewed as a prior expectation for f_i, and during model fitting deviations (ζ) were penalized. However, in cases where fishery effort was not considered to be very informative regarding fishing mortality (generally for the lake trout models), this penalty was reduced (see *Likelihood* below). At the limit, as the penalty approaches zero, the procedure becomes equivalent to estimating the $f(i)$ directly as free parameters. It is important to recognize that the ζ arise both because of errors in measurement of effort and because of year-to-year variation in catchability. Thus estimates of measurement error variance are minimal estimates of the variance of these deviations.

The background natural mortality was assumed constant over time. For models of wild lake trout in Lake Superior, M is assumed constant for all ages modeled, whereas for lake trout models in Lake Michigan and Lake Huron (which included age one), M is allowed to be higher for age one.

Values for natural mortality were fitted during the modeling process with a prior given according to the relationship between M (natural mortality) versus L_∞ and K , and T (temperature) as described by Pauly (1980):

$$\ln(M) = -0.0238 - 0.277(L_\infty) + 0.655\ln(K) + 0.465\ln(T) \quad (9)$$

with length measured in mm and temperature in ^{o}C. We obtained the parameters and other regression diagnostics (Ebener et al. 2005) for this equation by refitting Pauly's (1980) relationship to his original data to ensure correct interpretation of units and transformations. After taking into account the fact we used natural logs instead of $\log_{10}$ as Pauly apparently did, our parameter estimates differ slightly from those reported by Pauly, although careful checking did not reveal any discrepancy between the data we used and Pauly's published data. Note that for this relationship temperature is intended (according to Pauly) to be the mean annual temperature at the location where samples used to estimate M would be collected. Based on knowledge of the temperatures occupied by lake trout stocks in the Great Lakes, these temperatures were set to 5^{o} C, 6^{o} C, and 7^{o} C in lakes Superior, Huron and Michigan, respectively. Deviations from this prior value were penalized during model fitting (see *Likelihood* below). The log-scale standard deviation (0.057) about the Pauly linear relationship used in this penalty was based on the variation about the equations predictions in direct estimates of M from Shuter et al. (1998) for inland lake trout populations and from published and unpublished estimates for Great Lakes lake trout populations. Inadvertently the intercept in the above relationship was not included in the model code, causing the prior median or assumed values of M to be about 97.5% of the value predicted by equation 9.

For stocked lake trout (Huron and Michigan) natural mortality at age 1 was estimated and a log-normal prior was provided with a median of 0.916 in Lake Michigan and 0.8 in Lake Huron, with log-scale standard deviation of 0.175 in both lakes. The median for these priors is based on results reported by Rybicki (1990) for Lake Michigan and the standard deviation was taken from Sitar et al. (1999).

Sea lamprey mortality rates were not estimated during model fitting. For all stocks of lake trout they were calculated prior to the model fitting process based on observed wounding (sum of A1-A3 marks) seen in spring gill-net surveys, as was done by Sitar (1999). Rates calculated from a spring survey were applied to fish one year younger the previous year. Sea lamprey mortality rates in the last model year (2000) were set to rates in the previous year, because 2002 spring survey data were not available. Bence et al. (2003) and Ebener et al. (2003) discuss the assumptions underlying this approach and the properties of sea lamprey wounding/marking data. For a given size of fish, sea lamprey mortality was calculated by:

$$ML = w\frac{(1-p)}{p} \quad (10)$$

where w is the mean wounds per fish and p is an estimate of the probability of surviving an attack. The probability of surviving an attack was assumed to depend upon size for lake trout, and the values for four wide length categories (e.g., Eshenroder et al. 1995, Sitar et al. 1999) were used. Length specific mortality rates were converted to age-specific rates using an age-length key. For Lake Michigan models the sea lamprey wounding and mortality rates were calculated for four broad length classes (Eshenroder and Koonce 1984, Sitar et al. 1999) and the age-length key was applied to these broad categories. For lakes Huron and Superior the approach advocated by Rutter and Bence (2003) was applied, which models wounding rate as a logistic function of length. Rutter and Bence (2003) provide details of the application to Lake Huron. In Lake Superior data from MI-4 through MI-7 was used in the analysis. Common shape parameters for the logistic function (slope and inflection point) were assumed across all units. For the purposes of this analysis MI-4 and MI-5 were treated as one area, and MI-6 and MI-7 were treated as another. Separate asymptotes to the logistic function were estimated for each year for each of these areas. No effects for sampling locations within areas or for individual net-sets were included (Rutter and Bence 2003). For both Huron and Superior wounding rates were calculated for the mid-point of 2 cm length bins and then converted to age-specific rates. For all lakes, age length keys used to convert length based rates to age based rates were based on von Bertalanffy growth parameters and an assumed CV of 15% (Weeks 1997) about the resulting mean length-at-age, assuming a normal distribution of length at age.

To summarize the modeling of mortality, during model fitting from 4-6 parameters were estimated to describe each fisheries selectivity pattern, and a year specific parameter was estimated associated with each fisheries fishing intensity. Up to two (stocked lake trout) parameters were estimated to describe background natural mortality. No additional parameters were estimated during model fitting to describe sea lamprey mortality, as these rates were calculated directly from wounding data.

To complete the population model and describe stock dynamics over time it is necessary to specify the initial numbers at age in the first year and the recruitment of the youngest age in each subsequent year. In the simplest cases each of these would be estimated as a free parameter during model fitting. We deviated from this simplest case in various ways. For stocked lake trout stocks, we modeled recruitment as the number of yearling equivalents actually stocked and calculated to move into an area (see *Movement Matrices*) multiplied by a year-specific "survival adjustment" factor:

$$N_{1,y} = YE_y \exp(\xi_y) \quad (11)$$

In this case the "survival adjustment" factors (ξ) are estimated as parameters, with values deviating from 0 being penalized. This is equivalent to defining the yearling equivalents as the median of a lognormal prior on the number of age-1 recruits (see *Likelihood* below).

For wild lake trout models (Lake Superior), recruitment was estimated as a log-scale random walk:

$$\ln(N_{a_0,y+1}) = \ln(N_{a_0,y}) + \eta_y \quad (12)$$

with $\ln(N_{a0,y0})$ and the η_y estimated as parameters. This implementation is used because attempts to predict expected recruitment using a stock-recruit model produced implausible parameters. This captures some of the same behavior incorporated when a stock-recruit model is used, with expected recruitment being similar in years close in time, both because stock size would be similar, but also because of similar environmental conditions. Large changes from year to year are penalized because the most likely value for the prior distribution for the η is zero (see *Likelihood* below).

For stocked lake trout stocks, when age composition data was limited in earlier years, initial age compositions were based on the known number of lake trout that were stocked and a rough estimate of annual mortality, rather than being estimated during model fitting. For all the stocked lake trout stocks, initial numbers for year classes known not to be stocked were set to zero.

Movement Matrices
Assessment models for lake trout on lakes Michigan and Huron were for hatchery-reared lake trout stocked into the lakes. The effective number of yearling lake trout stocked into a management unit that was being modeled each year was calculated as follows. First, we assumed that lake trout that significantly contributed to recruitment were stocked as either yearlings or fall fingerlings. The number of yearling equivalents stocked at a location were calculated as the number of yearlings stocked that year plus 0.40 times the number of fall fingerlings stocked the year before (Sitar et al. 1999). Next the numbers stocked at various locations were adjusted for movement soon after stocking (before substantial spatially varying mortality comes into play.) This was done by apportioning fixed proportions of the numbers of yearling equivalents stocked at each location as being effectively stocked into each of the management areas (recruitment location) on the lake. These translations of numbers from stocking location to recruitment location were in the form of a "movement matrix." The numbers effectively stocked to a management unit (recruitment location) were then summed over the stocking locations. These effective numbers stocked were the yearling equivalent input, which was then adjusted upward or downward to account for year specific variations (see discussion of “survival adjustments” above).

The procedure used to develop the movement matrix for Lake Michigan is described in detail by Elliott (2002). The actual movement matrix used in the assessments described here differs slightly from that reported by Elliott, because it was based on an earlier version of the analysis he reports on. Here stocking locations were the northern refuge, the midlake refuge and each statistical district. Recruitment locations were the same, although fish recruiting to refuges were assigned to the statistical districts making up the refuges as described by Elliott. Transitions among statistical districts for fish stocked outside refuges were based on a review of the literature on lake trout movement. The working premise was that on average 50% of stocked lake trout remain within a 40 km radius of where stocked and 90% remain within 80 km. Specific transition rates took into account the proximity of stocking units, their areas, and specific geographic situations (e.g, the greater geographic isolation of MM-4). Together with stocking data, these transition rates allowed an estimate of non-refuge stocked lake trout recruiting to each district. The number of fish recruiting to each statistical district from the refuges was calculated based on the proportion of refuge fish recovered in the fisheries in each unit (using coded-wire tagged recoveries), and the estimates of non-refuge recruits. Transition rates from the refuges were adjusted to be consistent with these estimates. Predictions of proportions of fish from each stocking location residing in each statistical district, based on the transition matrix and stocking numbers, compared favorably with observed proportions in coded-wire tag recoveries.

The movement matrix for Lake Huron was based on catch rates of coded wire-tagged fish in graded-mesh gill-net surveys. An initial matrix was calculated treating the catch-rates as proportional to the number of fish recruiting to a region. The stocking locations were MH-1 (outside Drummond Island Refuge), Drummond Island, MH-2, MH-3, MH-4, Six fathom Bank, Ontario 4-3 and 4-4. The recruitment areas were the Northern area (MH-1 (including the refuge) and adjacent Ontario waters), The Central area (MH-2 and adjacent Ontario waters) and other (mainly main basin MH-3, MH-4, MH-5, MH-6 including Six fathom Bank). The transition values for the Ontario stocking locations were considered suspect because they were based on very little sampling in Ontario waters of the main basin and suggested none of the fish remained in the main basin. The values for these stocking areas were replaced by those for the nearest well sampled area (MH-2 for 4-3 and MH-4 for 4-4). Next, the values were adjusted for relative areas of lake trout habitat (amount of bottom 40 fathoms or less). The raw transition matrix treated catch per effort as being proportional to abundance in an area, and this conversion treated CPE as a density measure. In these calculations the area for "other" was assumed to be equivalent to the south area and the south area was taken as the sum of MH-3, MH-4 (excluding Saginaw Bay grids), OH-3 and OH-4. These are the statistical districts with historic spawning habitat and represent most of the "other" recoveries. The area for North was taken as MH-1 and 40% of OH-1. The area for Central was taken as MH-2, OH-2, and 60% of OH-1. Because the southern area was much larger than other areas this had a substantial impact on the implied movement into and out of the "other" category. When not considering MH-1 and the Northern area the resulting matrix appeared reasonable; for example more fish stocked in MH-3 remain in the other area, whereas without the area adjustment a majority of them recruited to the Central area.

The transition rates for the northern area were not reasonable and the resulting implied recruitment was not sufficient to support observed harvest. In particular the implication that more fish stocked in the north (MH-1 and adjacent Canadian waters) moved into the Central area (MH-2 and adjacent areas) than stayed in the north did not seem plausible. Initial fits of the model using this matrix led to consistent under predictions of fishery yield in the Northern area by about 40-50%. In large part, the problem appears to be that using the catch rates to construct the movement matrix makes an implicit assumption that mortality is equal in all areas. In reality mortality rates during the period experienced by fish recovered in the data used (1994-1998 recoveries) were much higher in the Northern area. The lack of fit of the model using the original matrix implies there must be more recruitment in the northern area than is suggested by the stocking data and movement matrix, and the only reasonable explanation is that there is more migration into the area by fish stocked elsewhere and retention of fish stocked in the area than implied by the original matrix. Examination of survey data since 1994 shows that young fish (ages 3-4) make up a much larger proportion of the survey catch in the Northern Area versus the Central area, than is evident when all ages are considered. This suggests that lower CPE in the north may be largely a mortality related phenomenon, rather than the early life movement assumed by the transition matrix. Accentuating the above observation was the fact that many of the CWT fish caught in the north were small enough so that they were not fully recruited to the gear and thus the CPE would underestimate abundance (which because of the differential mortality would already underestimate recruitment).

The approach we used to address these issues was much like an approach used in the 1991 assessments for the Technical Fisheries Review Committee (TFRC 1992). The migration of fish into (and tendency of fish to stay in) the northern area was increased repeatedly, with the assessment models for MH-2 and MH-1 refit each time until what was considered an adequate fit to the harvest and age composition information was obtained. This was implemented by increasing the relative values of the Northern column in the transition matrix by a multiple of their original values and then renormalizing the rows so they summed to 1.0. To achieve an adequate fit the northern values had to be increased by a factor of 5.0. Although this may seem extreme, differences in relative vulnerability and mortality could create a difference this large. The resulting matrix appeared reasonable, in light of what is known about lake trout movement. The migration rate from MH-2 to the Northern area is not markedly different than the migration rate from MH-3 to the Central area. The asymmetric movement from MH-2 toward the North, versus the modestly lower migration from MH-1 to the Central accord with current patterns, perceptions of habitat quality, and an early unpublished fin clipping study (before the period of very high mortality rates in the North) (Jim Johnson, personal communication regarding Michigan DNR study conducted by R. Eshenroder).

The Observation Sub-model

The observation sub-model predicts numbers of lake trout killed by each fishing component and catch per effort by age. Fishery kill is then converted into proportions-at-age and total number killed for comparison with data. Likewise, age-specific CPE is converted into proportions-at-age and total cpe for comparison with observed data.

Fishery kill is predicted using Baranov's catch equation:

$$C(i)a,y = \frac{F(i)_{a,y}}{Z_{a,y}} N_{ay} A(i)_{ay} \qquad (14)$$

Note that no additional parameters, not already needed for the population submodel, are added here.

For recreational fisheries, observed harvest-at-age was obtained from creel surveys for comparison with these predictions. For the MM-4 lake trout model, total recreational fishing mortality was partitioned into that due to retained (harvested) fish and that due to fishery-caused deaths of released fish (for details see the report for that model). Separate predictions of catch-at-age for these two components can be made using Baranov’s catch equation and only the predicted recreational harvest, and not total kill was compared with the observed creel harvests for that area. Commercial removals were provided in the model data files in the form of reported commercial yield (total weight for a particular gear type for the year) and age-compositions (proportions of each age observed in the harvest for that year for the major gear types). Adjustment for underreporting, deaths of fish released from trap net fisheries (for lake trout), accounting for survey kill (which is treated as part of commercial kill for the purposes of calibrating the model) and conversion from weight to numbers killed were required so these observations could be compared with model predictions of annual numbers killed by the commercial fishery.

For lake trout there was only one commercial fishery component in the model, and large-mesh gill net was the dominant source of this mortality. Age composition data were provided for large-mesh gill nets and assumed to reflect the age-composition of the overall commercial fishery kill. Observed information on kill from other netting and commercial devices was combined with gill net kill for comparison with model predictions as follows. First, for each type of commercial fishery, the average weight of a harvested fish was provided for each year. (For gear types with limited data this was sometimes assumed constant over time or equal to values for another component of the fishery.) Yield from each component of the commercial fishery was converted to numbers by dividing it by its corresponding average weight. The numbers harvested were then divided by a year-specific factor representing the proportion of killed fish that are reported harvested. These “under-reporting factors” were based on an analysis comparing of reported harvest and commercial wholesale slips in the CORA fishery (Ebener et al. 2005). These kills were summed and the numbers of fish harvested in the surveys and the number of deaths of lake trout released from state-licensed commercial gill and trap nets. Lake trout are not allowed to be retained in state-licensed commercial fisheries and are mandated to be returned to the water. Lake trout bycatch mortality in the state commercial fisheries was assumed to be 0.755 times the number of released fish from gill nets (based on mortality reported by Gallinat et al. 1997) and 0.054 times the number of released fish from trap nets (Roger Bergstedt, Hammond Bay Biological Station, USGS, Personal Communication).

Survey data were used for the lake trout models. Survey catch-per effort was predicted assuming proportionality between population abundance and expected catch per effort:

$$CPE(i)_{a,y} = q(i,s)S(i,s)_a N(i,s)_{a,y} \quad (15)$$

Where $q(i,s)$ is survey catchability, and $S(i,s)$ is survey selectivity, $N(i,s)$ is abundance adjusted to the time of the survey and i denotes the specific survey, because for the Lake Superior lake trout models there are two surveys. Survey selectivity was modeled in the same way as fishery selectivity. The parameters of the survey selectivity function and survey catchability are new parameters that need to be estimated, which were not needed for the population submodel.

Observed total CPE was on a log-scale and was calculated as the year-specific least-square mean from a linear mixed model fit using SAS Proc Mixed (Littell et al. 1996). Uncertainty for these indices was quantified in terms of the standard error for the least-squares mean. Our survey data comes from designs where the same fixed stations are generally sampled each year. In some cases at a station or site, samples (say gill net gangs) are taken along a depth profile. In other cases samples are taken at random locations within the station or site area. The analyses done for the 2001 assessments in treaty waters treated repeated samples within the same grid as occurring at the same “station”. This approach takes into account the systematic nature of the designs and offers substantial advantages over simply taking a geometric average. The idea is to extract variation due to systematic effects such as depth or station while acknowledging that samples collected close together in space during the same year may well be correlated and provide less information about regional abundance than the usual assumption of independence allows. Three other examples of this approach we know of in the Great Lakes include the analysis of trawl survey data on bloater and alewife (Krause 1999), analysis of lake trout survey/assessment fishery data from MI-4 on Lake Superior (Weeks 1997), and analysis of lake trout survey data from southern Lake Huron (Sitar et al. 1999). We clarify this approach by considering the large mesh lake trout survey for the management areas on Lake Superior, as the simplest base model. In this case there are fixed stations and many (but not all) are sampled each year. Within a small region (i.e., at a fixed station) and a few days several replicate samples are taken at the sampled locations. The mixed model used for this case is:

$$Y_{i,y,s} = \mu + \alpha_y + \gamma_{y,s} + \varepsilon_{i,y,s} \qquad (16)$$

where $Y_{i,y,s}$ is the log of CPE for the ith replicate in year y at station s, μ is an overall mean effect, α_y is a fixed year effect, γ_s is a fixed station effect, $_{y,s}$ is a random interaction of station and year and $\varepsilon_{i,y,s}$ is residual error. Here both $_{y,s}$ and $\varepsilon_{i,y,s}$ are assumed to be independent and normally distributed with mean zero. The least least-squares mean $\mu + \alpha_y$ was used as the index of abundance (An alternative is the fixed year effect, α_y). The inclusion of fixed station effects extracts variation that would otherwise be attributed to measurement error. It also automatically adjusts the estimated index of abundance if a station that usually produces high (or low catches) is not sampled in a given year. The inclusion of the random year by station interaction acknowledges that observations from the same station in the same year experience common variations and are thus correlated. An equivalent model would be to drop the explicit random effect and replace this by an assumption that the $\varepsilon_{i,y,s}$ from a station and year are each equally correlated with the other residual errors from that station-year combination but not with other residual errors (a so called compound symmetry assumption). Elaborations to this basic model have included the explicit inclusion of a depth effect as a class variable (shallow, intermediate and deep) for southern Lake Huron lake trout (Sitar et al. 1999) and modeling the depth effect as a polynomial of depth (up to a cubic function) for the Lake Michigan trawl survey (Krause 1999). The key is to explicitly include systematic and random terms that plausibly model the variation in the data. We note that on Lake Superior, for large-mesh gill net surveys, *Y* was the log of CPE adjusted for net saturation effects (Hansen et al. 1998). Similar adjustments have not been developed for the graded-mesh survey gear.

In Lake Superior the predicted $CPE_{a,y}$ and $C_{a,y}$ for lake trout were adjusted for aging error before comparison with observed quantities. For brevity we drop subscripts for data type and year and use vector/matrix notation. Let *T* be an aging error matrix, where typical element t_{ij} represents the probability that a fish that is really age *j* would be coded as age *i*, and let $\underline{n}$ be a column vector with typical element n_i, the predicted number of fish that are actually age *i* (this would be the output from the above equations for CPE-at-age or catch-at-age. Then:

$$\underline{\tilde{n}} = T\underline{n} \qquad (17)$$

where $\underline{\tilde{n}}$ is the column vector of predicted for the observed coded ages (this is what is compared with observed data). The typical element of $\underline{\tilde{n}}$ is $\tilde{n}_i = \sum_j t_{ij} * n_j$.

Likelihood (defining the best fit)
We use the parameters associated with the mode of the posterior density or what has been called the highest posterior density estimates (Schnute 1994) as our best (point) estimates of parameters. Formally:

$$L(\underline{\theta} \mid data) \;\alpha\; L(data \mid \underline{\theta})\, p(\underline{\theta}) \quad (18)$$

where $L(\underline{\theta} \mid data)$ is the posterior density of the parameters given the data, $L(data \mid \underline{\theta})$ is the likelihood of the data, and $p(\underline{\theta})$ is the prior density for the parameters (Gelman et al. 1995). For numerical and coding reasons it is convenient to maximize the posterior density (likelihood) by minimizing the negative log likelihood. Let L stand for the total posterior log-likelihood. Proportionality 18 can then be written as the sum of a set of K independent components plus a proportionality constant (C) (which can be ignored):

$$L = C + \sum_{i=1}^{i=k} \lambda_i L_i \quad (19)$$

Each component represents a data source or penalty associated with an informative prior, and the number of components varied among stocks and species. Strictly speaking every parameter has a prior associated with it. Unless otherwise stated these priors were bounded uniforms, which were implemented in the form of bounds on the parameters that were estimated on a log-scale. These drop out of the likelihood equations (but are implicit in the application of the bounds by the software), and are only weakly informative as all log-scale values of the parameters within the bounds are considered equally likely, *a priori*. Generally these bounds were set widely apart, so as to have little influence when the model converged to a solution away from the bounds. The reason for having the bounds is to ensure that the posterior distribution is a proper one, and to avoid the model becoming trapped in an implausible solution during the search process that did not maximize the likelihood. The λ's are "adjusting factors" and if the components of the likelihood (the L's) are properly defined these would all have values of 1.0. These adjustment factors were incorporated into the model code to allow one or more data sources to be easily down-weighted, to check the sensitivity of the model to the data source. Except as noted below for lake whitefish fishery effort deviations, these were kept at values of 1.0 in the final assessment runs for each model.

For each fishery that was included in the model there were three likelihood components: one for the total fishery kill each year, one for the fishery age-composition each year, and one for the effort deviations for each year. These likelihood components were calculated under the assumption that total fishery kill and effort deviations were log-normal and that the proportions-at-age acted as though they were based on a sample from a multinomial distribution. When a survey was available, this provided two likelihood components: one for the total CPE (lognormal) and one for the age composition (multinomial). An additional component came from the prior on recruitment (that is from variation about stock-recruit function ($\ln(N_{a0,y})$ - $\ln(R_{a0,y})$), variation over time for random walks (η) or variation about the number expected based on stocking (ξ)). In the calculation of this likelihood component these deviations were treated as normal with mean zero, as they are defined here on a log-scale. For "survival adjustments" for stocked lake trout this is equivalent to assuming a log-normal prior with a median given by the Ricker model or the number of yearling equivalents, respectively. When variation about a prior estimate of M (median of the prior distribution) was allowed, this contributed another term to the likelihood, and these variations were assumed to be log-normal.

Normal or lognormal components took the form:

$$L_i = -\frac{1}{2\sigma_i^2}\sum_j (x_{i,j} - \mu_{i,j})^2 + \text{IC} \qquad (20)$$

where μ is the mean for a normal component or the median for a lognormal component (sometimes assumed to be zero and thus dropped), the $x_{i,j}$ are the normal values or the $\log_e$ of lognormal values, σ_i is the standard deviation for the $x_{i,j}$, and IC is an "ignored constant". Typically small constants were added to both x and μ to avoid undue influence of small values and numerical problems (Hampton and Fournier 2001). Normal/lognormal likelihoods are sometimes written with additional terms (in our code as well as in other documents), which are part of the ignored constant as written here. Since they are additive constants they can be omitted and do not influence either estimation or assessment of uncertainty. Note that in our implementation we are not estimating the σ_i formally as part of model fitting – if we were, some omitted terms would need to be included as they would no longer be constant.

In some cases (in particular, for the survey indices), year-specific values of σ were specified and the likelihood components are modified as:

$$L_i = -\frac{1}{2}\sum_j \left(\frac{x_{i,j} - \mu_{i,j}}{\sigma_i}\right)^2 \qquad (21)$$

assuming one observation for each year, with j indexing year.

Multinomial components took the form:

$$L_i = \sum_y n_{i,y}^* \sum_a p_{i,a,y} \ln(\tilde{p}_{i,a,y}) \qquad (22)$$

where the n^*'s are the "effective sample sizes, the p's are the observed proportions and p's with tildas are proportions based on model predictions of numbers caught at age (by the fishery or survey gear in question). The effective sample sizes were set at the lesser of the actual number of fish that were aged or a specified upper bound on effective sample size, which was set to avoid overweighting highly sampled years (Fournier and Archibald 1982). Typically small constants were added to the predicted proportions to reduce the effect of very small proportions during model fitting (Fournier and Archibald 1982).

The various log-likelihood components are automatically weighted by either the inverse of the variance (σ_i^2) associated with them (normal or lognormal components) or the effective sample size (multinomial components). In the case of effort deviations, in those cases where effort was assumed to provide little information on fishing mortality (the lake trout models for which there were survey data) these components were down-weighted by an arbitrarily small λ value. The square root of the log-scale variances for the lognormal variables is approximately equal to the coefficient of variation (CV) on the arithmetic scale. In the case of a multinomial variable:

$$CV(p) = \sqrt{\frac{p(1-p)}{n}} \quad (23)$$

With these relationships in mind the Interagency Modeling Group (IMG) of the Technical Fisheries Committee (the precursor to the MSC) considered information on the likely measurement error associated with the various data sources and specified default variances and maximum effective sample sizes, or procedures for obtaining these for each data type. These defaults are still in use by the MSC. The default log-scale standard deviations for commercial fishery harvest and effort were both set to 0.15. The creel log-scale standard deviation default is based on sampling variance estimates from the creel survey. In particular it would be the average (over years) of the CV for harvest for the species and area in question. Because the fishery effort deviations incorporate process error and measurement error, the default is to double the average CV calculated from the creel survey sampling variance for effort. The default maximum effective sample size was set to 200 (Fournier and Archibald 1982). In general survey log-scale standard deviations would be based on estimated standard errors from the mixed model procedures used to generate the survey index values, and (in contrast with other standard deviations) would be year-specific. Adjustments to these defaults occur for specific models to account for known problems with particular data types, or because of patterns in residuals, suggesting that a particular data source is inconsistent with other information.

In the case of variations about recruitment expected based on the stock-recruit function, the numbers stocked, or the random walk, an iterative approach was followed during the process of model fitting to obtain σ values. An initial value for the standard deviations was specified and the model was fit. Then the standard deviation of the resulting deviations was calculated. The model was refit, adjusting the value of the input standard deviation until the difference between the standard deviation value specified prior to model fitting and the value calculated after model fitting was minimized. A minimum difference was defined when the ratio of pre- to post-standard deviation was closest to 1.0.

Calculation of Recommended Total Allowable Catch (TACs) and Total Allowable Effort (TAEs)

In general, upper bound recommendations on yield and effort were calculated by first estimating population abundance at age at the start of the year and then adjusting fishing mortality either to meet mortality targets or to follow guidelines established in the Consent Decree for phasing in the targets. The resulting projection of yield or the effort associated with the fishing mortality then formed the basis of the recommendations.

We start by describing how the maximum amount of yield that could be taken, consistent with a specific upper bound on total mortality, was determined. This is the procedure that underlies the MSCs recommendations regarding TACs and TAEs. We then describe how the procedures were modified to account for specific details that only apply to some areas. For some areas these details include how the target mortality rates were "phased-in" in the Consent Decree.

Target Mortality Rates

The Consent Decree specifies a "fully-phased in" upper bound target for total mortality (i.e., A = the proportion of the population that dies in a year). These rates are between 40-45% (depending on area) for lake trout. As demonstrated by the IMG during the period that the Consent Decree was negotiated, these target rates require additional structure in order to be uniquely defined. This occurs because mortality rates vary among ages, so whether or not a population is above a mortality target depends upon what ages are considered and how the mortality rates for the different ages are combined.

Following the procedure of the IMG, we uniquely define mortality rates by making use of the idea of spawning stock biomass per recruit (SSBR). For lake trout, we first calculate spawning stock biomass for a default target mortality schedule. Any age-specific mortality schedule that produces as much spawning stock biomass as the default schedule is considered to be at or below the target mortality rate. The default schedule was to have only natural mortality (excluding sea lamprey-induced mortality) for ages below a specified age, and mortality equal to the target rate for ages equal to or above the specified age. The specified age at which the target rate first applied varied among areas depending upon maturity schedules and precedence.

Female SSBR per recruit was calculated by following one hypothetical recruit (0.5 females) exposed to the specified mortality schedule (either the default target or one projected for 2001) and calculating the sum of the expected spawning biomass present at the time of spawning each year over the entire lifespan of a lake trout. This is equivalent to the amount of spawning biomass present per recruit in the population at equilibrium, assuming mortality remains at the hypothesized schedule. Thus:

$$
\begin{aligned}
SSBR &= \sum_{i=1}^{15} N_{sp,i} mat_i W_{sp,i} + N_{sp,16+} mat_{16+} W_{sp,16+} \\
N_{sp,1} &= 0.5\exp(-\tau_{sp} Z_1) \\
N_{sp,i} &= 0.5\exp(-\sum_{j=1}^{i-1} Z_j - \tau_{sp} Z_i) \qquad i \in \{2,3,...15\} \qquad (24) \\
N_{sp,16+} &= 0.5\exp(-\sum_{j=1}^{15} Z_j)\left[\frac{1}{1-\exp(-Z_{15})} - 1\right]\exp(-\tau_{sp} Z_{15})
\end{aligned}
$$

Where $W_{sp,i}$ is weight-at-age at the time of spawning, mat_i is the proportion of females that are mature at age-i, and $N_{sp,i}$ is the number of females alive at each age at the time of spawning (for one recruit). These calculations assume the exponential mortality model operates for τ_{sp} yr from the start of the year until spawning. $N_{sp,16+}$ is the number of spawners alive of age 16 and older. This number is based on the assumption that mortality rates remain at the same rate as for age 15, and its calculation takes advantage of the series solution:

$$\sum_{i=0}^{\infty} p^i = \frac{1}{1-p} \quad p \in \Re(0,1) \quad (25)$$

so, for $p = \exp(-Z_{15})$, $\left[\frac{1}{1-\exp(-Z_{15})} - 1\right]$ is the cumulative sum

$\exp(-Z_{15}) + \exp(-Z_{15})\exp(-Z_{15}) + ...$ Weight-at-age and proportion mature was assumed to be the same for ages 16 and older as it was for age 15. Maturity schedules were included in the data files as year-specific schedules for lakes Michigan and Huron. Although in the form of year-specific schedules the same schedule was used for each year. For Lake Superior, maturity schedules were calculated based on a logistic function of maturity-at-length observed in graded-mesh surveys and the length-at-age data (for each year for a management unit) and the logistic parameters (one set for Lake Superior) were included in the data files, with maturity at age calculated by the admb code. Weight-at-age at the time of spawning was calculated from input weight-at-age observed in spring gill-net surveys, assuming exponential growth from the time of the survey until the time of spawning:

$$W_{sp,a,y} = W_{sv,a,y} \exp(G_{a,y}[\tau_{sp} - \tau_{sv}])$$
$$G_{a,y} = \ln\left(\frac{W_{sv,a+1,y+1}}{W_{sv,a,y}}\right) \quad (26)$$

In cases where survey weight-at-age schedules varied over time, maturity schedules from the last year in the assessment were used in projections.

Population at the Start of the Current Fishing Year
The SCAA stock assessment models for lake trout directly estimate population abundance at the start of 2000 and mortality rates during 2000. Thus abundance-at-age (except for recruitment to the youngest age in the model) at the start of year 2001 can be calculated directly from these using equations 1&2. Recruitment was set at a value reflecting recent levels of recruitment (Lake Superior) or expected stocking. Note that assumed recruitment has little influence on calculations of harvest during 2001, as these fish are either not selected or only weakly selected by the fishery.

Projections during the 2001 Fishing Season
Starting with the estimates or projections of age-specific abundance at the start of 2001, the population was projected forward over the year accounting for age-specific mortality rates by source, using the same equations described above for the SCAA models. Numbers harvested at age were calculated by application of the Baranov catch equation. Harvest-at-age was converted to yield by multiplying numbers harvested-at-age by weight-at-age for the fishery and summing over ages.

In these calculations background natural mortality (*M*) was left at the same value as was used or estimated in the SCAA assessments. Depending upon species and area sea lamprey-induced mortality is either left at the average of the values in recent years of the SCAA (1997-1999) or is adjusted from that level to account for possible improvements in sea lamprey control due to treatment of the St Marys River (See alternative sea lamprey scenarios).

Fishing mortality rates by type (sport and commercial) were based on average rates estimated by the assessment model for recent years (usually three years). These average rates were adjusted to account for changes stipulated in the Consent Decree or known changes in fishing activity by multiplying the baseline age-specific rates by an appropriate multiplier. For example, if a gill-net fishery existed in an area prior to 2001 but did not in 2001, then in projecting whitefish yield the multiplier for gill-net fishery was set to zero. When fishing mortality is adjusted to account for a specified change in fishing effort, or when fishing effort was calculated to correspond with a specific level of fishing mortality rate, effort and fishing mortality were treated as being directly proportional. This basic approach to fishing mortality assumes that selectivity for each source will remain the same as it was on average in recent years, and that catchability will also be the same as it was on average in recent years.

The one exception to this assumption regarding selectivity was when it was assumed that the minimum size limit for the recreational fishery for lake trout was being increased for 2001. In this case we assumed that a captured fish of less than the new legal size limit and greater than the one enforced during the last assessment year would have previously been retained (all would have died), but now would be released. A specified proportion (0.15 in all cases) of these then died due to fishing mortality. Thus, the baseline fishing mortality rates were adjusted for a change in size limit by:

$$F_a^R = \tilde{F}_a^R \frac{1+(h-1)\cdot\Phi(l_{new},\bar{L}_a,\sigma_{L_a}^2)}{1+(h-1)\cdot\Phi(l_{old},\bar{L}_a,\sigma_{L_a}^2)} \qquad (27)$$

where F_a^R represents the baseline recreational fishing mortality rate on age-*a* after adjustment for the size limit, $\tilde{F}_a^R$ is the baseline rate prior to the adjustment, *h* is the hooking mortality rate (0.15), l_{new} and l_{old} are the new and old size limits, $\bar{L}_a$ is the mean size of fish of age-a in the population, $\sigma_{L_a}^2$ is the variance in length among fish of age-*a*, and $\Phi(l,\bar{L}_a,\sigma_{L_a}^2)$ the cumulative distribution function for the assumed normal distribution giving the proportion of fish of age-*a* that are less than length *l*. In these calculations, any size limit less than 16 inches (15 inches for Lake Superior) was assumed to have had negligible impact on the retention of fish, and in these cases the limit was set to one inch during calculations. Mean length-at-age was calculated based on the length based von Bertalanffy model (e.g., Quinn and Deriso 1999), with parameters L_∞, *K*, and t_0 specified as input data. Age specific standard deviations (σ_{L_a}) were assumed to be 15% of the corresponding mean length (i.e., a CV of 15%) based on results from Weeks (1997).

Detail on how fishing mortality rates were adjusted to meet mortality and allocation targets is covered in the next section.

Setting Fishing Mortality Rates for 2001

Details on how fishing mortality rates were adjusted depended on specific details of how an area was designated in the Consent Decree. The simplest case was for areas calculated under the assumption of no phase-in and meeting Consent Decree mortality rate and allocation standards: MM-5, MM-67, MH-2, MI-5, and MI-7. This was accomplished by setting the multipliers for the recreational and commercial fisheries so as to simultaneously meet the mortality target (expressed in terms of SSBR) and the designated allocation. The process of finding the correct multipliers was expedited by making use of the Solver utility within Excel spreadsheets. In MM-5 the target mortality rate was 45% and the allocation was 60% state and 40% tribal. In MM-67 the target mortality rate was 40% and the allocation was 90% state, 10% tribal. In MH-2 the target mortality rate was 40% and the allocation was 95% state and 5% tribal. In MI-5 the target mortality rate was 45% and the allocation was 95% state and 5% tribal. In MI-7, the target mortality rate was 45% and the allocation was 30% state and 70% tribal. In MI-5 and MI-7, (and MI-6 described below) adjustments were made to TACs to include hatchery lake trout. This was done because on Lake Superior mortality targets are for wild lean lake trout, whereas TACs apply to total lean lake trout yield. (Note that the harvest and survey data was also adjusted so it reflected only lean wild fish before it was compared with model predictions.) In this case recommended yields for wild lean lake trout were expanded to account for estimates of the proportion of the harvest that hatchery lake trout compose. The recreational fishing mortality rates used to produce recommended TACs came from equation 27, and include all projected recreational kill. Using this as the recreational fishing mortality rate in the Baranov catch equation to set total allowable weight of the recreational yield is reasonable if hooking mortality is a minor factor. Actual weight killed will exceed the target if this is not so. Commercial fishing mortality rates used in projections were based on estimates of actual kill. However the corresponding commercial TAC projection was adjusted downward to account for underreporting. E.g., if only 84% of the yield was assumed to be reported the total allowable weight that could be killed by the commercial fishery was multiplied by 0.84 to obtain the commercial TAC. The adjusted commercial number was also used in calculations of allocation. Assuming only minor recreational hooking mortality, and a substantial adjustment for commercial underreporting, this procedure acts to set TACs that are consistent with mortality targets, and the allocation to the tribal commercial fishery is higher than would be the case if the allocation calculations had been based on weight killed rather than reported yield.

TACs for MH-1, MM-4, and MI-6 were calculated under a phase in of effort guidelines for commercial effort, recreational regulations, and associated harvest limits. The base period for commercial effort was 1997-1999. Hence we adjusted the average commercial fishing mortality rates by age during that period by multiplying them by the proportion of 1997-1999 large-mesh gill-net effort that was remaining after conversion. Recreational effort was left at the average of 1998-2000 values, adjusted for any change in size limits. There was no change in size limit for MM-4 and an increase to the 20-inch size limit was assumed for MH-1 and MI-6. Commercial TACs were based on predicted kill adjusted to account for any under-reporting and then the commercial yield was increased by 20%, in accord with the MSCs interpretation of the Consent Decree at the time, providing a buffer for such an increase in CPE.

TAC calculations for MM-123 were more complicated than for other areas because of special provisions in the Consent Decree. Potential TACs were calculated three ways. First, TACs were calculated assuming that target mortality rates and allocation were fully phased in (40% mortality, Allocation 10% state: 90% tribal). Second, TACs were calculated using a phase in approach that differed somewhat from that specified for other areas. Finally, TACs were calculated assuming the tribal TAC would be 450,000 pounds. Then, the largest tribal TAC among these three options was chosen, along with the associated state TAC. For the second and third option we followed the same approach as we used in other areas (i.e., recreational effort based on 1998-2000 levels and any regulation change). The phase-in approach was guided by the Consent Decree's requirement that the tribal TAC be set to the 1997-1999 harvest adjusted for any change in effort. We did this by first calculating a 2001 yield based on no-conversion of gear (1997-1999 effort) and then calculating taking into account the proportion of large-mesh gill net that was converted (as for phase in rules in other areas). The 1997-1999 tribal harvest was multiplied by the resulting ratio of (with conversion / without conversion) yield to establish the phased in TAC. In contrast with MH-1, MM-4, and MI-6, there was no adjustment to buffer for changes in CPE.

Alternative Sea Lamprey Scenarios
For MM-123, MM-4, MM-5, MH-1, and MH-2 the above TAC calculations for lake trout were done with different assumptions about sea lamprey control. In particular calculations were done for three options: (1) GLFC based assumptions regarding improved control (51% of 98-00 mortality in the Michigan units, 47% of the 98-00 sea lamprey induced mortality in the Huron units.), (2) 75% of the 98-00 baseline values, and (3) 100% (status quo) of the baseline values.

Total Allowable Effort
The Decree specifies that the TFC shall establish "reasonable commercial effort limits…based upon the lake trout harvest limits and catch per effort data" that would be used to manage commercial lake trout harvest. For units which were not subject to special phase-in effort rules, the MSC used recent commercial fishing mortality estimates and fishing effort to determine the TAE. For each of the most recent three years, maximum commercial fishing mortality (F^C_{max}), as estimated during model fitting, was divided by actual commercial gill-net effort to approximate *q (see equation 8)*. In this case, F^C was assumed to be directly proportional to effort. The TAE was derived by utilizing the current year's commercial multiplier and three-year average values for F^C_{max} and q, to calculate the amount of effort expected to result in yield commensurate with the TAC.

$$TAE = multiplier \left(\frac{\bar{x}\, F^C max}{\bar{x}\ q} \right) \qquad (28)$$

For units with specific phase-in effort rules, TAEs were calculated in accordance with the provisions described in the Decree.

TACs and TAEs for each management unit were forwarded to the TFC for review by the April 30th deadline established in the Decree.

Status of Lake Trout in Lake Michigan

Jory Jonas

Management Units

Lake trout populations have been modeled within four management units in 1836 waters of Lake Michigan. The management units represent a "best guess" at allocations of lake trout stocks within Lake Michigan and are delineated by combinations of pre-defined statistical districts (Smith et al. 1961). The northern region is represented by statistical districts MM-1, 2, and 3, the Grand Traverse Bay region is represented by statistical district MM-4, district MM-5 represents a single region and the southern region is a compilation of districts MM-6 and 7.

Potential lake trout spawning grounds have been identified from historical records of commercial catch rates when lake trout populations were thriving (Ward et al. 2000). Records indicate that the majority of lake trout spawning habitat is in the northern region of Lake Michigan. Refuge areas in both the northern and southern regions protect some of the critical habitat for lake trout reproduction (Figure 1).

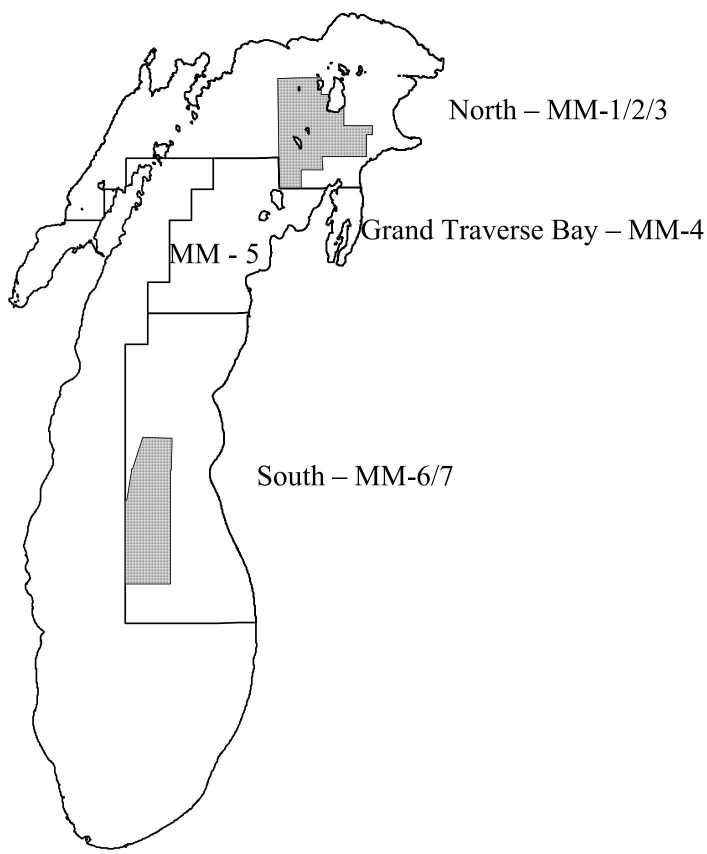


Figure 1. Lake trout management units defined in the 2000 Consent Decree. The northern and southern refuge areas are shaded.

Stocking
Stocking is the sole source of recruitment for lake trout populations in Lake Michigan. The stocking of lake trout began in the 1950s in efforts to supplement and rehabilitate dwindling native lake trout populations. The total number of lake trout stocked into Lake Michigan has never reached the level specified in rehabilitation plans (5.84 million fish; Figure 8; Holey et al. 1995). Stocking goals were set by managers through the Lake Michigan Technical Committee (LMTC) to achieve a target density of 2.47 yearling lake trout per hectare in all non-refuge waters less than 80 m (depth range considered suitable for lake trout) in depth (LMTC 1996). The two refuge areas which contain suitable spawning habitat were each to receive 750,000 lake trout. Actual stocking levels have increased from 1.07 million fish in 1965 to approximately 2.4 million fish in the early 1970s. Total stocking of yearling lake trout in Lake Michigan peaked in 1991 at nearly 2.4 million fish (Figure 2). The largest portion of stocked lake trout went to the northern and southern refuge areas after they were established in 1984 (south) and 1985 (north). The refuge areas combined have received 40-96% (average 63%) of the lake trout stocked since 1985. Fall fingerlings (age 0) have also been stocked, though in far fewer numbers due to their poor performance compared to yearlings (Figure 2; Rybicki 1990[a]).

The effective number of yearling lake trout stocked into a management unit each year was calculated as follows. First, we assumed that lake trout significantly contributing to recruitment were stocked as either yearlings or fall fingerlings. The number of yearling equivalents stocked at a location was calculated as the number of yearlings stocked that year plus 0.40 times the number of fall fingerlings stocked the year before (Holey et al. 1995; Elrod et al. 1988). Since yearling lake trout survive better than fall fingerlings, the multiplier accounts for previously measured differences in survival.

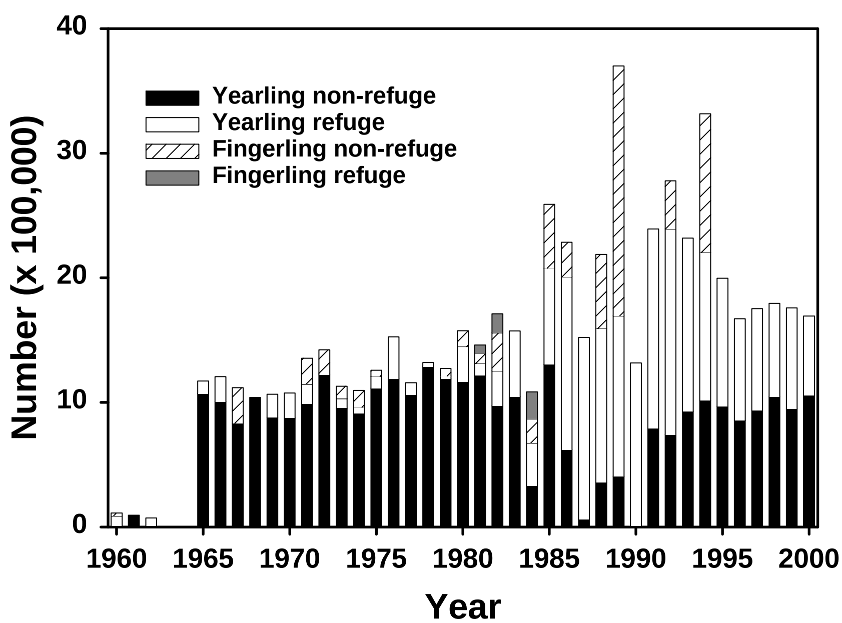


Figure 2. Number of lake trout stocked annually in Lake Michigan. Includes fish stocked in all state of Michigan waters, the southern refuge, WM-02 and WM-03 that have potential to stray into treaty-ceded waters.

Life History

Timing of lake trout spawning depends on temperature conditions, and in Lake Michigan it typically peaks sometime between October 15 and the first week of November. On average a female lake trout will produce 1,508 eggs per kilogram of body weight (Peck 1986). Biological data from lake trout collected in fishery independent surveys conducted from 1981-1998 were used to determine the maturity status of lake trout populations in Lake Michigan. Mature female lake trout were first observed at age 3, 78% were mature at age 5, and 100% were mature by age 12. The proportion of females in the population was assumed to be 50% while the proportion of females spawning varied with the age of the fish. Maturity schedules and average weight-at-age were estimated for all modeled waters of Lake Michigan combined, summary information is available in any of the <model name>.dat files (see Appendix). In Lake Michigan few reproductively viable fish live longer than 15 years and the majority are ages 7 and 8. In general lake trout fecundity is highest after age 7 (O'Gorman et al. 1998).

To facilitate the estimation of population biomass, fishery yield, and spawning stock biomass, we determined the average weight-at-age of Lake Michigan lake trout. For fish age 3 to 15, estimates were calculated from biological data collected in MDNR fishery independent surveys. The average weight of 1 and 2 year old lake trout was determined by first estimating the length-at-age with von Bertalanffy parameter approximations. The weight was then estimated from the length-weight relationship determined from survey data.

A matrix was developed to adjust for the movement of stocked lake trout among regions in Lake Michigan. The numbers stocked (yearling equivalents) at various locations were adjusted for movement soon after stocking (before substantial spatially varying mortality comes into play). This was done by apportioning fixed proportions of the numbers of yearling equivalents stocked at each location as being effectively stocked into each of the management areas (recruitment location) on the lake. These translations of numbers from stocking location to recruitment location were in the form of a "movement matrix." The numbers effectively stocked into a management unit (recruitment location) were then summed over the stocking locations.

The procedure used to develop the movement matrix for Lake Michigan is described in detail by Elliott (2002). The actual movement matrix used in the assessments described here differs slightly from that reported by Elliott, because it was based on an earlier version of his analysis (see the mistock.dat file in Appendix for the matrix that was used in Lake Michigan lake trout models). Here stocking locations were the northern refuge, the midlake refuge, and each statistical district. Recruitment locations were the same, although fish recruiting to refuges were assigned to the statistical districts making up the refuges as described by Elliott (2002). Transitions among statistical districts for fish stocked outside refuges were based on a review of the literature on lake trout movement. The working premise was that, on average, 50% of stocked lake trout remain within a 40 km radius of their stocking location and 90% remain within 80 km. Specific transition rates took into account the proximity of stocking units, their size, and specific geographic locations (e.g, the greater geographic isolation of Grand Traverse Bay). Together with stocking data, these transition rates allowed an estimate of non-refuge stocked lake trout recruiting to each statistical district. The number of fish recruiting to each statistical district from the refuge areas was calculated based on the proportion of refuge fish recovered in the fisheries of each unit (using coded-wire tagged recoveries). Estimates of refuge recruits were combined with estimates of non-refuge recruits to describe recruitment in a given region.

Growth

Lake trout growth was indexed by length-at-age for a northern (MM-1, 2, 3, 4, and 5) and a southern (MM-6 and 7) region in Lake Michigan. Although the SCAA models do not require growth information for model parameterization, mean length-at-age data were needed to estimate numerous population quantities. In preliminary data analysis there did not appear to be significant annual variation during the 18-year time period. Therefore, estimates of length-at-age, weight-at-age, and maturity-at-age were held constant through time in Lake Michigan lake trout models.

The mean length-at-age values for each year and region were based on estimates from a growth model. Biological data from MDNR fishery independent surveys conducted in the spring and summer were pooled for the years 1981 – 1999 to calculate the Von Bertalanffy parameter estimates of L_{∞}, K and t_o (using SAS). Mean length-at-age data (from spring surveys) were used to translate length-based estimates of sea lamprey-induced mortality to age-based values for the SCAA models. Age-specific female maturity was estimated using mean length-at-age data applied to the entire lake not by region (Figure 3). Weight-at-age (W_a) was estimated for the defined northern and southern regions of Lake Michigan using a von Bertalanffy weight model incorporating the 15 year series of survey data from MDNR assessments.

Figure 3. Plot of female lake trout maturity-at-age schedule for Lake Michigan. Estimates were made from biological data collected in fishery independent MDNR surveys conducted in 1836 Treaty waters from 1981-1998. Data based on annual mean length-at-age data applied to a length-based logistic model for female maturity.

Natural Mortality
When developing natural mortality parameters for the stock assessment model, literature values were consulted for reference but not explicitly used in modeling process. Natural mortality values from previous work conducted in Lake Michigan (Rybicki 1978) were estimated to be 25% annually. For age 1 lake trout, we used the value 0.91629 y^{-1} (Rybicki 1990[b]) as a prior for M in the assessment models. For age-2 and older lake trout, the prior for M was derived using Pauly's equation correlating growth model parameters and water temperature (7°C, Lake Michigan) to determine natural mortality (Pauly 1980; see Stock Assessment Models section for detailed description).

Sea Lamprey Mortality
Sea lamprey mortality rates were not estimated during model fitting, they were calculated prior to the model fitting process based on observed wounding (sum of A1-A3 marks) seen in spring gill-net surveys, as was done by Sitar (1999). For Lake Michigan models, the sea lamprey wounding and mortality rates were calculated for four broad length classes (Eshenroder and Koonce 1984, Sitar et al. 1999) and an age-length key was applied to these broad categories. Age-length keys used to convert length based rates to age based rates used von Bertalanffy growth parameters and an assumed CV of 15% (Weeks 1997) about the resulting mean length at age, assuming a normal distribution of length at age. Mortality rates calculated from spring surveys were applied to lake trout population estimates at age from the previous year. Sea lamprey mortality rates in the last model year (1998) were set to rates in the previous year, because 2000 spring survey data were not available. Bence et al. (2003) and Ebener et al. (2003) discuss the assumptions underlying this approach and the properties of sea lamprey wounding/marking data. For a given size of fish, sea lamprey mortality was calculated by:

$$ML = w\frac{(1-p)}{p} \quad (10)$$

where w is the mean wounds per fish and p is an estimate of the probability of surviving an attack. Wounding rates for lake trout ages 1 and 2 were set to 0. Lamprey wounding rates were calculated for two regions the north (MM – 1, 2, 3, 4 and 5 combined) and the south (MM – 6, and 7 combined) in Lake Michigan.

Since the late 1980s lamprey wounding rates have been relatively high in northern Lake Michigan, with a five-year average (1996 to 2000) of 0.14 y^{-1} on lake trout ages 6-11. During the same time period lamprey wounding rates were generally lower in southern Lake Michigan, averaging 0.08 y^{-1}.

Fisheries

Commercial Fishing
For lake trout, there is only one "commercial fishery" component in the model. Of the three gear-types (large-mesh gill nets, small-mesh gill nets, and trap nets) included in commercial fishery summaries, large-mesh gill nets were the dominant source of mortality. For each gear type, yield (kg) was converted to numbers of fish by dividing the corresponding average weight of a harvested fish into the yield. Under-reporting and discards in commercial fisheries were

acknowledged in the models by using the proportion of reported to actual harvest based on analyses of tribal commercial fisher reported harvest versus wholesale records of fish harvest. These under-reporting adjustments were only applied to reported tribal commercial harvest. Survey catch and state-licensed commercial fishery bycatch in gill and trap nets were also included as commercial harvest. Mortality rates of lake trout captured and released as bycatch by state licensed commercial fishermen were adjusted to account for release mortality. A mortality rate of 0.054 was applied to trap net-released fish (Jim Johnson, personal communication) and 0.755 applied to gill net-released fish (Gallinat et al. 1997). These kills were summed and the number of fish harvested in the surveys and the number of deaths of lake trout released from commercial fisheries were added in. Adjustment for underreporting, deaths of fish released from trap-net fisheries, accounting for survey kill (which is treated as part of commercial kill for the purposes of calibrating the model) and conversion from weight to numbers killed were required so these observations could be compared with model predictions of annual numbers killed by the commercial fishery.

Recreational Fishing

For recreational fisheries, the observed harvest-at-age was obtained from information collected in creel surveys. For all units with the exception of the Grand Traverse Bay lake trout model, total recreational harvest was estimated based on the number of lake trout captured and retained in the fishery. For Grand Traverse Bay, total recreational fishing mortality was partitioned into that for retained fish and that due to mortality of released fish. Separate predictions of catch-at-age for these two components can be made using Baranov's catch equation and only the predicted recreational harvest, and not total kill was compared with the observed creel harvests for that area.

Population Surveys

Aging

Lake trout were aged by evaluating scale samples collected from sampled fish. The age was determined through a combination of evaluating the scale structure for annuli and comparisons with expected age based on unique fin clip patterns assigned to each cohort. The fin clip pattern is repeated every five years, which improved the reliability of age assignments for most fish.

Commercial Fishery Data

Commercial yield and effort records were obtained from wholesale reports and reports from individual fishermen. Commercial fishery data was summarized for individual years from 1981 through 1998. Commercial removals were provided in the model data files in the form of reported commercial yield (total weight for a particular gear type for the year) and age-compositions (proportions of each age observed in the harvest for that year for the major gear types). The $\log_e$-scale standard deviations for commercial harvest and effort were set to 0.1 and 0.15, respectively. Age composition of the catch was obtained through tribal biologists' systematic sub-sampling of the lake trout catch. Age compositions were calculated as proportions by pooling all fish sampled and aged by year. Because age composition data were most abundant from surveys of large-mesh gill net fisheries, and often not collected from other gear-types, they were assumed to reflect the age-composition of the overall commercial fishery kill. For each type of commercial fishery (gear), the average weight of a harvested fish was determined for each year (for gear types with limited data this was sometimes assumed constant over time or equal to values for another component of the fishery). See <model>.dat files (Appendix) for commercial fishery harvest, effort, and age composition data.

Recreational Fishery Data

For a complete description of State of Michigan creel survey estimation methods see Lockwood et al. (1999). Recreational fishery harvest and effort data collected from 1985 through 2000 were summarized in the model by year for each region. The $\log_e$-scale standard deviations for harvest and effort were based the average coefficients of variation (CV). The $\log_e$ SD for effort was doubled in the models to account for discrepancies between fishing power and measured effort due to measurement and process error. The average weight of a recreationally harvested fish was estimated each year and used to calculate the yield of lake trout in recreational fisheries. The proportion of lake trout harvested from each age class was calculated by pooling all fish sampled and aged from each unit in a given year. We assumed that the samples were collected in proportion to the harvest. Unpublished analyses indicate that any bias from violating this assumption were minimal. See <model>.dat files (Appendix) for recreational fishery harvest, effort, age composition and sample sizes of data used in the models.

Fishery Independent Surveys

For Lake Michigan lake trout populations, survey catch per unit effort (CPUE) estimates were obtained from 1981 through 2000, and were derived from standard graded-mesh (2.5 to 6.0 inch) surveys conducted during the spring and summer. In the models, survey CPUE was predicted assuming proportionality between population abundance and expected CPUE. The analyses done for the 1981 to 1999 assessments in treaty waters treated repeated samples within the same grid as occurring at the same “station”. This approach takes into account the systematic nature of the designs and offers substantial advantages over simply taking a geometric average. Samples collected close together in space during the same year may well be correlated and provide less information about regional abundance. Observed spring survey CPUE was expressed on a log-scale and was calculated as the year-specific least-square mean from a linear mixed model fit using SAS Proc Mixed (Littell et al. 1996). Uncertainty for these indices was quantified in terms of the standard error for the least-squares mean. The mixed model accounted for the systematic effects of fixed sampling stations in specific statistical grids and the random interaction of grid and year. The model was:

$$Log_e(CPUE+c)_{y,g} = \mu + \alpha_y + \beta_g + \gamma_{y,g} + \varepsilon_{y,g} \qquad (28)$$

where c was a constant added to avoid $\log_e$ of zeros when no fish were captured; subscripts y *and* g refer to year and grid respectively; μ was the overall mean; α, and β were the fixed effects of year and grid, respectively; γ was the random effect of year and grid; and ε was the random sampling error term. Both γ and ε were assumed to be normally distributed with mean of 0. Survey CPUE indices are reported in the <model>.dat files (Appendix).

Characteristics of Lake Trout Statistical Catch-At-Age Models

SCAA Model

Statistical catch-at-age models (SCAA) were developed for the north (MM-1, 2, and 3 combined), Grand Traverse Bay (MM-4), central (MM-5), and the southern (MM-6 and 7 combined) regions of Lake Michigan. The overall model structure was similar for all areas. Description of the structure and methods for the statistical catch-at-age models used was provided earlier in this document (see Stock Assessment Models section). Lake trout populations were modeled from 1981-1999, the first population age was 1 and the last age was 15 in all units. The models for each area estimate abundance and partition mortality rates for each age group of lake trout. The mortality sources include commercial fishing, recreational fishing, sea lamprey, and natural (excluding sea lamprey parasitism) mortality. All of these models were fit to data on harvest, effort, and age compositions for recreational and commercial fisheries. Auxiliary fishery-independent data from spring and summer surveys were used to fit SCAA models. The survey data included a relative abundance index (CPUE) and age compositions. Overall model fit was penalized by deviations from priors. The objective function of the SCAA models for northern, Grand Traverse Bay and MM-5 models comprised nine $\log_e$-likelihood components including: recreational effort, commercial effort, recreational harvest, commercial harvest, survey CPUE, recreational age compositions, commercial age compositions, survey age compositions, and prior information on natural mortality rates. The southern unit does not have significant commercial harvest and thus, commercial effort and age compositions were not estimated in the model. In all models, each of the $\log_e$-likelihood components were assumed to be from a $\log_e$-normal distribution except for the age composition components, which were assumed to be multinomial. Log_e-scale standard deviations for each $\log_e$-normal data source were estimated external to the model fitting process. The $\log_e$ SD for recruitment was calculated iteratively in the model fitting process by changing the prior value until it matched the model's estimate.

Further assumptions defined in the Lake Michigan lake trout models:

- With the exception of recreational fisheries, the selectivity for the fisheries and surveys were assumed to vary by age but were treated as constant through time. Recreational selectivity patterns were adjusted to account for changing regulations of size-limits in recreational lake trout fisheries.
- Recruitment was set at a value reflecting expected stocking in 1999. Note that assumed recruitment has little influence on calculations of harvest during 2000, as these fish are either not selected or only weakly selected by the fishery.
- Fishery effort data from recreational and commercial sources were de-emphasized in the model fitting process by setting the emphasis factor for the effort likelihood components to 0.01. This was done because lake trout fishing effort data may not be directly proportional to mortality because commercial fisheries may be targeting lake whitefish and recreational effort was measured for all salmonines and not specific to lake trout.
- Prior values for natural mortality and the $\log_e$ SD were estimated using Pauly's equation as described earlier.

Projections
Projections of future stock size and allowable harvest levels were based on assumptions that mortality rates, catchability coefficients, female maturity, weight at spawning, and recruitment were equal to the average of 1995-1998 (previous 3 yr) values estimated by the SCAA models. Projected population weight-at-age was assumed equal to 1998 values (previous yr). Total allowable catch (TAC) and total allowable effort (TAE) were based on comparing the current quantity of spawning stock biomass per recruit to the quantity produced at established target maximum mortality rates. The target maximum total annual mortality rate (*A*) for Lake Michigan lake trout varied by region and was 40% in the northern and southern regions and 45% for Grand Traverse Bay and MM-5. Target mortality was further modified in the context of these SCAA models to account for differences in age-specific mortality rates. The first age at which the target maximum *A* applied was age 5 for Lake Michigan. This first age was based on the consensus of the modeling group to apply specified annual harvest mortality rates at ages beginning where approximately 20% of the females or more were mature.

Status of Lake Trout in the Northern Unit (MM-123)

Spatial Summary
The northern lake trout management unit is made up of statistical districts MM-1, MM-2 and MM-3 and encompasses Michigan's waters of northern Lake Michigan and northern Green Bay (Figure 1). This management unit covers 5,000 square miles. Water depths in the northern management unit are for the most part less than 150 feet, and approximately 3,800 square miles are less than 240 feet. In the southern portions of the unit, depths can be greater than 550 feet. Most of the historically important lake trout spawning reefs in Lake Michigan are located in the northern unit. The unit also contains many islands including the Beaver Island complex (Beaver, Hat, Garden, Whiskey, Trout, High and Squaw Islands), North and South Fox Islands, and Gull Island in Lake Michigan. Another series of islands form a line separating Green Bay from Lake Michigan; these include Little Gull, Gravely, St. Martins, Summer and Poverty Islands. The western half of MM-1 is outside the 1836 Treaty waters, but this area holds lower lake trout populations than the remainder of the unit. This unit contains the northern refuge, which occupies nearly 900 square miles and is comprised of the southern ½ of grids 313 and 314, grids 413, 414, 513-516, the northwest quarter of grid 517, grid 613, and the northern ½ of grid 614.

Stocking
Recruitment of lake trout in the northern management unit of Lake Michigan is currently based entirely on stocking. During the 1990s, approximately 791,000 yearling lake trout were annually stocked into northern Lake Michigan and approximately 88 percent of these fish were stocked into the northern refuge area (Figure 2). To more accurately estimate recruitment in the model, the number of fish stocked is adjusted to account for mortality and movement among the various regions in the lake. During this same time period, the recruitment to age one has averaged 664,000 fish in northern Lake Michigan.

Fishery Independent Surveys
Fishery independent gill-net surveys were conducted in the northern unit by the Michigan Department of Natural Resources from 1981 to 1990 and again in 1998. The Grand Traverse Bay Band conducted gill net surveys in the unit from 1992-1998. A total of 56 gill-net sets were

incorporated into the model of this region. All survey nets were comprised of graded-mesh (2.5 to 6.0 inch) gill nets at a range of lengths. The catch was expressed as catch per 1,000 feet of graded mesh gill net set overnight. Nets set in grids 615 and 616 were excluded from post-1990 analyses. These grids represent the conversion zone from Grand Traverse Bay into northern Lake Michigan. Because of this, survey data were not available for the years 1991 to 1997. Years without data were entered as -1 and not used to fit the model.

Fisheries
Both state and tribal commercial fisheries operate in northern Lake Michigan. State-licensed commercial fishermen are not permitted to harvest lake trout and therefore are not included in lake trout harvest allocations. While the current tribal commercial fishery primarily targets lake whitefish, lake trout are sometimes targeted or kept as by-catch. Since 1981 commercial fishing has killed more harvestable lake trout (fish > 17 in.) than other sources of mortality in northern Lake Michigan (Figure 4).

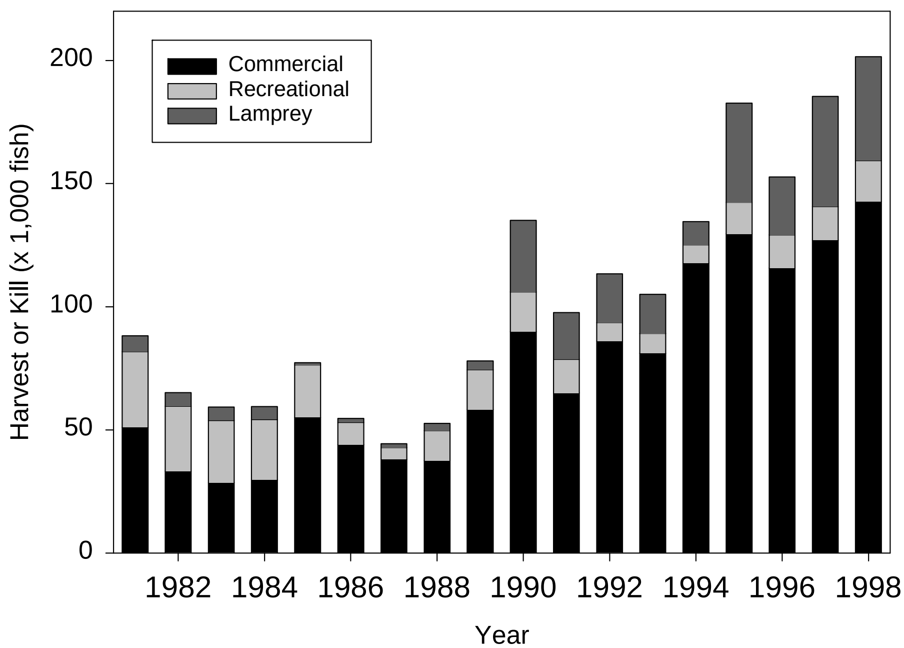


Figure 4. Number of lake trout killed each year (1981-1998) by three mortality sources (commercial fishing, recreational fishing and lamprey predation) in northern Lake Michigan.

It is illegal for recreational fishers to retain lake trout when fishing in the northern refuge and gill-net fishing (both commercial and subsistence) is also prohibited. Commercial trap net operations are permitted; however, the retention of lake trout is prohibited. Commercial fishing is also illegal in the innermost area of Little Traverse Bay (grid 519) and portions of grid 306 in northern Green Bay.

There are three types of tribal commercial fisheries (large-mesh gill net, small-mesh gill net, and trap net) in the unit. Tribal commercial yield increased from 156,000 lb in 1987 to 737,000 lb in 1998. The large-mesh gill-net fishery accounts for the majority of the yield. Large-mesh gill-net effort in tribal fisheries has been declining from 23 million feet in 1993 to 14 million feet in 1998 (Figure 5). The number of lake trout harvested in northern Lake Michigan tribal fisheries had increased from 65,000 fish in 1991 to 143,000 fish in 1998 (Figure 4).

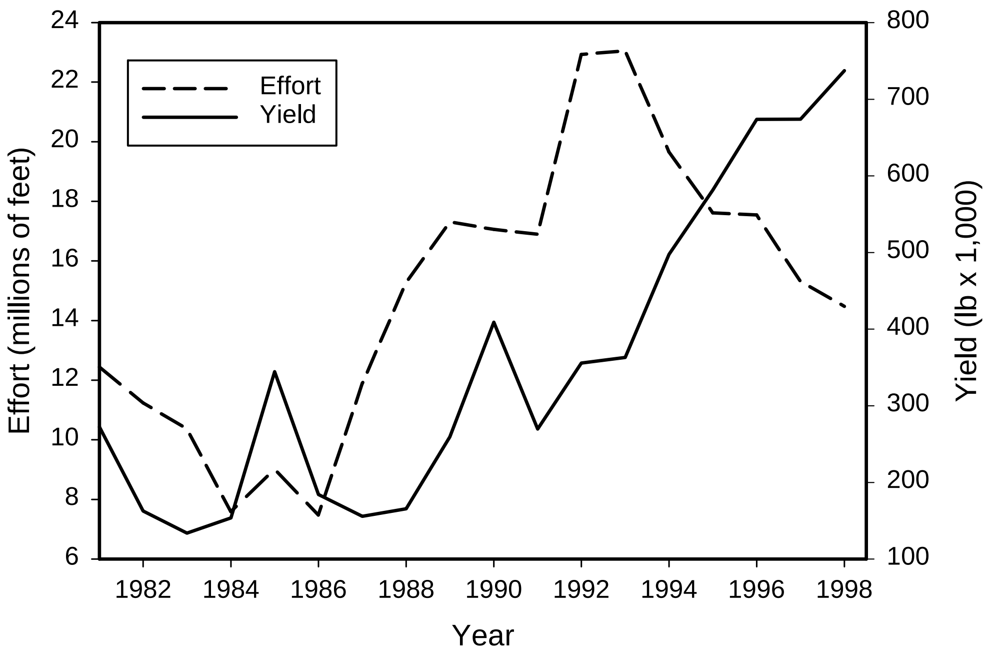


Figure 5. Northern Lake Michigan observed commercial gill-net fishery effort and total commercial yield from 1981-1998.

The management of recreational fisheries for lake trout is the primary responsibility of the State of Michigan and fisheries are comprised of both charter and sport anglers. In 1991, the minimum size limit for sport fishing in the northern management unit of Lake Michigan was increased from 10 to 24 inches and a modest decline in recreational yield resulted. In recent years, recreational yield had increased from 44,000 lb in 1994 to 119,000 lb in 1998. Angling effort has also increased. Angler hours rose from 54,000 in 1994 to 136,000 in 1998 (Figure 6). However, the mortality rate and number of lake trout harvested from recreational fishing in the northern management unit of Lake Michigan is significantly lower than rates associated with commercial fishing or sea lamprey predation (Figure 7).

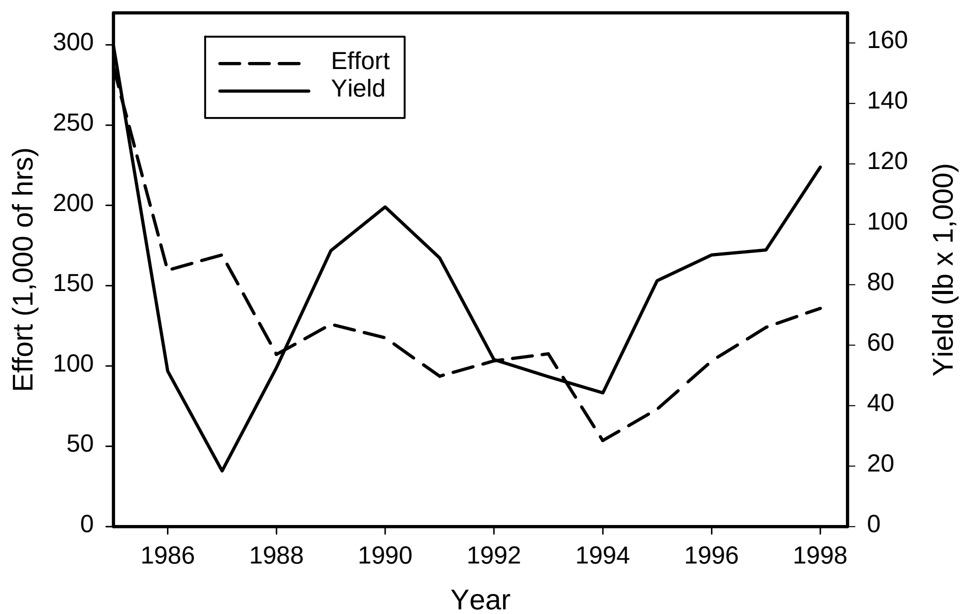


Figure 6. Northern Lake Michigan observed recreational fishery effort and yield from 1981-1998.

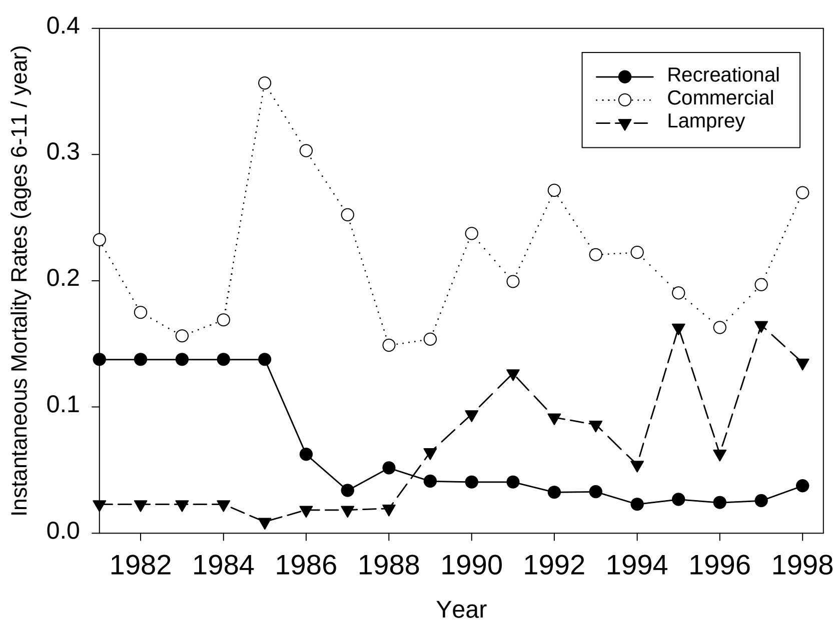


Figure 7. Instantaneous mortality rates of lake trout (average for ages 6-11) in northern Lake Michigan summarized for three mortality sources (recreation fishing, commercial fishing and sea lamprey predation).

The number of lake trout killed by sea lamprey has increased from an average of 4,700 during 1981-1985 to an average just over 32,000 during 1994-1998 (Figure 4). During 1989-1998, sea lamprey-induced mortality was the second highest source of mortality for lake trout in northern Lake Michigan (Figure 7).

Selectivity

Commercial and recreational fishery selectivity patterns were represented by a flattened dome shapes with selectivity peaking after age 5 (Figure 8). Survey selectivity patterns were represented by a more classic dome shape with peak selectivity occurring around age 5.

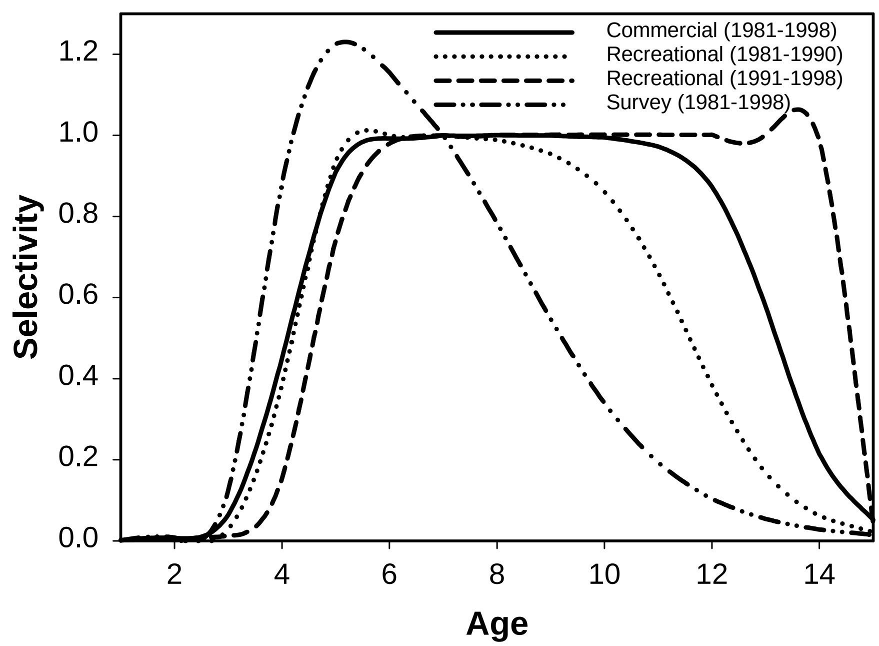


Figure 8. Estimated selectivity patterns in commercial, recreational and survey fisheries. Recreational size limits were changed from 10 to 24 inches in 1991 resulting in two selectivity pattern estimates for this fishery.

Population Summary

In northern Lake Michigan, lake trout generally are both spawning and recruited into commercial and recreational fisheries by age 6. The biomass of lake trout had been increasing in northern Lake Michigan since 1986, but has decreased slightly from 1997 to 1998 (Figure 9). Spawning biomass is much lower for the non-refuge area when compared to the refuge and non-refuge areas combined, indicating that the refuge is protecting spawning lake trout. Further, increases in biomass are less pronounced and the decline since 1997 is more pronounced when considering the biomass of non-refuge fish only. The total biomass of lake trout outside the refuge averaged 2.0 million lb during 1989-1998, compared to 3.8 million lb when refuge and non-refuge fish were considered together (Figure 9).

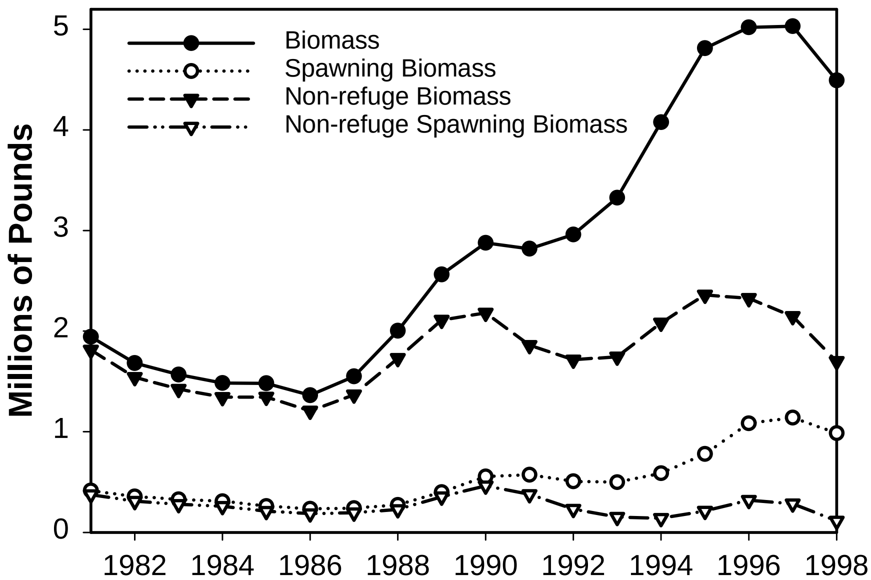


Figure 9. Modeled estimates of biomass and spawning biomass of lake trout northern Lake Michigan (1981-1998). Circles represent estimates for refuge and non-refuge fish combined. Triangles represent non-refuge lake trout only.

Status Relative to Reference Point in Northern Region

<u>Mortality and spawning stock biomass per recruit (SSBR)</u>

Based on recent model estimates (1996-1998), mortality rates are above the established target maximum and SSBR was less than the target SSBR for lake trout outside of the refuge. The average *Z* for age 6 to 10 yr old lake trout during 1996-98 was 0.58 (range: 0.48-0.68, target was 0.51). The SSBR was 1.04 lb for refuge and non-refuge fish combined and 0.73 lb for non-refuge lake trout only. The target SSBR was 0.91 lb, indicating that the refuge is affording some protection for spawning lake trout in the northern region of Lake Michigan. Lake trout outside of the refuge area are being depleted at a rate greater than management objectives would dictate.

<u>Harvest and TAC</u>

Until the year 2005 the northern region of Lake Michigan will not be fully phased-in as a management unit. This means that harvest may exceed advised levels to allow agencies to adjust management practices to meet the harvest requirements for the unit by 2005. Harvest limits during this time period are not to be set below 450,000 pounds. Phase-in options will allow for temporary increases in mortality rates above the 40% target level.

<u>Model fit</u>

Generally, model predictions of harvest and catch were consistent with observed data (Figure 10). Some patterns were observed in residuals for the survey fishery, but the magnitude of difference was very small (Figure 11). Residuals for recreational harvest were extremely low. In 1985, both recreational and commercial harvest residual differences were relatively high

(Figure 11). For the recreational fishery this was the first year modeled and the fit in later years was extremely good. For commercial fishery harvest the strong deviations occurred early in the modeling process and became less significant over time. In both cases, the model was underestimating the harvest.

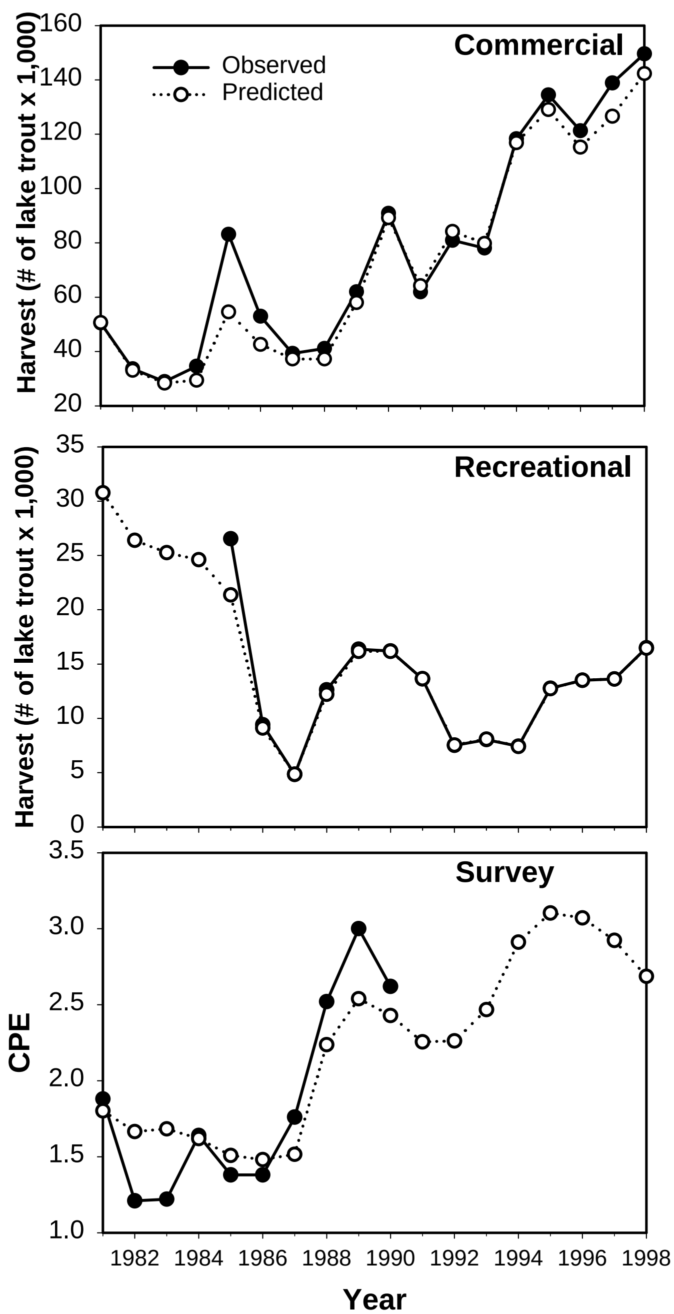


Figure 10. Observed and predicted survey catch-per-unit effort (CPUE), recreational harvest, and commercial harvest for the northern region during 1981 to 1998.

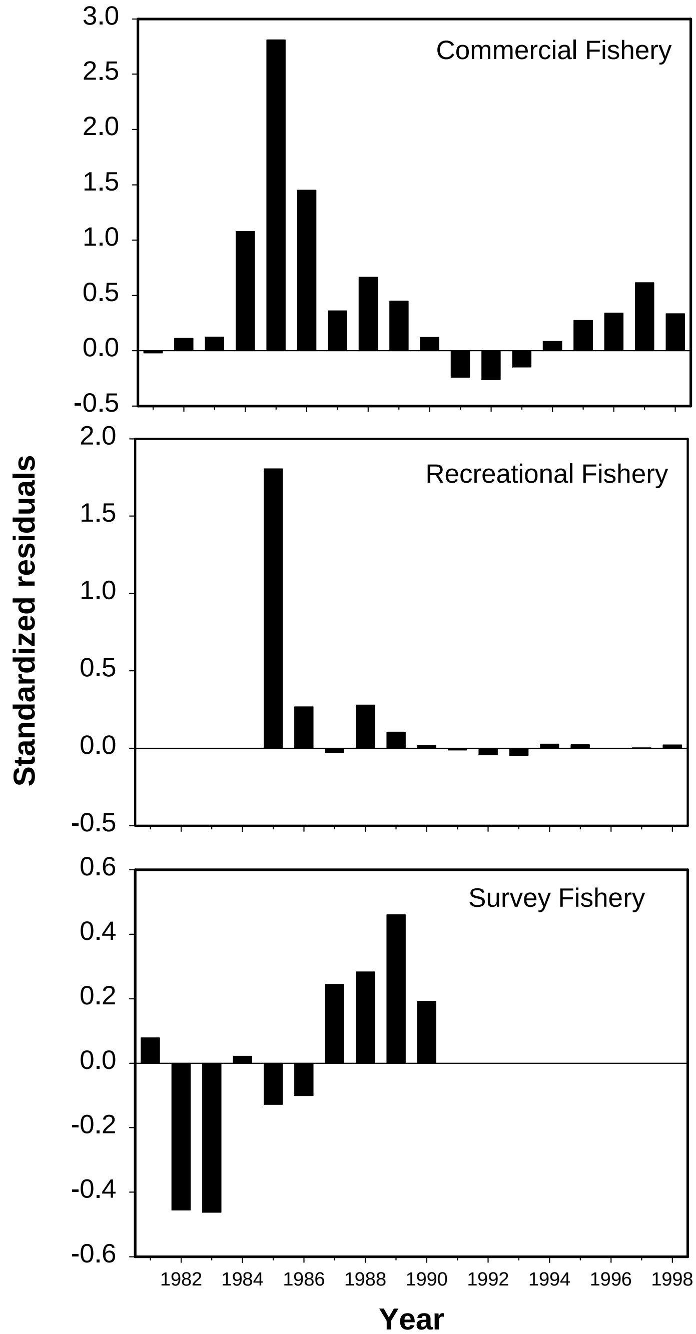


Figure 11. Standardized residual values for survey CPUE, recreational harvest, and commercial fishery harvest from 1981-1998. Standardized residuals are calculated as observed minus predicted values divided by the estimated standard deviation. Recreational harvest was not estimated prior to 1985.

The average age of lake trout captured in commercial, recreational and survey fisheries was between 5 and 6 yrs (range 3.9 to 7.3 across years; Figure 12). The observed and predicted values for average age in commercial and recreational fisheries varied to a greater extent than the harvest estimates, but generally trended in similar directions (Figure 12). The model did not fit the survey age compositions very well in 1983 and 1987, when the observed average age displayed marked increases from the prior year (Figure 12). Non-standardized residuals of average age data do not show any significant patterns for commercial, recreational or survey fisheries (Figure 13). The model tended to underestimate survey age data when observations of age changed dramatically in a positive direction (e.g. 1983 and 1987).

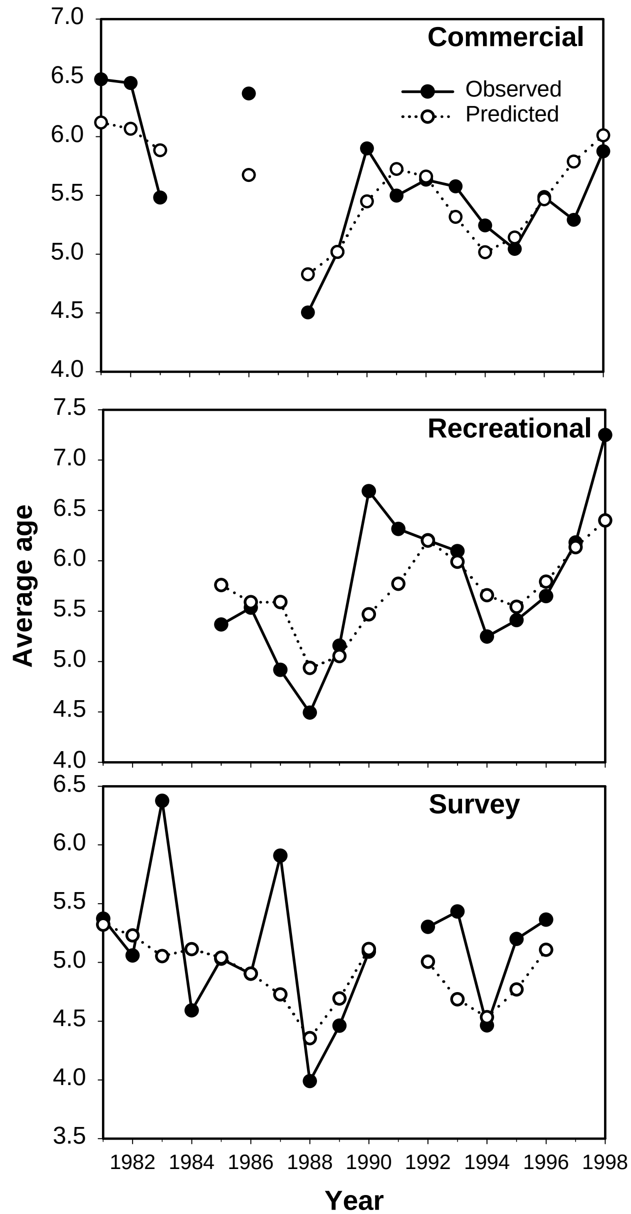


Figure 12. Observed and predicted average age for lake trout collected in commercial, recreational and survey samples from the northern region during 1981 to 1998. Recreational harvest was not estimated prior to 1985, commercial age composition data were not available for 1984, 1985 or 1987, and recreational age composition data were not available for 1991, 1997 and 1998. Commercial age compositions were estimated for lake trout age 3 to 15, survey for age 3 to 12+ and recreational fisheries for ages 1 to 15.

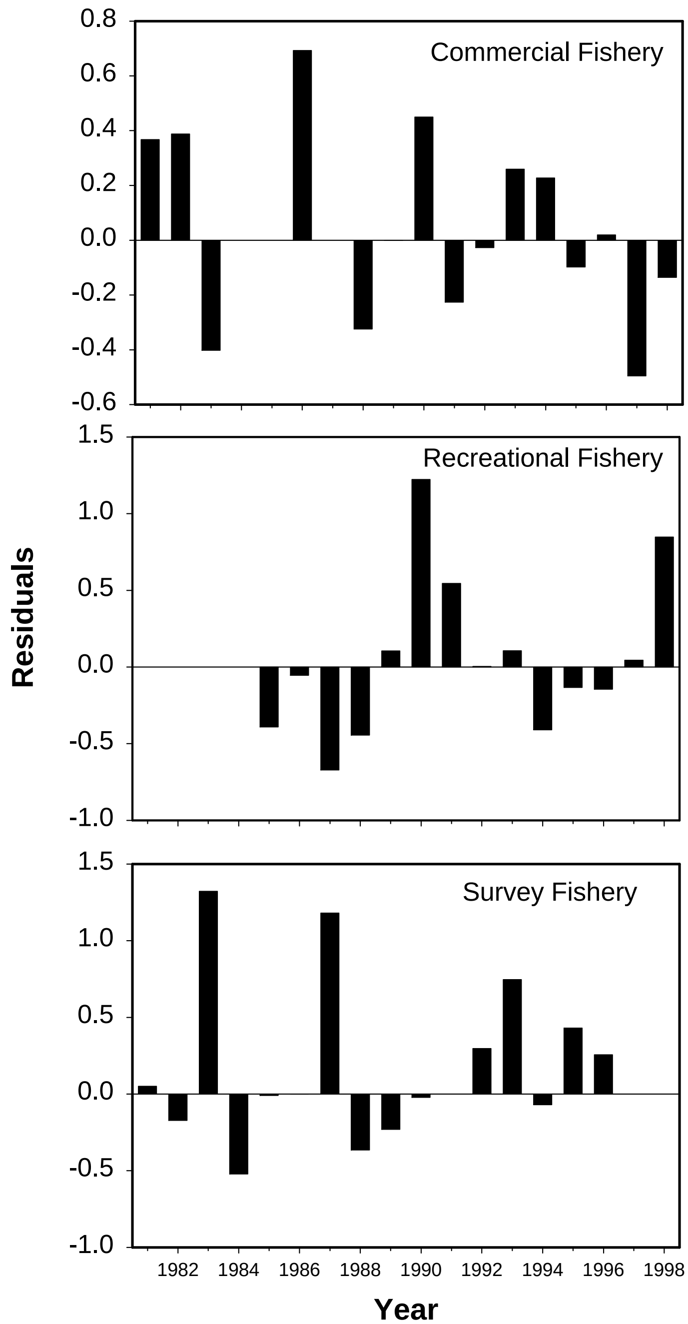


Figure 13. Non-standardized residual values for recreational, commercial, and survey average age data. Residuals are calculated as observed minus predicted values. Recreational harvest was not estimated prior to 1985, commercial age composition data were not available for 1984, 1985 or 1987, and recreational age composition data were not available for 1991, 1997 and 1998. Commercial age compositions were estimated for lake trout age 3 to 15, survey for age 3 to 12+ and recreational fisheries for ages 1 to 15.

Status of Lake Trout in Grand Traverse Bay (MM-4)

Spatial Summary

The Grand Traverse Bay lake trout management unit encompasses the Grand Traverse Bay region of Lake Michigan, and is also called the MM-4 statistical district. There are two islands in this management unit, Bellow and Marion Island, and a large peninsula bisects the southern half of the bay. For the most part water depths in the bay range up to 280 feet. However, waters on either side of the peninsula are much deeper, ranging to 440 feet in the west arm and 640 feet in the east arm. This management unit is entirely in 1836 Treaty waters and there are no refuge areas allocated. However, commercial fishing is prohibited in the southernmost portion of the bay (grids 915 and 916). The total area of the unit is 255 square miles of which 168 square miles are less than 240 feet in depth. Based on estimates from historical commercial catch rates only a small amount of lake trout spawning habitat is located in the management unit. Despite this, Grand Traverse Bay is one of the only areas of Lake Michigan where the recruitment of naturally reproduced lake trout has been documented. In the mid-1980s the frequency of unclipped fish in the bay increased significantly leading biologists to believe that rehabilitation efforts were succeeding. Unfortunately, in more recent evaluations few unclipped lake trout have been seen. This area constitutes an area of high use by both tribal and state interests.

Stocking

The recruitment of lake trout in the Grand Traverse Bay management unit of Lake Michigan is based entirely on stocking. The U.S Fish and Wildlife Service is the primary agency responsible for stocking lake trout in Lake Michigan. In each of the last ten years, approximately 220,000 yearling lake trout have been stocked into the Grand Traverse Bay management unit. To more accurately estimate recruitment in the model, the number of fish stocked is adjusted to account for mortality and movement among the various regions in the lake. Over the last 10 years (1989-1998) the recruitment to age one has averaged 242,000 fish.

Fishery Independent Surveys

Fishery independent gill-net surveys were conducted in Grand Traverse Bay by the Michigan Department of Natural Resources from 1981 to 1990 and again in 1997. The Grand Traverse Bay Band conducted surveys from 1992 to 1998. Surveys were not conducted in 1991. A total of 176 gill-net sets were incorporated into the model of this region. All survey nets were comprised of graded-mesh (2.5 to 6.0 inch) gill nets at a range of lengths. The catch was expressed as catch per 1,000 feet of graded-mesh gill net set overnight. Years without data were entered as -1 and not used to fit the model.

Fisheries

Only tribal fishermen commercially harvest fish in this management unit. There are three types of tribal commercial fisheries: large-mesh gill net, small-mesh gill net, and trap net. The large-mesh gill-net fishery is responsible for the greatest number of harvested lake trout. The commercial harvest of lake trout in tribal large-mesh gill-net fisheries rose from a low of 6,000 fish in 1991 to 34,000 fish in 1998. Tribal commercial yield of lake trout peaked in 1998 at 137,000 lb. Large-mesh gill-net effort in tribal fisheries has been between 1.5 and 2 million feet for the last five years (1994 to 1998; Figure 14). It is expected that major decreases in the currently high commercial harvest of lake trout in the Grand Traverse Bay management unit will be sustained in future years as a result of converting the region's largest gill-net fisher to a trap-net operation.

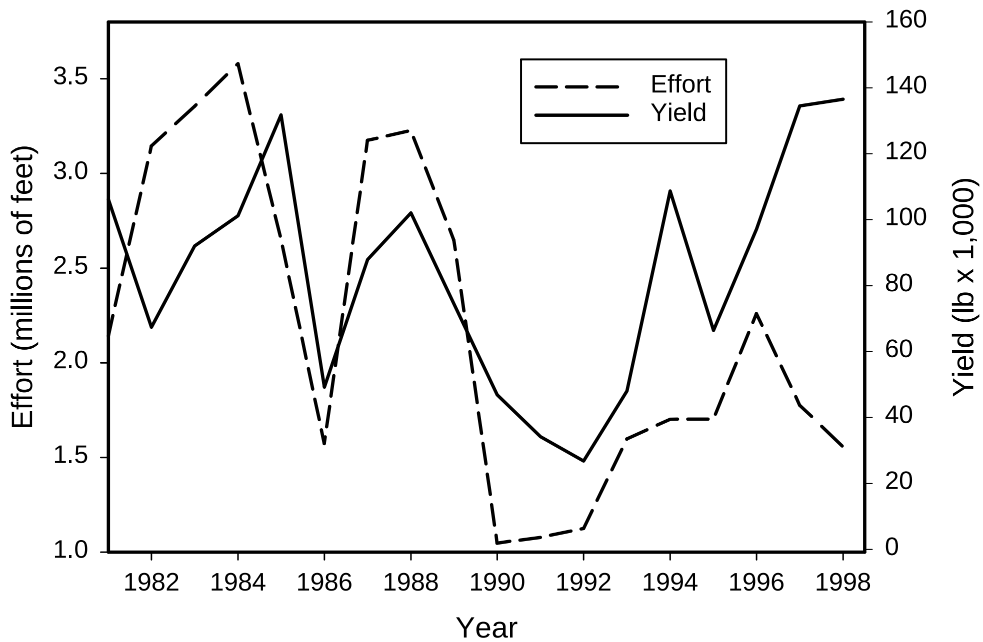


Figure 14. Grand Traverse Bay management unit observed commercial gill-net fishery effort and total commercial yield from 1981-1998.

From 1993 until 1997 more lake trout were killed by commercial fishing than by either sea lamprey or sport fishing (Figure 15). Commercial fishing mortality in Grand Traverse Bay peaked in 1994 at 0.48 y^{-1}, declined in 1995 to 0.20 y^{-1}, and rose steadily to 0.34 y^{-1} in 1998 (Figure 17).

The management of recreational fisheries for lake trout is the primary responsibility of the State of Michigan and fisheries are comprised of both charter and sport anglers. The sportfishing harvest regulations in the Grand Traverse Bay management unit have changed significantly over the last 10 years, affecting recreational fishing mortality rates and harvest levels. From 1992-1996 the minimum size limit for lake trout harvest increased from 10 to 24 inches. In 1996 the season for harvesting lake trout was lengthened, so that it extended from Jan 1 through September 30, in contrast to the previous season of May 1 through Labor Day. Mid-way through the year in 1997 the minimum size limit was decreased to 20 inches. The mortality rates of lake trout resulting from recreational fishing have steadily declined from 1991 (0.23 y^{-1}) to 1996 (0.07 y^{-1}). Since 1996 mortality rates have increased to 0.29 y^{-1} in 1998 (Figure 17). The estimated recreational yield of lake trout in Grand Traverse Bay had been relatively consistent during the years 1992-1996 averaging 39,000 lb. However, from 1996 to 1998 the recreational yield of lake trout increased dramatically to 131,000 lb (Figure 16). The numbers of lake trout harvested followed similar patterns to that observed for yield. Harvest remained stable from 1992 through 1996 averaging 6,000 fish. Harvest then increased dramatically peaking at 26,000 fish in 1998 (Figure 15). Recreational fishing effort levels were also relatively low from 1992 to 1996 averaging 189,000 angler hours. The effort value observed in 1998 had increased to 303,000 angler hours (Figure 16). In the future, more stringent fishing regulations adopted in 1997 should reduce the mortality due to recreational fishing in the Grand Traverse Bay region.

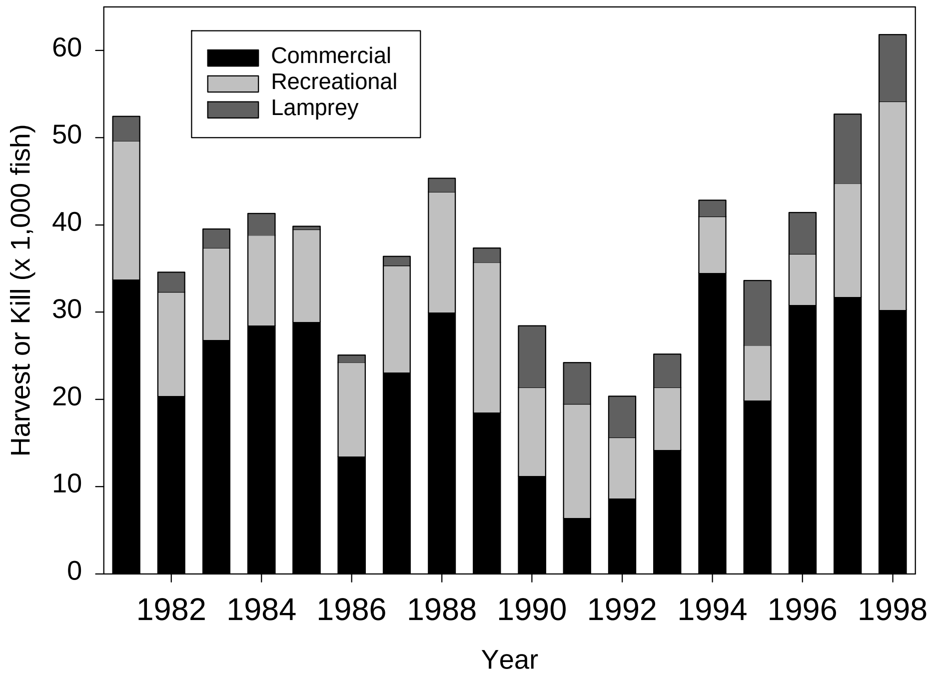


Figure 15. Number of lake trout killed each year (1981-1998) by three mortality sources (commercial fishing, recreational fishing and lamprey predation) in Grand Traverse Bay.

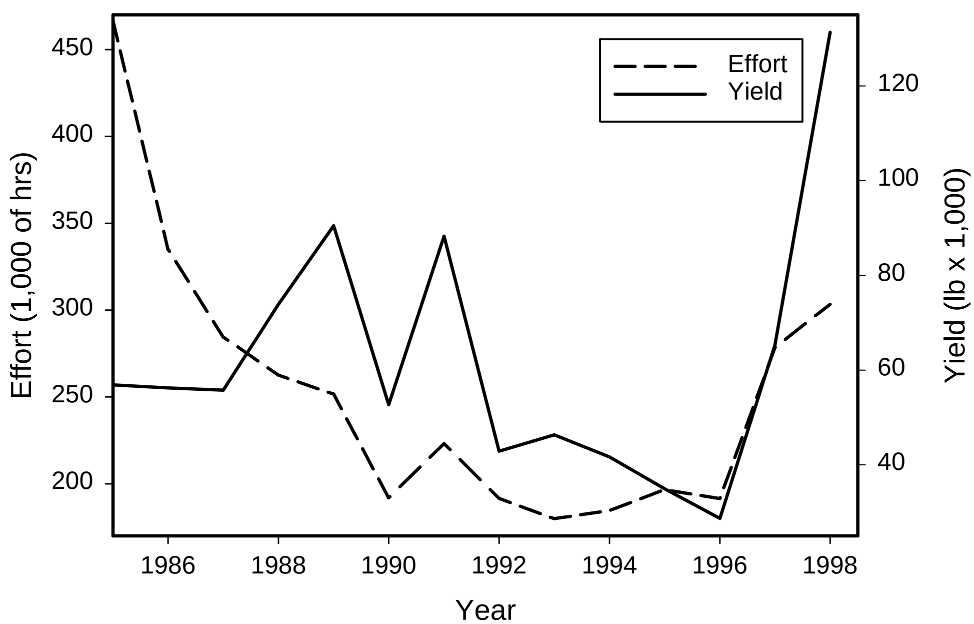


Figure 16. Observed recreational fishery effort and yield from Grand Traverse Bay 1981-1998.

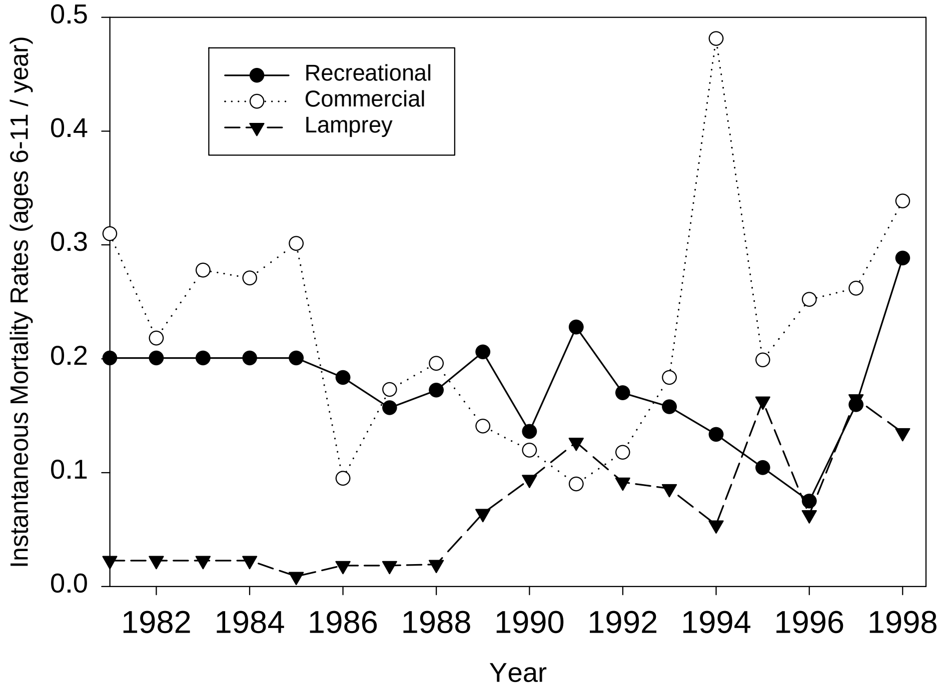


Figure 17. Instantaneous mortality rates of lake trout (average for ages 6-11) in the Grand Traverse Bay management unit, summarized for three mortality sources (recreation fishing, commercial fishing and sea lamprey predation).

From 1981-1990 sea lamprey mortality was less than either recreational or commercial mortality. Since 1988 however, sea lamprey mortality rates have been generally increasing in the unit. From 1995 to 1998 lamprey mortality averaged 0.13 y^{-1}on lake trout age 6 to 11 (Figure 17). The highest sea lamprey mortality rate was observed in 1997 at 0.16 y^{-1} (Figure 17). The average number of deaths of lake trout from sea lamprey during 1997 and 1998 has been 7,800 fish (Figure 15).

Selectivity

Commercial selectivity patterns were represented by a flattened dome shape with peak selectivity occurring around age 5 (Figure 18). The survey selectivity also peaked at age four, however the curve was skewed to the right with a long declining tail after age four. Regulation changes did influence selectivity patterns in the recreational fishery. The 10 and 20 inch size limits exhibited similar flattened, dome-shaped patterns with peak selectivity around age 5. Selectivity patterns for the 24 inch size limit were different, exhibiting a dome-shaped pattern that is skewed to the right with peak selectivity occurring around age 11 and declining rapidly at older ages.

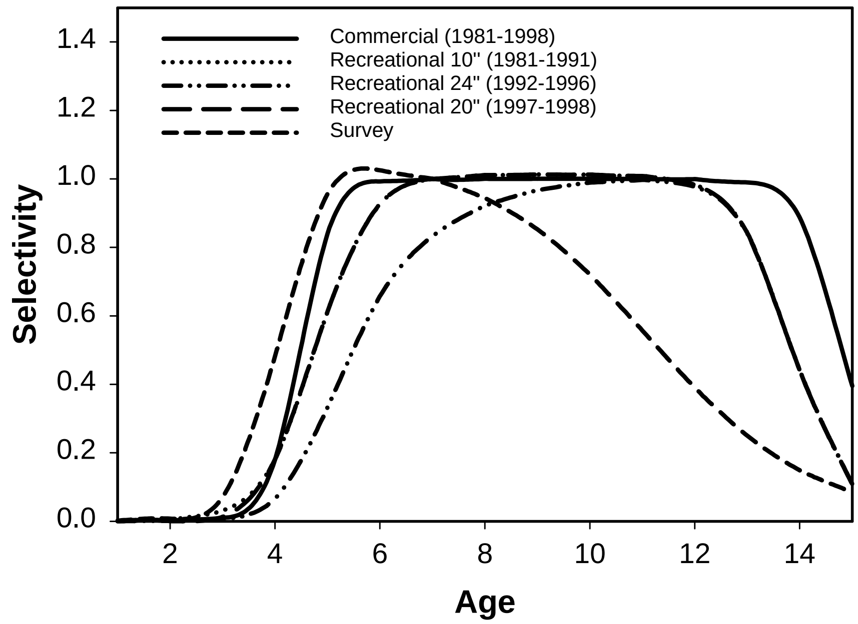


Figure 18. Estimated selectivity patterns in commercial, recreational and survey fisheries in Grand Traverse Bay.

Population Summary

Lake trout in Grand Traverse Bay are generally recruited into commercial fisheries by age 6 and recreational fisheries by age 7. Lake trout in this management unit first spawn at age 3 and 50 percent or more are spawning by age 6. Biomass of lake trout increased from a low of 0.9 million lb in 1991 to a high of 1.5 million pounds in 1996. In 1998, the total biomass of lake trout was 1.3 million pounds. The biomass of spawning lake trout in Grand Traverse Bay has been relatively consistent and low since 1981, never getting above 200,000 pounds.

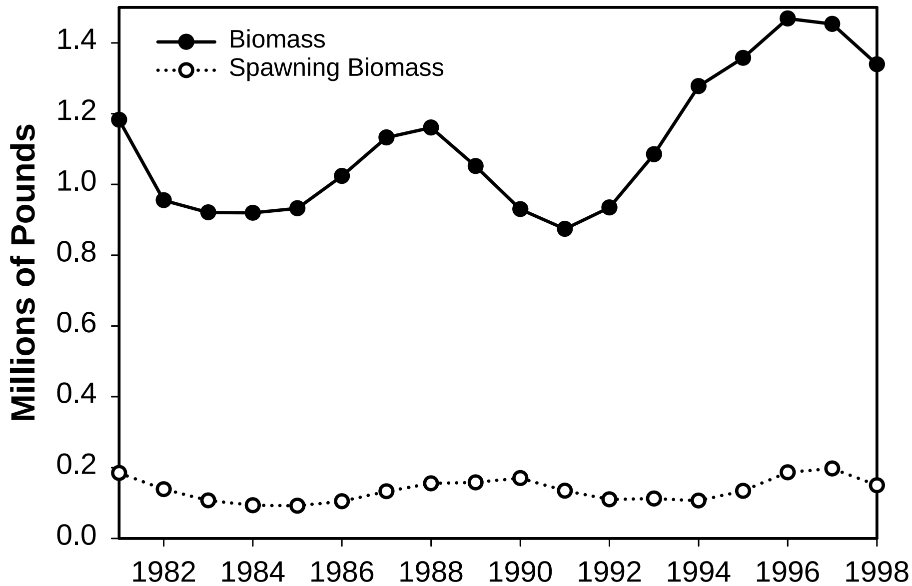


Figure 19. Modeled estimates of biomass and spawning biomass of lake trout in the Grand Traverse Bay management unit (1981-1998).

Status Relative to Reference Point in the Grand Traverse Bay Management Unit

Spawning stock biomass per recruit (SSBR)

The spawning stock biomass produced per recruit (0.249 lb) is below the target value (0.529 lb), indicating that the mortality rate is too high to meet management objectives in Grand Traverse Bay. Based on the recent five-year model estimates (1994-1998), mortality rates are high and above the established target maximum. The average *Z* for age 6 to 10 yr old lake trout during 1994-98 was 0.84 (range: 0.65-1.02, target is 0.60).

Harvest and TAC

Grand Traverse Bay represents an area where unique phase in requirements were considered in establishing yield limits. From 2001 to 2005 commercial yield limits are to be set based on the mean yield and effort in Grand Traverse Bay from 1997-1999. For commercial fishing, the yield and effort limit is determined as the mean minus the conversion of gill-net effort to trap nets. Recreational yield limits are set at the mean for the previous three years and are to be adjusted for regulation changes. After 2005 yield and effort limits will be set to meet the target mortality rate for this area of 45%, with a 40 percent allocation to the state of Michigan and a 60 percent allocation to tribal fisheries.

Model Fit

With the exception of survey data, model predictions of harvest and catch were generally consistent with observed data (Figure 20). Commercial fishery harvest values early in the modeling process (1981 to 1990) were generally underestimated. Some patterns were observed in residuals for the recreational fishery, but the magnitude of difference was very small (Figure

21). The model tended to underestimate recreational harvest prior to 1994 and overestimate after.

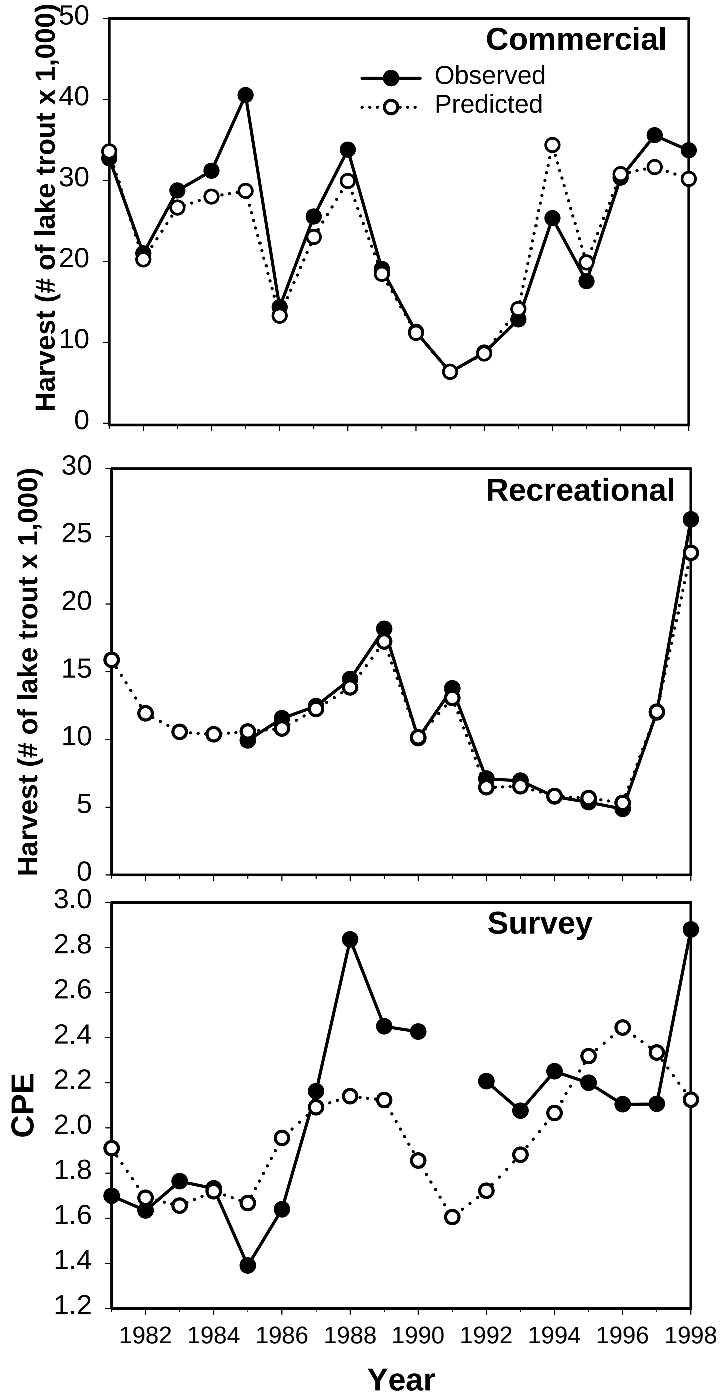


Figure 20. Observed and predicted survey catch-per-unit effort (CPUE), recreational and commercial harvest for the Grand Traverse Bay management unit during 1981 to 1998. Survey data were not available for 1991.

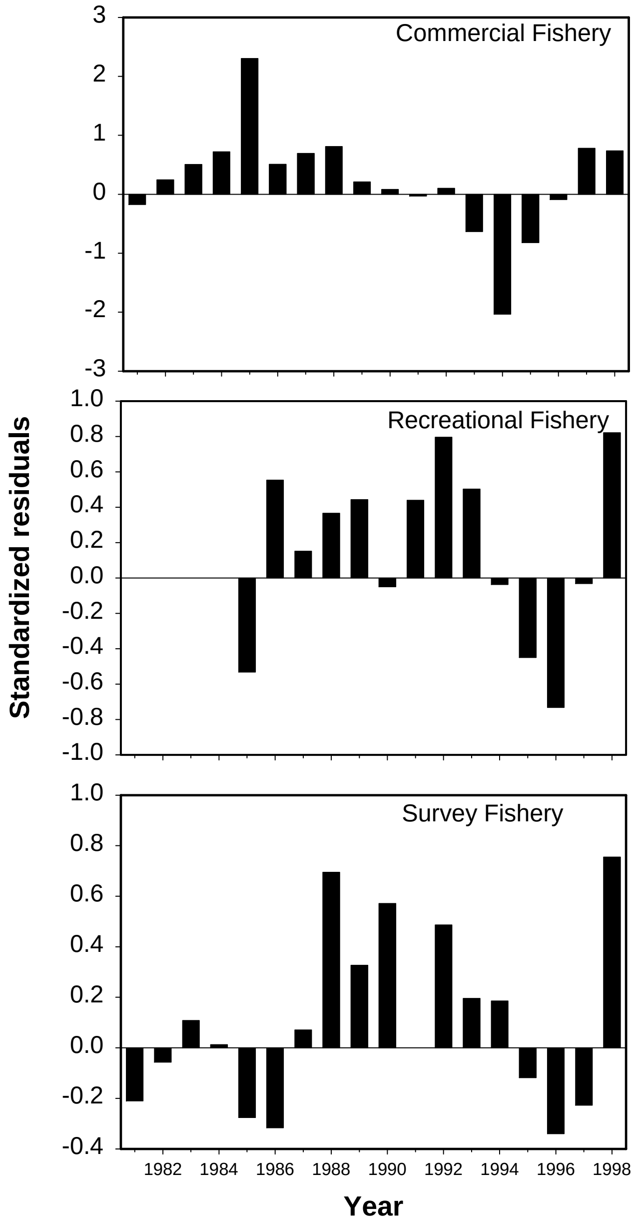


Figure 21. Standardized residual values for survey, recreational, and commercial fishery harvest from 1981-1998, Grand Traverse Bay. Standardized residuals are calculated as observed minus predicted values divided by the estimated standard deviation. Recreational harvest was not estimated prior to 1985.

In general, the average age of lake trout captured in commercial, recreational and survey fisheries was between 5 and 6 yrs (range 4.6 to 6.9 across years; Figure 22). As expected, the survey tended to capture younger fish than the commercial or recreational fisheries. The observed and predicted values for average age in commercial and recreational fisheries did not match as well as the harvest estimates (Figure 22). The observed age composition data from the recreational and survey fisheries showed higher variation from year to year than modeled estimates (Figure 22). Non-standardized residuals of average age data do not show any significant patterns for commercial, recreational or survey fisheries (Figure 23). The model tended to under- or over-estimate age data when observations of age changed dramatically in the opposite direction for all three fishery types (recreational, commercial and survey).

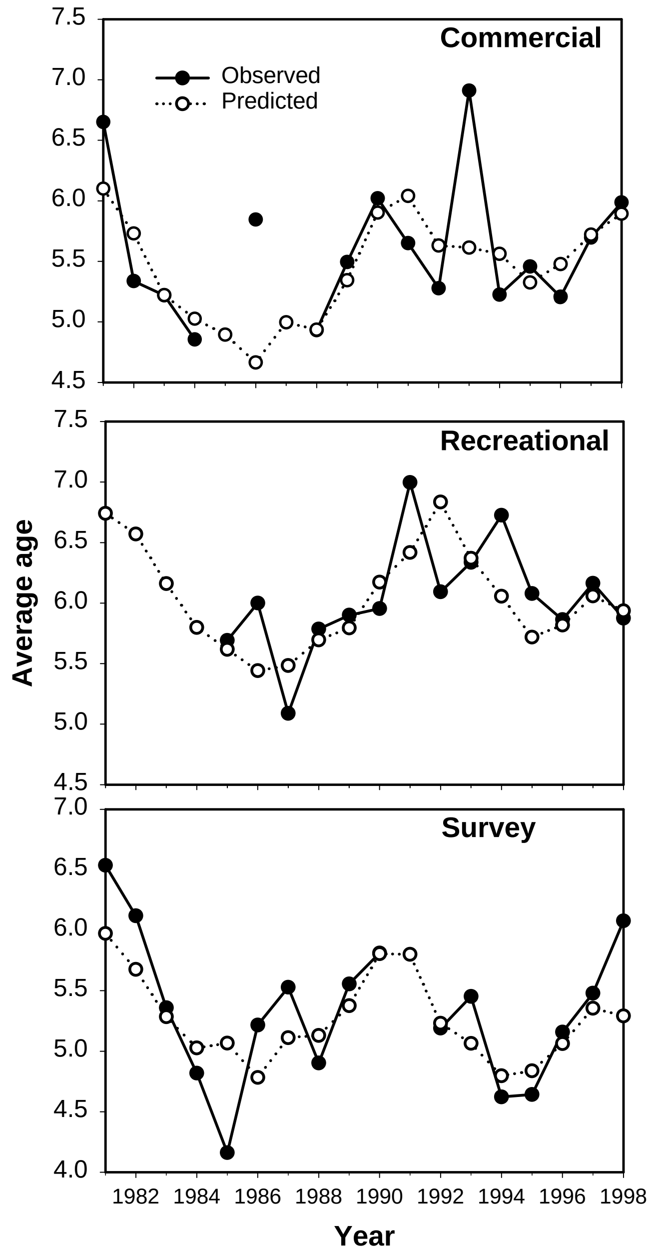


Figure 22. Observed and predicted average age for lake trout collected in commercial, recreational, and survey samples from the Grand Traverse Bay management unit during 1981 to 1998. Recreational harvest was not estimated prior to 1985, commercial age composition data were not available for the years 1985 and 1987, and survey data were not available from 1991. Commercial age compositions were estimated for lake trout age 3 to 15, survey for age 3 to 12+ and recreational fisheries for ages 1 to 15.

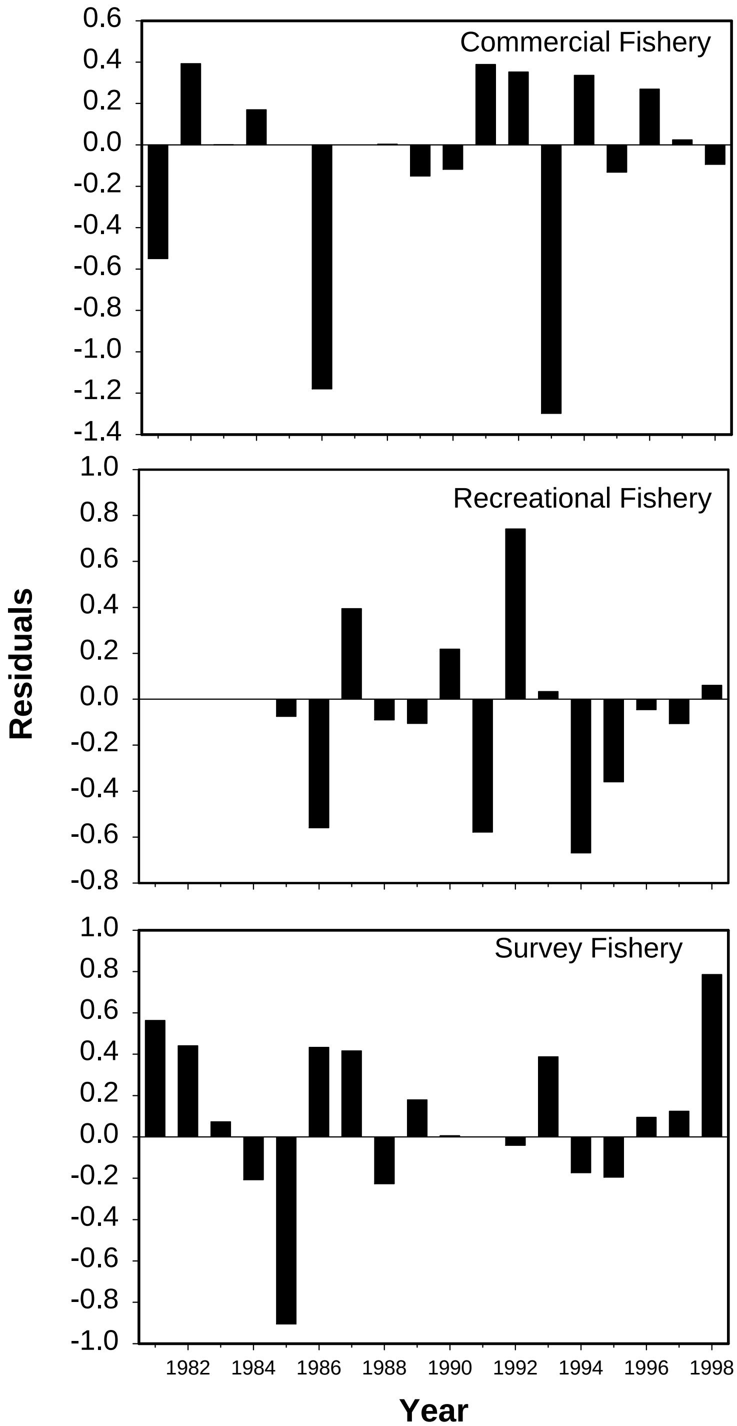


Figure 23. Non-standardized residual values for recreational, commercial, and survey average age data from Grand Traverse Bay. Residuals are calculated as observed minus predicted values. Recreational harvest was not estimated prior to 1985, commercial age composition data were not available for the years 1985 and 1987, and survey data were not available from 1991. Commercial age compositions were estimated for lake trout age 3 to 15, survey for age 3 to 12+ and recreational fisheries for ages 1 to 15.

Status of Lake Trout in the Central Unit (MM-5)

Spatial Summary

Lake trout management unit MM-5 is located in eastern central Lake Michigan and corresponds to the MM-5 statistical district. This area constitutes an area of high use by both tribal and state interests. The unit covers 2,100 square miles and encompasses Michigan's waters of Lake Michigan from Arcadia north to the tip of the Leelanau Peninsula, extending to the state line bisecting the middle of the lake. There are two islands in this management unit, the North and South Manitou Islands. Some of the deepest waters and largest drop-offs in Lake Michigan occur in MM-5. Water depths range to 825 feet and for the most part are greater than 400 feet. Only 440 square miles of the unit are at depths less than 240 feet. The entire area is in 1836 Treaty waters and there are no refuges allocated within the management unit. Only a small amount of lake trout spawning habitat is located here, most of which is located in the nearshore zone and around the North and South Manitou Islands.

Stocking

The recruitment of lake trout in the MM-5 management unit of Lake Michigan is based entirely on stocking. The U.S Fish and Wildlife Service is the primary agency responsible for stocking lake trout in Lake Michigan. In each of the last ten years, approximately 208,000 yearling lake trout have been stocked into the MM-5 management unit. To more accurately estimate recruitment in the model, the number of fish stocked is adjusted to account for mortality and movement among the various regions in the lake. Over the last 10 years (1989-1998) the recruitment to age one has averaged 237,000 fish in MM-5.

Fishery Independent Surveys

Fishery independent gill-net surveys were conducted in the MM-5 unit by the Michigan Department of Natural Resources from 1981 to 1989 and again in 1997 and 1998. A total of 57 gill-net sets were incorporated into the model of this region. All survey nets were comprised of graded-mesh (2.5 to 6.0 inch) gill nets at a range of lengths. The catch was expressed as catch per 1,000 feet of graded-mesh gill net set overnight. Years without data were entered as -1 and not used to fit the model.

Fisheries

Although both state and tribal commercial fishermen harvest fish in the MM-5 management unit, state-licensed commercial fisheries are primarily trap-net operations targeting lake whitefish. State licensed fishermen are not permitted to harvest lake trout, and as a result, are not included in lake trout harvest allocations.

There are three types of tribal commercial fisheries (large-mesh gill net, small-mesh gill net, and trap net) in the unit. Tribal commercial yield increased from 862 lb in 1993 to 64,000 lb in 1997. The large-mesh gill-net fishery accounts for the majority of the yield. Large-mesh gill-net effort in tribal fisheries increased from 22,000 feet in 1993 to 500,000 feet in 1998 (Figure 25). The number of lake trout harvested in northern Lake Michigan tribal fisheries increased from 249 fish in 1992 to 13,000 fish in 1997 (Figure 24).

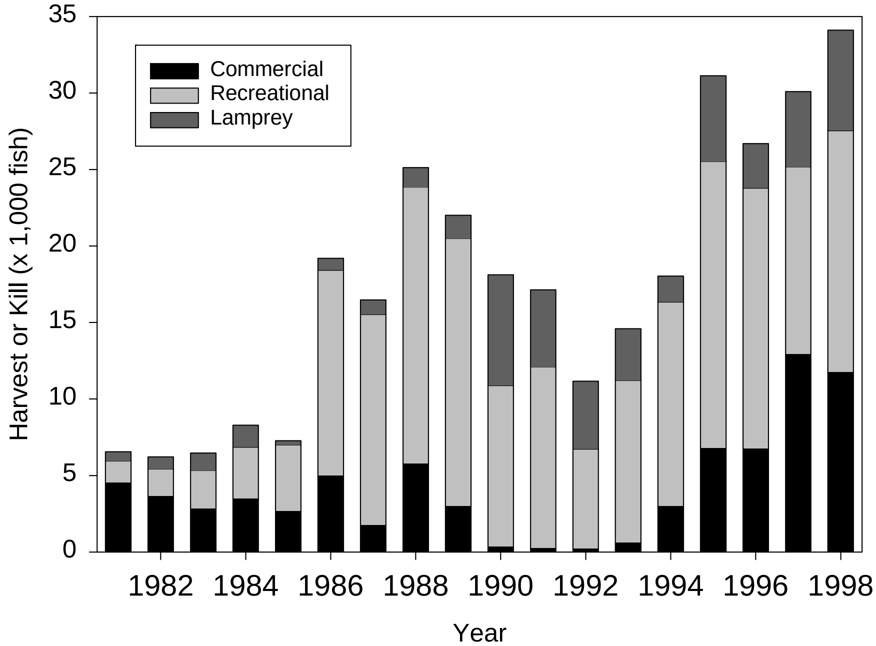


Figure 24. Number of lake trout killed each year (1981-1998) by three mortality sources (commercial fishing, recreational fishing and lamprey predation) in Lake Michigan management unit MM-5.

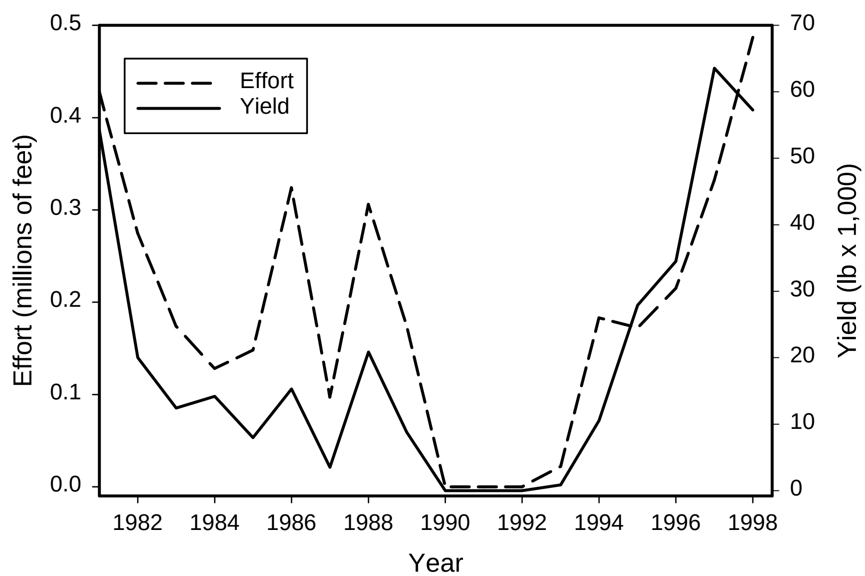


Figure 25. Observed commercial fishery effort and yield from 1981-1998, Lake Michigan management unit MM-5.

The management of recreational fisheries for lake trout is the primary responsibility of the state of Michigan and fisheries are comprised of both charter and sport anglers. The minimum size limit for sport fishing in the MM-5 management unit of Lake Michigan remained 10 inches from 1981-1996. In 1997 and 1998 the northern half of the unit was subject to a 24 inch size limit. Until the late 1990s, recreational fishing mortality had exceeded sea lamprey and commercial fishing mortality in MM-5. In recent years recreational fishing mortality rates on lake trout (averaged over ages 6-11) have dropped significantly from the high of 0.28 y^{-1} observed in 1995 to a low of 0.16 y^{-1} in 1997. In the last two years (1997 and 1998), recreational and commercial fisheries are more similar in their contributions to the number of lake trout killed (Figure 24). The recreational yield of lake trout was highest in the late 1980s, averaging 122,000 lb. In recent years, recreational yield had been decreasing, declining from 95,000 lb in 1995 to 59,000 lb in 1997. A slight increase to 77,000 lb was observed in 1998 (Figure 26). Angling effort was not always directly linked to harvest, though large overall trends were similar- greatest effort in the late 1980s and significantly reduced for the 1990s (Figure 26).

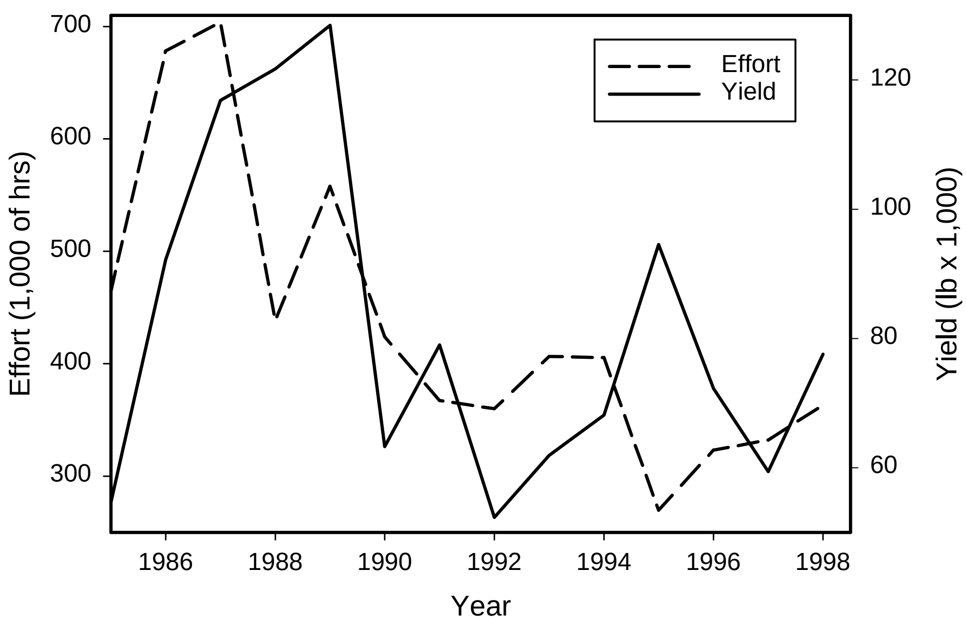


Figure 26. Observed recreational fishery effort and yield from 1981-1998, Lake Michigan management unit MM-5.

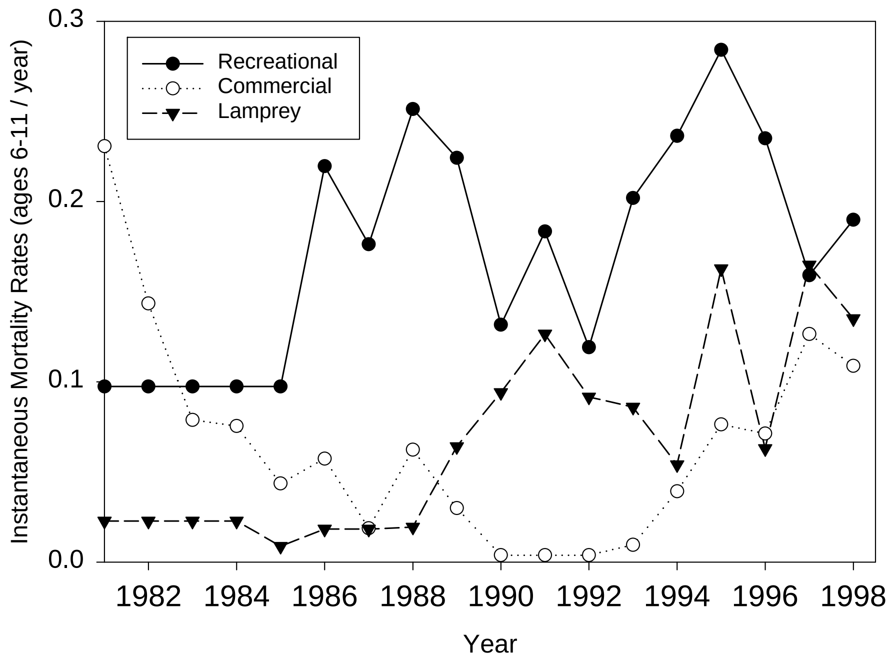


Figure 27. Instantaneous mortality rates of lake trout (averge for ages 6-11) in Lake Michigan management unit MM-5, summarized for three mortality sources (recreation fishing, commercial fishing and sea lamprey predation).

From 1981-1988 sea lamprey mortality was less than either recreational or commercial mortality. From 1988-1991 sea lamprey mortality rates steadily increased, and the rates remained high and were much more variable from 1991 to 2001 (Figure 27). Peak sea lamprey mortality rates in the management unit were observed in 1997 at 0.17 y^{-1} (Figure 27). The average number of lake trout deaths attributed to sea lamprey during 1995-1998 was 5,000 fish (Figure 24).

Selectivity

Commercial, recreational and survey fishery selectivity patterns were represented by flattened, dome shapes with peak selectivity occurring around age 5 (Figure 28). It is possible that we are not estimating selectivity for fish older than age eight correctly in the model. This issue will need further evaluation in the future, particularly as the population ages.

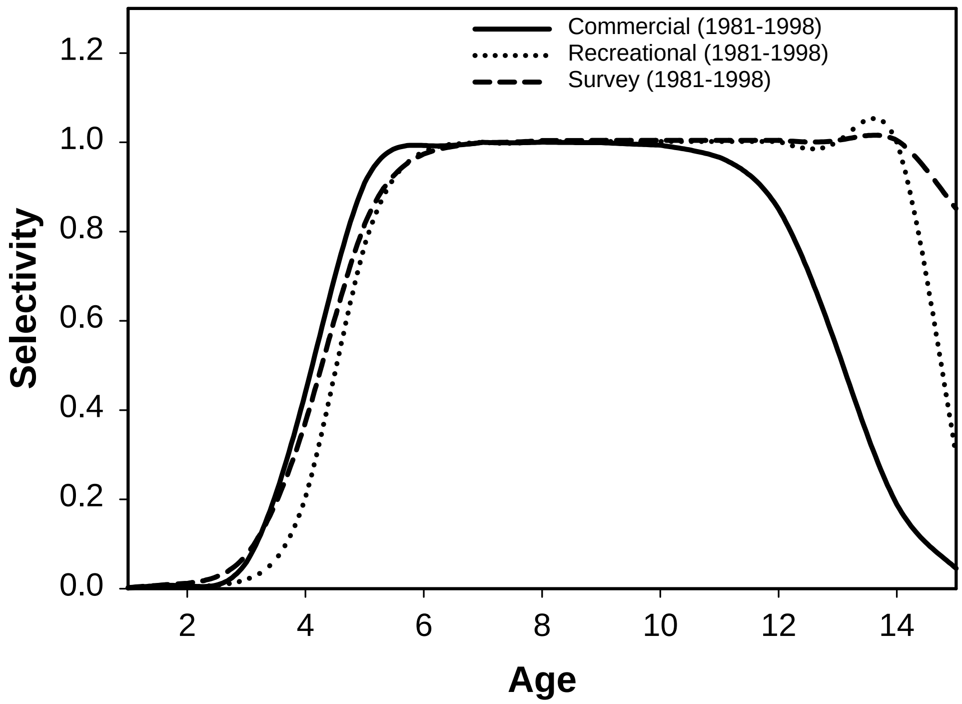


Figure 28. Estimated selectivity patterns in commercial, recreational and survey fisheries, Lake Michigan management unit MM-5.

Population Summary

In general, lake trout in MM-5 are both spawning and recruited into commercial and recreational fisheries by age 6. The total biomass of lake trout has been generally rising. Biomass was high in 1988 at 990,000 lb, declined in 1989 and the early 1990s, and then rose to a high value in 1998 of 1,100,000 lb (Figure 29).

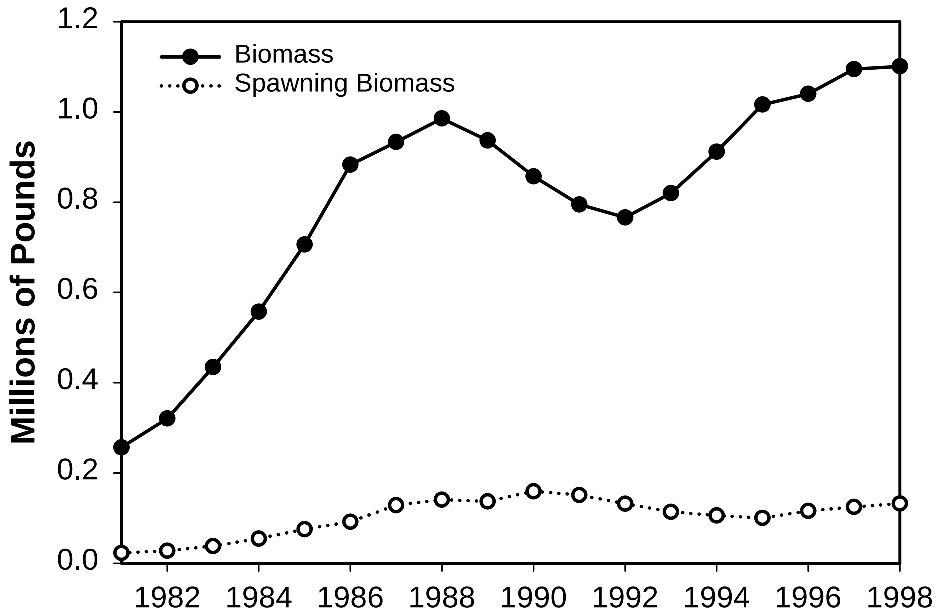


Figure 29. Modeled estimates of biomass and spawning biomass of lake trout in management unit MM-5 Lake Michigan (1981-1998).

Status Relative to Reference Point in Management Unit MM-5

<u>Spawning stock biomass per recruit (SSBR)</u>
The spawning stock biomass produced per recruit (0.359 lb) is above the target value (0.288 lb), indicating that as of 1998, the spawning stock of lake trout is high enough to meet management objectives for the MM-5 unit. Based on the recent five-year model estimates (1994-1998), mortality rates are high and above the established target maximum. The average Z for age 6 to 10 yr old lake trout during 1994-98 was 0.72 (range: 0.62-0.82, target is 0.60).

<u>Harvest and TAC</u>
The target mortality rate in the MM-5 management unit was set at 45%. Fisheries are allocated at 60 percent to the state of Michigan and 40 percent to tribal fisheries. Language in the negotiated Consent Decree states that fishery TAC limits will not vary by more than 15 percent among years. In all other aspects this unit is considered fully phased to management objectives.

Model Fit
With the exception of survey data, which were sparse in recent years, model predictions of harvest and catch were generally consistent with observed data (Figure 30). Some patterns were observed in residuals for the recreational fishery, but the magnitude of difference was very small (Figure 31). We tended to overestimate recreational harvest prior to 1992 and underestimate thereafter. For commercial fishery harvest the strong deviations occurred early in the modeling process and became less significant over time.

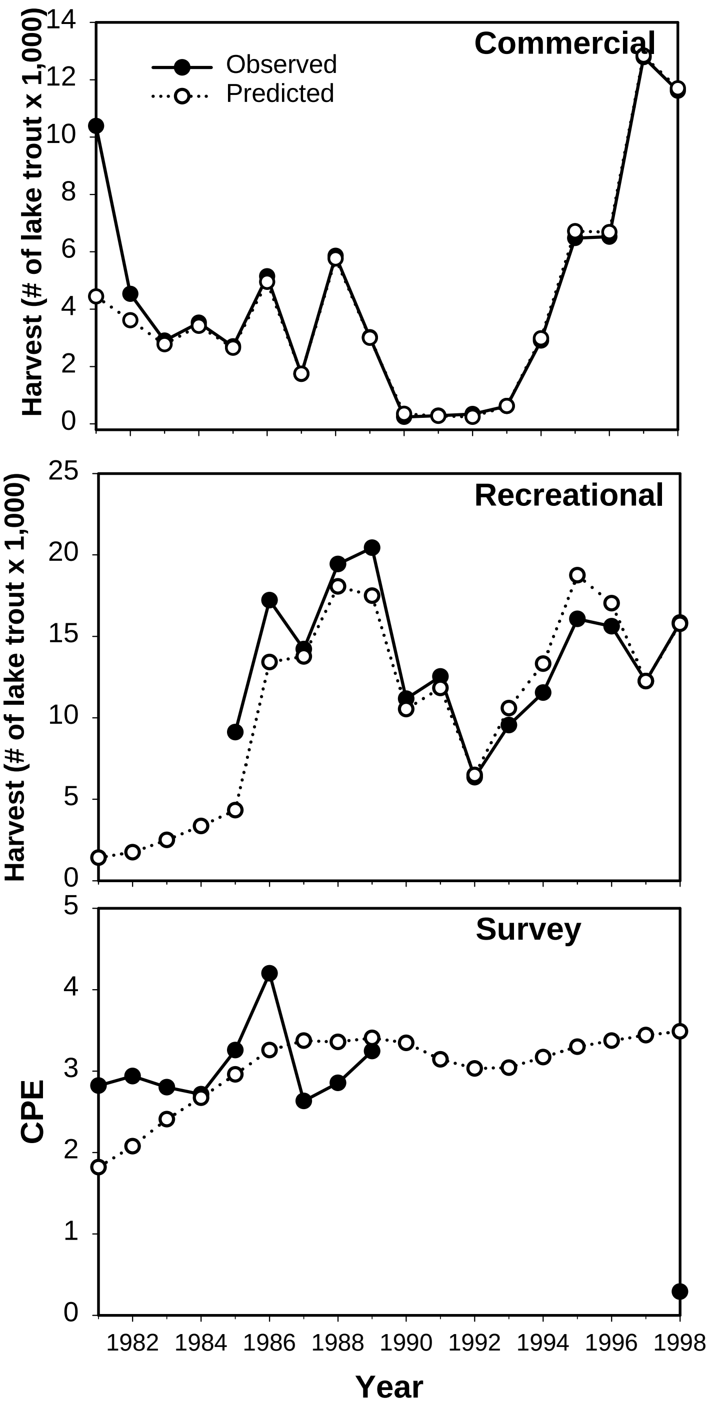


Figure 30. Observed and predicted survey catch-per-unit effort (CPUE), recreational harvest and commercial harvest for the MM-5 management unit during 1981 to 1998.

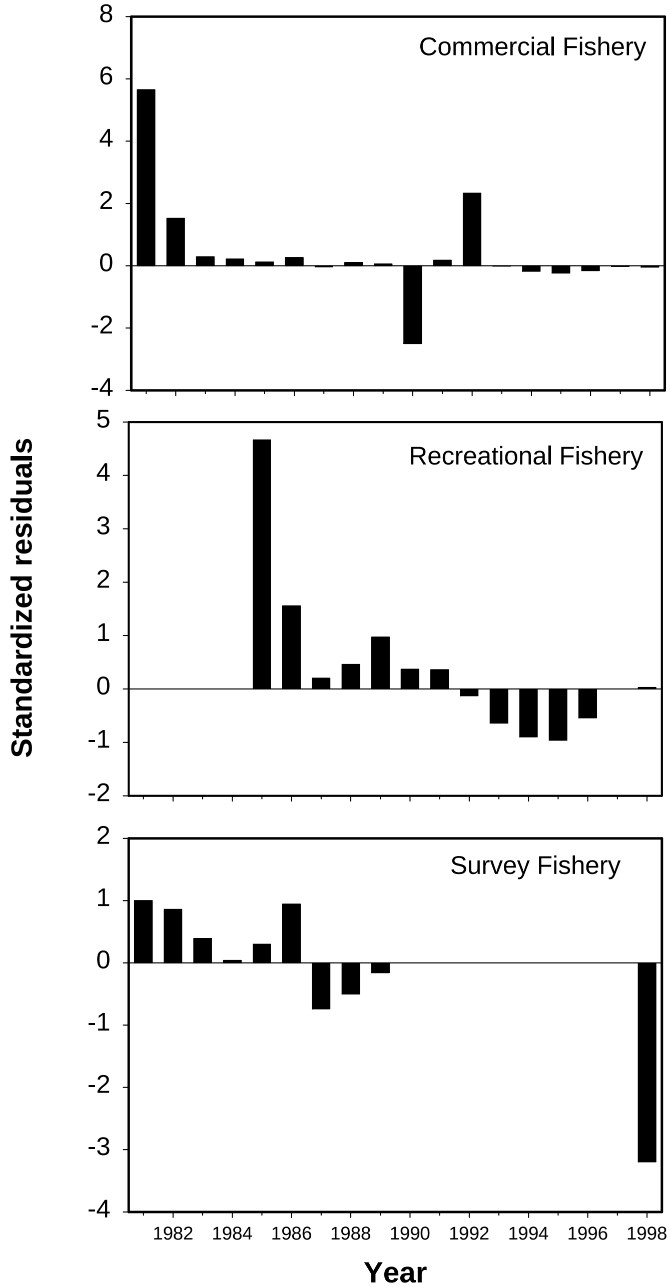


Figure 31. Standardized residual values for survey catch, recreational fishery harvest, and commercial fishery harvest from 1981-1998 in Lake Michigan management unit MM-5. Standardized residuals are calculated as observed minus predicted values divided by the estimated standard deviation. Recreational harvest was not estimated prior to 1985.

In general, the predicted average age of lake trout captured in commercial, recreational and survey fisheries was between 5 and 6 yrs (range 4.1 to 7.6 across years; Figure 32). The observed and predicted values for average age in commercial and recreational fisheries did not match as well as the harvest estimates (Figure 32). The commercial fishery only had two years in which age data were collected, making the fitting process difficult. The observed age composition data from the recreational and survey fisheries showed higher variation from year to year than modeled estimates (Figure 32). Non-standardized residuals of average age data do not show any significant patterns for commercial, recreational or survey fisheries (Figure 33). The model tended to under- or over-estimate age data when observations of age changed dramatically in the opposite direction (e.g. 1987, 1992 and 1996 for recreational fisheries and 1981, 1982 and 1997 for the survey).

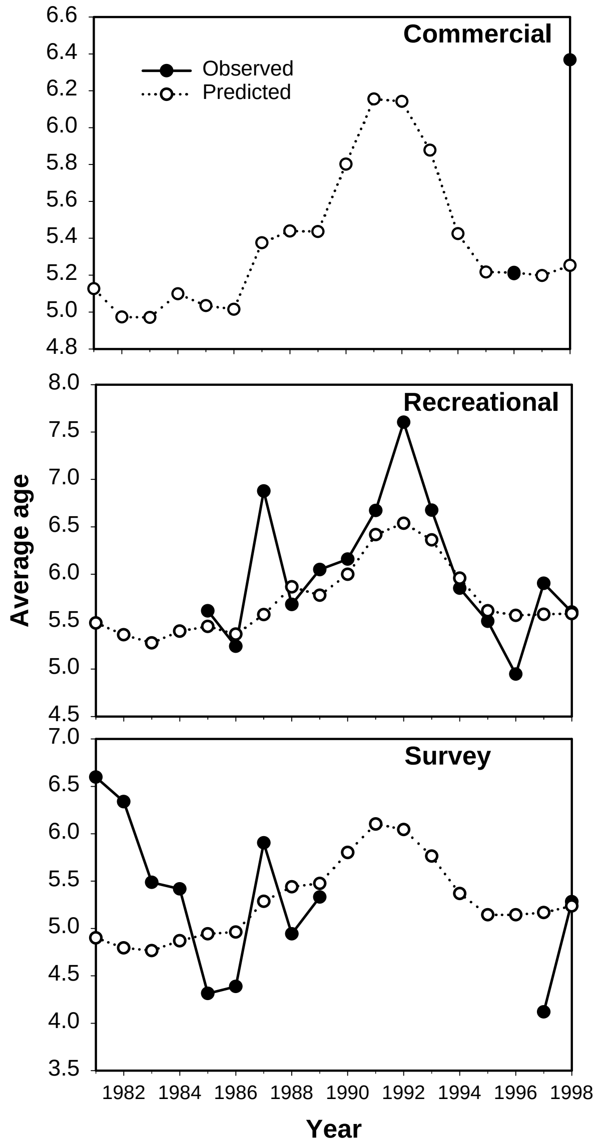


Figure 32. Observed and predicted average age for lake trout collected in commercial, recreational and survey samples from the MM-5 management unit during 1981 to 1998. Recreational harvest was not estimated prior to 1985, commercial age composition data were only available for the years 1996 and 1998, and survey data were not available from 1990 to 1996. Commercial age compositions were estimated for lake trout age 3 to 15, survey for age 3 to 12+ and recreational fisheries for ages 1 to 15.

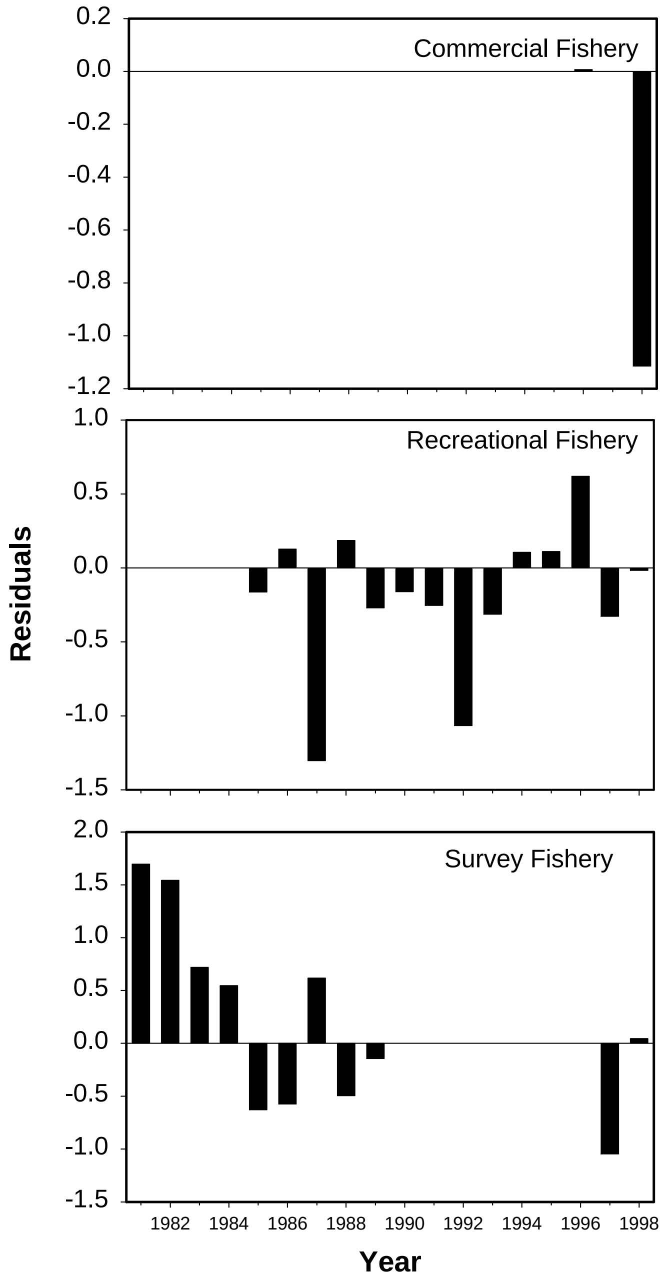


Figure 33. Non-standardized residual values for recreational, commercial, and survey average age data from management unit MM-5. Residuals are calculated as observed minus predicted values. Recreational harvest was not estimated prior to 1985, commercial age composition data were only available for the years 1996 and 1998, and survey data were not available from 1990 to 1996. Commercial age compositions were estimated for lake trout age 3 to 15, survey for age 3 to 12+ and recreational fisheries for ages 1 to 15.

Status of Lake Trout in the Southern Unit (MM-67)

Spatial Summary

The southern lake trout management unit is made up of statistical districts MM-6 and MM-7 (Figure 1). The area includes Michigan's waters of Lake Michigan from Arcadia to Holland, extending to the state line bisecting the middle of the lake. This management unit covers 4,460 square miles, of which 930 square miles are less than 240 feet in depth. The northern section of the region (MM-6) is deeper ranging in depth from 0 up to 900 feet and is characterized by greater slope than the southern section (MM-7). For the most part water depths in MM-7 are less than 400 feet. There are no islands or structures in southern treaty waters, and there is little lake trout spawning habitat with the exception of offshore deepwater spawning reefs located within the southern refuge. Stocked lake trout almost certainly attempt to spawn in the nearshore zones. However, the likelihood of successful recruitment is negligible. The southern treaty management unit is not entirely comprised of 1836 waters', the northern section (MM-6) is entirely treaty ceded territory while only the northern two-thirds of the southern section (MM-7) is within treaty territory. A total of 690 square miles in the unit are outside treaty waters. A line running parallel to the northern side of the Grand River (located approximately ¾ of the way through grids in the 1900 series) out to the state line in the middle of the lake delineates the southern boundary of treaty territories in the unit. Management unit MM-67 contains a portion of the deepwater mid-lake lake trout refuge, which comprises 850 square miles of the unit (grids 1606, 1607, 1706, 1707, 1806, 1807, 1906 and 1907).

Stocking

Recruitment of lake trout in the southern management unit of Lake Michigan is currently based entirely on stocking. In each of the last ten years, approximately 614,000 yearling lake trout have been stocked into the unit and approximately 50 percent of these fish are stocked into the southern refuge area (Figure 2). To more accurately estimate recruitment in the model, the number of fish stocked is adjusted to account for mortality and movement among the various regions in the lake. Over the last 10 years (1989-1998) the recruitment to age one has averaged 366,000 fish in the southern management unit of Lake Michigan.

Fishery Independent Surveys

Fishery independent gill-net surveys were conducted in the southern unit by the Michigan Department of Natural Resources from 1981 to 1990 and again in 1997 and 1998. A total of 74 gill-net sets were incorporated into the model of this region. All survey nets were comprised of graded-mesh (2.5 to 6.0 inch) gill nets at a range of lengths. The catch was expressed as catch per 1,000 feet of graded-mesh gill net set overnight. Years without data were entered as -1 and not used to fit the model.

Fisheries

As of 1998, the commercial fishery in southern treaty waters of Lake Michigan is comprised of only a few state-licensed commercial fishers. State-licensed commercial fisheries primarily target lake whitefish and chubs, and are not permitted to harvest lake trout. As a result, state commercial fisheries are not included in lake trout harvest allocations. Since 1981 commercial fishing has killed fewer lake trout than other sources of mortality in southern Lake Michigan (Figure 34).

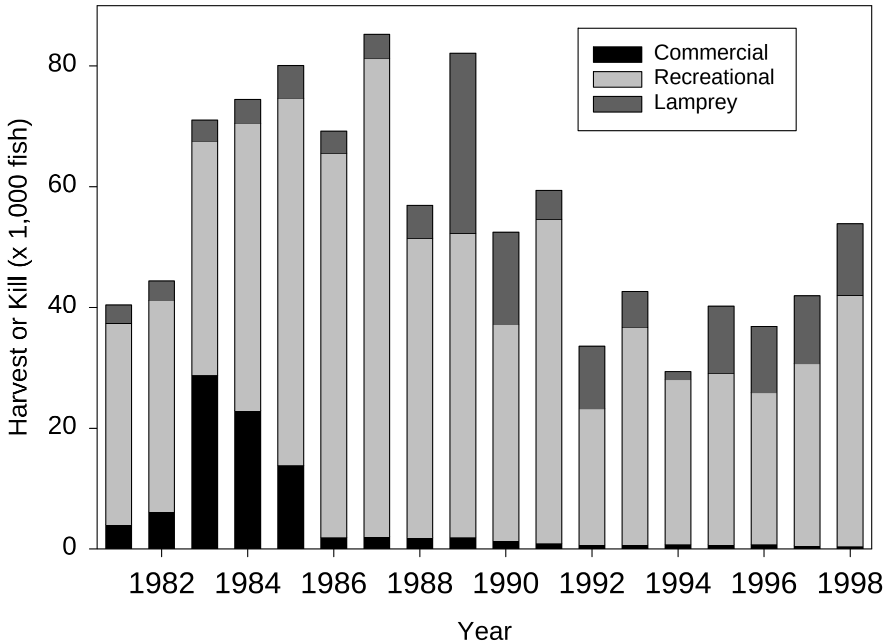


Figure 34. Number of lake trout killed each year (1981-1998) by three mortality sources (commercial fishing, recreational fishing and lamprey predation) in Lake Michigan.

It is illegal for recreational fishers to retain lake trout when fishing in the southern refuge and gill-net fishing (both commercial and subsistence) is also prohibited. Commercial trap-net operations are permitted; however, the retention of lake trout is prohibited. As of the year 1998 there was no tribal commercial fishing effort in management units MM-67; all commercial fishing efforts were state-licensed. Lake trout harvest is prohibited for state-licensed commercial fisheries therefore the commercial harvest of lake trout is extremely low is this region (Figure 35).

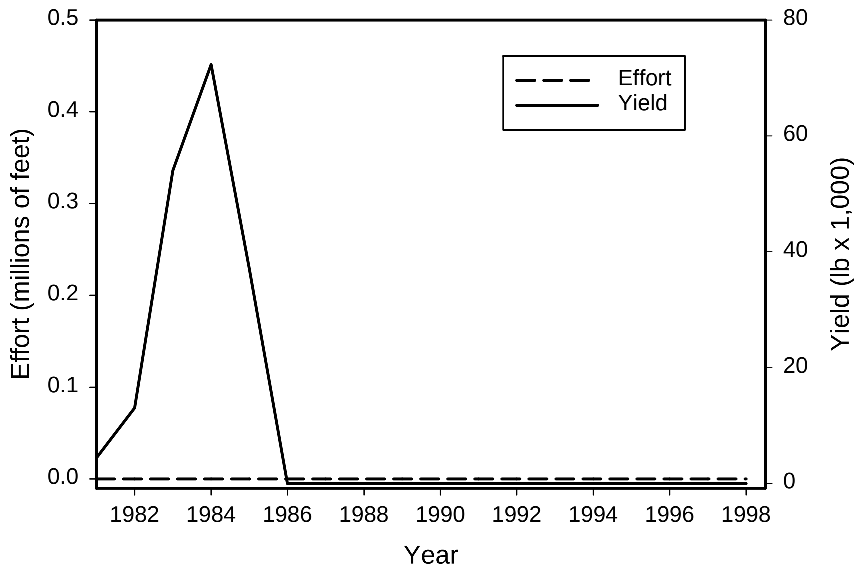


Figure 35. Southern Lake Michigan observed commercial fishery yield from 1981-1998. Effort was not recorded for this region.

State recreational fisheries for lake trout are comprised of both charter and sport anglers. In general, recreational fishing mortality has been higher than either commercial fishing mortality or mortality due to sea lamprey (Figure 37). The minimum size limit for lake trout in the MM-67 management unit is 10 inches, the bag limit is two fish per day, and the recreational fishing season extends from January 1 until Labor Day. The size and bag limits have not changed since 1981. However, the fishing season has changed twice, once in 1984 where the season was restricted from the entire year to May 1 through August 15th, and again in 1989 when the season was extended through Labor Day. Angling effort and yield have been declining since 1987. In recent years however, recreational yield has increased from 115,000 lb in 1996 to 203,000 lb in 1998, still significantly lower than the 668,000 lb observed in 1987. Angling effort indicates similar patterns though lagging yield by one year. Angler hours rose from 677,000 in 1995 to 1,360,000 in 1998 (Figure 36). Recreational effort was highest in 1986 at 3,500,000 hours.

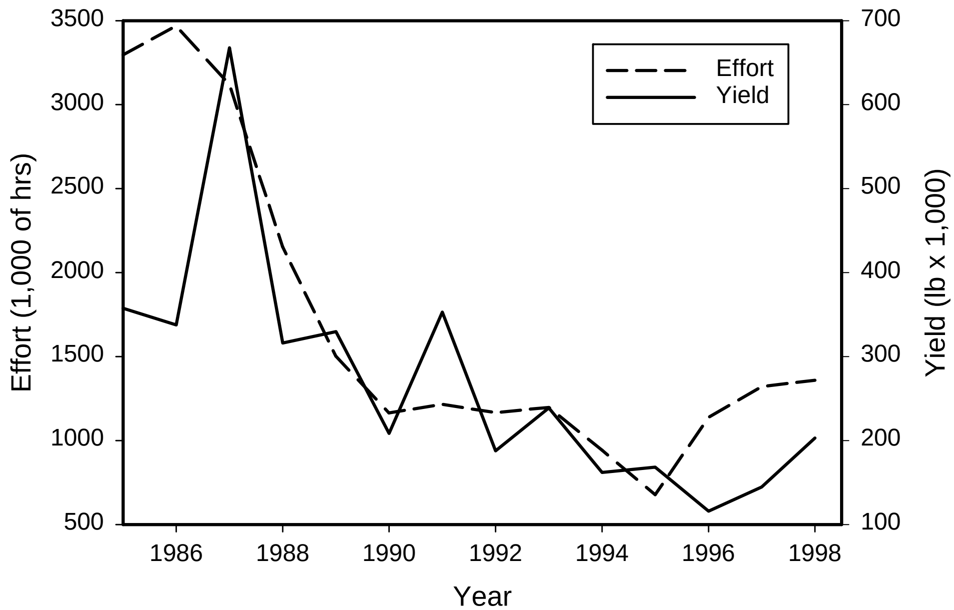


Figure 36. Southern Lake Michigan observed recreational fishery effort and yield from 1981-1998.

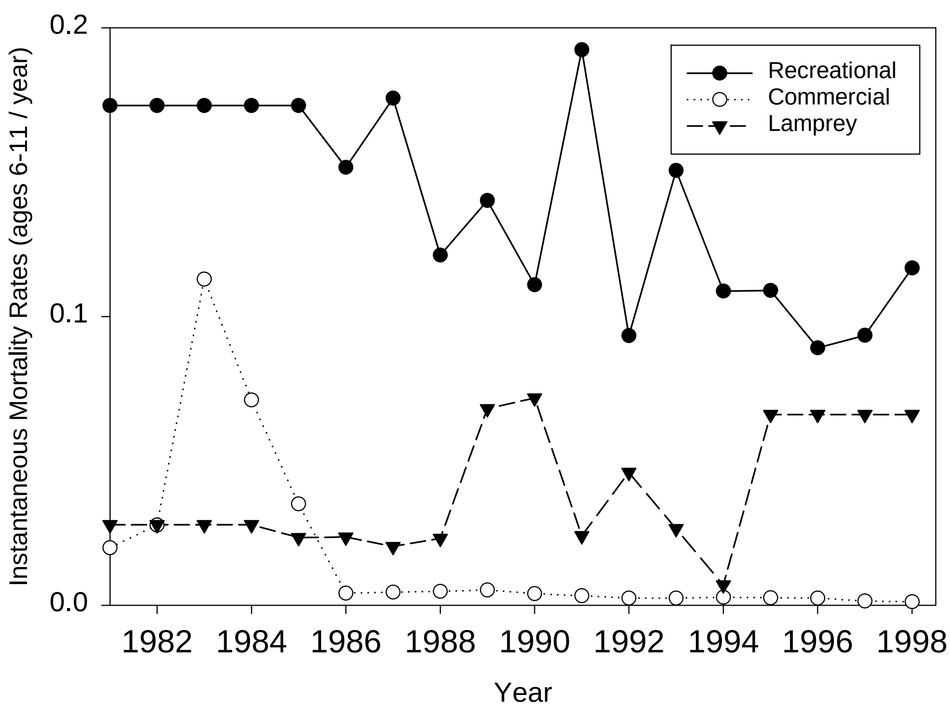


Figure 37. Instantaneous mortality rates of lake trout (average ages 6-11) in southern Lake Michigan summarized for three mortality sources (recreation fishing, commercial fishing and sea lamprey predation).

The number of lake trout killed by sea lamprey was higher in the late 1990s as compared to previous observations, with the exceptions of 1989 and 1990 (Figure 34). Since 1986, sea lamprey-induced mortality has been the second highest source of mortality for lake trout in southern Lake Michigan (Figure 37). Despite this ranking, lamprey mortality rates are relatively low in the southern unit when compared to the northern regions of Lake Michigan.

Selectivity

Commercial fishery selectivity patterns were represented by a flattened dome shape with peak selectivity occurring around age 5 (Figure 38). Recreational selectivity patterns were represented by a more classic dome shape with peak selectivity also occurring somewhat later around age 5. Survey selectivity patterns peaked at age 4 flattened out and began declining around age 9.

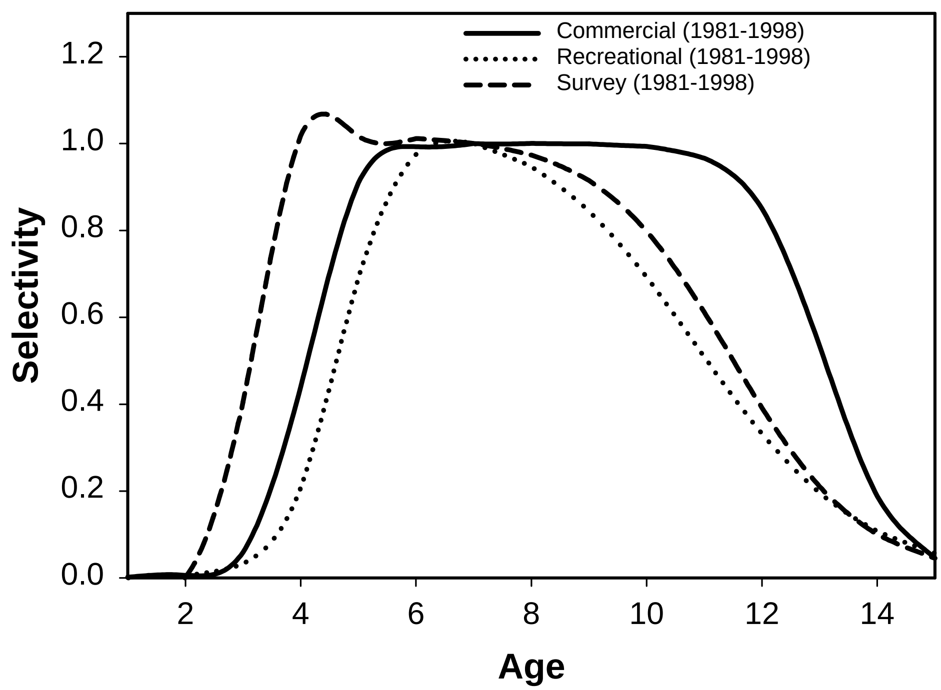


Figure 38. Observed selectivity patterns in commercial, recreational and survey fisheries.

Population Summary

In southern Lake Michigan, lake trout generally are both spawning and recruited into commercial and recreational fisheries by age 6. The biomass of lake trout has been increasing in southern Lake Michigan since 1992 (Figure 39). The spawning biomass indicates similar patterns with less pronounced peaks. The difference between the spawning biomass in refuge and non-refuge fish has remained relatively constant since offshore refuge sampling was initiated. The total biomass of lake trout outside the refuge averaged 1.9 million lb during 1989-1998, compared to 2.7 million lb when refuge and non-refuge fish were considered together (Figure 39).

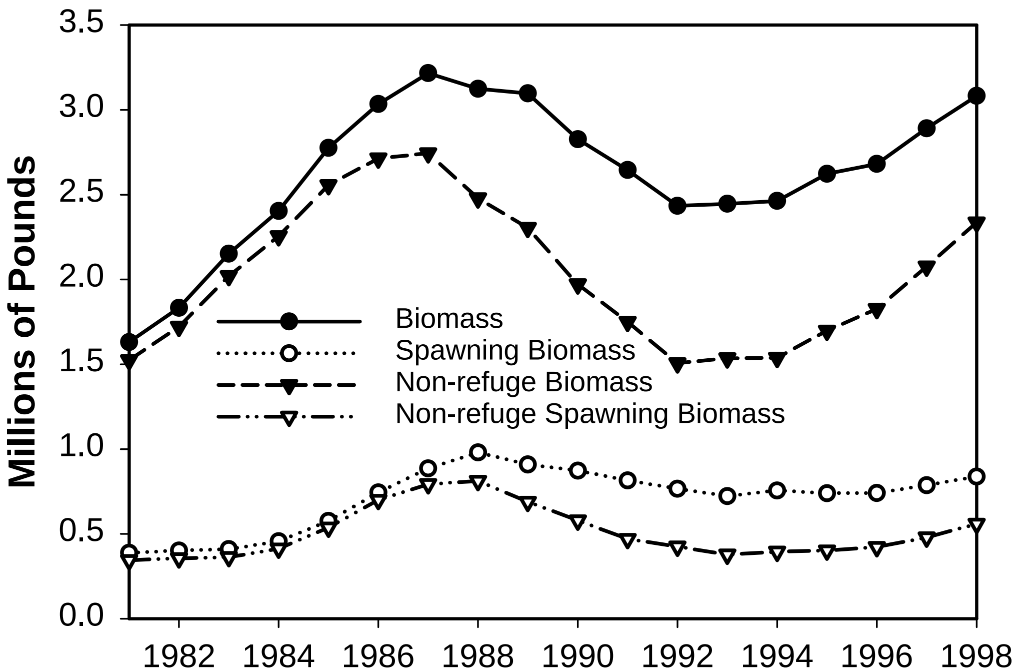


Figure 39. Modeled estimates of biomass and spawning biomass of lake trout in southern Lake Michigan (1981-1998). Circles represent estimates for refuge and non-refuge fish combined. Triangles represent non-refuge lake trout only.

Status Relative to Reference Point in the Southern Region

Spawning stock biomass per recruit (SSBR)

The spawning stock biomass produced per recruit (1.24) is significantly above the target value (0.63) indicating that target mortality rates have been achieved in MM-67. The average Z for age 6 to 10 yr old lake trout during 1996-98 was 0.37 (range: 0.36-0.38, target is 0.51). The SSBR was 1.24 lb for refuge and non-refuge fish combined and 1.96 lb for refuge lake trout only while the target SSBR was 0.63 lb. The refuge appears to afford some protection for spawning lake trout in the southern region of Lake Michigan despite the fact that harvest levels are low and lake trout populations relatively high.

Harvest and TAC

The yield limit and allocations in this management unit are set to achieve a total mortality rate target of 40% and establish a 90 percent allocation to the state of Michigan and a 10 percent allocation to tribal fisheries. Both recreational and commercial fisheries are well below established TAC levels. Language in the negotiated Consent Decree states that fisheries TAC limits will not vary by more than 15 percent among years. In all other aspects this unit is considered fully phased to management objectives.

Model Fit

Generally, model predictions of harvest and catch were consistent with observed data (Figure 40). The residuals for the survey were the highest, indicating a tendency to overestimate CPE in recent years (Figure 41). This is likely due to sparse data during recent time periods. The model tended to overestimate harvest in the early years, though general residuals for commercial harvest were extremely low. The recreational harvest residuals were also small and in general, the model tended to overestimate harvest.

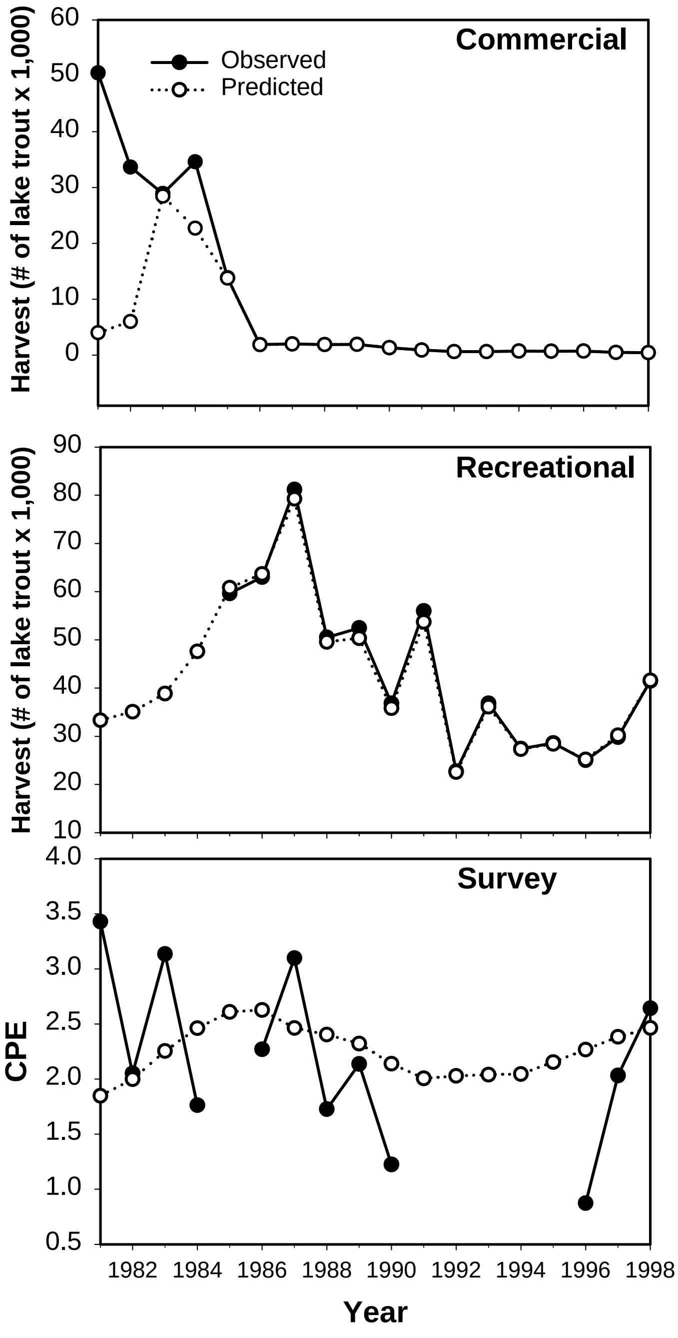


Figure 40. Observed and predicted survey catch-per-unit effort (CPUE), recreational harvest, and commercial harvest for the southern region during 1981 to 1998. Recreational fishery harvest was not recorded prior to 1985. Fishery independent surveys were not conducted in 1985, 1991, 1992, 1993, 1994, and 1995.

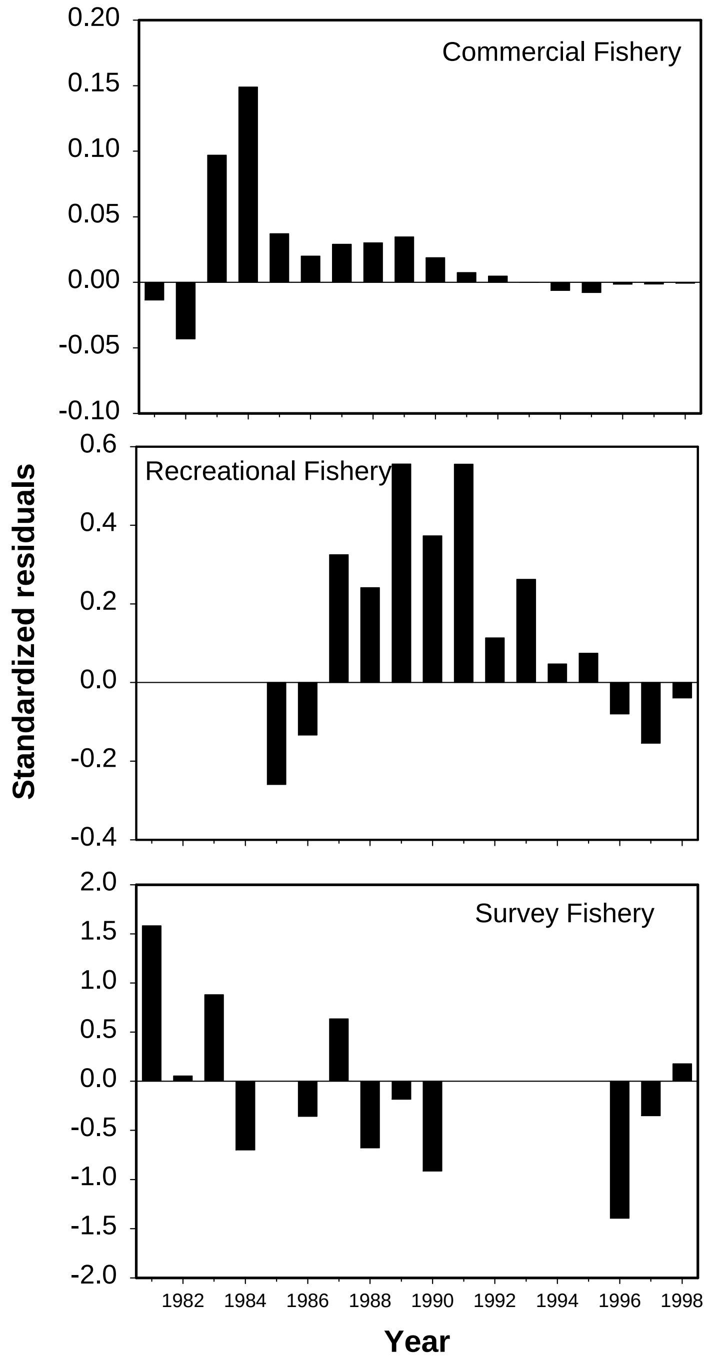


Figure 41. Standardized residual values for survey catch, recreational fishery harvest, and commercial fishery harvest from 1981-1998. Standardized residuals are calculated as observed minus predicted values divided by the estimated standard deviation. Recreational harvest was not estimated prior to 1985 and survey data were not collected in 1985, 1991, 1992, 1993, 1994, and 1995.

The average age of lake trout captured in commercial, recreational and survey fisheries was around 6 yrs (range 4.1 to 7.3 across years; Figure 42). The observed and predicted values for average age in commercial and recreational fisheries varied to a greater extent when compared to the harvest estimates. Non-standardized residuals of average age data do not show any significant patterns for recreational or survey fisheries (Figure 43). The model tended to underestimate recreational and survey age data when observations of age changed dramatically in a positive direction while overestimating when observations were in a positive direction (Figure 43).

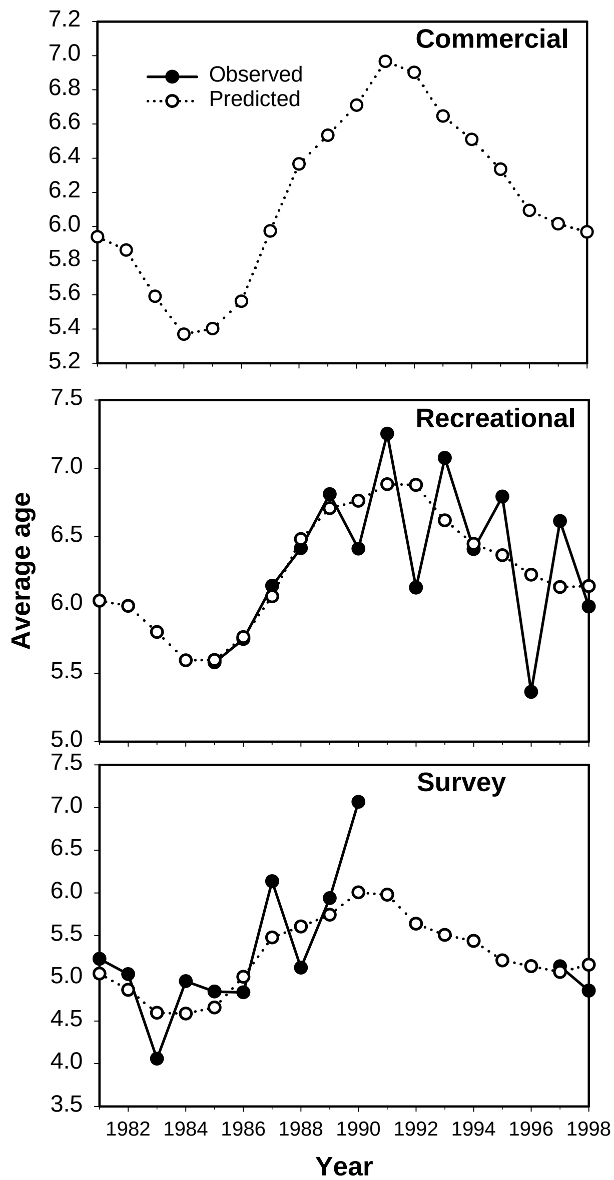


Figure 42. Observed and predicted average age for lake trout collected in commercial, recreational and survey samples from the southern region during 1981 to 1998. Recreational harvest was not estimated prior to 1985, observed commercial age composition data were not available, and recreational age composition data were not available for 1991 through 1996. Commercial age compositions were estimated for lake trout age 3 to 15, survey for age 3 to 12+ and recreational fisheries for ages 1 to 15.

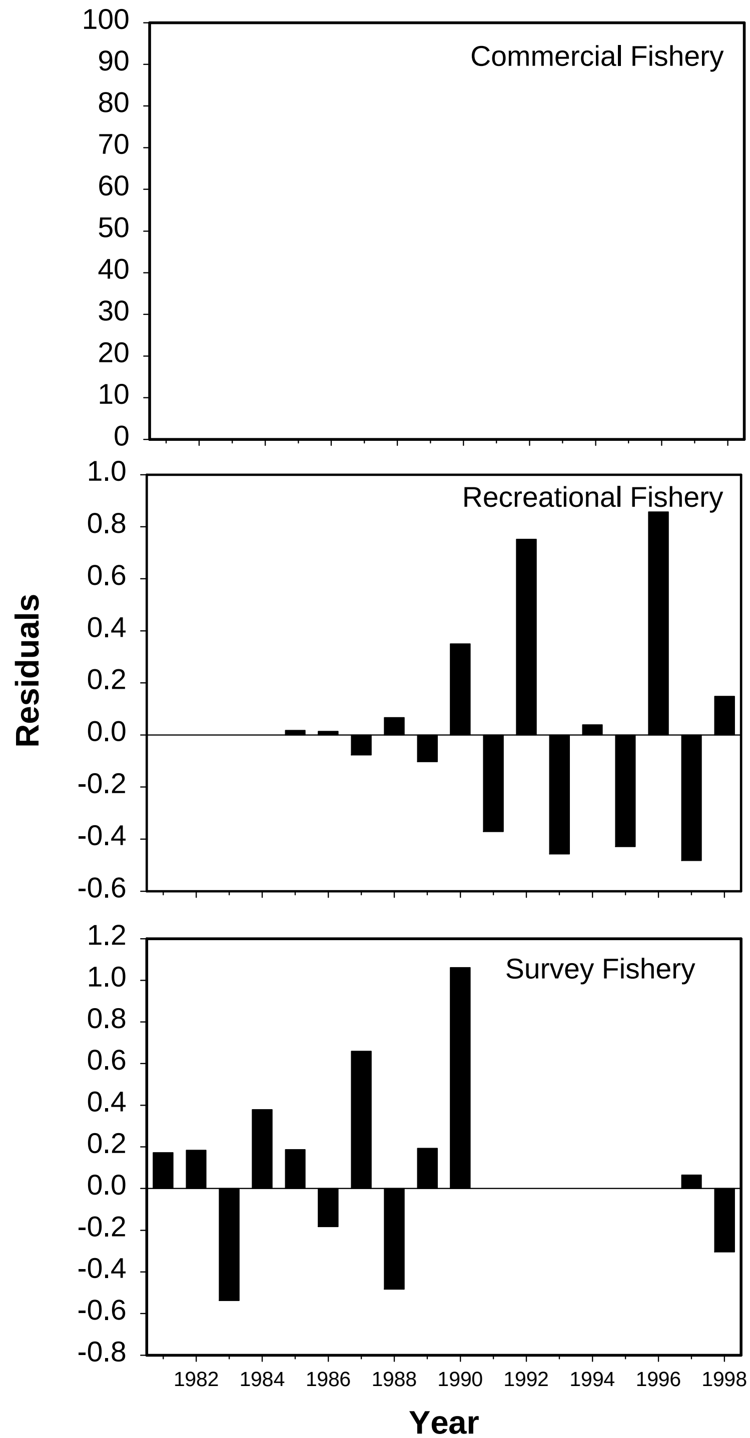


Figure 43. Non-standardized residual values for recreational, commercial, and survey average age data. Residuals are calculated as observed minus predicted values. Recreational harvest was not estimated prior to 1985, commercial age composition data were not available for the entire period, and recreational age composition data were not available from 1991 through 1996. Age compositions were estimated for surveys age 3 to 12+ and recreational fisheries ages 1 to 15.

Status of Lake Trout in Lake Huron

Aaron Woldt

Management Units

Statistical catch-at-age (SCAA) models were developed for two statistical districts in northern Lake Huron, MH-1 and MH-2 (Figure 44). These statistical districts contain all 1836 treaty ceded waters in Lake Huron. The boundary between MH-1 and MH-2 differs from that shown in past Technical Fisheries Review Committee (TFRC) fishery status reports written since the 1985 negotiated Consent Decree (TFRC 1985, 1986, 1987, 1988, 1989, 1992). The new boundary was drawn along grid lines by the Lake Huron Technical Committee with the intent of simplifying allocation of grid-based harvest and survey data to statistical districts. Commercial lake trout harvest in adjacent Canadian management areas (4-1, 4-2, 4-3, 4-7) was included in SCAA models (Figure 44). Area 4-1 was included in the MH-1 model, and areas 4-2, 4-3, and 4-7 were included in the MH-2 model.

Stocks

Lake trout stocks declined dramatically in the 1940s due to overfishing and sea lamprey predation (Berst and Spangler 1973; Coble et al. 1990; Eshenroder et al. 1992; Eshenroder et al. 1995). From 1912 to 1940 annual commercial harvests of lake trout averaged 2.4 million kg (DesJardine et al. 1995), but due to declining abundance commercial harvests of lake trout were minimal in the main basin by 1946 and minimal in Georgian Bay and the North Channel by 1960 (Ebener 1998). In 1998, only two remnant lake trout populations remained, one in Iroquois Bay in the North Channel and one in Parry Sound in Georgian Bay. Only the Parry Sound population had a large enough standing stock to sustain itself without supplemental stocking (Ebener 1998).

Stocking

Supplemental stocking of lake trout began in 1973 with the goal of re-establishing self-sustaining stocks of lake trout in Lake Huron. In MH-1 and MH-2, four distinct areas were stocked with hatchery fish. From north to south they were 1)Drummond Island Refuge (grids 307-310, northern ½ of 407, 408-410); 2) nearshore MH-1; 3) nearshore MH-2; and 4) Six Fathom Bank Refuge (eastern ½ of 913, 914, 915, eastern ½ of 1013, 1014, 1015). Stocked lake trout were primarily yearlings, but fall fingerlings have also been planted, although to a lesser degree due to their lower survival rates. Stocking of yearling lake trout in northern Lake Huron peaked in 1992 with 1.14 million fish (Figure 45a), and stocking of fall fingerlings peaked in 1985 with 507,000 fish (Figure 45b).

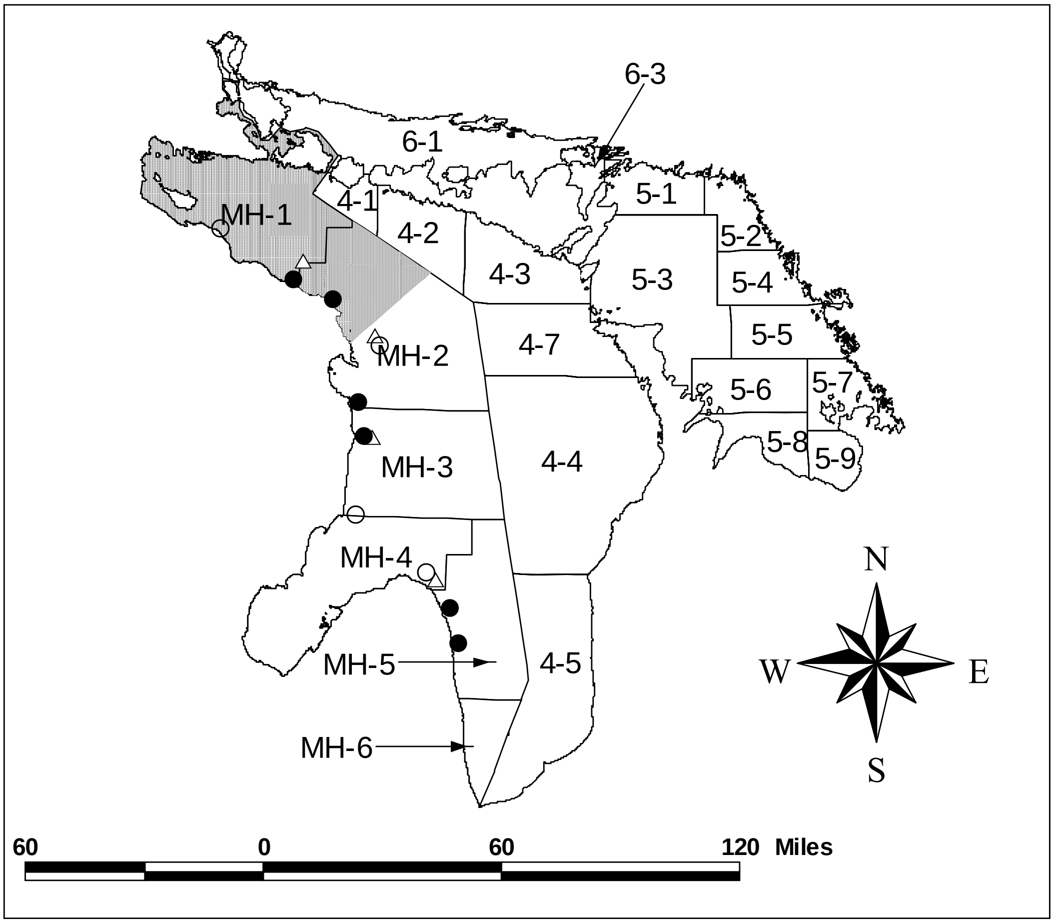
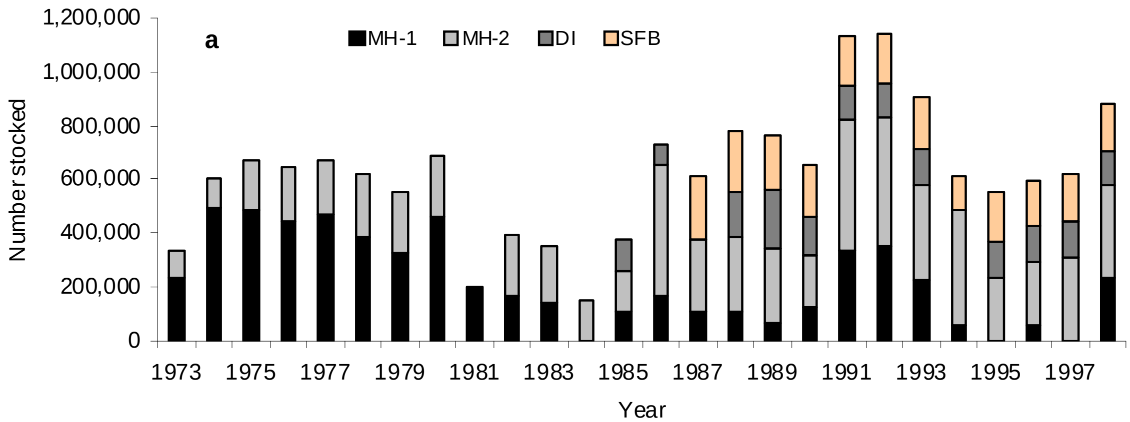


Figure 44. Map of Lake Huron showing U.S. statistical districts and Canadian management areas. 1836 treaty-ceded waters are shaded in gray. Circles denote current MI DNR lake trout spring assessment sites. Open circles denote MI DNR index sampling stations that date back to 1975. Open triangles denote USFWS stocking sites for CWT movement study lake trout.



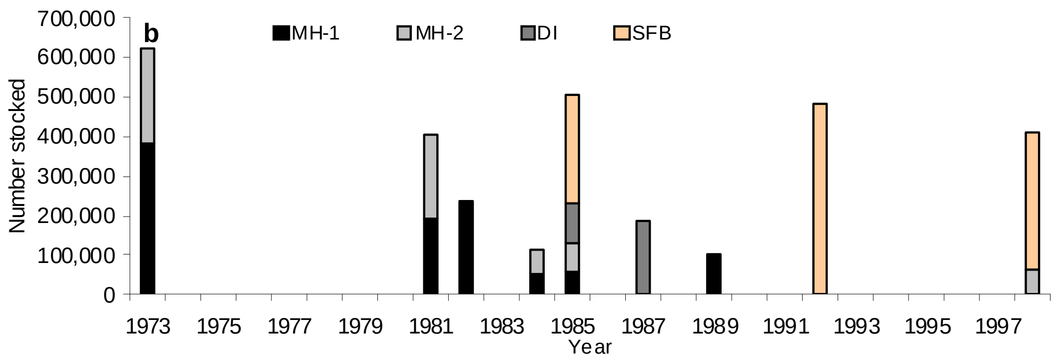


Figure 45. Lake trout stocking in treaty-ceded waters of Lake Huron, 1973-1998. (a) yearling. (b) fall fingerling. Data from Green Bay Fishery Resources Office, USFWS. (SFB = Six Fathom Bank, DI = Drummond Island)

As of 1998, wild lake trout production was negligible, and recruitment was assumed to equal stocking for each statistical district. We essentially assumed each statistical district was its own stock. Movement of fish among the statistical districts was quantified using coded-wire-tag return data. 60,000 yearling lake trout (Lewis Lake strain) were stocked at each of four sites (Figure 44) in 1992, 1994, 1996, and 1998 to assess lake trout movement among statistical districts. Returns of tagged lake trout stocked at Drummond Island and Six Fathom Bank since 1992 were also used to assess movement. Returns of these fish in survey and commercial nets showed significant movement among statistical districts in Lake Huron, so a movement matrix (see hustock.dat data file in Appendix) was applied to adjust stocking/recruitment levels for each statistical district. Emigration and immigration was assumed to occur at age 1 in the models by applying the movement matrix to stocking data.

Life History

Despite high levels of stocking, little evidence has been found of naturally produced juvenile lake trout in Lake Huron. Nester and Poe (1984) and Johnson and VanAmberg (1995) captured unclipped, presumably wild age-0 lake trout on reefs near Alpena, MI, and Anderson and Collins (1995) captured age 0-2 wild lake trout in South Bay, Manitoulin Island. Unclipped lake trout have also been captured by the United States Geological Survey Biological Resource Discipline (USGS BRD) on Six Fathom Bank every year since 1992. However, catches of wild lake trout have been small at these sites, and wild lake trout production has not been recently documented on any other historic lake trout spawning sites (Figure 46).

In treaty waters of MH-1 and MH-2 in 1998, nearly all lake trout were of hatchery origin. The proportion of adults without fin clips was considered to be background at less than 5%. This level could result from missed clips at the hatchery or fin regeneration due to partial clips before stocking. Lake trout are typically a long-lived species; however, due to mortality levels in the late 1990s, few individuals in the treaty waters of Lake Huron lived past age 8. As a result, spawning stock biomass was low and a critical mass required for natural reproduction may not have been present. Although successful natural reproduction was not being achieved, the hatchery lake trout did congregate around spawning reefs in October and deposit eggs. Eggs incubated over the winter and some fry hatched in early spring. It is hypothesized that a vitamin deficiency caused mortality at this life stage. Thiaminase is an enzyme that breaks down vitamin B1 and was prevalent in alewives, one of the lake trout’s main prey items. As long as mortality remains high, preventing lake trout from reaching advanced ages, and alewives remain in the diet of adult lake trout, natural reproduction may be hindered.

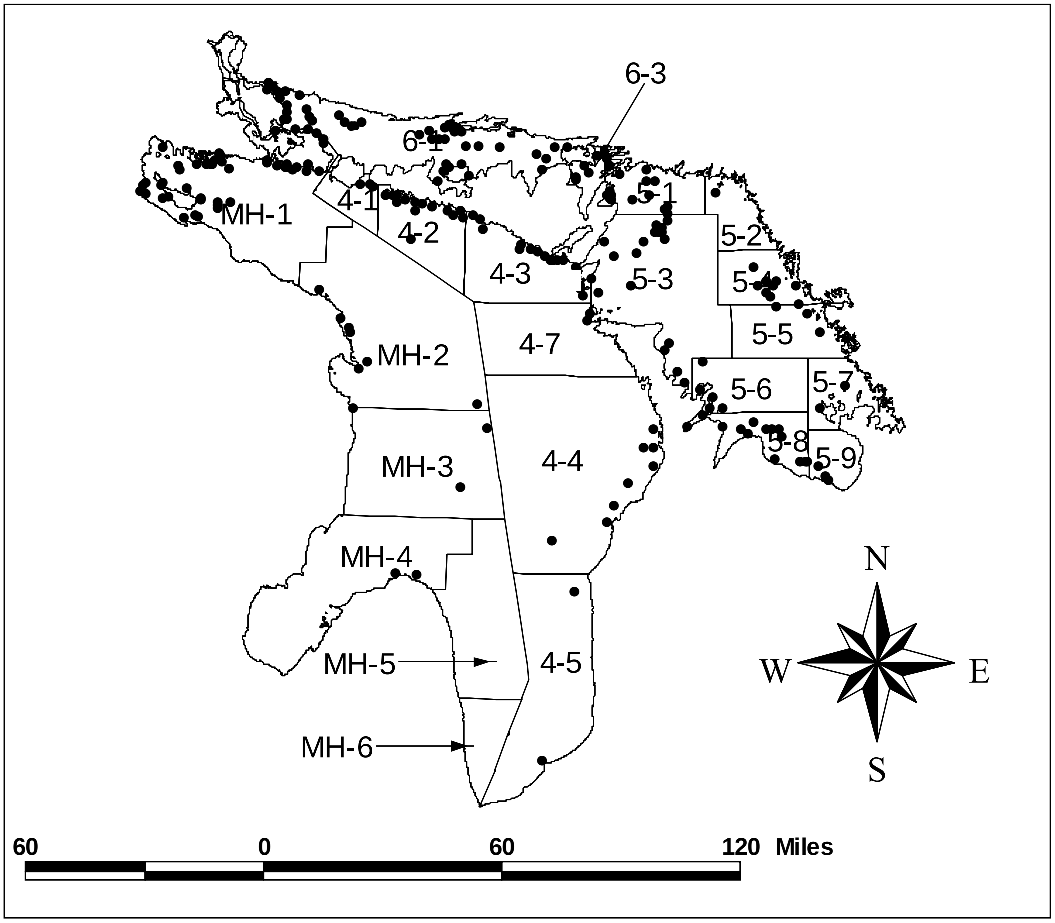


Figure 46. Map of historic lake trout spawning reefs in Lake Huron.

Fisheries

General

Both commercial and recreational lake trout fisheries were present in MH-1. As part of the 1985 negotiated Consent Agreement between the Tribes and the State of Michigan, tribal commercial fishers could fish north of a line running northeasterly from the Hammond Bay Harbor buoy to the point where grids 406, 407, 506, and 507 intersect, and state-licensed commercial fishers could fish south of this line. Tribal commercial fishers deployed large-mesh gill nets (>11 cm stretch) and trap nets that targeted lake whitefish and salmonids, and small-mesh gill nets (≈ 6 cm stretch) that targeted bloater chubs. Lake trout were caught in these fisheries as bycatch and were marketed by tribal fishers. As of 1998, one state-licensed commercial fisher operated a trap-net operation in MH-1. The fisher targeted lake whitefish and was not allowed to market lake trout bycatch. All lake trout were required to be returned to the water, regardless of condition and reported as dead or released. Bycatch mortality of trap-net caught lake trout was estimated to be as high as 5.4% (Roger Bergstedt, Hammond Bay Biological Station, personal communication). So, lake trout mortality due to state-licensed tap-net fishers was calculated as reported number of dead fish plus 5.4% of total number released. After negotiations for the 2000 Consent Decree, the State fisher was moved south of treaty waters.

The recreational fishery in MH-1 was comprised of both charter and non-charter fisherman. Lake trout were frequently caught as bycatch by salmon fishermen trolling at or near the surface, but some anglers targeted lake trout by fishing the lower parts of the water column. Recreational effort and harvest was estimated from individual month and port creel surveys conducted by MDNR. In MH-1, the port of Rogers City was creel surveyed annually, and other areas (St. Ignace to St. Martins Bay, Les Cheneaux Islands, St. Vital Pt. to Detour, Drummond Island) were surveyed less frequently. Yearly creel estimates were expanded to include areas not regularly sampled based on the ratio of harvest in those areas to the harvest at regularly sampled ports. Subsistence fishing permits were also issued to tribal members in 1836 treaty waters.

In contrast to MH-1, MH-2 had no commercial gill-net fishery in the late 1990s. Two state-licensed commercial trap-net fishing operations targeted lake whitefish in MH-2 prior to the signing of the 2000 Consent Decree. As in MH-1, state-licensed commercial fishers were required to return all lake trout to the water and report lake trout deaths. As of 1999 there were no tribal commercial fisherman operating in MH-2, except for one Bay Mills sponsored fisherman who took part in a recent gill-net assessment fishery study between Hammond Bay and Alpena. The recreational fishery in MH-2 is composed of both charter and non-charter fisherman. In general, recreational effort and harvest is higher in MH-2 than in MH-1. Annual creel surveys are conducted at Rockport and Alpena, and Presque Isle was creel surveyed in 1998 and 1999.

Commercial Harvest and Effort

<u>MH-1</u>

Total commercial harvest of lake trout has averaged 71,804 kg a year (range: 6,125-163,043 kg) from 1977 to 1998. The majority of this yield was taken in tribal large-mesh gill nets (Figure 47), but harvest in large-mesh gill nets in adjacent Canadian waters has become increasingly significant in recent years. From 1994 to 1998 Canadian harvest of lake trout averaged 11.6% of the total commercial harvest in MH-1. Lake trout yield in tribal trap nets has also increased in recent years. From 1994 to 1998 tribal trap-net harvest averaged 3,940 kg. Relatively few lake trout are harvested each year in state trap nets or in tribal small-mesh gill nets.

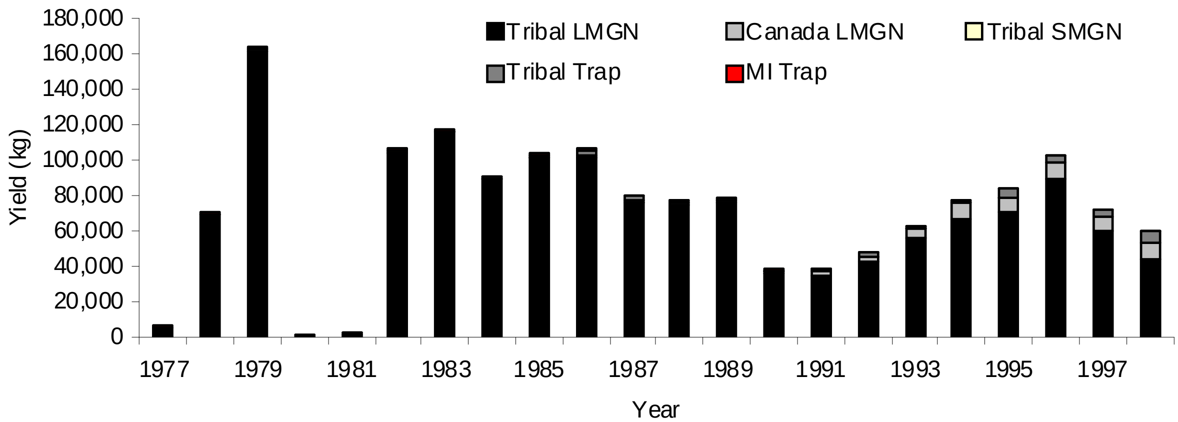


Figure 47. Commercial lake trout harvest by fisher and gear in MH-1 and adjacent Canadian waters.

Between 1977 and 1998 large-mesh gill-net effort in MH-1 and adjacent Canadian waters averaged 3,175,206 m annually with a peak of 5.6 million meters in 1995 and 1996 (Figure 48). The majority of this effort was tribal, but Canadian effort in waters adjacent to MH-1 was substantial and has averaged 494,000 m annually from 1979-98.

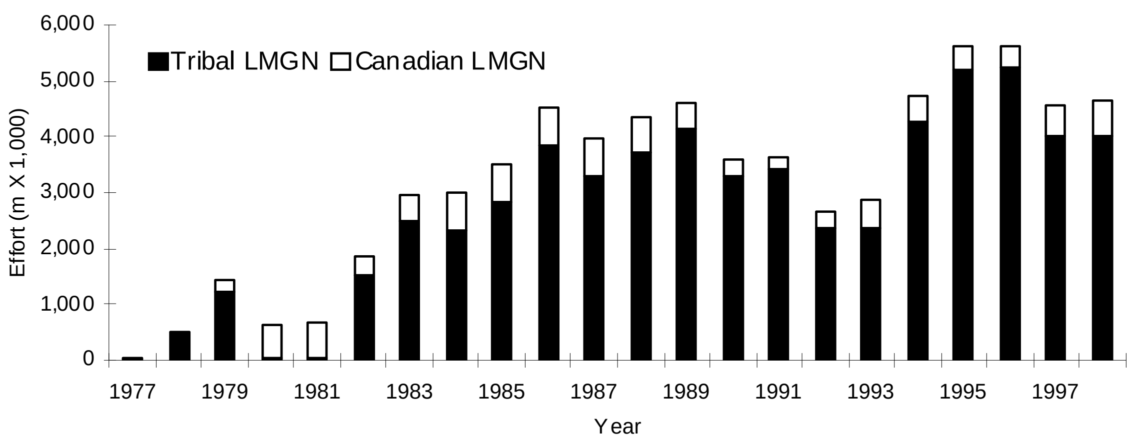


Figure 48. Large-mesh gill-net effort by year and by source in MH-1.

The amount of small-mesh gill-net set by the tribes in MH-1 has declined markedly in recent years, while the number of tribal trap-net lifts has increased from 256 in 1981 to 2,225 in 1998 (Figure 49). Over the same time period, the number of state-licensed trap-net lifts has dropped from 2,155 to 56 in MH-1. The modal age of commercially harvested lake trout varied from age 4 to 6 between 1977 and 1998 in MH-1.

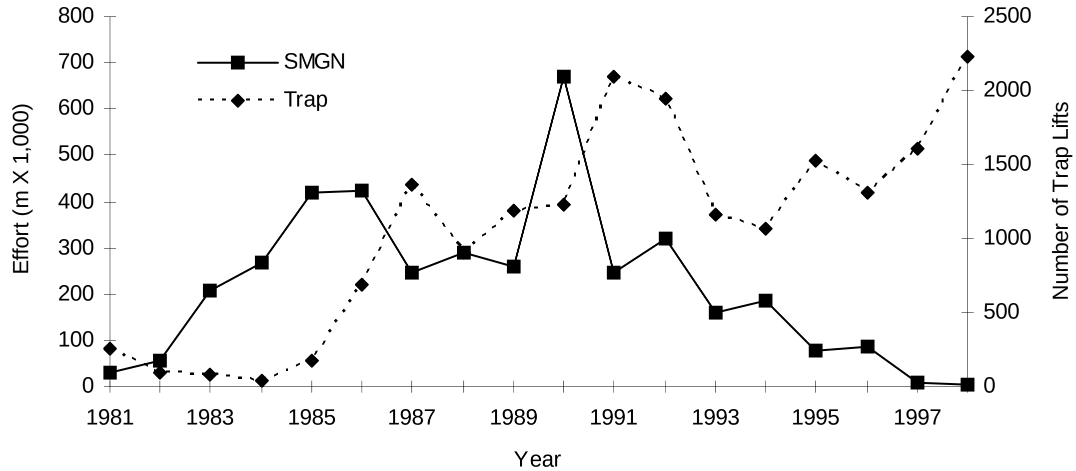


Figure 49. Tribal small-mesh gill-net and trap-net effort in MH-1.

MH-2

Total commercial harvest of lake trout in MH-2 and adjacent Canadian waters averaged 6,081 kg (range: 529-12,931 kg) from 1984 to 1998. The majority of this yield was caught in Canadian waters in large-mesh gill nets, and the rest was calculated as by-catch mortality in the Michigan state-licensed trap-net fishery (Figure 50).

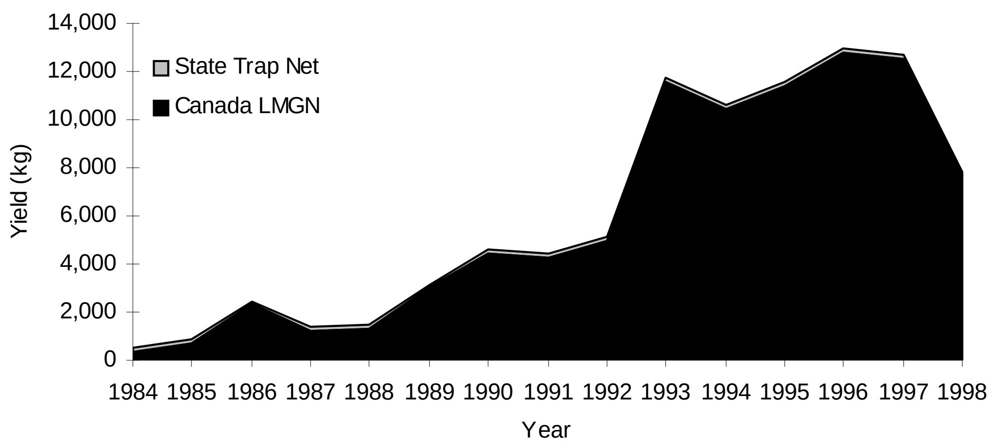


Figure 50. Commercial lake trout harvest by fisher and gear in MH-2 and adjacent Canadian waters.

Between 1984 and 1998, large-mesh gill-net effort in Canadian waters adjacent to MH-2 averaged 1,704,376 m with a peak of 2.3 million m in 1987 (Figure 51). The number of state-licensed trap-net lifts in MH-2 remained relatively constant from 1984 to 1998 averaging 513 lifts per year (Figure 51). The modal age of commercially harvested lake trout varied from age 3 to 5 between 1984 and 1998 in MH-2 and adjacent Canadian waters.

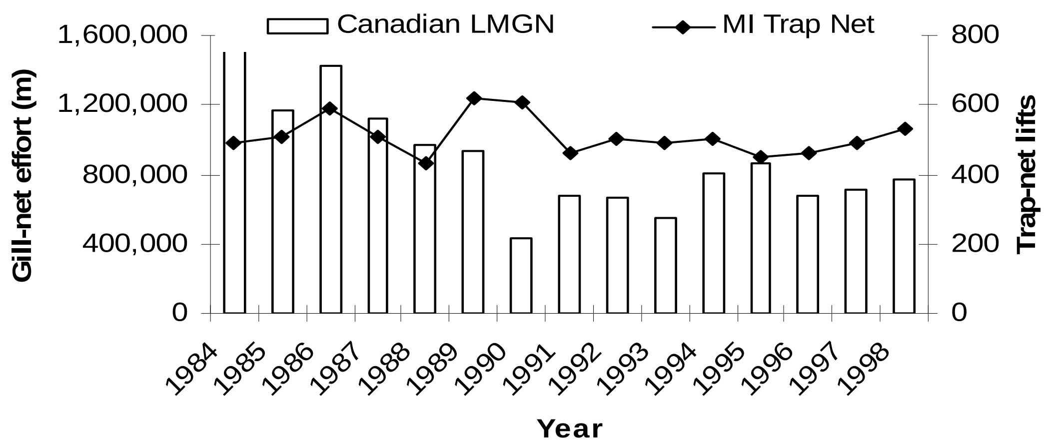


Figure 51. Canadian large-mesh gill net and state-licensed trap-net effort in MH-2 and adjacent Canadian waters.

Recreational Harvest and Effort

<u>MH-1</u>

From 1985 to 1998, catch of lake trout in the recreational fishery was highly variable in MH-1 (Figure 52). On average, recreational fishers caught 2,119 lake trout annually (range: 250-4,694), and relative to the early part of the time series, the number of lake trout caught increased dramatically during 1994-1998.

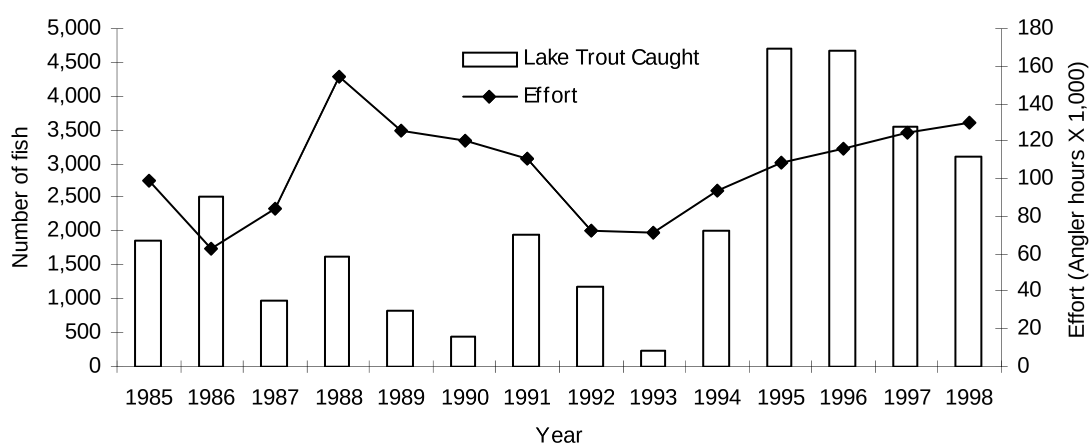


Figure 52. Recreational harvest and effort for lake trout in MH-1. Data includes both charter and non-charter fishers.

Total effort averaged 105,000 angler hours from 1985 to 1998 with an increasing trend from 1993 to 1998. Angling effort peaked in 1988 at 155,000 angler hours. The modal age of recreationally harvested lake trout varied from age 4 to 6 between 1985 and 1998 in MH-1.

MH-2

From 1985 to 1998, recreational harvest of lake trout in MH-2 increased steadily from 454 lake trout in 1985 to 12,370 in 1998 (Figure 53). On average, recreational fishers caught 4,194 lake trout annually over this time period.

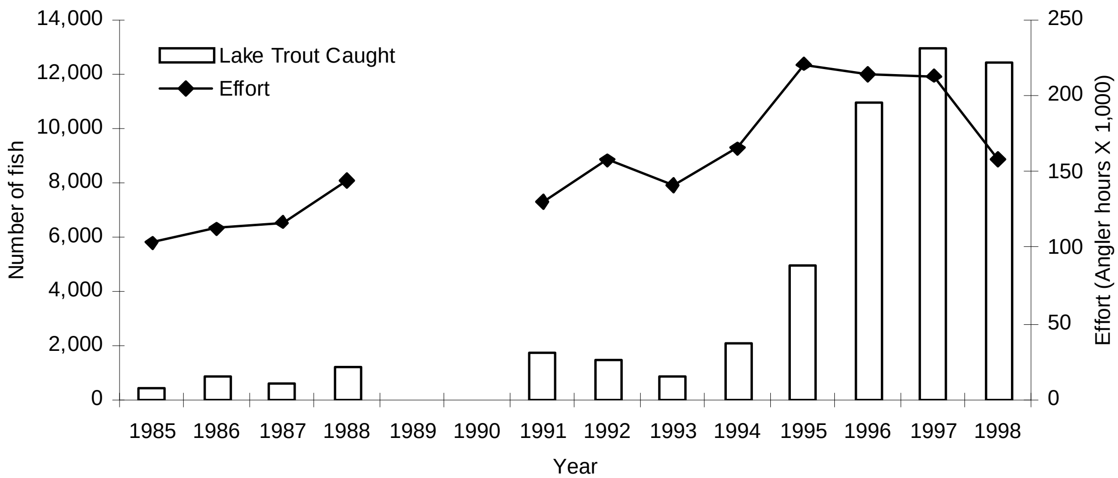


Figure 53. Recreational harvest and effort for lake trout in MH-2. Data includes both charter and non-charter fishers. There was no creel surrvey in 1989 or 1990.

Total effort averaged 156,000 angler hours from 1985 to 1998. Angling effort peaked in 1995 at 221,000 angling hours, and effort declined each subsequent year. The modal age of recreationally harvested lake trout varied from age 4 to 6 between 1985 and 1998 in MH-2.

Population Surveys

Spring Survey

The Michigan DNR has conducted an annual, lake-wide, spring (mid-May to mid-June) graded-mesh gill-net survey in Michigan waters of Lake Huron since 1975. Approximately 10 nearshore sites are fished each year (Figure 44), four of which are index stations that have been fished annually since the beginning of the study (denoted with open circles in Figure 44). With few exceptions, sampling methodologies and gears had remained constant since the beginning of the study. The standard unit of gear is a 274.5 m long by 2 m deep nylon gill net containing nine 30.5 m long panels with the following stretch mesh sizes: 5.1, 6.4, 7.6, 8.9, 10.2, 11.4, 12.7, 14.0, and 15.2 cm. Several units of gear may be fished at each station. All gill nets were bottom sets and were fished for 24 hours at a target depth of 10 to 40 m. The following data were recorded for all fish caught in the spring survey: catch-per-unit-effort (CPUE), length, weight, fin clip (if any), coded-wire-tag number (if any), lamprey wounds, sex, maturity, visceral fat index (VFI), stomach contents, and age.

COTFMA conducted annual spring (May) graded-mesh gill net surveys in and around the Drummond Island Refuge (grids 307-310, northern ½ 407, 408-410) since 1992. In general, COTFMA used the same gears and methodologies as listed above for the State of Michigan.

<u>MH-1</u>

Catch-per-unit-effort of lake trout declined from peak values in the late 1970s and early 1980s and remained low (Figure 54). In 1997 and 1998 CPUEs were the lowest in survey history. The large drop in relative abundance in the late 1970s correlates with increased commercial fishing pressure in MH-1. In 1979, tribal fishers exercised their commercial fishing rights and deployed gill nets in MH-1. Increased fishing pressure coupled with high levels of lamprey predation drastically reduced lake trout abundance in MH-1. The modal age of lake trout in the survey varied from age 3 to 5 between 1977 and 1998.

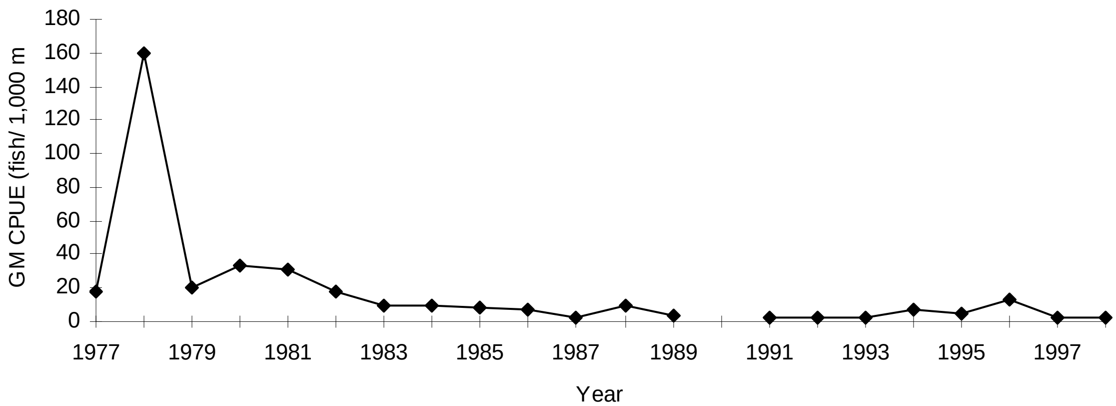


Figure 54. CPUE of lake trout in MH-1 from spring survey data, 1977-98. There were no survey data in 1990. CPUE is expressed as the geometric mean (GM) of fish per 1,000 m of net based on estimates from mixed model analysis.

<u>MH-2</u>

Catch-per-unit-effort of lake trout was fairly constant from the mid-1980s to the mid-1990s, averaging 8.16 lake trout per 1,000 m of gill net from 1984 to 1993 (Figure 55). After 1993, there was a steady increase in the relative abundance of lake trout in MH-2. CPUE in 1998 was the highest in survey history at 36.33 lake trout per 1,000 m. The modal age of lake trout in the survey data varied from age 3 to 6 between 1984 and 1998.

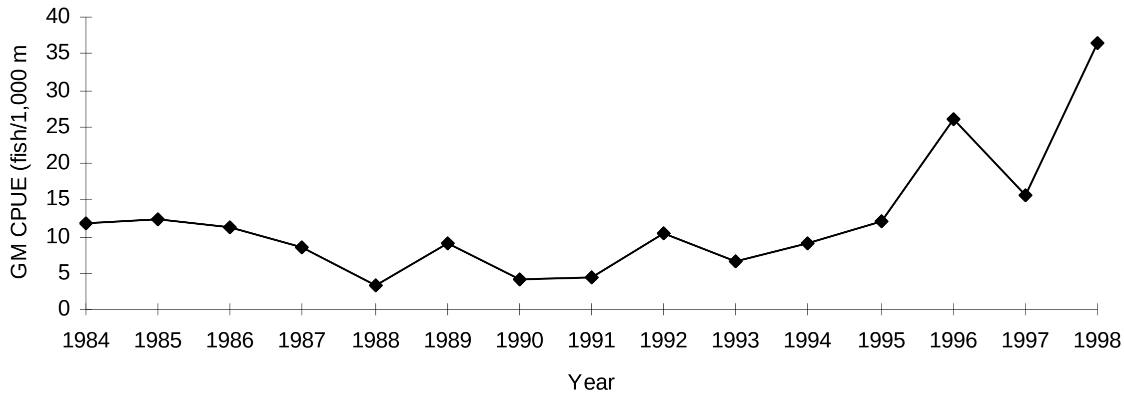


Figure 55. CPUE of lake trout in MH-2 from spring survey data, 1984-98. CPUE is expressed as the geometric mean (GM) of fish per 1,000 m of net based on estimates from mixed model analysis.

Juvenile Trawling

Since 1986, the MDNR has annually conducted a summer (August) trawling survey of historic spawning reefs adjacent to Alpena (grids 810 and 910) in MH-2. The standard unit of effort was a 30-foot bottom trawl towed for 10 minutes. Catch rates of unclipped, presumably wild young-of-the-year (YOY) lake trout were consistently low over the history of the survey, suggesting a low level of sustained use of these reefs by spawning lake trout (Figure 56). The YOY catch rate of 0.05 in 1998 was the lowest in the history of the survey. The Alpena site, along with 2 sites in Canadian waters, were the only areas in Lake Huron with documented YOY lake trout production.

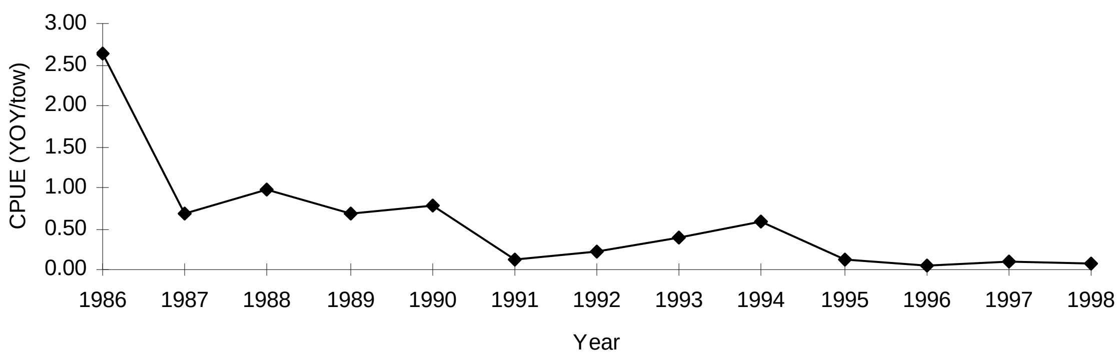


Figure 56. CPUE of young-of-year lake trout in MH-2 (grids 810 and 910).

Characteristics of Lake Trout Statistical Catch-At-Age Models

SCAA Model

Statistical catch-at-age models (SCAA) were separately developed for MH-1 and MH-2 though the overall model structure was nearly identical for both areas. A description of the structure and methods of the statistical catch-at-age models used in this report is provided earlier in this document (see Stock Assessment Models section). The lake trout populations were modeled from 1977-98 in MH-1 and from 1984-98 in MH-2. The first population age was 1 and the last age was 15 in both models. The models for each area estimated abundance and partitioned mortality rates for each age. The mortality rates included commercial fishing, recreational fishing, and natural (excluding sea lamprey parasitism). Also incorporated into the model was age-specific sea lamprey-induced mortality which was estimated external to the SCAA model using spring wounding data and a sea lamprey-lake trout functional response model (see Stock Assessment Models section). Recruitment at age 1 for each year was estimated as effective numbers stocked using stocking data in conjunction with post-stocking survival parameters (see Stock Assessment Models section). Both models were fit to data on harvest, effort, and age compositions for recreational and commercial fisheries. Auxiliary fishery-independent data from spring surveys were also used to fit these SCAA models. The survey data included a relative abundance index (i.e., CPUE) and age compositions.

Additionally, the SCAA models were fit to prior information on natural mortality and post-stocking survival. Overall model fit was penalized by deviations from these priors. The objective function of the SCAA models for MH-1 and MH-2 comprised nine $\log_e$-likelihood components, including recreational effort, commercial effort, recreational harvest, commercial harvest, spring survey CPUE, recreational age compositions, commercial age compositions, spring survey age compositions, and prior information on natural mortality rates and post-stocking survival. All of the $\log_e$-likelihood components were assumed to be from a $\log_e$-normal distribution except for the age composition components, which were assumed to be multinomial. Log_e-scale standard deviations for each $\log_e$-normal data source were estimated external to the model fitting process. The $\log_e$ SD for post-stocking was calculated iteratively in the model fitting process by changing the prior value until it matched the model's estimate.

Further assumptions defined in the MH-1 and MH-2 models were

- selectivity for the fisheries and surveys were assumed to be time-varying and modeled using a double-logistic function (e.g., Bence et al. 1993) to account for changes in growth;
- effort data for recreational and commercial fisheries were de-emphasized in the model fitting process by setting the emphasis factor for the effort likelihood components to 0.01 (see Stock Assessment Models section). This was done because lake trout effort data may not be directly proportional to fishing mortality because commercial fisheries are targeting lake whitefish and recreational effort is measured for all species combined and not specifically for lake trout;
- prior value for age-1 natural mortality was 0.8 based on Rybicki and Keller (1978) and $\log_e$ SD for prior M_1 was 0.175 from Sitar et al. (1999);
- prior values for age-2 and older natural mortality and the $\log_e$ SD were estimated using Pauly's equation as described earlier (see Stock Assessment Models section);

Survey CPUE

Spring survey CPUE (catch per unit effort) indices for MH-1 and MH-2 were estimated using mixed model analysis (see Stock Assessment Models section). The mixed model accounted for the systematic effects of fixed sampling stations in specific statistical grids and the random interaction of grid and year. The model was:

$$Log_e(CPUE+c)_{y,g,d} = \mu + \alpha_y + \beta_g + \delta_d + \gamma_{y,g} + \varepsilon_{y,g,d} ,$$

where c was a constant added to avoid $\log_e$ of zeros when no fish were captured; subscripts $y,g,$ and d referred to year, grid, and depth strata respectively; μ was the overall mean; α, β, and δ were the fixed effects of year, grid, and depth strata, respectively; γ was the random effect of year and grid; and ε was the random sampling error term. Both γ and ε were assumed to be normally distributed with mean of 0. There were two depth strata defined in the MH-1 and MH-2 mixed models: shallow (< 30 m) and deep (≥30 m).

Commercial Fishery Data
Canadian and Tribal yield were combined in the SCAA model and assumed to represent a large-mesh gill-net fishery. Tribal trap-net and small-mesh gill-net harvest in MH-1 were minimal (on average, <5% of large-mesh gill-net harvest) and integrated into the MH-1 large mesh harvest. There is no tribal harvest in MH-2. All commercial harvest in MH-2 is Canadian. Commercial harvest was reported as yield and was converted to harvest in numbers of fish by dividing annual yield by the annual sampled mean weight of harvested fish. Under-reporting and discards in the commercial fisheries were acknowledged in the models by using the proportion of reported to actual harvest based on analyses of tribal commercial fisher reported harvest versus wholesale records. These under-reporting adjustments were only applied to reported commercial harvest. Survey catch and state-licensed commercial fishery bycatch in gill and trap nets were also included as commercial harvest. The $\log_e$-scale standard deviations for commercial harvest and effort were nominally set to 0.15 for MH-1 and MH-2. Age compositions were calculated as proportions by pooling all fish sampled and aged by year. See <model>.dat files in Appendix for commercial fishery harvest, effort, and age composition data.

Recreational Fishery Data
Sport harvest for MH-1 and MH-2 were available back to 1985. In both MH-1 and MH-2, expansion factors for reported harvest were estimated to account for sites that were not sampled each year. This expansion factor was estimated as a ratio of harvest in sites not sampled regularly to harvest in regularly sampled sites. The $\log_e$-scale standard deviations for harvest and effort were based on variances reported during 1986-98. These variances were converted to coefficients of variation (CV) and then $\log_e$-scale SDs. The $\log_e$ SD for effort was doubled in the models to account for discrepancies between fishing power and measured effort due to measurement and process error. The $\log_e$ SD for harvest was increased by approximately 50% in MH-1 and MH-2 to account for uncertainty in the expansion ratios and process error. Age compositions were calculated as proportions by pooling all fish sampled and aged by year. We assumed that the samples were collected in proportion to the harvest. Unpublished analyses indicate that any bias from violating this assumption were minimal.

Projections
Projections of future stock size and allowable harvest levels were based on assumptions that mortality rates, catchability coefficients, and recruitment were equal to the average of 1996-98 values estimated by the SCAA models. Projected weight-at-age and female maturity were assumed equal to 1998 values.

Total allowable catch (TAC) was based on comparing the current quantity of spawning stock biomass per recruit to the quantity produced at established target maximum mortality rates.

Under the 2000 Consent Decree, the target maximum total annual mortality rate (*A*) for ages 5 and older was 47% from 2001 through 2011 and 45% from 2012 through 2020 in MH-1 and was 40% in MH-2.

Status of Lake Trout in MH-1

Growth

Growth of lake trout in MH-1 was expressed by both length and weight-at-age over time. MDNR spring graded-mesh gill-net survey data (1977-1998) were combined with Chippewa Ottawa Treaty Fishery Management Authority (COTFMA) spring graded-mesh survey data from Drummond Island (1992-1998). Age of fish was determined from age-specific fin clips or from scale analysis. There were no obvious patterns in mean length or weight at age in MH-1 from 1979 to 1998 (Figure 57).

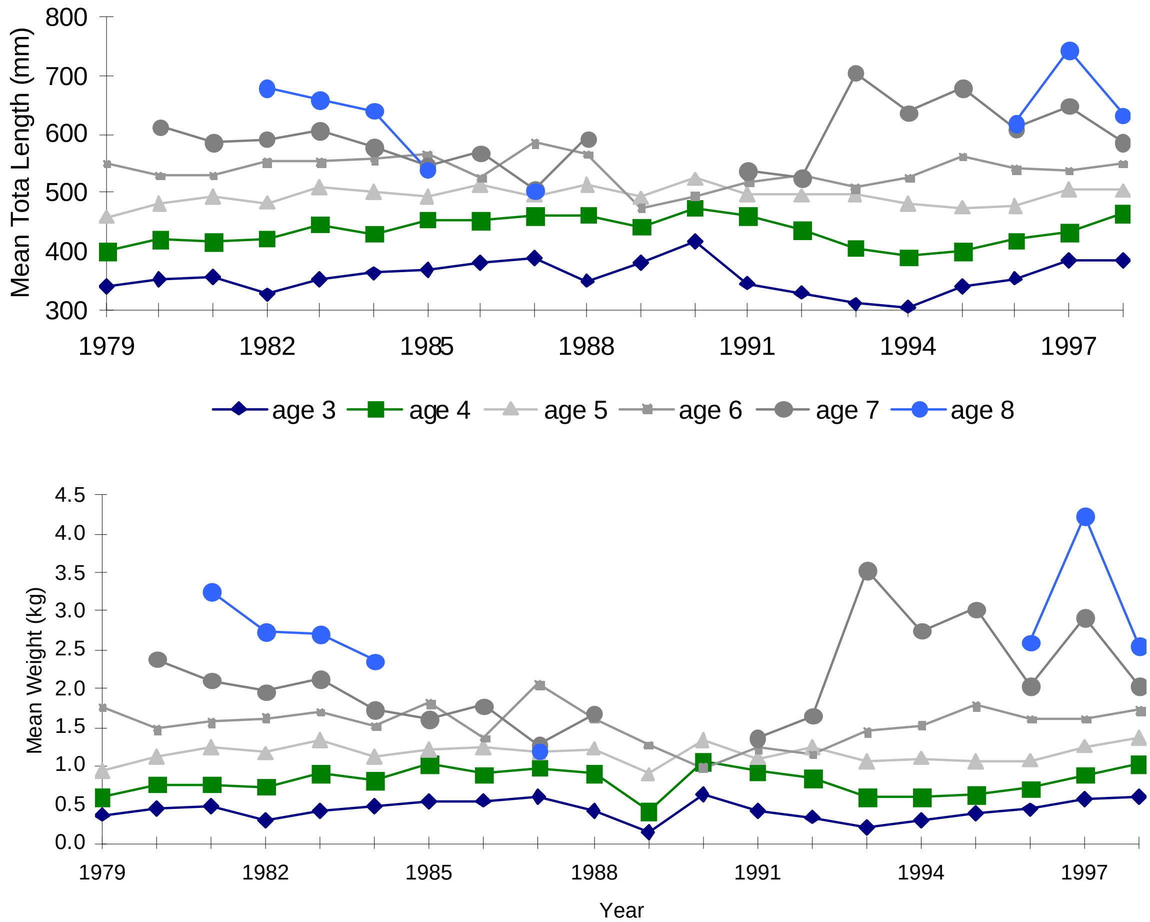


Figure 57. Mean total length and mean weight of lake trout caught in survey gear in MH-1 1979-1998.

Maturity
Female lake trout maturity was calculated from maturity-at-age data collected in MDNR spring, graded-mesh gill nets (1977-1998) and COTFMA spring, graded-mesh gill nets from Drummond Island (1992-1998). Lake trout maturity-at-age data were fit with a logistic function to predict the proportion of mature females from ages 1 to 15. A very small proportion of females in MH-1 was mature at age 4, 50% of females were mature at age 7, and 100% of females were mature by age 12 (Figure 58). The predicted maturity schedule was assumed to be constant for the modeled time series.

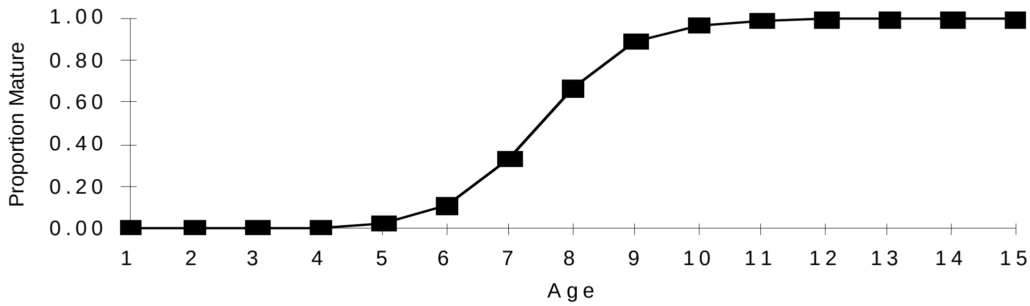


Figure 58. Predicted female lake trout maturity at age in MH-1.

Fecundity
Lake trout fecundity per kg of body weight was estimated for hatchery fish in Lake Superior by Peck (1986). No documented fecundity estimate is available for Lake Huron, but spawning populations in Lake Huron are primarily composed of hatchery fish. The mean number of eggs per kg for hatchery fish was 1,508 ± 274 (Peck 1986) and this value was applied to the Huron units.

Special Characteristics Unique to MH-1 SCAA Model and Data

<u>Commercial fishery</u>
Tribal small-mesh gill-net and trap-net harvest was integrated with large-mesh gill-net harvest after conversion from yield to harvest in numbers of fish. The mean weight of a harvested fish for small-mesh gill-net yield was 0.37 kg (based on mean of 1982-95) and for tribal trap-net yield was 1.84 kg (based on mean of 1991-98). The mean weight of a harvested fish for tribal large-mesh gill nets was not available for data from 1977-81 and was assumed to be equal to the average of 1980 and 1981 values. The mean weight of a harvested fish for Canadian yield prior to 1990 was not available and was assumed equal to the tribal large-mesh gill-net values. Canadian commercial yield data were not available for 1977-83 and was estimated based on the mean ratio of tribal to Canadian yield for 1984-86. The Canadian yield for 1977-83 was estimated as 0.004227 * tribal yield.

Under-reporting and discards in the commercial fisheries were acknowledged in the models by using the proportion of reported-to-actual harvest based on analyses of tribal commercial fisher reported harvest versus wholesale records of fish harvest. These under-reporting adjustments were only applied to reported tribal commercial harvest. Survey catch, state-licensed commercial fishery bycatch in gill and trap nets were incorporated into the total commercial harvest.

Due to incomplete harvest data, individual commercial fishing intensities were estimated as parameters for 1977 and 1978. The 1979-98 commercial *F*'s were estimated by equation 4 (see Stock Assessment Models section). The commercial $\log_e$-scale standard deviations (SD) for commercial harvest and effort were nominally set to 0.15.

Recreational Fishery
Sport harvest data based on on-site standardized creel surveys were only available back to 1985. The 1985-98 recreational *F*'s were estimated by equation 4 (see Stock Assessment Models section). No creel data were available prior to 1985, so the fishing intensities for 1977-84 were set equal to the estimated value for 1985. The $\log_e$ SD for harvest was 0.3, while the $\log_e$ SD for effort was 0.13.

<u>Other information</u>
The prior estimate of *M* for ages 2 and older fish for MH-1 was based on using Pauly's equation with the following parameter values: temperature = 6^o C; L_∞ = 76.71 cm; K = 0.2095; and SE = 0.057. The Von Bertalanffy parameters were based on the average values from 1977-98.
The abundance of ages 6 and older lake trout in 1977 was set to zero because these cohorts were not stocked.

Results of MH-1 SCAA Model

<u>Selectivity</u>
The commercial fishery selectivity pattern for lake trout in MH-1 was dome shaped, and selectivity peaked at age 6 with a value of 1.01 (Figure 59). The selectivity pattern for the recreational fishery was S-shaped, reaching an asymptote of 1.05 by age 8 (Figure 59). The asymptotic nature of the recreational selectivity pattern suggests anglers and/or angling gears select for older lake trout.

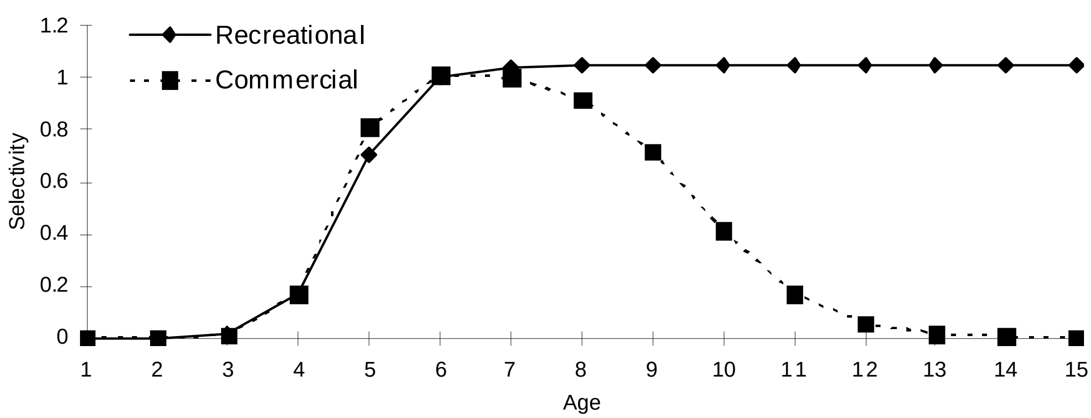


Figure 59. Fishery selectivity patterns for lake trout in MH-1.

Fishing Mortality
From 1977 to 1998, the average commercial instantaneous mortality rates for ages 3-13 lake trout were higher than recreational mortality rates (Figure 60). The age range of 3-13 was chosen for analysis of yearly trends because this range encompasses the majority of both fisheries' selectivity patterns. From 1977 to 1991, commercial fishing mortality was highly variable, reaching peaks in 1979 and 1988. From 1992 to 1998, commercial fishing mortality has been more stable, averaging 0.28. Recreational fishing mortality was low in all years relative to commercial fishing mortality in MH-1.

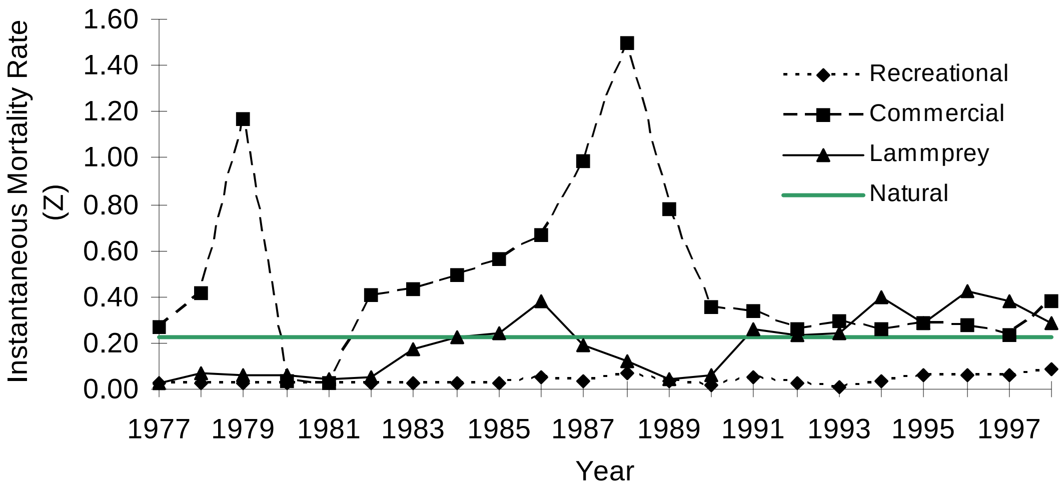


Figure 60. Average instantaneous mortality rates for ages 3-13 lake trout in MH-1.

Lamprey Induced Mortality
Sea lamprey mortality rates have been cyclic in MH-1, reaching peaks in 1986, 1994, and 1996 (Figure 60). From 1977 to 1990, sea lamprey induced mortality was lower than commercial fishery mortality. Between 1991 and 1998, however, sea lamprey mortality was approximately equal to or greater than commercial fishing mortality in MH-1 (Figure 60).

Natural Background Mortality
The model's estimate of natural mortality for all ages 2-13 was 0.222. This was about 10% lower than the prior estimate of 0.248 from the Pauly equation. Natural mortality was a significant source of mortality in MH-1, but in almost all years it was secondary to mortality rates due to commercial fishing (Figure 60).

Population Abundance, Biomass, and Spawning Stock Biomass
Total abundance of lake trout (ages 3-15) in MH-1 increased by a factor of 2 from 1977 to 1998 (Figure 61). However, abundance of mature (age 8-15) lake trout was consistently low over this time period, averaging 1,106 fish per year from 1981 to 1998.

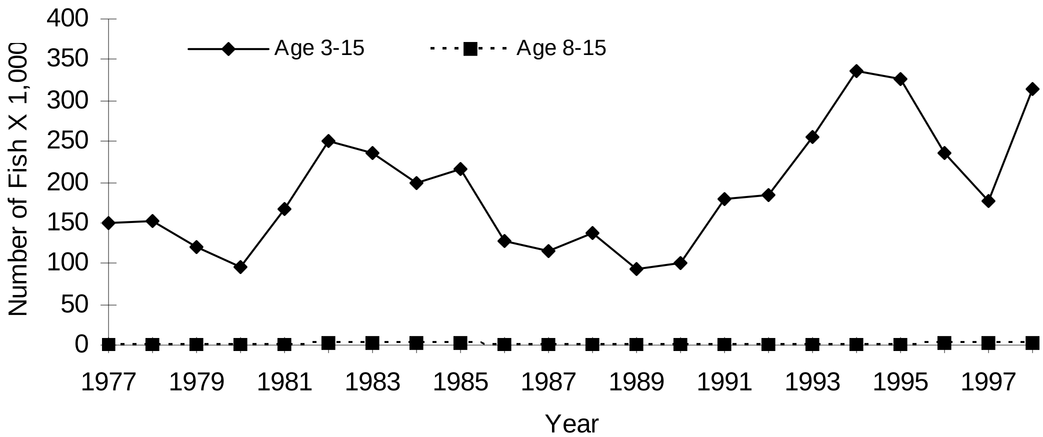


Figure 61. Estimated lake trout abundance in MH-1, 1977 to 1998.

Total biomass of lake trout (all ages) also increased by a factor of 2 from 1977 to 1998 (Figure 62). Spawning stock biomass (SSB), however, remained consistently low. SSB averaged only 1,732 kg from 1981 to 1998.

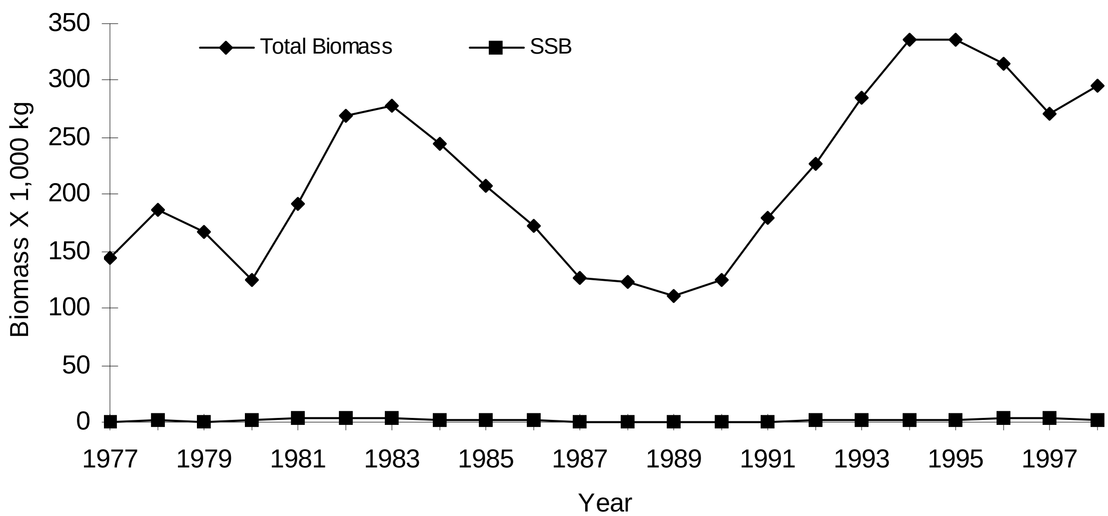


Figure 62. SCAA model estimates of lake trout biomass in MH-1.

Model Fit

Modeled results fit the observed data relatively well overall. There were no major patterns in residuals for commercial harvest (Figure 63a) or recreational harvest (Figure 63b); although, the model tended to under-predict both commercial and recreational harvest levels in recent years (1994-1999).

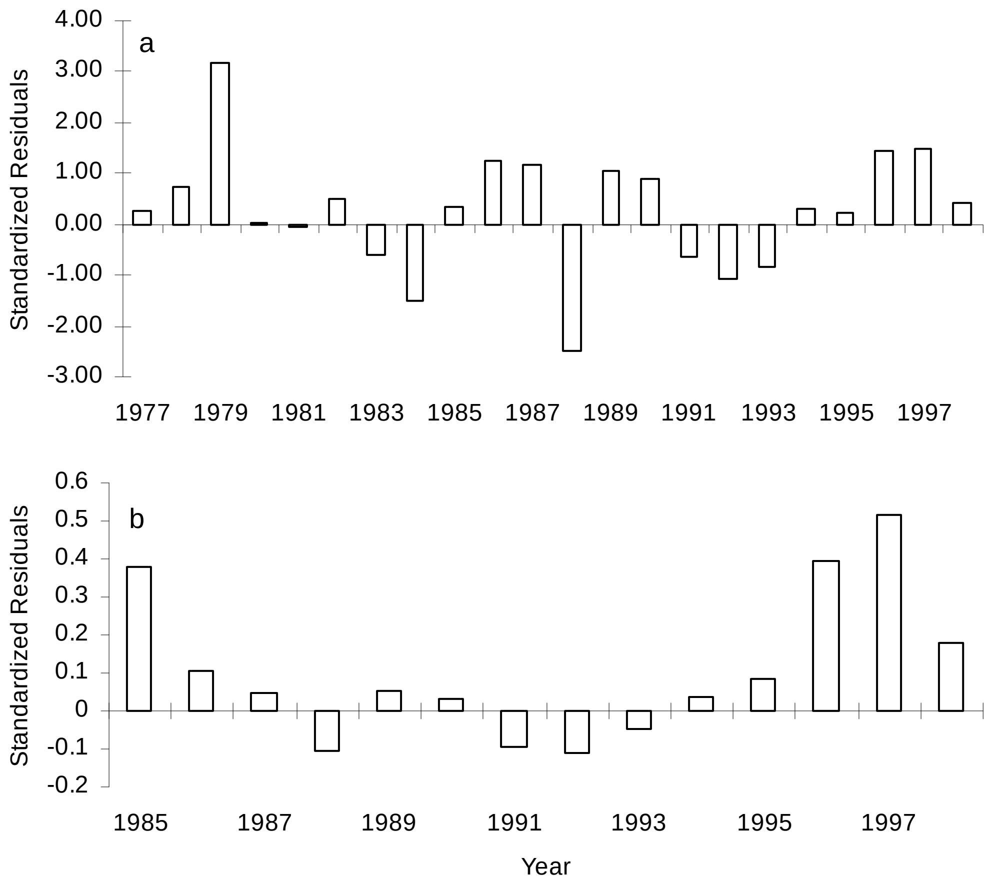


Figure 63. Standardized residuals for MH-1 lake trout harvest in (a) the commercial fishery and (b) the recreational fishery.

The SCAA model matched survey CPUE for lake trout in MH-1 relatively well (Figure 64). The model underestimated survey CPUE from 1977 to 1981, but observed and predicted CPUE values converged for the remainder of the time series.

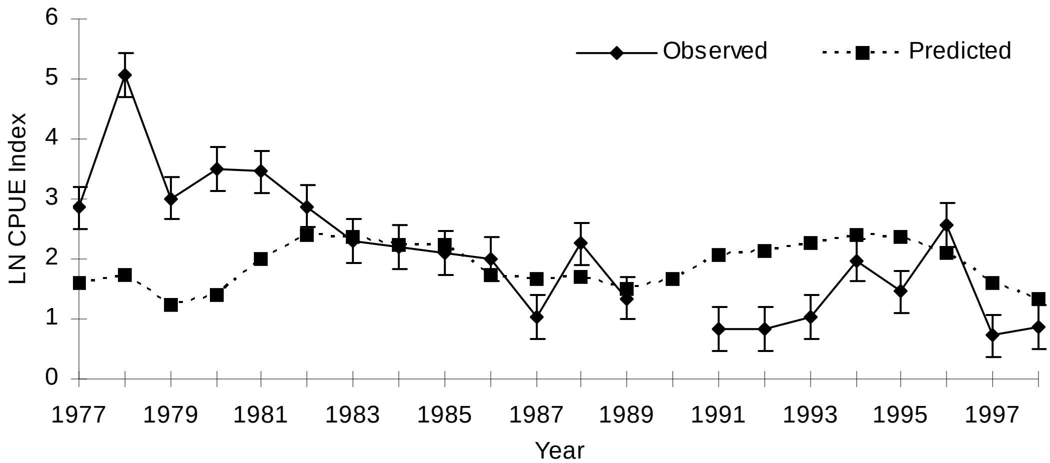


Figure 64. Plot of observed versus predicted survey CPUE for lake trout in MH-1. Error bars around observed CPUE values represent two standard errors.

Finally, there were no obvious patterns in residuals in the fishery or survey age composition data (Figure 65).

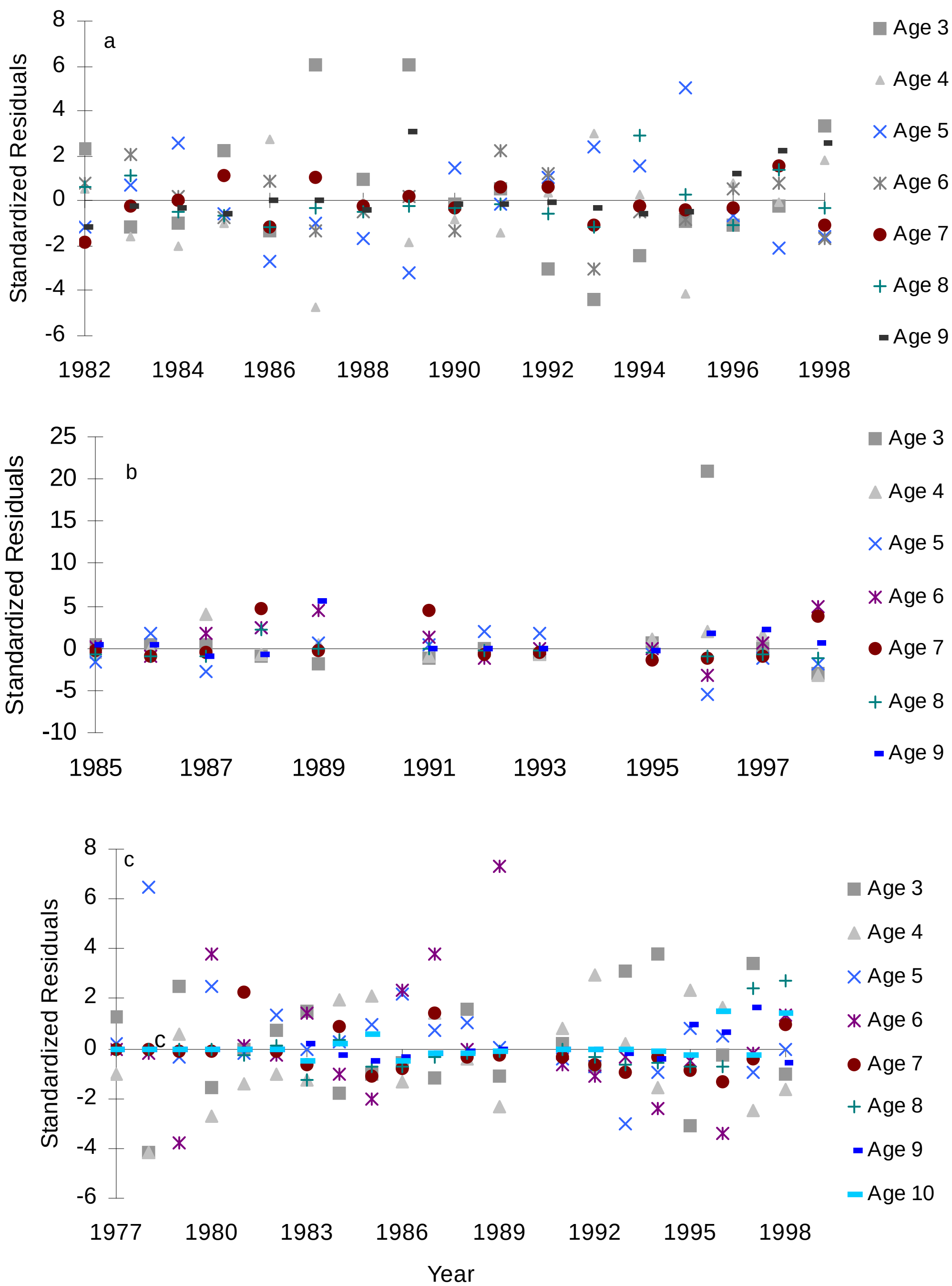


Figure 65. Standardized residuals for MH-1 lake trout age composition data. (a) Commercial fishery (b) Recreational Fishery (c) Survey.

MH-1 Status Relative to Reference Point

Mortality and SSBR
From 1996 to 1998, the average instantaneous mortality rate (Z) for age 5 and older lake trout in MH-1 was 0.995 (range: 0.939-1.027). This equates to a total annual mortality of 63% per year. As a result of this excessive mortality, 1998 standing stock biomass per recruit (SSBR) is 0.0087. This is well below the target SSBR at 47% total annual mortality on age 5 and older lake trout of 0.1228. From 1996 to 1998 the two largest mortality sources in MH-1 were lamprey-induced mortality and commercial fishing mortality (Figure 60).

Effort and TAC
Given conditions (high total mortality and low spawning stock biomass) in MH-1 in 1998, SSBRT could not be reached (Figure 66). SSBR was below target level at any relative *F*. As a result, there was no projected surplus yield of lake trout for fishing year 2001. If, however, relative fishing rates were to remain the same as the 1996-98 average, the model estimates that 25,253 lake trout with a total biomass of 39,967 kg would be harvested in MH-1 in fishing year 2001.

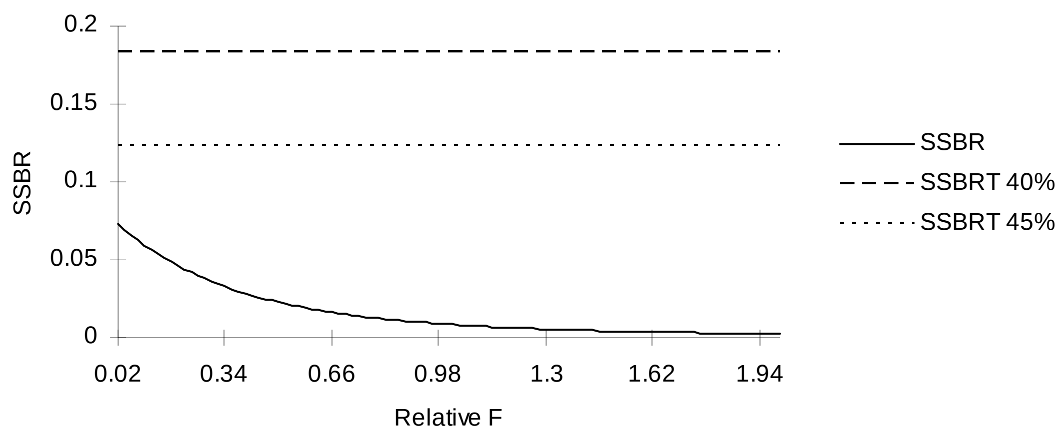
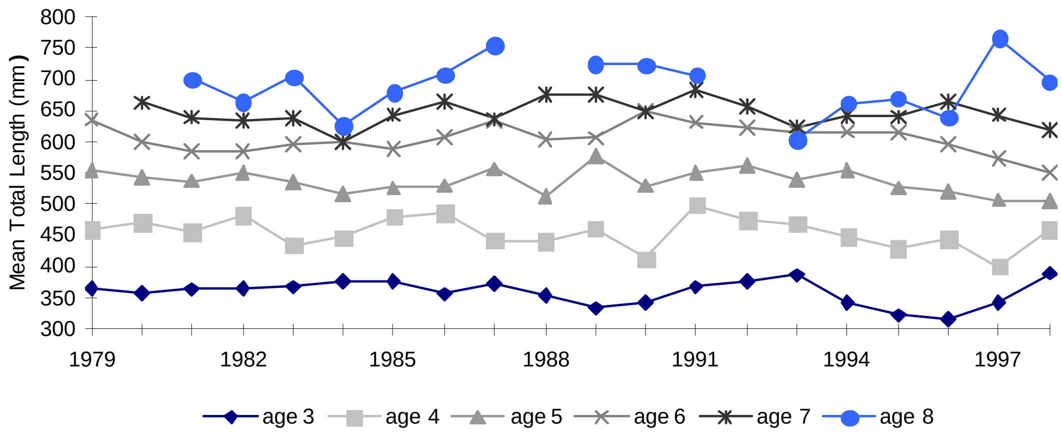


Figure 66. SSBR versus relative F under status quo conditions in MH-1.

Status of Lake Trout in MH-2

Growth
Growth of lake trout in MH-2 was expressed by both length and weight-at-age over time. MDNR spring, graded-mesh gill-net survey data (1979-1998) were used to determine growth. Age of fish was determined from age-specific fin clips or from scale analysis. Length and weight-at-age of young fish remained relatively constant over time, but mean length and weight at age declined after 1990 for older age classes (age 6+) (Figure 67).



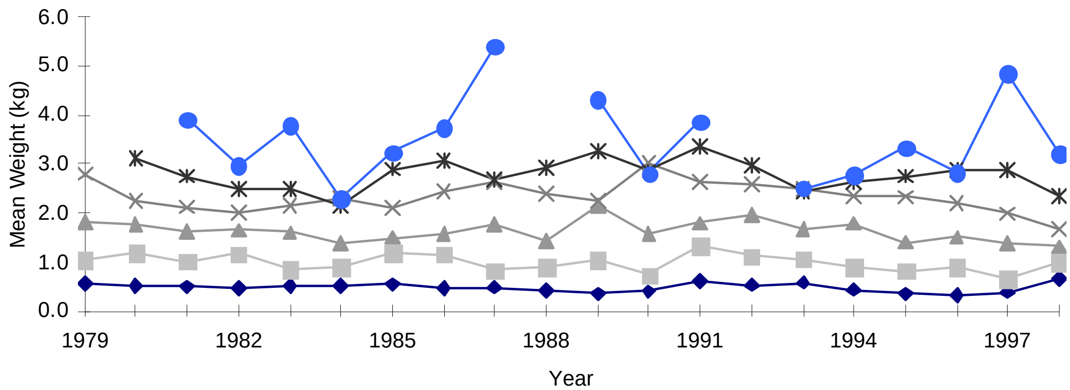


Figure 67. Mean total length and mean weight of lake trout caught in survey gear in MH-2, 1979-1998.

Maturity

Female lake trout maturity was calculated from maturity at age data collected in MDNR spring, graded-mesh gill nets (1979-1998). Lake trout maturity-at-age data were fit with a logistic function to predict the proportion of mature females from ages 1 to 15. A very small proportion of females in MH-2 was mature at age 4, 50% of females were mature at age 7, and 100% of females were mature by age 11 (Figure 68). The predicted maturity schedule was assumed to be constant for the modeled time series.

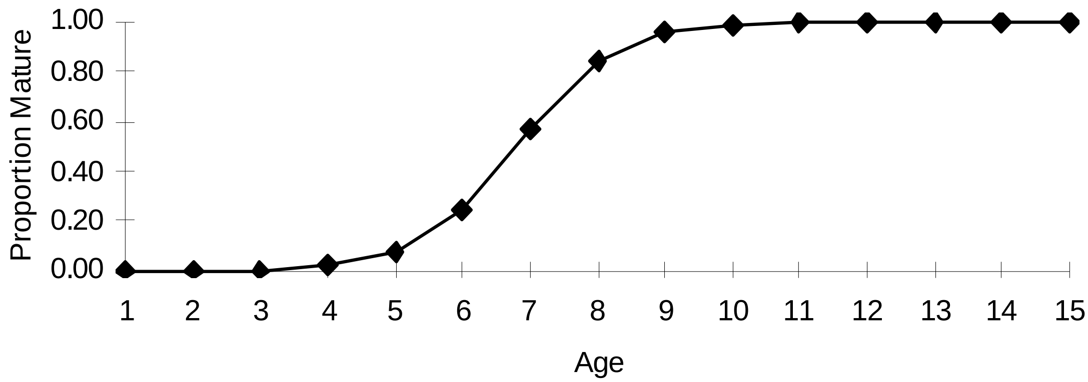


Figure 68. Predicted female lake trout maturity at age in MH-2.

Fecundity
Lake trout fecundity per kg of body weight was estimated for hatchery fish in Lake Superior by Peck (1986). No documented fecundity estimate is available for Lake Huron, but spawning populations in Lake Huron are primarily composed of hatchery fish. The mean number of eggs per kg for hatchery fish was 1,508 ± 274 (Peck 1986).

Special Characteristics Unique to MH-2 SCAA Model and Data

<u>Commercial fishery</u>
Three Canadian management units comprised the MH-2 commercial harvest: 4-2, 4-3, and 4-7. With the exception of unit 4-7 in 1996, commercial yield data were available for all management units during 1984-98. The 1996 yield for 4-7 was assumed to equal the mean of 1995 and 1997 yield. The mean weight of a harvested fish was available for most years during 1990-98. In each management unit, the mean weight of a harvested fish for 1984-89 was assumed equal to the 1990 value. For area 4-2, the mean weight of a harvested fish for the missing value in 1996 was assumed to equal the mean of 1995 and 1997. In area 4-7, the missing mean weight value in 1998 was assumed equal to the 1997 value. Commercial effort in area 4-7 was not available for 1996 and 1998. The 1996 commercial effort for 4-7 was assumed equal to the average of the 1995 and 1997 values, and the 1998 effort was assumed equal to 1997 effort.

Under-reporting and discards in the commercial fisheries were acknowledged in the models by using the proportion of reported-to-actual harvest based on analyses of tribal commercial fisher reported harvest versus wholesale records of fish harvest. These under-reporting adjustments were applied to Canadian commercial harvest to account for known indications that bycatch and discards has been ongoing. Survey catch, state-licensed commercial fishery bycatch in gill and trap nets were incorporated into the total commercial harvest.

Commercial fishing mortality for 1984-98 was estimated by equation 4 (see Stock Assessment Models section). The commercial $\log_e$-scale standard deviations (SD) for commercial harvest and effort were nominally set to 0.15. Due to the lack of commercial age composition data prior to 1990, commercial selectivities prior to 1990 were set equal to the survey selectivity values.

Recreational fishery

Sport harvest data based on on-site standardized creel surveys were only available back to 1985. Sport harvest data were not available in 1989-90. Recreation fishing mortality during 1985-88 and 1991-98 was estimated by equation 4 (see Stock Assessment Models section). The fishing mortality for 1989 was assumed equal to 1988 and the *F* for 1990 was assumed equal to the 1991 *F*. No creel data were collected prior to 1985, so the fishing mortality for 1984 was set equal to the estimated value for 1985. The $\log_e$ SD for harvest was 0.1492, while the $\log_e$ SD for effort was 0.0699.

Other information

The prior estimate of *M* for ages 2 and older fish for MH-2 was based on using Pauly's equation with the following parameter values: temperature = 6^o C; L_∞ = 89.28 cm; K = 0.1756; and SE = 0.057. The von Bertalanffy parameters were based on the average values from 1977-98. The abundance of ages 11 and older lake trout in 1984 was set to zero because these cohorts were not stocked.

Results of MH-2 SCAA Model

Selectivity

The selectivity patterns for both the commercial and recreational fisheries in MH-2 were dome shaped (Figure 69). Commercial selectivity peaked at age 6 with a value of 1.47, and the recreational fishery selectivity peaked at age 6 with a value of 1.27 (Figure 69).

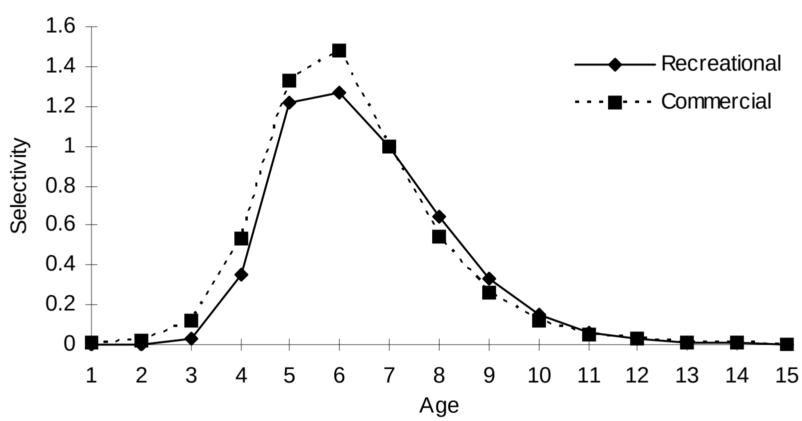


Figure 69. Fishery selectivity patterns for lake trout in MH-2.

Fishing Mortality

From 1984 to 1998, the average instantaneous mortality rates due to fishing for age 3-13 lake trout were relatively low (Figure 70). Recreational fishing mortality rates averaged 0.010 from 1984 to 1998, and commercial fishing mortality rates averaged 0.008. The absence of a large scale commercial fishery and a larger stock size of lake trout than in MH-1 (see Abundance and Biomass section below) account for these low fishing mortality rates.

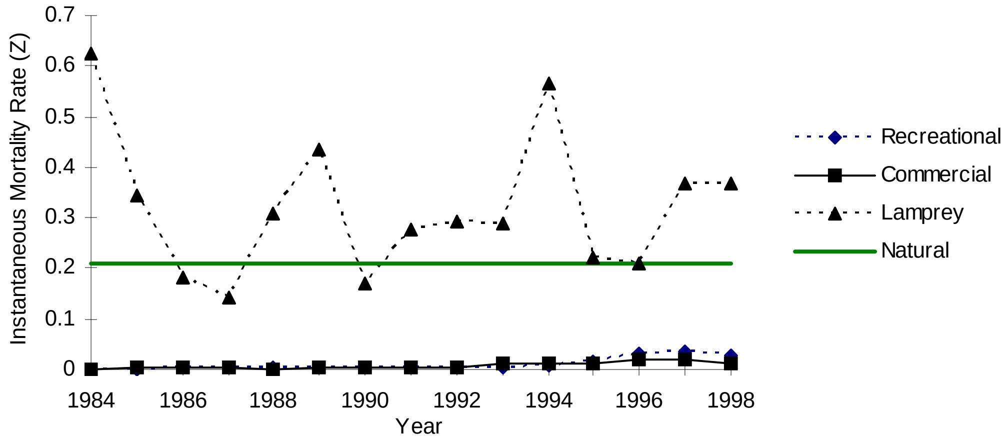


Figure 70. Average instantaneous mortality rates for ages 3-13 lake trout in MH-2.

Lamprey Induced Mortality

The dominant source of mortality for age 3-13 lake trout in MH-2 was lamprey-induced mortality (Figure 70). Lamprey induced mortality was greater than all other mortality sources during this time span with the exception of 1986, 1987, and 1990, when natural mortality was the largest single mortality source. Sea lamprey mortality rates have been cyclic in MH-2, reaching peaks in 1989, 1994, and 1997 (Figure 70). From 1984 to 1998, sea lamprey induced mortality averaged 0.320 in MH-2. Over the same time period in MH-1, lamprey induced mortality rates were lower and averaged 0.251.

Natural Background Mortality

The model's estimate of natural mortality for ages 2-13 was 0.209, only slightly lower than the prior estimate of 0.212 from the Pauly equation. Natural background mortality was a significant mortality source in all years in MH-2, but in almost all years it was secondary to lamprey-induced mortality (Figure 70).

Population Abundance, Biomass, and Spawning Stock Biomass

Total abundance of lake trout (ages 3-15) in MH-2 increased by a factor of 1.7 from 1984 to 1998 (Figure 71). In 1998, lake trout abundance in MH-2 was approximately 608,000 fish. In 1998, the estimate of the MH-2 lake trout population was almost double the 1998 model estimate of 314,000 lake trout in MH-1.

Abundance of mature lake trout in MH-2, however, remained relatively constant from 1984 to 1998, averaging 55,250 fish per year (Figure 71). While the average number of mature lake trout in MH-2 was considerably higher than the average number of mature lake trout in MH-1, abundance of mature fish in MH-2 did not increase at the same rate as total lake trout abundance. This may have been due to size selective harvest of larger, older fish by lamprey and recreational fishermen. The larger number of mature fish in MH-2 may also have explained the presence of the sustained source of lake trout production on the reefs adjacent to North Point near Alpena, MI.

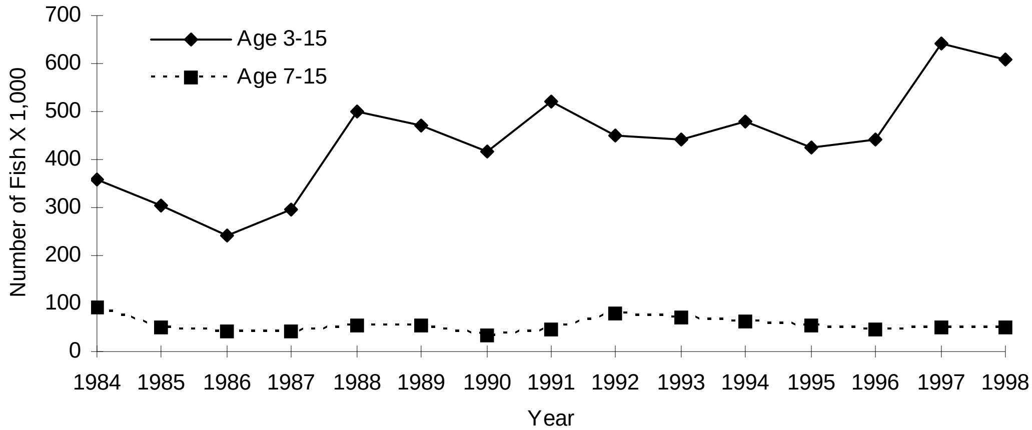


Figure 71. Estimated lake trout abundance in MH-2, 1984 to 1998.

Total biomass of lake trout (all ages) has not increased at the same rate as total abundance. Total lake trout biomass in MH-2 only increased by a factor of 1.1 from 664,000 kg in 1984 to 743,000 kg in 1998 (Figure 72). This may indicate a reduction in lake trout growth over this time period, or it may be indicative of a population composed of many small, young fish and few old, large fish. SSB was relatively constant from 1984 to 1998 averaging 62,000 kg per year, and it did not increase at the same rate as total biomass from 1984 to 1998.

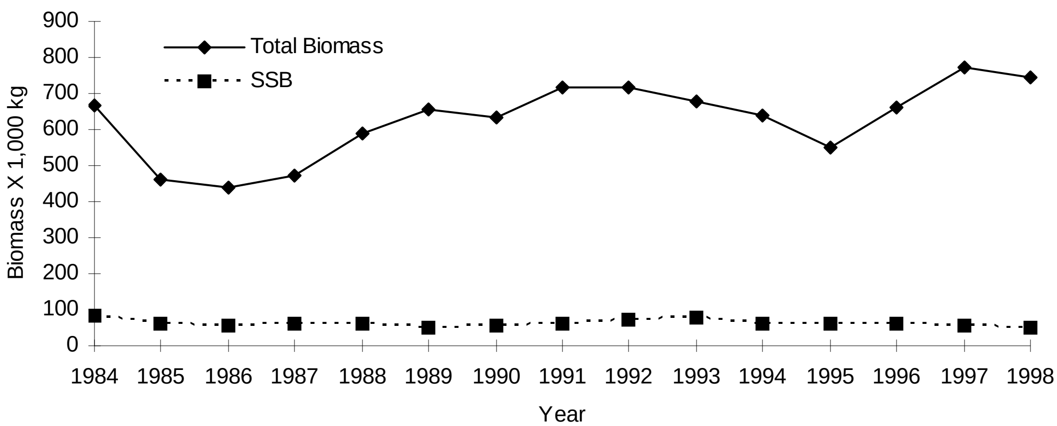


Figure 72. SCAA model estimates of lake trout biomass in MH-2.

<u>Model Fit to Observed Data</u>

Modeled results fit the observed data relatively well overall. There were, however, some patterns in residuals for commercial harvest (Figure 73a) and recreational harvest (Figure 73b). The model predicted higher than observed commercial catches from 1984 to 1989 (Figure 73a). Also, the model tended to predict slightly higher than observed recreational catches in MH-2 in most years (Figure 73b). However, in 1997 and 1998 the model under-predicted the number of recreational harvested lake trout in MH-2 (Figure 73b).

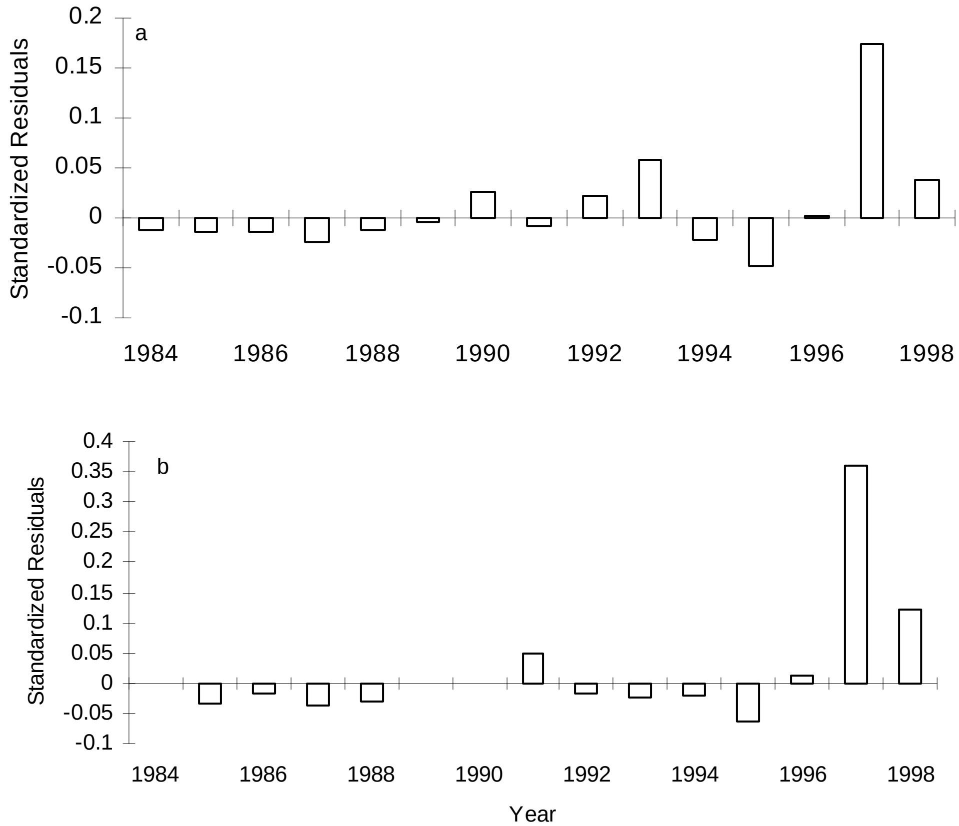


Figure 73. Standardized residuals for MH-2 lake trout harvest in (a) the commercial fishery and (b) the recreational fishery.

The SCAA model matched survey CPUE for lake trout in MH-2 relatively well (Figure 74). The model overestimated survey CPUE from 1988 to 1991, and the model underestimated survey CPUE from 1996 to 1998. Observed and predicted CPUE values matched reasonably well for all other years.

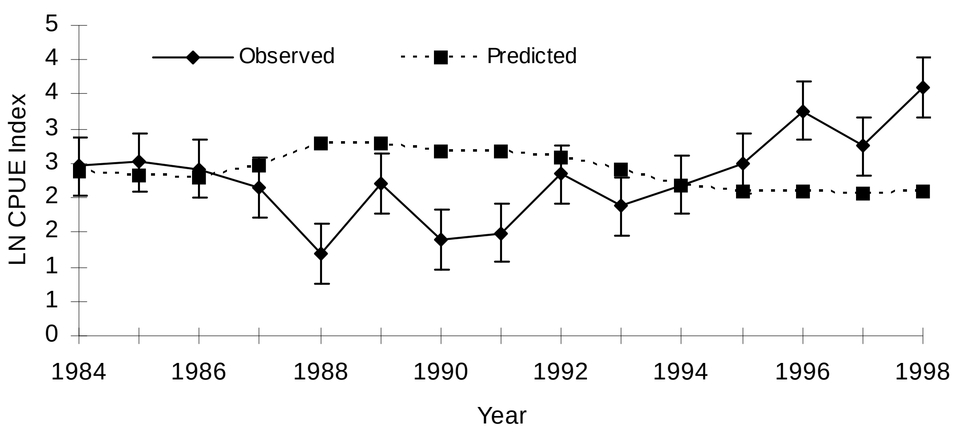


Figure 74. Plot of observed versus predicted survey CPUE for lake trout in MH-2. Error bars around observed CPUE values represent two standard errors.

Finally, there were no obvious patterns in residuals in the fishery or survey age composition data (Figure 75).

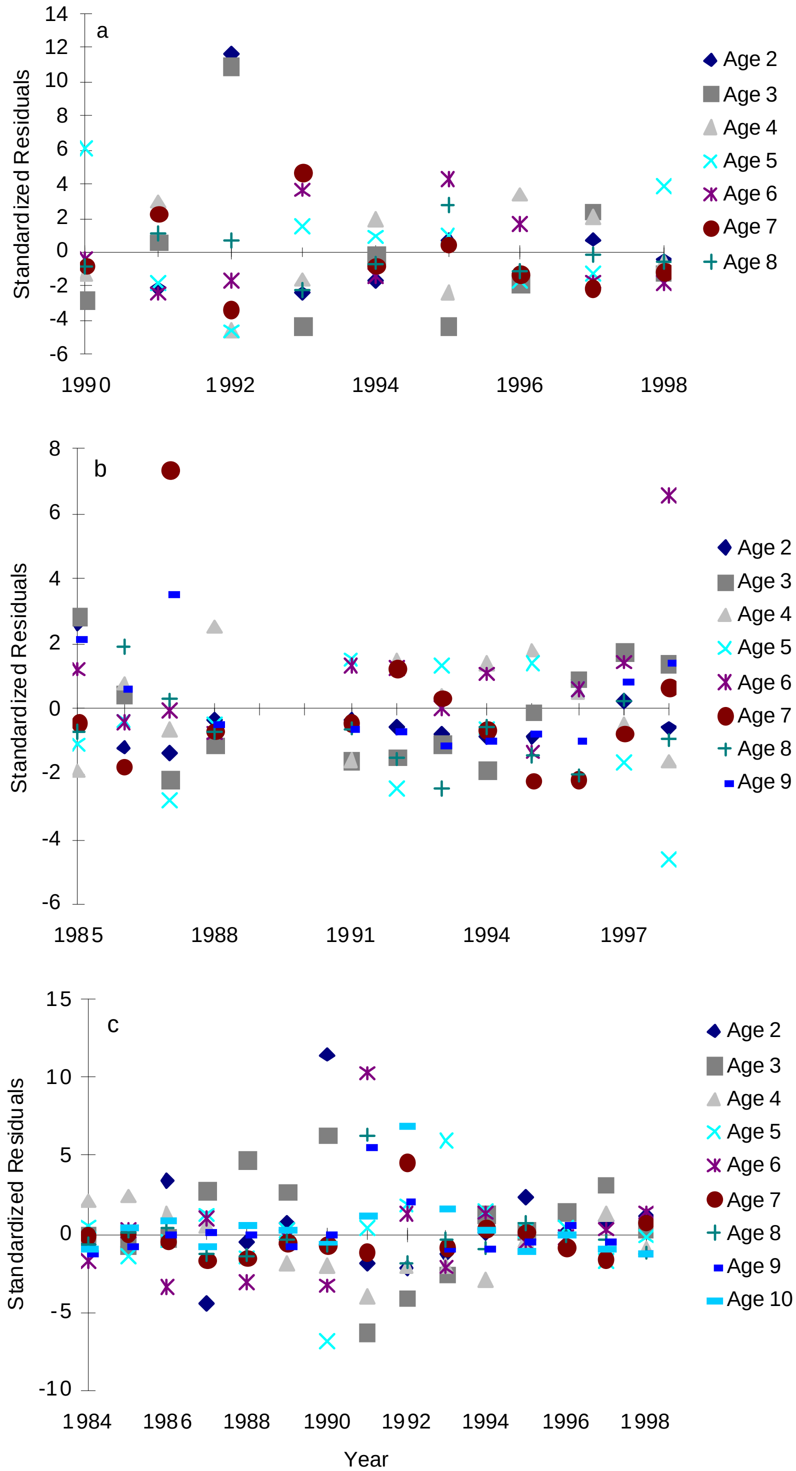


Figure 75. Standardized residuals for MH-2 lake trout age composition data (a) commercial fishery (b) recreational fishery (c) survey.

MH-2 Status relative to reference point

Mortality and SSBR
From 1996 to 1998, the average instantaneous mortality rate (*Z*) for age 5 and older lake trout in MH-2 was 0.612 (range: 0.494-0.678). This equated to a total annual mortality of 46% per year. 1998 SSBR in MH-2 was 0.137 kg/recruit. This was a little less than half the target SSBR at 40% annual mortality on age 5 and older lake trout of 0.322 kg/recruit. In 1998 in MH-2, SSBR was below target SSBR (0.221 kg/recruit) at 45% annual mortality. From 1996 to 1998, the largest source of mortality in MH-2 was lamprey-induced mortality (Figure 70).

Effort and TAC
Given conditions in MH-2 in 1998, (high levels of lamprey induced mortality), SSBRT could not be reached (Figure 76). SSBR was below target levels at any relative *F*. As a result, there was no projected surplus yield of lake trout for fishing year 2001. If, however, relative fishing rates were to remain the same as the 1996-98 average, the model estimates that 18,102 lake trout with a biomass of 31,541 kg would be harvested in MH-2 in fishing year 2001.

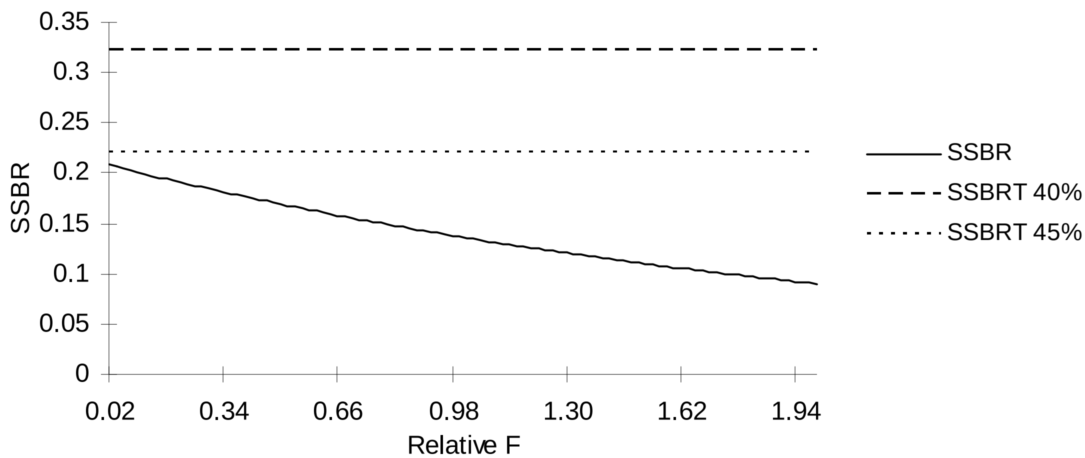


Figure 77. Estimated SSBR versus relative F under status quo conditions in MH-2.

Status of Lake Trout in Lake Superior

Shawn Sitar

Management Units

There are four lake trout management units in 1836 treaty-ceded waters of Lake Superior: MI-5, MI-6, MI-7, and MI-8 (Figure 79). Only the eastern portion of MI-5 is in 1836 treaty waters, the western part is in 1842 treaty waters. These management units differ from statistical districts (Smith et al. 1961) in that these lake trout management units follow statistical grid boundaries and represent managed lake trout stocks (Hansen 1996). The total surface area considered to be lean lake trout habitat (defined as depths less than 74 m) is 756 km^2 in MI-5, 749 km^2 in MI-6, 372 km^2 in MI-7, and 1,508 km^2 in MI-8. Statistical catch-at-age (SCAA) models were developed for wild lake trout in MI-5, MI-6, and MI-7. Due to the lack of data and the deferred status in MI-8, models were not developed for this management unit.

Stocks

There are multiple stocks of lean lake trout within some management units, however, no recent detailed information were available at this spatial scale to quantify movement. Some of these stocks may be isolated from the rest of the population within a management unit. For example, Curtis (1990) reported on the rehabilitation of lake trout at Stannard Rock, an offshore reef that is approximately 72 km from Marquette and over 50 km from Big Bay. Curtis (1990) indicated that very few nearshore lake trout move out to Stannard Rock, but no information was reported regarding movement inshore from Stannard Rock. However, there was sport and charter boat harvest of Stannard Rock lake trout. Therefore, the MI-5 model includes the Stannard Rock stock. Likewise, Big Reef is an offshore shoal-complex (approximately 48 km NE of Munising) that is inhabited by an isolated lake trout stock. Sport fishing also occurs at Big Reef and was assumed to be represented in the MI-6 model.

Based on previous tagging studies, it is likely that the size of a management unit is within the typical home range of lake trout (Eschmeyer et al. 1953; Pycha et al. 1965; Ebener 1990; Peck and Schorfhaar 1991; Peck 1979; Smalz 1999). Thus, it was assumed that the nearshore lake trout stocks within a management unit were well mixed. However, due to the lack of information to estimate the net migration rates between lake trout management units, population models were constructed at the management unit scale. It is assumed that each management unit contains a discrete lake trout population (comprising multiple stocks) with no net migration with other management units. These population models can be modified to account for migration when the information becomes available, and the parameter estimates are likely to change if there is significant net migration.

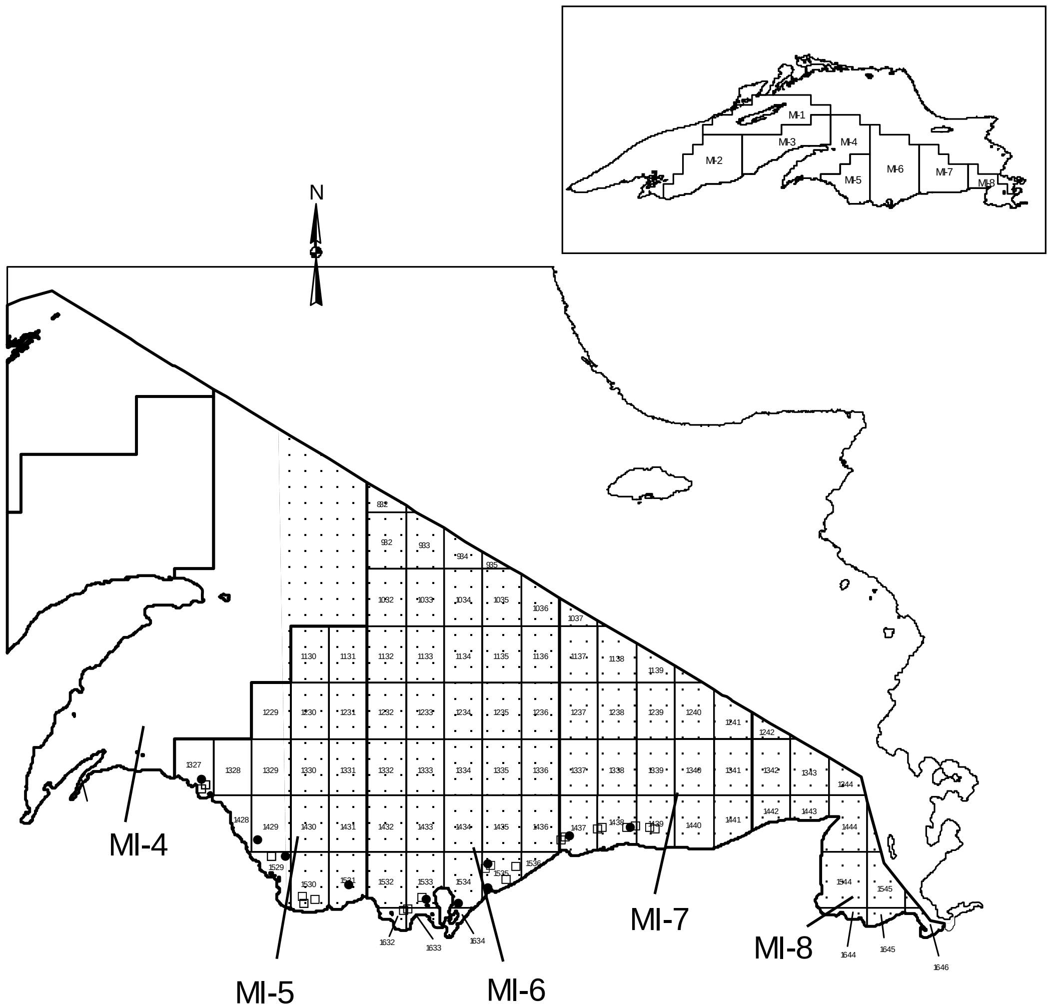


Figure 79. Lake Superior lake trout management units. Shaded area represents 1836 Treaty-ceded waters. Open squares represent spring lake trout survey stations, and solid circles represent pre-recruit survey stations.

Stocking

A major component in the lake trout rehabilitation program prior to 1997 was stocking of hatchery-reared fish to develop spawning stocks that would reproduce naturally. Stocking of lake trout began in the 1950s, and has been ongoing until recently. With the great progress in rehabilitation in most of Michigan waters, stocking was discontinued in 1997 in all areas except MI-4 (1842 treaty waters) and MI-8. Total stocking of yearling lake trout in MI-5 to MI-8 peaked in 1968 at nearly 1.3 million fish (Figure 80a). Most stocked lake trout went into 1842 treaty-ceded waters. The Marquette area, MI-5, was the most intensely stocked management area with 47.3% of all yearlings stocked between 1952 and 1996. Yearling lake trout have not been stocked in MI-7 since 1985. Fall fingerlings (age 0) have also been stocked, though in far fewer numbers due to their poor performance compared to yearlings. Most of the fall fingerlings (77.6%) have been stocked in MI-8 during 1952-2000, with the exception of four years of stocking in MI-5 and one in MI-6 (Figure 80b).

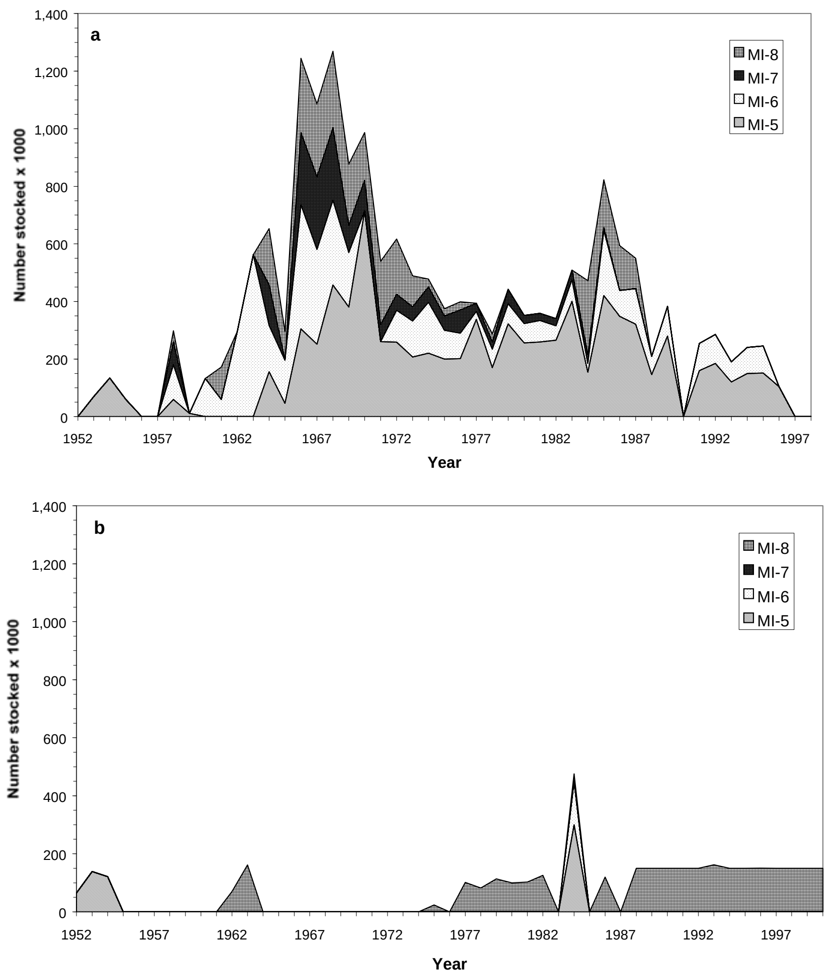


Figure 80. Lake trout stocking in management areas MI-5, MI-6, MI-7, and MI-8 of Lake Superior from 1952-2000. (a) yearling (age 1). (b) fall fingerling (age 0). Data from Green Bay Fishery Resources Office, U.S. Fish and Wildlife Service.

Life History
Lean lake trout in Lake Superior generally spawn between mid-October and mid-November at bottom water temperatures ranging from 8 to12^{O}C (Peck 1979). With the exception of a few isolated offshore areas, most spawning takes place on nearshore shallow reefs (<1 to 30 m deep), many of which have been previously stocked with hatchery lake trout. Larval lake trout hatch during March and April (Martin and Olver 1980; Stauffer 1981). Age-0 lake trout depart the spawning reefs by May and eventually move to deeper water after they are 12 weeks old (Stauffer 1978; Peck 1982). In general, juvenile and adult lean lake trout are demersal, although adults may become more pelagic in the summer months (Martin and Olver 1980). In addition to natural sources of mortality (e.g., predation, parasitism, starvation), there are fishery exploitations of lake trout in Lake Superior. The post-sea lamprey invasion life span of lean lake trout in Lake Superior has been reported to exceed 40 years (Schram and Fabrizio 1998).

Fisheries
There are recreational, commercial, and tribal subsistence fisheries in 1836 treaty-ceded waters that harvest lake trout in Lake Superior. The recreational fishery comprises both charter and individual sport boat anglers that target lake trout primarily by trolling. Mail surveys of a small (2-4%) random subsample of licensed sport anglers was conducted between 1967-82 to measure sport harvest and effort, however the mail survey data were highly biased and unreliable when compared to on-site creel survey data (Peck and Schorfhaar 1991). Therefore, any sport harvest and effort data prior to the start of the standard on-site creel survey was not used in the models. Standardized on-site creel surveys, which began at Marquette in 1984 and at Munising in 1987, included data from both charter and non-charter sport anglers. Starting in 1990, charter boat captains have been mandated to report harvest and effort, and these data have been reported separately from the general creel survey. Recreational effort is indexed as angler hours targeting salmonines. Although the creel survey does not measure effort specifically targeting lake trout, generally, Lake Superior salmonine effort during the summer months was representative of lake trout targeted effort. As of 1999, no on-site creel surveys had been conducted in MI-7 or MI-8. However, after the signing of the 2000 Consent Decree, Grand Marais, in MI-7, became a regularly monitored site. Management of sport fishery lake trout harvest in Lake Superior has been done through creel limits. The State of Michigan reduced the lake trout daily creel limit from five to three fish in 1979. The current minimum length limit for lake trout is 10 inches. Sport effort has been limited by allowing two fishing lines per angler, and no seasonal closures are currently in effect for lake trout in Michigan waters of Lake Superior.

The commercial fishery is comprised of Michigan state-licensed and tribal-licensed fishing operations. In general, the commercial fisheries target lake whitefish with lake trout caught as bycatch. Large-mesh gill nets (>11 cm stretch measure) and trap nets are the primary gears used by commercial fishers in Lake Superior. Michigan state-licensed commercial harvest of lake trout has been prohibited in Lake Superior since 1962 (Brege and Kevern 1978). However, some lake trout are caught incidentally in state-licensed trap and gill nets that target coregonines, but lake trout bycatch from gill nets fished in waters shallower than 109.7 m and trap nets is required to be returned to the water regardless of the condition of the fish. Based on the study by Gallinat et al. (1997), there was 75.5% mortality of lake trout caught in commercial gill nets, which included live fish released when the nets were lifted. Schorfhaar and Peck (1993) reported that the average mortality rate during 1983-89 for lake trout bycatch in state-licensed trap nets was

3.6%. Based on unpublished trap-net bycatch data from Lake Huron, the bycatch mortality was as high as 5.4%. Since there was likely under-reporting of state-licensed bycatch, the 5.4% value from Lake Huron was applied to the reported lake trout bycatch from state-licensed commercial fishers to estimate the total deaths due to discard. We did recognize that state-licensed commercial reporting of lake trout bycatch was likely to be under-reported, however, there was insufficient information to estimate state-licensed under-reporting. This approach was reasonable since total deaths due to state-licensed bycatch were relatively minor in comparison with other mortality sources.

The tribal commercial fishery began in 1971 in MI-8 and is based mostly on large-mesh gill nets fished from both small and large boats. No harvest and effort data were available for the 1971-1975 period, but were available after that time. The 1836 treaty-ceded waters extend from the Chocolay River in MI-5 to the international boundary in MI-8 (see Figure 79). There was also tribal subsistence fishing with gill nets, although at a small level. Most of this activity was localized spatially and temporally.

Population Surveys

Standardized spring gill-net lake trout surveys have been ongoing in Michigan waters of Lake Superior since 1959 (Pycha and King 1975; Peck and Schorfhaar 1991; Peck and Schorfhaar 1994). These surveys provide comparisons of the relative abundance of commercial-sized (>431 mm total length) lake trout across time and areas. The spring surveys began with contracted commercial fishers conducting the sampling in exchange for the fish captured. Currently, all of the spring lake trout surveys are conducted by agency crews (i.e., BMIC, CORA, and MDNR). Although there have been some slight variations, the sampling methodology has remained essentially the same in all years, with the use of 11.4 cm mesh (stretch measure) gill nets deployed for 72 hours at a target bottom depth range between 36 and 74 m. Presently, the standard unit of gear is a 457.2 m x 1.8 m net gang consisting of five equal-sized panels. At each sampling station, either one or multiple net gangs were deployed. The sampling stations were generally fixed at the same coordinates over the years and were established based on traditional commercial fishing grounds. The data gathered for each gang of net from the spring surveys included geometric mean catch-per-unit-effort (CPUE), age composition, sex, birth origin (hatchery vs. wild), length, weight, diet, and sea lamprey wounding.

Pre-recruit lake trout surveys (targeting fish <432 mm TL) have also been conducted in Michigan waters of Lake Superior (Figure 79), but did not begin until 1975. The USFWS conducted these surveys in MI-5 and MI-6 in 1975, 1978, 1981, and 1984. Standardized pre-recruit surveys were conducted by MDNR starting in 1985 in MI-5 and MI-6, and starting in 1986 in MI-7. This survey is conducted between the last week in July until the beginning of September. Graded-mesh gill nets were used in this survey at a target depth range between 27.4 and 73.2 m. Although there have been slight changes in gear specifications over time, the current standard is a 548.6 x 1.8 m net gang consisting of six equal-sized panels with the following mesh sizes (stretch measure): 5.1, 5.7, 6.4, 7.0, 7.6, and 8.9 cm. At each sampling station, one or two net gangs were deployed for approximately 24 hours. The sampling stations were generally fixed at the same coordinates over the years. The data gathered for each gang of net from the pre-recruit surveys include geometric mean CPUE, age composition, sex, maturity, birth origin (hatchery vs. wild), length, weight, diet, and sea lamprey wounding.

Spawning surveys have been conducted by the MDNR during 1973-76 in MI-5 through MI-8 (Peck 1979) and during 1982-86 in MI-5 (Peck and Schorfhaar 1991). These surveys were conducted between 15 October to 15 November on spawning reefs. The 1973-76 survey incorporated large-mesh gill nets with 11.4 to 15.2 cm meshes (stretch measure), while the 1982-86 surveys had 11.4 cm mesh nets. The nets were 1.8 m wide and the length of net deployed was variable. The nets were fished for 20-24 hours at each sampling site. Fish were also tagged and released during the 1982-86 spawning surveys. Age information from the MDNR fall surveys have been deemed unreliable due to the use of scales. However, tagging information, sex ratio, gonad condition, relative abundance, and the ratio of wild versus hatchery fish on spawning sites have been reported. A tagging/spawning survey has been conducted by the Great Lakes Indian Fish and Wildlife Commission (GLIFWC) since 1987 in 1842 treaty-ceded waters that has extended to Big Bay in MI-5 and to Marquette in 1999. Though, only data up until 1990 are reported by GLIFWC (Ebener 1990). The GLIFWC spawning survey protocol generally follows Peck (1979).

Characteristics of Wild Lake Trout Statistical Catch-At-Age Models

SCAA Model

Statistical catch-at-age models (SCAA) were separately developed for MI-5, MI-6, and MI-7, though the overall model structure was nearly identical for all areas. Description of the structure and methods of the statistical catch-at-age models used in this report is provided earlier in this document (see Stock Assessment Models section). The lake trout populations were modeled from 1975-2000 in MI-5 and MI-7, and from 1978-2000 in MI-6. The first population age was 3 and the last age was 15 in all of the models. The models for each area estimate abundance and partitioned mortality rates for each age. The mortality rates included commercial fishing, recreational fishing, and natural (excluding sea lamprey parasitism). Also incorporated into the model was age-specific sea lamprey-induced mortality which was estimated external to the SCAA model using spring sea lamprey wounding data (see Stock Assessment Models section). Recruitment at age 3 for each year was estimated during the model fitting and was modeled as a random walk process.

All of these models were fit to data on harvest, effort, and age compositions for recreational and commercial fisheries. Auxiliary fishery-independent data from spring and pre-recruit surveys were also used to fit these SCAA models. The survey data included a relative abundance index (i.e., CPUE) and age compositions. Additionally, the SCAA models were fit to prior information on natural mortality and recruitment variability. Overall model fit was penalized by deviations from these priors. The objective function of the SCAA models for MI-5, MI-6, and MI-7 comprised eleven $\log_e$-likelihood components including: recreational effort, commercial effort, recreational harvest, commercial harvest, spring survey CPUE, pre-recruit survey CPUE, recreational age compositions, commercial age compositions, spring survey age compositions, pre-recruit survey age compositions, and prior information on natural mortality rates and recruitment variability. All of the $\log_e$-likelihood components were assumed to be from a $\log_e$-normal distribution except for the age composition components, which were assumed to be multinomial. Log_e-scale standard deviations for each $\log_e$-normal data source were estimated external to the model fitting process. The Log_e SD for recruitment was calculated iteratively in the model fitting process by changing the prior value until it matched the model's estimate.

Further assumptions defined in the MI-5, MI-6, and MI-7 models were

- selectivity for the fisheries and surveys were assumed to be time-varying and modeled using a double-logistic function (e.g., Bence et al. 1993) to account for changes in growth;
- selectivity for all data types were set constant from 1994-2000 to allow the model to distinguish selectivity from recent recruitment during model parameterization;
- recruitment in the last year was assumed equal to the model's estimate for the previous year. This was done because of the lack of observed data for that cohort;
- effort data for recreational and commercial fisheries were de-emphasized in the model fitting process by setting the emphasis factor for the effort likelihood components to 0.01 (see Stock Assessment Models section). This was done because lake trout effort data may not be directly proportional to fishing mortality because commercial fisheries were targeting lake whitefish and recreational effort was measured for all salmonines and not specific for lake trout;
- prior values for natural mortality and the $\log_e$ SD were estimated using Pauly's equation as described earlier (see Stock Assessment Models section);
- the 1998 spring survey CPUE index was omitted from the model fitting process because of unusual limnological conditions that caused the spring surveys to under-sample lake trout lake-wide. This was done so the model did not estimate higher mortality rates and lower abundance in 1998;

Aging Error

Errors in lake trout age determinations using scales and otoliths were addressed in the wild lake trout models. The age compositions for each data source contained errors caused by the readers determining ages and intrinsic variability in the fish aging structures (i.e., scales and otoliths). Generally, lake trout ages determined from scales tend to be underestimated for older fish (e.g., Schram and Fabrizio 1998). Otoliths are also prone to the same errors, but are less biased than scales. Aging error matrices were applied in these models in an attempt to correct for these biases and to match true age compositions to observed age compositions. The methods of applying the aging error matrices in the SCAA model is described previously in this report (see Stock Assessment Models section). The aging error matrices for Lake Superior were based on analysis of aged, hatchery lake trout from spring survey data from 1993-98 following the procedures by Weeks (1997). The true ages were determined from the unique fin clip pattern assigned to each cohort. The fin clip pattern repeated every five years, which made age assignments reliable for most fish. Data from the aged hatchery fish were used to develop two aging error matrices: one based on scale-only aging to apply to the age compositions from 1975-1988; and the other based on scales for ages <9 and otoliths for ages 9-15. Prior to 1989, all ages were based on scale aging done at the USGS lab in Ashland, Wisconsin (formerly the USFWS). From 1989 to the present, lake trout aging was done by MDNR using scales and otoliths. An important assumption in the use of these aging error matrices was that the aging error measured by MDNR is applicable to fish aged from 1975-88 by the USGS. The aging data for 1975-88 were only available as year-specific age-length keys and were not available for each individual fish in electronic form. Therefore, we were not able to develop aging error matrices from those data. However, the application of the 1975-88 aging error matrix developed by MDNR seems reasonable in that the biases of scale aging were likely similar among scale readers.

Survey Age Composition

Spring survey age compositions for 1975-88 were based on age-length keys developed from a subsample of all fish collected from the combined areas of MI-4 to MI-7. This age-length matrix was multiplied by a length-frequency vector of non-aged survey fish for each individual management unit to get the overall age composition. The age-length key was regional, which may mask any age composition differences among the management units. The protocol at the USGS lab was to age ten hatchery fish per 25.4 mm length bin for each fin clip collected per year. For wild fish, ten fish were aged per 25.4 mm length bin. Spring survey age compositions for 1989-2000 were based on age-length keys developed for each management unit based on a stratified random subsample of 20 fish per 25.4 mm length bin. All hatchery fish collected were aged. Subsampled lake trout less than 584 mm were aged by scales, and fish greater than 583 mm were aged using otoliths. The age compositions were calculated by multiplying the age-length matrix by a length-frequency vector of non-aged survey fish. To reduce bias from over-sampling young and old fish from the survey catch, age compositions were weighted by CPUE-at-age for each sampling station within each management unit. The spring survey age compositions have under-represented fish shorter than 432 mm. The spring survey protocol was to only count and return lake trout <432 mm. Therefore, age and length information were lacking for these fish and caused the under-representation of young fish in the spring survey age composition. All fish collected in the pre-recruit survey were aged. Pre-recruit survey age compositions were calculated as proportions by pooling all fish sampled and aged by year. See Lake Superior model data (.dat) files in Appendix for survey age compositions.

Survey CPUE

Spring and pre-recruit survey CPUE indices for MI-5, MI-6, and MI-7 were estimated using mixed model analysis (see Stock Assessment Models section). The mixed model accounted for the systematic effects of fixed sampling stations in specific statistical grids and the random interaction of grid and year. The model was a variant of equation 16:

$$Log_e(CPUE+c)_{y,g,d} = \mu + \alpha_y + \beta_g + \delta_d + \gamma_{y,g} + \varepsilon_{y,g,d}$$

where c was a constant added to avoid $\log_e$ of zeros when no fish were captured; subscripts $y,g,$ and d refer to year, grid, and depth strata respectively; μ was the overall mean; α, β, and δ were the fixed effects of year, grid, and depth strata, respectively; γ was the random effect of year and grid; and ε was the random sampling error term. Both γ and ε were assumed to be normally distributed with mean of 0. There were two depth strata defined in the mixed models: deep (spring survey: ≥ 54.9 m; pre-recruit survey: ≥ 41.1 m) and shallow (spring survey: <54.9 m; pre-recruit survey: <41.1 m).

The mesh sizes used in the pre-recruit survey has varied over time. In order to standardize the pre-recruit CPUE over time, only data from mesh sizes common across all years were used in the SCAA models. These common mesh sizes included: 5.1, 5.7, 6.4, 7.0, 7.6, and 8.9 cm. Survey CPUE indices are included in the Lake Superior model data (.dat) files found in Appendix.

Commercial Fishery Data

Tribal commercial lake trout harvest reports do not distinguish wild from hatchery fish. Commercial monitoring data do distinguish hatchery versus wild catch; however, sample sizes were low, and therefore the proportion wild from the spring surveys was used to partition wild and hatchery harvest. We assumed that the commercial fishery extracts wild and hatchery lake trout in proportion to their abundance in the population. Commercial harvest was reported as yield and was converted to harvest in numbers of fish by dividing annual yield by the annual sampled mean weight of harvested fish. Under-reporting and discards in the commercial fisheries were acknowledged in the models by using the proportion of reported to actual harvest based on analyses of tribal commercial fisher reported harvest versus wholesale records of fish harvest. These under-reporting adjustments were only applied to reported tribal commercial harvest. Survey catch, state-licensed commercial fishery bycatch in gill and trap nets were also included as commercial harvest. The $\log_e$-scale standard deviations for commercial harvest and effort were nominally set to 0.15 for MI-5, MI-6, and MI-7. Age compositions were calculated as proportions by pooling all fish sampled and aged by year. Commercial fishery harvest, effort, and age composition data are included in the Lake Superior model data (.dat) files in Appendix.

Recreational Fishery Data

Sport harvest reports do not distinguish wild from hatchery fish, and we assumed that the sport fishery extracts wild and hatchery lake trout in proportion to their abundance in the population. Therefore, the proportion wild from the spring surveys was used to partition wild and hatchery sport harvest. The $\log_e$-scale standard deviations for harvest and effort were based on variances reported during 1991-93. These variances were converted to coefficients of variation (CV) and then $\log_e$-scale SDs. The $\log_e$ SD for effort was doubled in the models to account for discrepancies between fishing power and measured effort due to measurement and process error. Age compositions were calculated as proportions by pooling all fish sampled and aged by year. We assumed that the samples were collected in proportion to the harvest. Unpublished analyses indicate that any bias from violating this assumption were minimal.

Growth

Lake trout growth was indexed by length- and weight-at-age data over time for each management unit. Trends in growth were also evaluated by comparing the exponent (β) from a weight-length allometric growth model: $W=\alpha L^{\beta}$, where W was weight, L was length, and α and β were parameters defining the shape of the function. Although the SCAA models do not require growth information for model parameterization, mean length- and weight-at-age data were needed to estimate numerous population quantities. Mean length-at-age data (from spring surveys) were used to translate length-based estimates of sea lamprey-induced mortality to age-based values for the SCAA models. Age-specific female maturity was also estimated using mean length-at-age data. Mean weight-at-age data were required to convert numbers of fish estimated in the SCAA models to population biomass, fishery yield, and spawning stock biomass.

The mean length-at-age values for each year and management unit were based on estimates from a von Bertalanffy (VB) growth model. For many of the years, there were no data or very low sample sizes for the young and old fish. Therefore, some consecutive years of data were combined and VB growth models (using FISHPARM 3.08) were used to better estimate length-at-age for ages 3-15. The specific years that were combined in the VB models were based on observed trends in length for ages that had reasonable sample sizes (ages 7-10). Those adjacent years with similar mean length-at-age were combined for the VB models. The VB model fit was further evaluated by comparing the observed versus estimated mean length-at-age for ages 7-10 fish.

The observed mean length-at-age data for 1975-88 were based on the length-frequencies from the spring survey catch applied to the age-length keys described above (see "Aging error" and "Survey age composition"). Mean length-at-age data for 1989-2000 were estimated from spring survey data and weighted by CPUE. Observed mean weight-at-age was estimated by applying annual length-age keys to a vector of mean weight per length bin. Individual fish weight data were not available for all fish in all years. For years with weight data, a weight-length allometric growth model (see above) was developed and weights were estimated for fish without weights. Since weight data were not available in all years, an assumption was made that the parameters α and β for each year followed the growth trends observed in mean length-at-age and trends in rainbow smelt and lake herring abundance (e.g., Hansen 1994). Therefore, the α and β for years without weight data were interpolated following the trends in length-at-age. Weight-at-age (W_a) for each year was estimated using a VB weight model:

$$W_a = W_\infty \left(1 - e^{K(a-t_o)}\right)^\beta \text{ and } W_\infty = \alpha L_\infty{}^\beta \quad (29)$$

where a was the subscript for age; W_∞ was the asymptotic weight; K and t_o were parameters from the VB length model; α and β were parameters from the weight-length growth model; and L_∞ was the asymptotic length from the VB length model. The VB weight model predictions were compared to the observed weight-at-age for years with weight data to assess quality of model fit.

Female Maturity

A logistic function was used to estimate female maturity as a function of length where: $\Omega_a=1/(1+\exp(-K_m(\psi-\Omega_o)))$, where Ω_a was the proportion of females that were mature, ψ was the mean total length at age a in mm, and K_m and Ω_o were parameters that define the shape of the function. The parameter Ω_o was the length at which 50% of the females were mature. These maturity parameters were estimated by pooling all of the wild and hatchery lake trout female maturity data from 1985-1996 and 1998 and across all management units. Maturity curves were then developed for each year from 1975-2000 based on applying the estimated annual mean length-at-age to the maturity function. In using this logistic model, we assumed that female maturity was based on length and that K_m and Ω_o applied to the time period 1975-2000.
The observed female maturity data used to fit the logistic function were determined from data collected in the pre-recruit survey. Data were collected from the end of July to the beginning of September during 1985-96 and 1998. Although this survey targets pre-recruits, sufficient numbers of larger (older) lake trout were sampled to evaluate female maturation. The maturation data from the spring surveys were not used because of the high uncertainty in staging maturity at this time of year for young adults.

Fecundity

Wild and hatchery lake trout fecundity were based on values estimated by Peck (1988) from samples collected during 1977-83 from Keweenaw Point to Munising. The mean number of eggs per kg was 1,431 (95% CI: 1,169-1,693) for wild lake trout and 1,508 (95% CI: 1,234-1,782) for hatchery fish. The relationship between fecundity and length and weight for wild and hatchery lake trout was described by: -19,019+34.2*(TL) or –3,400+2,450*(W) where *TL* was total length in mm, and *W* was weight in kg.

Projections

Projections of future stock size and allowable harvest levels were based on assumptions that mortality rates, catchability coefficients, female maturity, weight at spawning, and recruitment were equal to the average of 1998-2000 values estimated by the SCAA models. Projected population weight-at-age was assumed equal to 2000 values. Total allowable catch (TAC) and total allowable effort (TAE) were based on comparing the current quantity of spawning stock biomass per recruit to the quantity produced at established target maximum mortality rates (see Stock Assessment Models section). The target maximum total annual mortality rate (*A*) for Lake Superior lake trout was 40%, which was based on adjusting the target *A* of 45%, as reported by Hansen (1996), for gill-net selectivity. This was further modified in the context of these SCAA models to account for differences in age-specific mortality rates. The first age at which the target maximum *A* applied was age 7 for Lake Superior. This first age was based on the consensus of the modeling group to estimate this as the first age where approximately 20% of the females were mature.

Status of Lake Trout in MI-5

Growth

Wild lake trout weight data from surveys for MI-5 were measured in 1975, 1986, 1989, 1991, 1994, 1995, 1997, and 1998-2000. Overall, mean length- and weight-at-age for wild lake trout have declined from 1975 to 2000 (Figure 80a, 80b). Mean length at age 7 during 1996-2000 was about 10% lower than during 1975-1979. Mean weight at age 7 was 33% lower during 1996-2000 than during 1975-79. The β for wild lake trout has declined from 3.46 in 1975 to 2.80 in 2000 (Figure 80c). Although under-aging may have had an influence in trends in mean length- and weight-at-age, other sources of information indicate that the declines were real. The declining trend in growth may be due to intensified density-dependent effects, competition, and declines in forage fish abundance (Hansen 1990). Hatchery lake trout growth trends likely parallel wild lake trout.

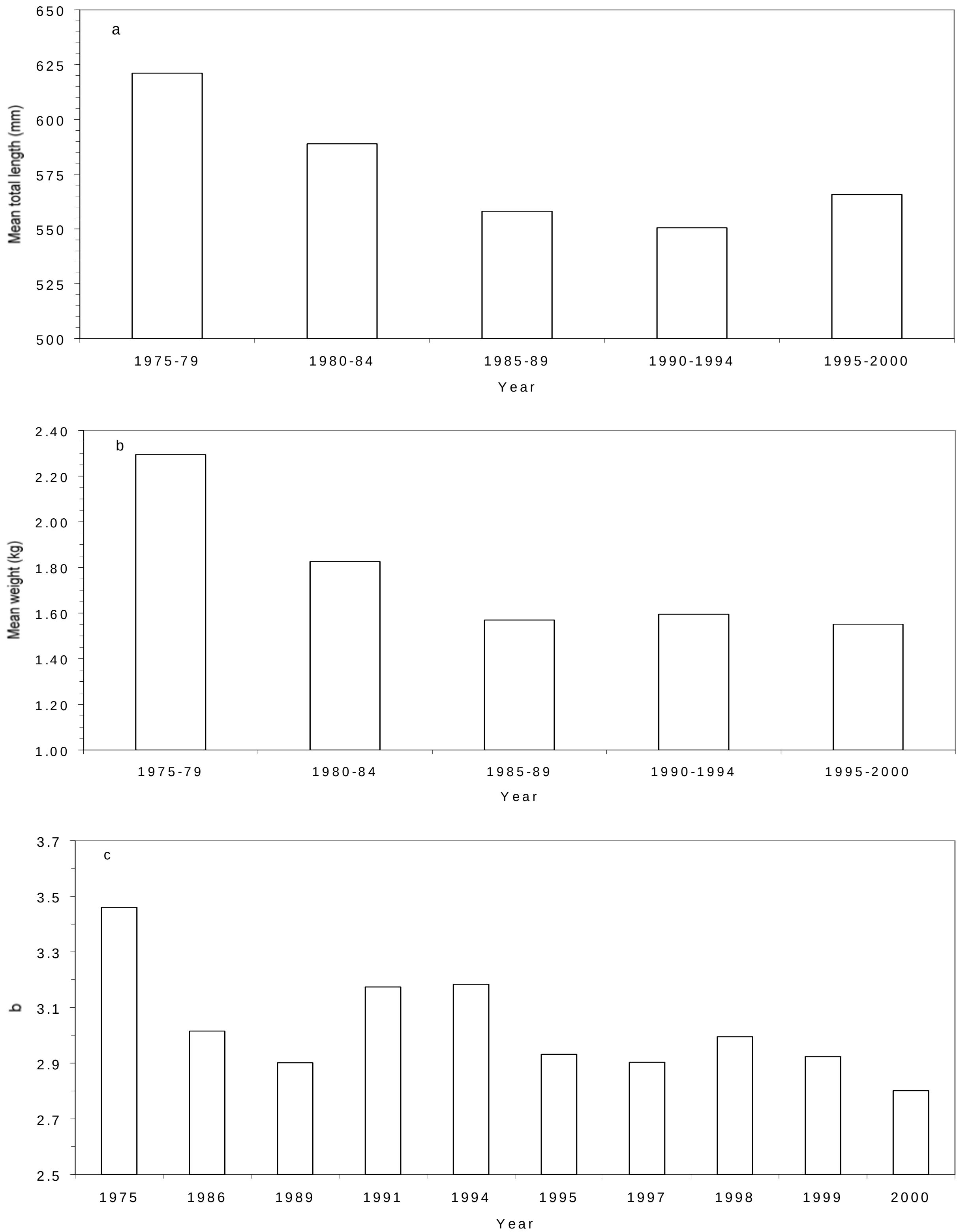


Figure 80. Growth of wild lake trout in MI-5 during 1975-2000 as indexed by (a) mean length of age 7; (b) mean weight of age 7; and (c) exponent from weight-length allometric growth model.

Maturity
The age at 50% maturity has increased over time due to changes in mean length-at-age (Figure 81). The age at 50% maturity was age 7 during 1975-79, and increased to about age 9 during 1995-2000.

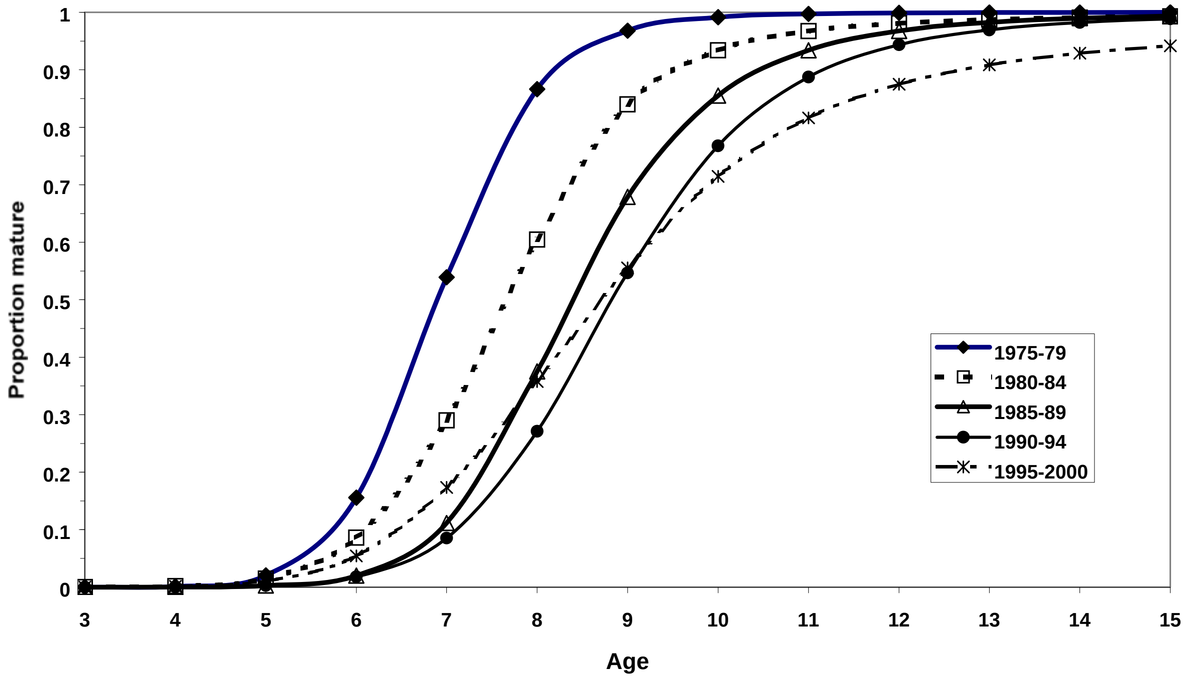


Figure 81. Female maturity-at-age for wild lake trout in MI-5 from 1975-2000. Data based on annual mean length-at-age data applied to a length-based logistic model for female maturity.

Spawning Stock
Spawner CPUE (fish per km of 11.4 cm mesh net per night) was reported by Peck and Schorfhaar (1991) to range from 161 to 384 at Garlic and Partridge Island in MI-5 during 1982-85. The percentage of these spawners that were wild fish ranged from 62 to 82. During 1973-76, spawner CPUE at these sites ranged from 197 to 400 with the percentage wild ranging between 27 and 52 (Peck 1979).

Fisheries

<u>Commercial Fishery</u>
The only commercial fishery for lake trout in MI-5 is operated by tribal-licensed fishers in 1842 treaty-ceded waters (grids 1229, 1327, 1328, 1329, 1428, 1429, and 1529). This tribal fishery began in 1986 and is a large-mesh gill-net fishery that primarily targets lake whitefish. The tribal fishery began mainly with large boats and has shifted to mostly small boats in recent years. Tribal harvest of wild lake trout averaged 5,300 fish per year from 1986-2000, while the average harvest of hatchery lake trout was about 800 fish per year. In most years, total commercial harvest has been below 6,000 fish per year except in 1988, 1993, 1998, and 2000. On average, hatchery lake trout comprise 15% of the total commercial harvest. Between 1986 and 2000,

tribal gill-net effort averaged 72 km per year with the peak in 2000 of 149 km (Figure 82). For years with sample sizes greater than 50 fish, the modal age of wild lake trout harvested ranged between 4 and 10. The annual mean dressed weight of a harvested fish ranged from 0.74 to 1.38 kg.

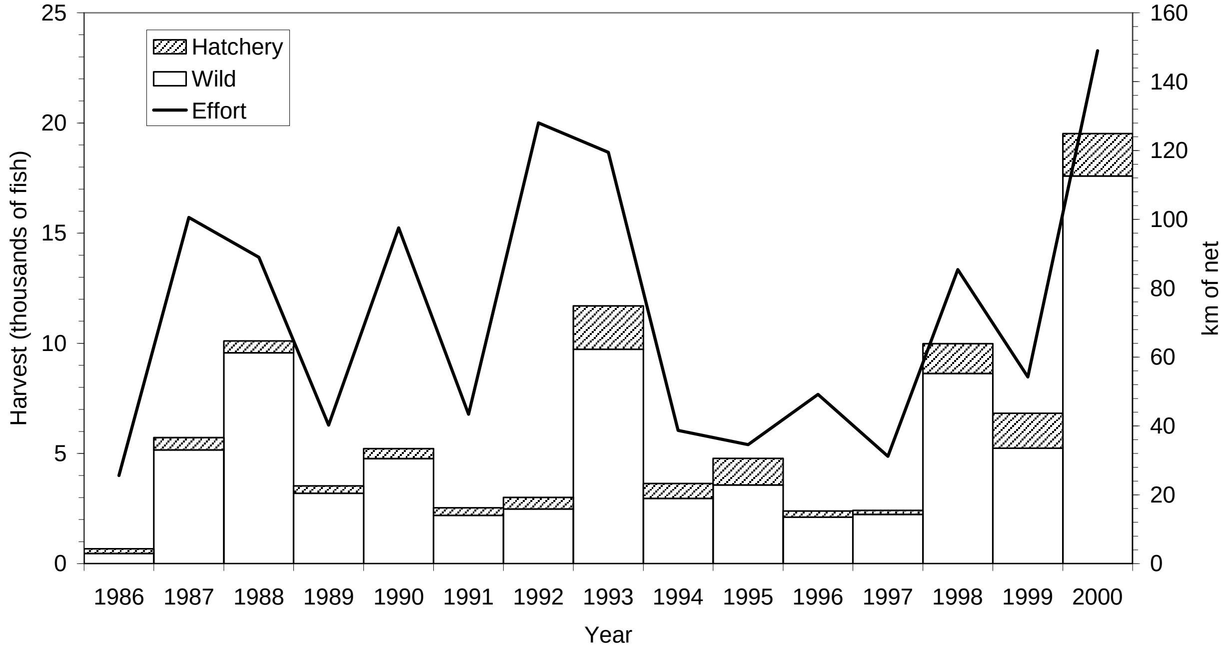


Figure 82. Tribal commercial large-mesh gill-net harvest and effort index for lake trout in MI-5. All tribal harvest is in 1842 treaty-ceded waters. Data from Great Lakes Indian Fish and Wildlife Commission.

<u>Recreational fishery</u>

During 1984-2000, recreational harvest of wild lake trout in MI-5 has increased and averaged 9,900 fish per year, while harvest of hatchery fish has declined and averaged 2,200 fish per year (Figure 83). The index of effort has declined from a peak of 146,000 angler hours in 1986 to 50,000 angler hours in 2000 (Figure 83). The modal age of wild lake trout caught in the sport fishery was between 7 and 9 during 1988-2000. The annual mean weight of a harvested fish ranged from 1 to 2.3 kg.

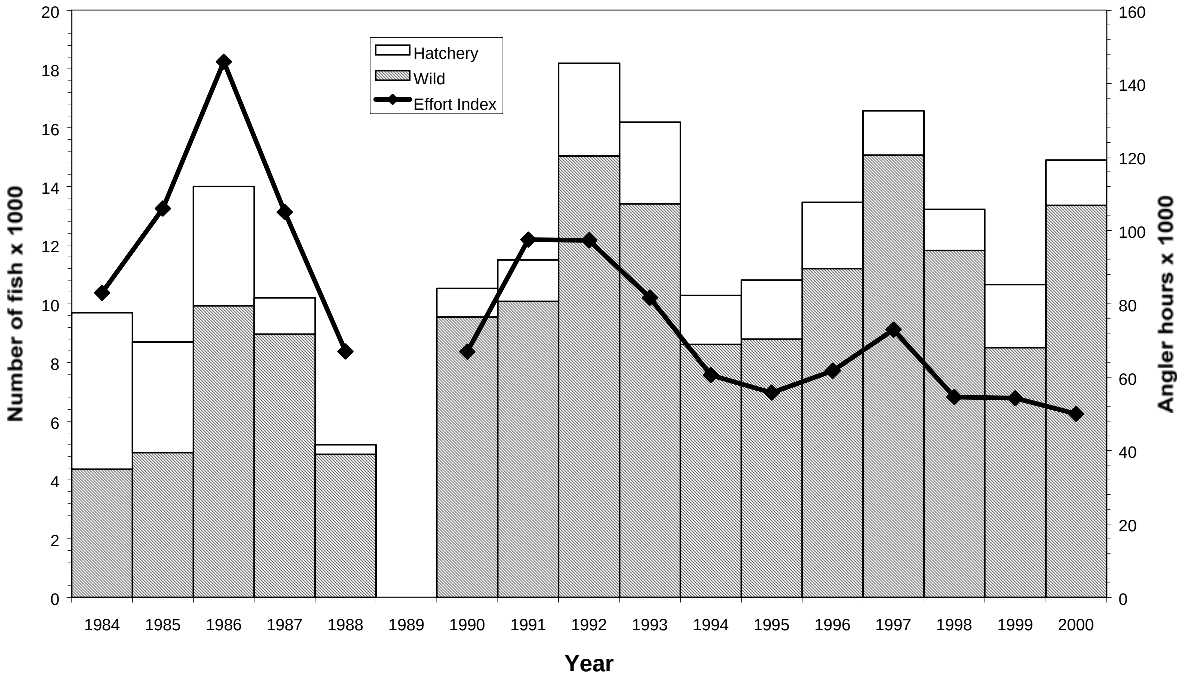


Figure 83. Sport harvest and index of effort for lake trout in MI-5. Data includes both charter boat and sport angler data. Data from Michigan Department of Natural Resources creel survey program and charter boat reports. No creel survey was conducted in 1989.

Population Surveys

<u>Spring survey</u>
The CPUE of wild, commercial-sized lake trout has declined since the peak in 1986 (Figure 84a). Since 1994, wild lake trout CPUE has been relatively constant with the exception of 1998. Unusually warm temperatures in 1998 likely caused the low CPUE, rather than an actual decline in abundance. This is supported by the return of the 1999 CPUE to the trajectory of 1994-1997. Furthermore, sport and commercial fishery CPUE did not decline in 1998. Hatchery CPUE has declined since the peak in 1975. In recent years, hatchery fish make up less than 20% of the fish sampled. The modal age of wild lake trout sampled in the spring survey was between 6 and 9 years during 1975-2000.

<u>Pre-recruit survey</u>
Wild pre-recruit lake trout CPUE has increased two-fold since 1985, whereas hatchery pre-recruit CPUE has remained low without trend (Figure 84b). The modal age of wild lake trout was between 5 and 7 years.

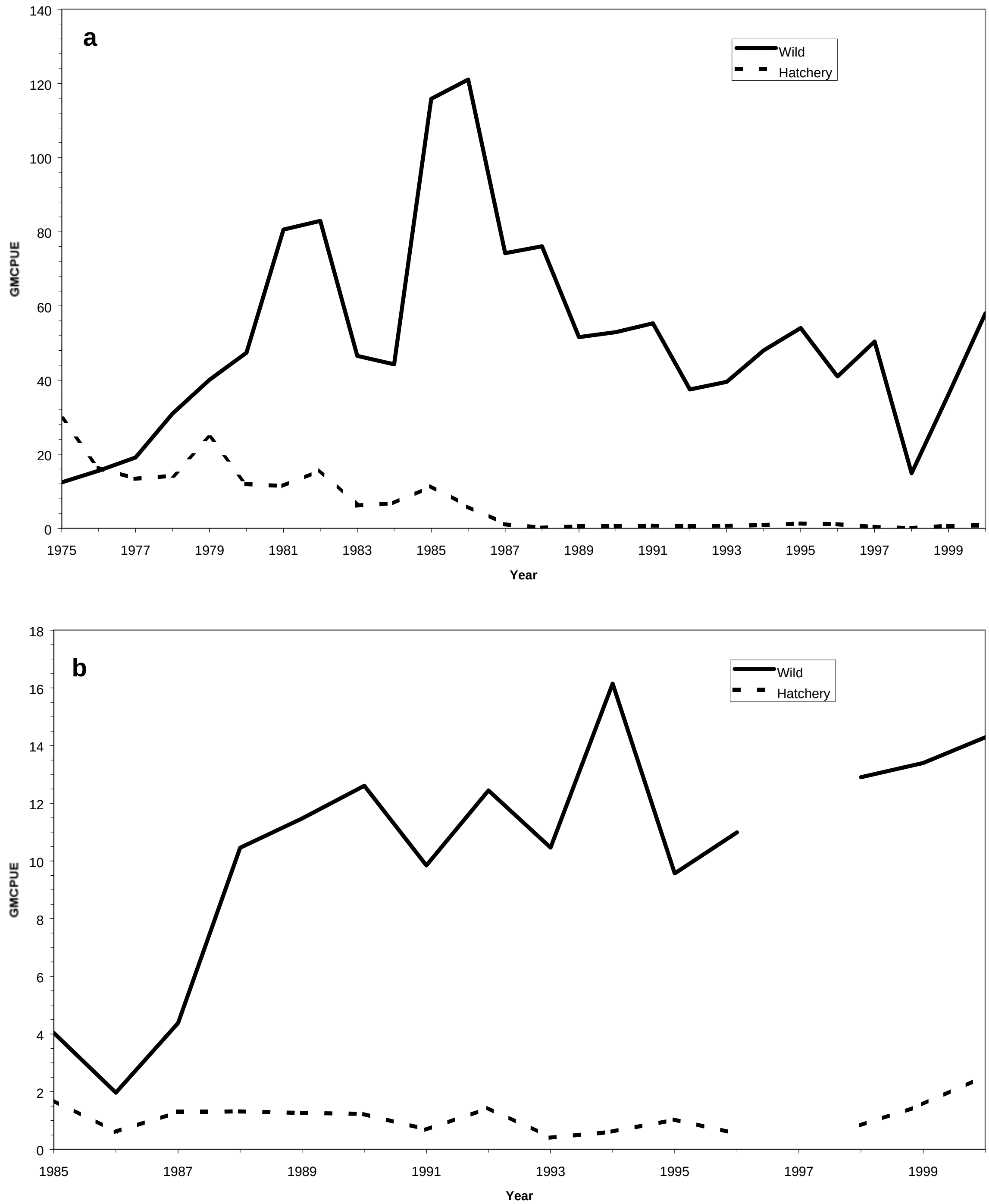


Figure 84. Index of relative abundance of lake trout in MI-5 from (a) the spring lake trout survey from 1975-2000 and (b) the pre-recruit survey from 1985-2000. No pre-recruit survey was conducted in 1997. Relative abundance index expressed as the geometric mean number of fish per km of net per night (GMCPUE) based on estimates from mixed model analysis.

Special Characteristics of MI-5 Wild Lake Trout SCAA Model and Data

Commercial fishery

The sample sizes for the mean weight of a harvested fish from commercial monitoring ranged from 1 to 324 fish per year during 1986-2000. The mean weight of a harvested fish for 1988 was not measured and was assumed equal to the average of 1987 and 1989 values. The 1986 mean weight of harvested fish was based on only one fish, so we assumed the 1986 mean weight to be equal to 1987. Survey catch and state-licensed commercial fishery bycatch in gill and trap nets were incorporated into the total commercial harvest. Since there was no tribal commercial harvest during 1975-85, but there was survey catch and state-licensed bycatch, we assumed that commercial selectivity, age compositions and sample sizes for aged fish during 1975-85 to be equal to the survey values during those years. Individual commercial fishing intensities were estimated as parameters for 1975-85. The 1986-2000 commercial *F*'s were estimated as model parameters. The commercial $\log_e$-scale standard deviations (SD) for commercial harvest and effort were nominally set to 0.15

Recreational fishery

Sport harvest data based on standardized creel surveys were only available back to 1984. The 1984-98 recreational *F*'s were estimated as model parameters. No creel data were available for 1989, so the *F* for 1989 was assumed to be equal to the average of 1988 and 1990 values. Since there were no reliable sport harvest data prior to 1984, the *F*'s for 1975-83 were set equal to the estimated value for 1984. The $\log_e$ SD for harvest was 0.5664, while the $\log_e$ SD for effort was 0.0518.

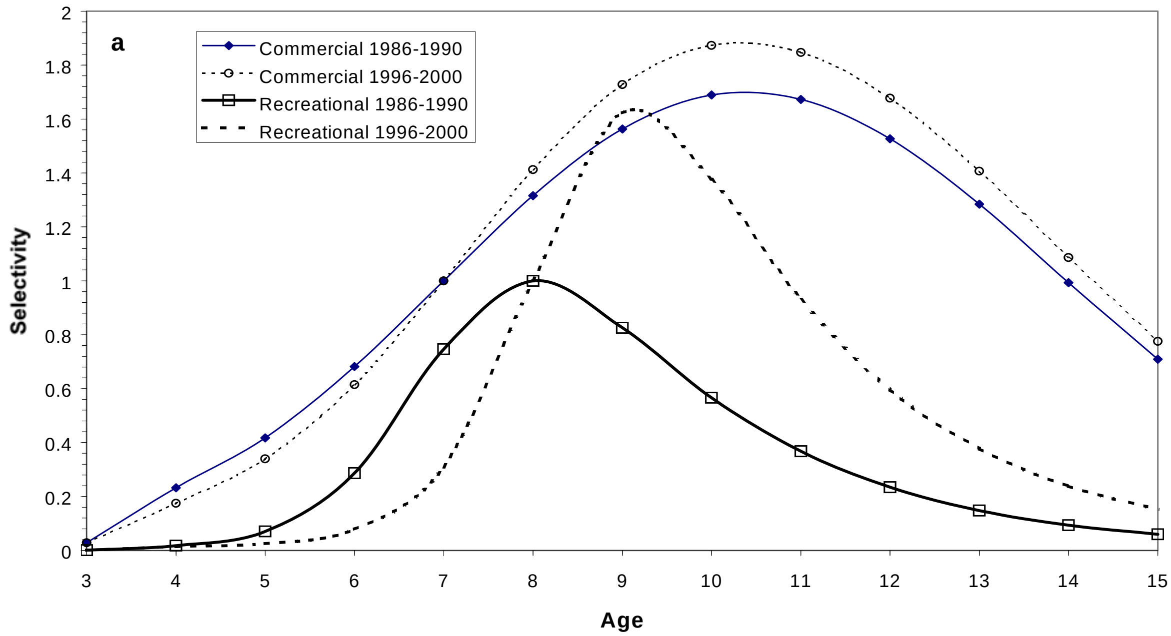
Other information

The prior estimate of *M* for MI-5 was based on using Pauly's equation with the following parameter values: temperature = 5^o C; L_∞ = 86.76 cm; K = 0.163363; and SE = 0.057. The von Bertalanffy parameters were based on the average values from 1975-98. The abundance of age 14 and 15 lake trout in 1975 was set equal to the model's estimate for age 13. This was done because of unstable model convergence properties when those two ages were estimated as individual parameters during earlier model runs. This is likely due to insufficient data in the model for those cohorts.

Results of MI-5 SCAA Model

Selectivity

Commercial fishery selectivity patterns were dome shaped with peak selectivity varying between age 10 and 11 during 1986-2000 (Figure 85a). Recreational fishery selectivity was also dome shaped with peak selectivity shifting from age 8 to age 9 during 1975-2000 (Figure 85a). Spring survey and pre-recruit survey selectivity patterns were both dome shaped. The peak selectivity for the spring survey was between age 7 and 8 during 1975-2000 (Figure 85b). Peak selectivity for the pre-recruit survey was age 4 in all years (Figure 85b).



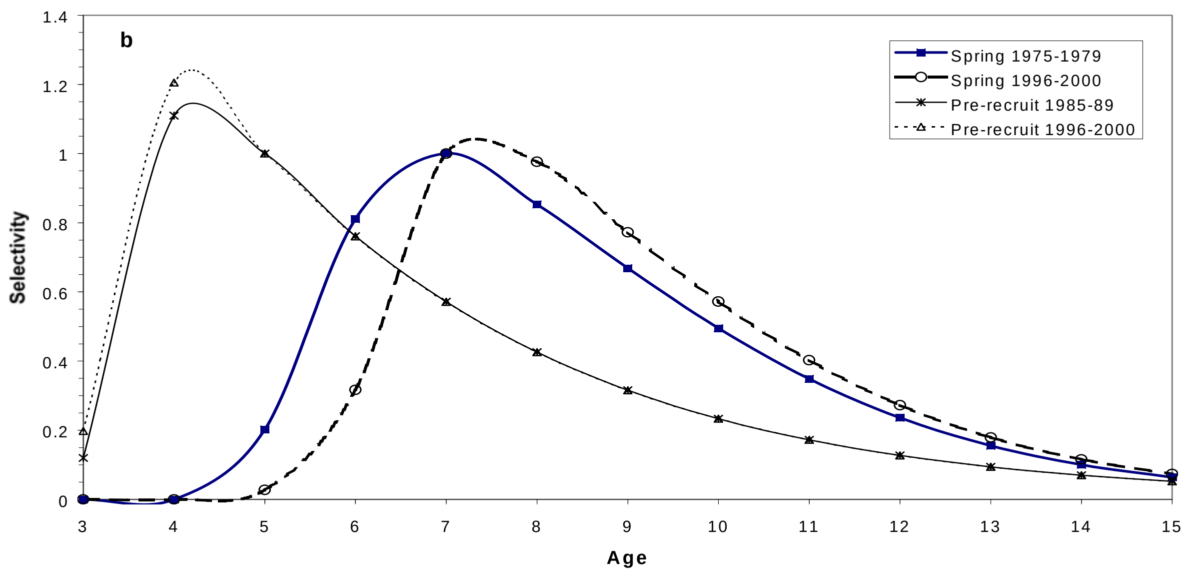


Figure 85. Selectivity patterns for wild lake trout in MI-5 estimated by statistical catch-at-age analysis: (a) commercial and recreational fisheries, and (b) spring and pre-recruit surveys. Tribal commercial fishing began in 1986, and pre-recruit surveys began in 1985. Selectivity patterns for all fisheries were assumed to be constant from 1994-2000 in the model. Recreational fishery selectivity prior to 1984 was assumed equal to 1984.

<u>Fishing mortality (ages 6 to 11)</u>

Age-specific patterns in fishing mortality follow selectivity patterns. Temporal trends in fishing mortality rates were based on the average rates for ages 6 to 11 lake trout. During 1986-2000, average recreational fishing mortality rates for ages 6-11 lake trout were higher than commercial fishing in all years except in 1988 and 2000 (Figure 86). Commercial fishing mortality peaked in 2000 at 0.05. Recreational fishing mortality increased from 0.01 in 1988 to 0.04 in 2000.

Sea lamprey-induced mortality (ages 6 to 11)

Sea lamprey-induced mortality has declined from 1975 to 2000 (Figure 86). Sea lamprey-induced mortality rates have declined over 70% from the peak in 1981 of 0.19 to 0.04 in 1998. In most recent year of data (1999), sea lamprey mortality has increased to 0.10. The lowest sea lamprey-induced mortality rate was in 1987 (0.02). Excluding background natural mortality, sea lamprey-induced has been the dominant mortality source (Figure 86).

Natural mortality

The SCAA model's estimate of background natural mortality for all ages was 0.184, which was about 2% lower than the prior estimate of 0.187 from Pauly's equation. Natural mortality has been the dominant mortality source in all years modeled except 1977 and 1981 (Figure 86).

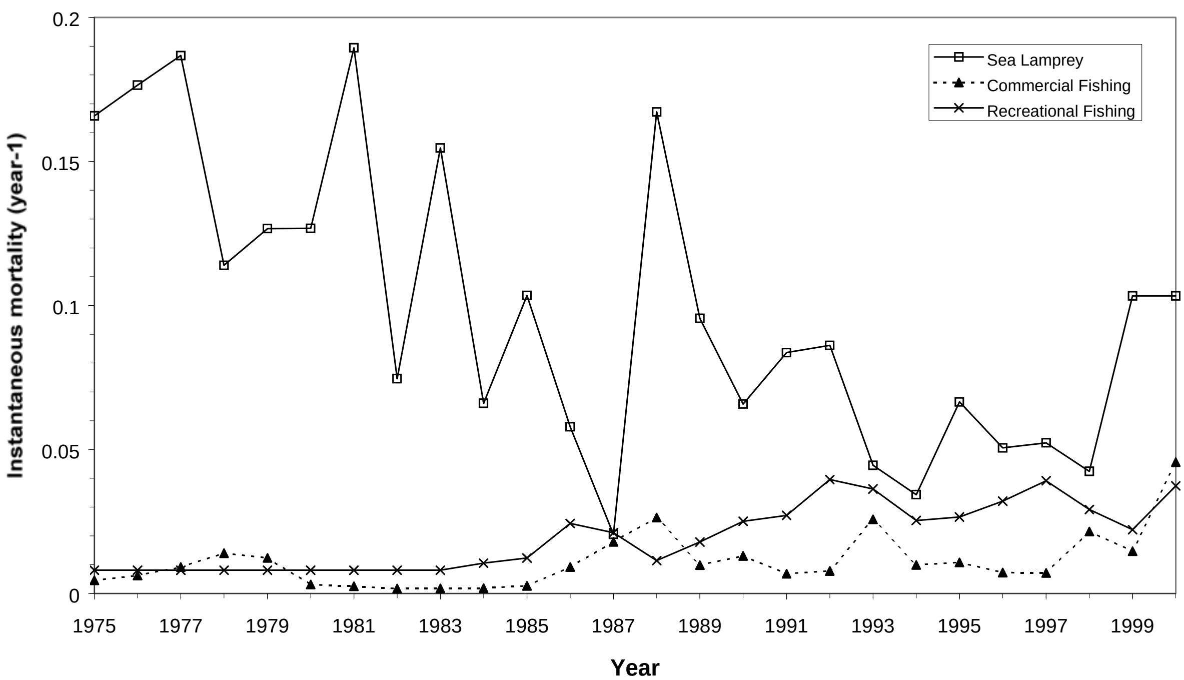
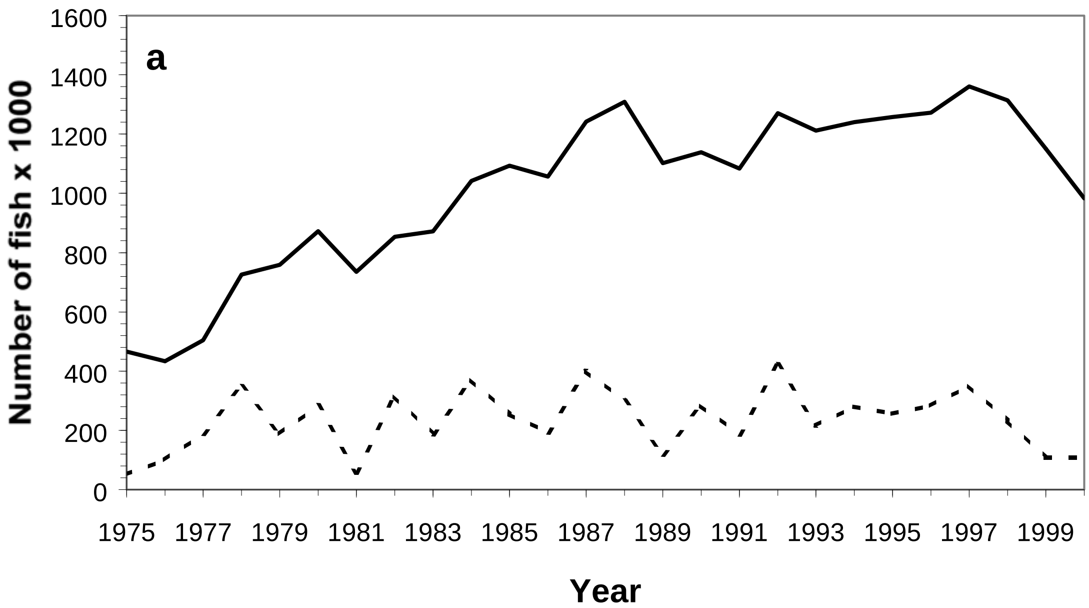


Figure 86. Average instantaneous mortality rates for ages 6-11 wild lake trout in MI-5. Fishing mortality rates were estimated by the statistical catch-at-age (SCAA) model. Commercial fishing mortality was based on a large-mesh gill net fishery. Tribal commercial fishing began in 1986. Commercial fishing mortality rates prior to 1986 were estimates for survey extractions and state-licensed bycatch and discards. Recreational fishing mortality rates were assumed constant from 1975-83.

Abundance

Total abundance (ages 3-15) has increased three-fold from 465,000 fish in 1975 to 1.4 million fish in 1997 (Figure 87a). Recruitment at age 3 has increased over four-fold since 1975 and has averaged 244,000 fish per year from 1991-2000 (Figure 87a). Total annual biomass did not increase as much as numerical abundance due to declines in growth (Figure 87b). Likewise, spawning stock biomass has not increased since 1975 due to declines in growth and increased age at maturity even though there were more fish in the population (Figure 87b).



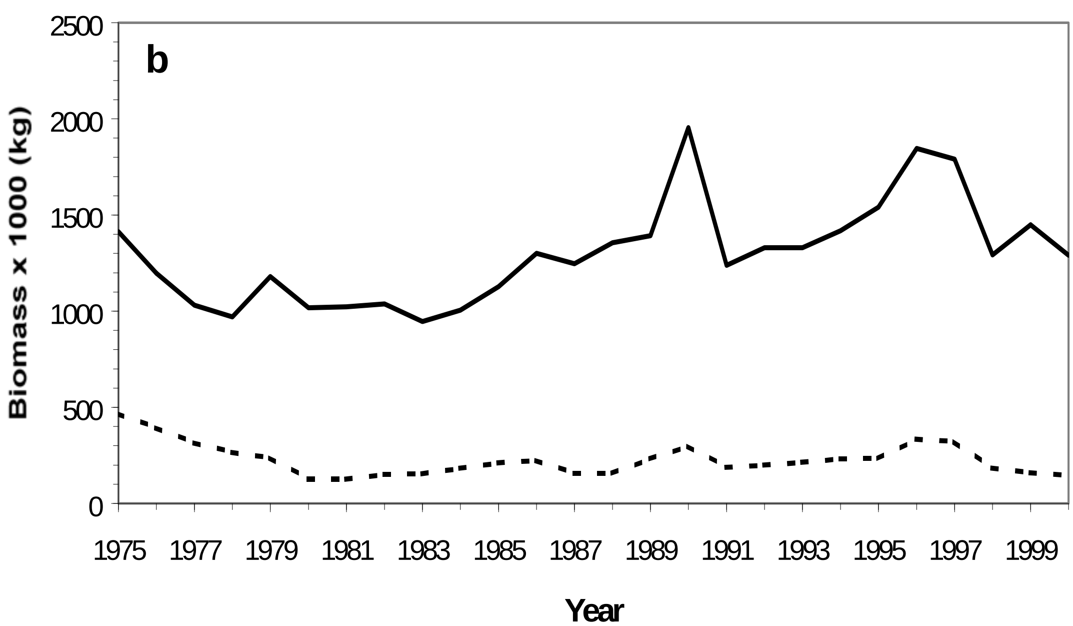


Figure 87. Statistical catch-at-age model estimates of wild lake trout abundance in MI-5. (a) Total abundance of ages 3-15 fish (solid line) and recruitment at age 3 (dashed line). (b) Total biomass (solid line) and spawning stock biomass (dashed line).

Model fit

Overall, model predictions were consistent with observed data. No systematic patterns in residuals were evident in commercial harvest (Figure 88a). There was a minor pattern in recreational harvest residuals with model predictions of harvest being higher than observed values during 1984-1991, and lower than observed harvest during 1992-2000 (Figure 88b). However, the differences between observed and predicted values were less than 1% for all years except 1985 where the difference was 1.2%. The greatest difference between observed and predicted recreational harvest was 129 fish.

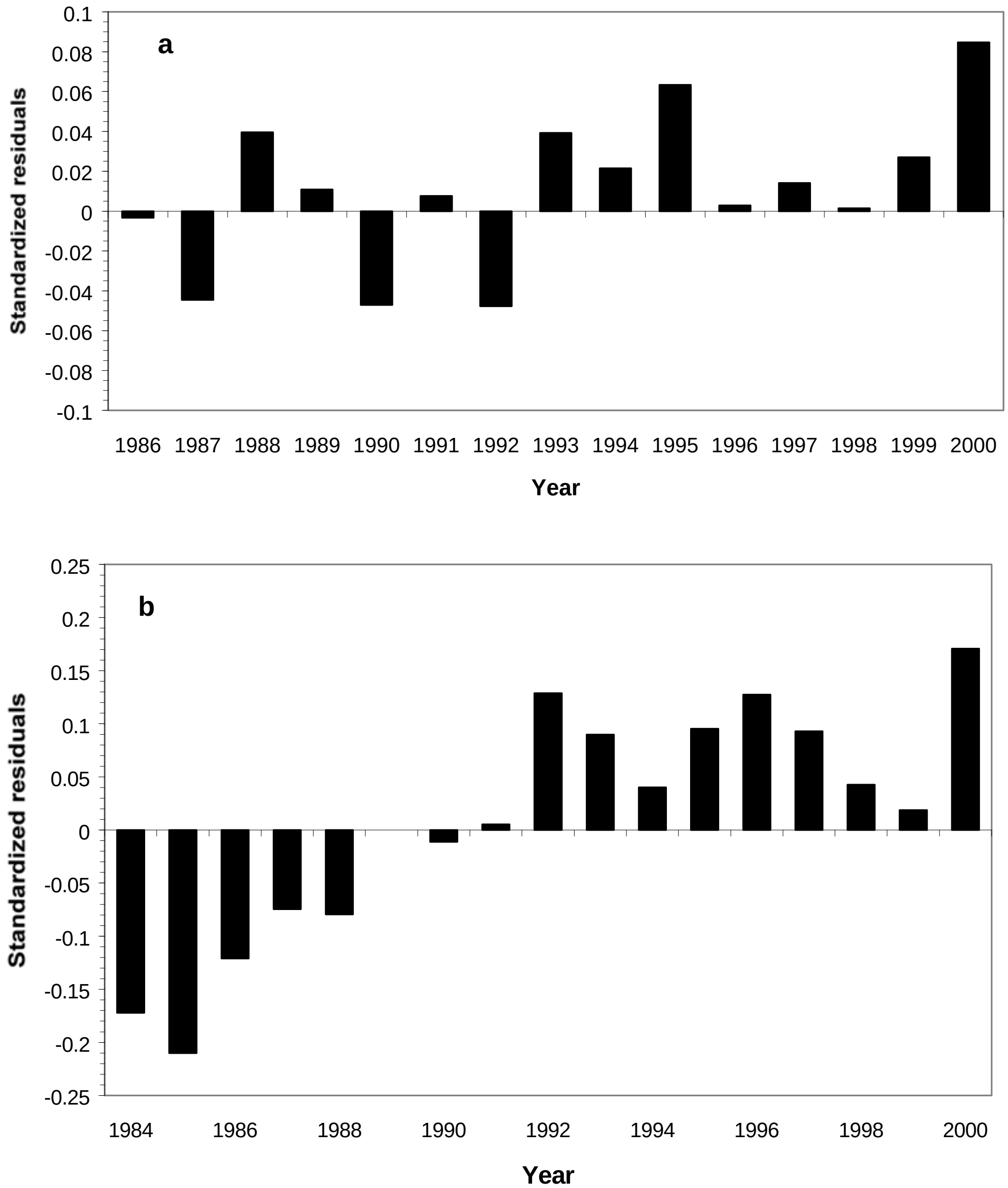
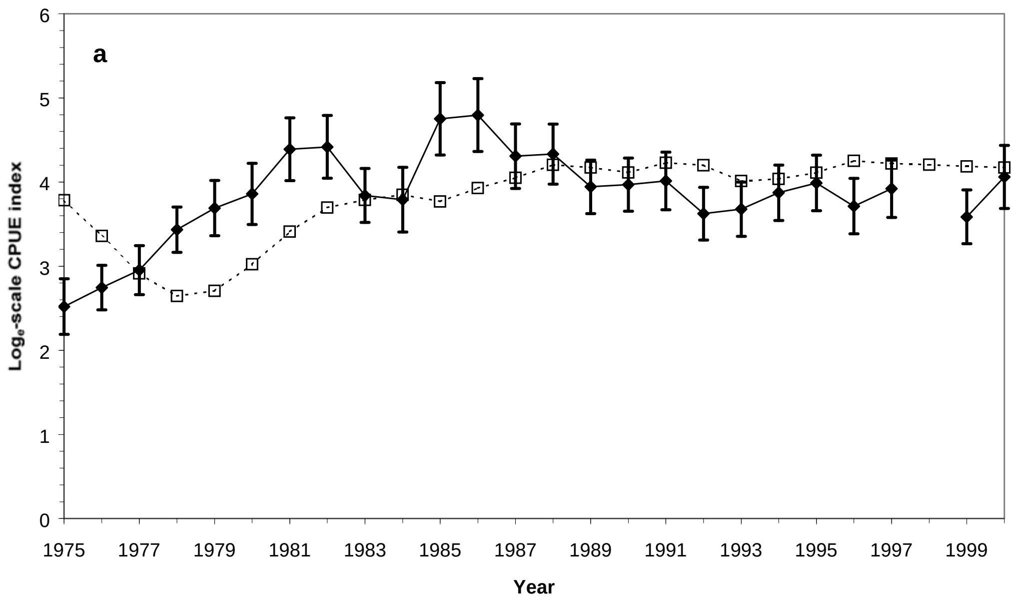


Figure 88. Standardized residuals for MI-5 wild lake trout harvest from (a) tribal commercial fishery, and (b) recreational fishery. Observed recreational harvest was not available in 1989 and prior to 1984. Standardized residuals calculated as observed minus predicted divided by the estimated standard deviation.

The model's estimates of survey CPUE were less variable from year to year than observed values (Figure 89). Considering the high inter-annual variability in observed CPUE indices, the model was able to match the major temporal trends in the observed CPUEs. Model predictions of spring survey CPUE for 1989-2000 were higher than observed values (Figure 89a). Predicted pre-recruit survey CPUEs for 1988-2000 were lower than observed values (Figure 89b).



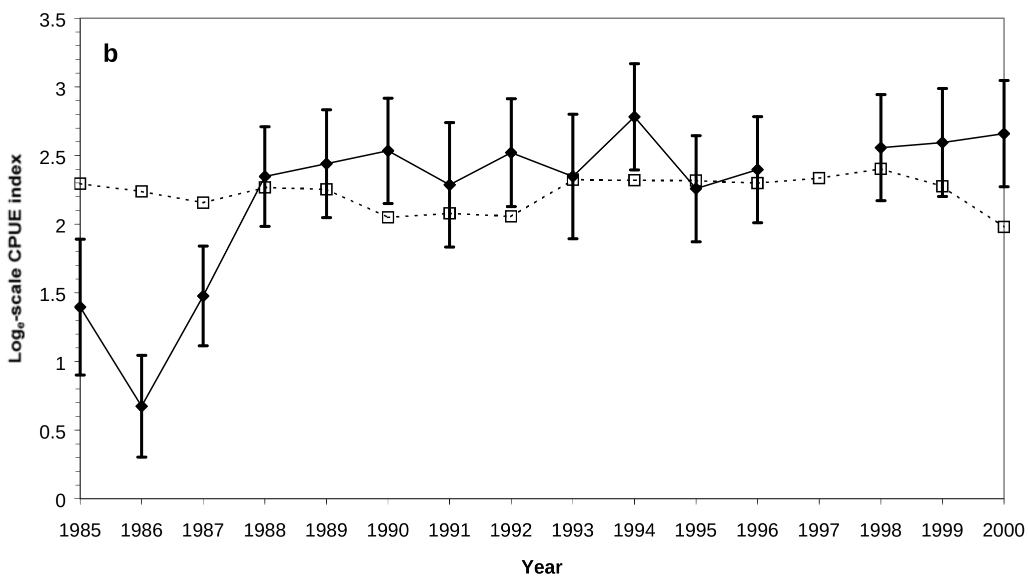


Figure 89. Comparison of MI-5 statistical catch-at-age model predictions to observed values for survey CPUE. (a) Spring survey. (b) Pre-recruit survey. Survey CPUE expressed as a $\log_e$-scale index. Error bars represent one standard error. Solid lines are observed values and dashed lines are model estimates. No pre-recruit survey was conducted in 1997. The observed 1998 spring survey CPUE was not used in the analysis because it was strongly biased and unrepresentative of lake trout relative abundance.

Some systematic patterns were observed in fishery and survey age composition residuals. The model tended to over-estimate the proportion of ages 3 and 4 fish in most years in the recreational, commercial, and spring survey age compositions (Figures 90, 91). This pattern in the residuals is likely due to a bias in the observed age compositions because of under-sampling and discard of small fish in the commercial fishery, and because of under-reporting of fish <432 mm in the spring surveys. The commercial fishery in MI-5 has operated under a quota system (number of fish) and it was possible that the fishers selected for larger fish and discarded small fish in order to optimize harvest and revenue. No significant patterns in residuals were observed for the pre-recruit survey age compositions (Figure 91b).

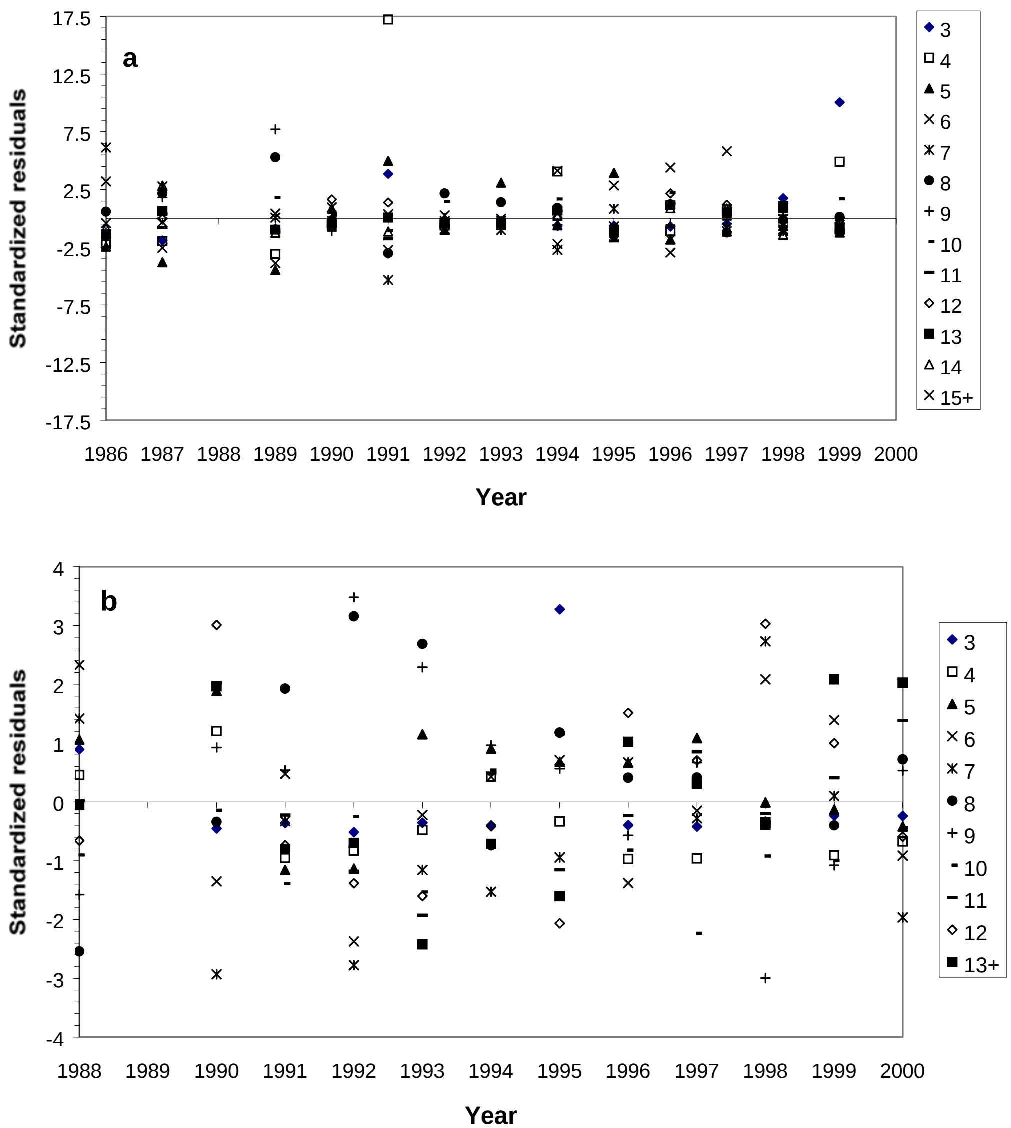
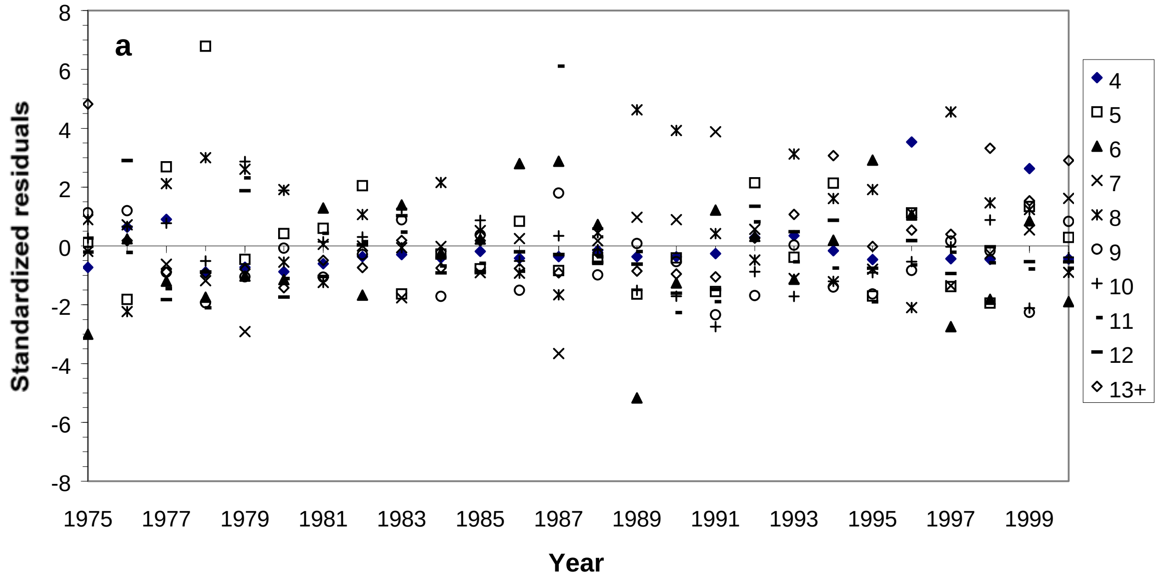


Figure 90. Standardized residuals for MI-5 wild lake trout age composition data from (a) tribal commercial fishery, and (b) recreational fishery. Observed recreational age compositions were not available in 1989 and prior to 1988. Standardized residuals calculated as observed minus predicted proportions at age divided by the estimated standard deviation.



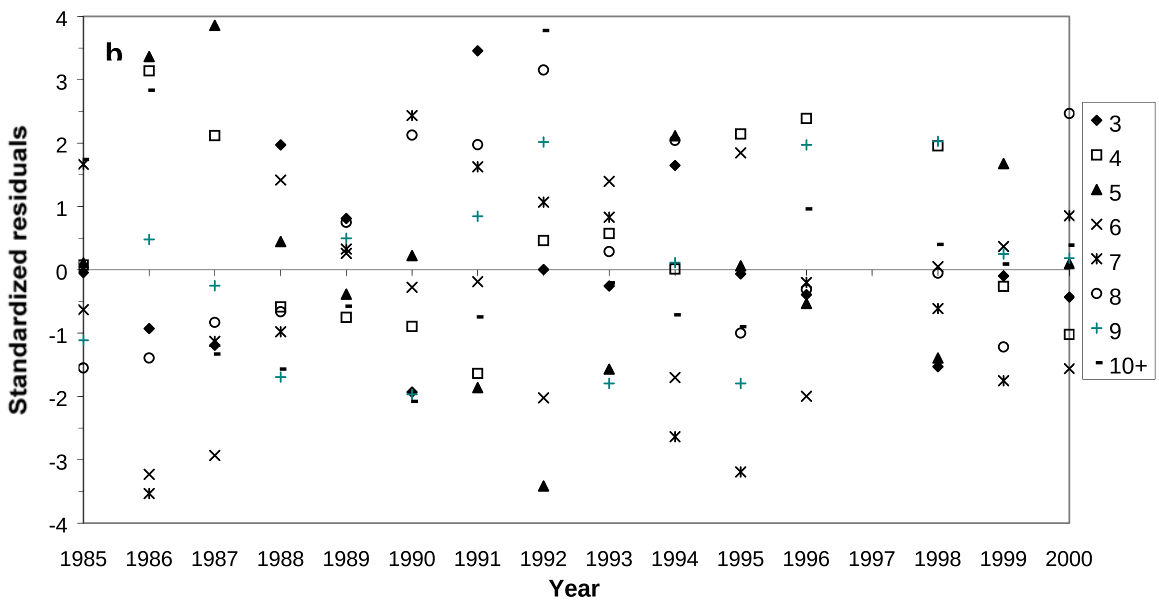


Figure 91. Standardized residuals for MI-5 wild lake trout age composition data from (a) spring survey, and (b) pre-recruit survey. The pre-recruit survey was not conducted in 1997. Standardized residuals calculated as observed minus predicted proportions at age divided by the estimated standard deviation

Status Relative to Reference Point in MI-5

<u>Mortality and SSBR</u>

Based on recent model estimates (1998-2000), mortality rates were below the established target maximum and SSBR was greater than SSBR_T. The average Z for ages 6-11 lake trout during 1998-2000 was 0.32 (range: 0.28-0.37), which is lower than the target maximum of 0.60 (*A* =

45%). The SSBR was 0.482 kg while SSBR_T was 0.240 kg. Spawning potential ratio was 0.305. The highest mortality source (excluding background natural mortality) during 1998-2000 was sea lamprey predation (see Figure 86) with lamprey mortality rates averaging 0.08 for ages 6-11.

<u>Harvest and TAC</u>
Recent combined fishery yield has averaged about 22,000 kg annually (1998-2000). Using the SCAA model results and following the requirements of the Consent Decree, the recommended yield limit for MI-5 (1836 Treaty waters) for 2001 is 65,300 kg with 62,200 kg allocated to the recreational fishery and 3,100 kg for the tribal fishery. This includes an allowance for hatchery lake trout (13%). All commercial harvest in this unit is lean lake trout, therefore an expansion of the TAC to account for siscowet does not occur as it does in MI-6 and MI-7.

Status of Lake Trout in MI-6

Growth
Wild lake trout weight data for MI-6 were measured only in 1975, 1989, 1991, 1994, 1996, 1997, and 1998-2000. Overall, mean length- and weight-at-age for wild lake trout have declined from 1975 to 2000 (Figure 92a and b). Mean length at age 7 during 1995-2000 was about 6% lower than during 1975-1979. Mean weight at age 7 was 26% lower during 1995-2000 than during 1975-79. The β for wild lake trout has declined from 3.26 in 1975 to 3.08 in 2000 (Figure 92c). Although under-aging may have had an influence in trends in mean length- and weight-at-age, other sources of information indicate that the declines were real. The declining trend in growth may be due to intensified density-dependent effects, competition, and declines in forage fish abundance (Hansen 1990).

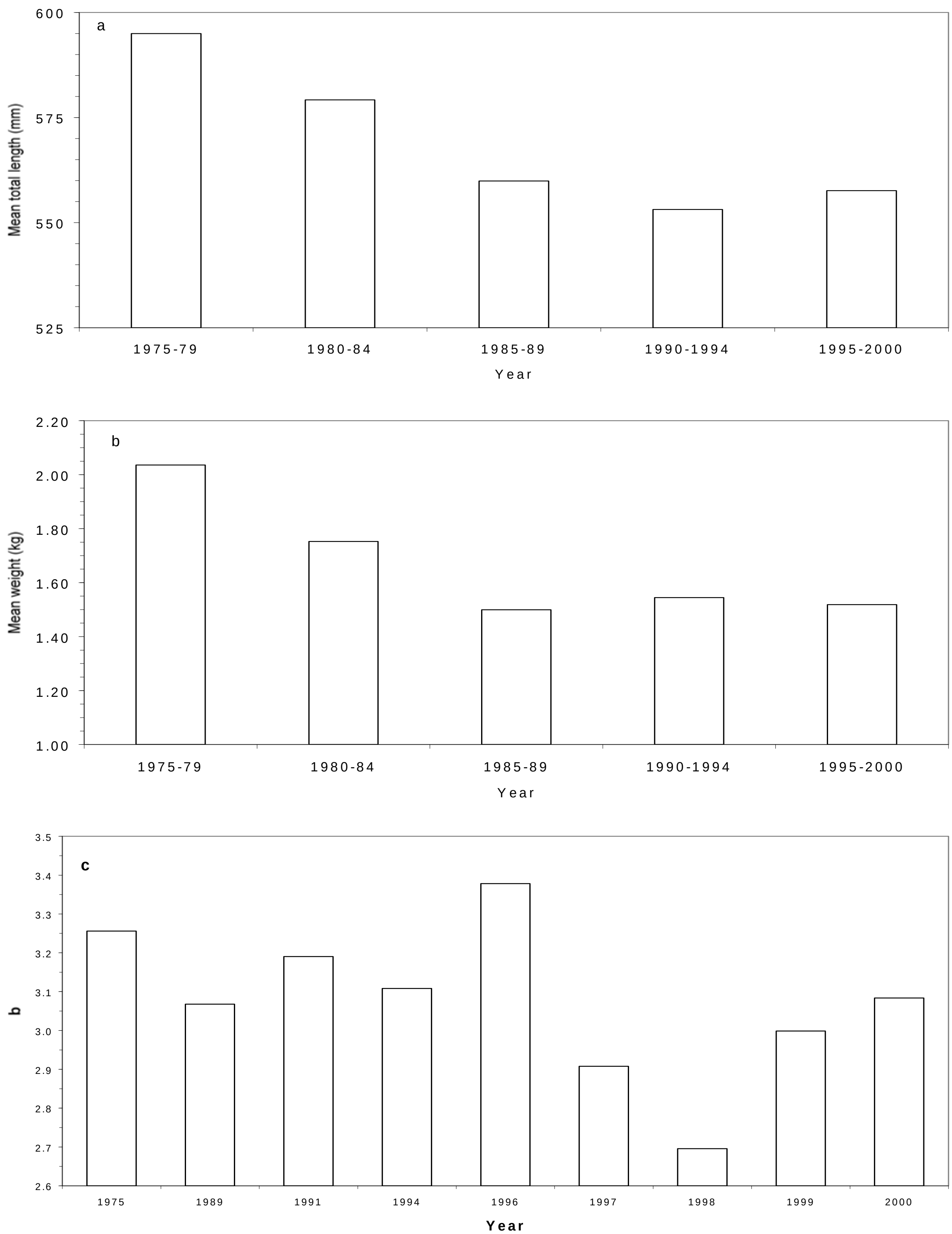


Figure 92. Growth of wild lake trout in MI-6 during 1975-2000 as indexed by (a) mean length of age 7; (b) mean weight of age 7; and (c) exponent from weight-length allometric growth model.

Maturity
The age at 50% maturity has increased from 1978 to 2000. The age at 50% maturity for wild lake trout was age 8 during 1978-1982 and increased to age 9 during 1999-2000 (Figure 93).

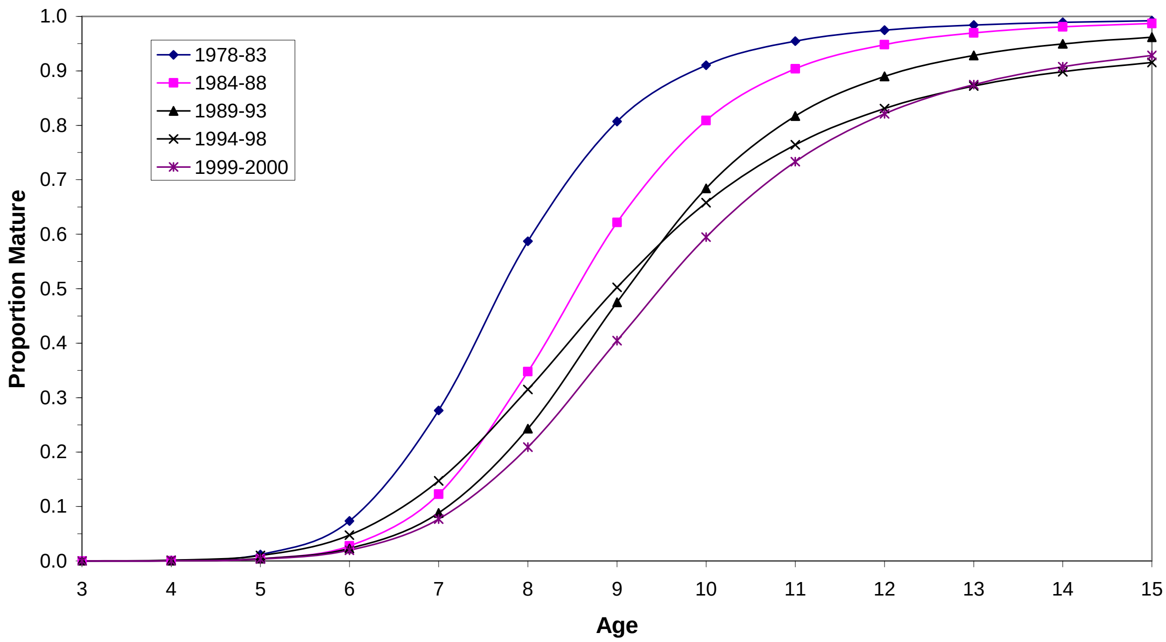


Figure 93. Female maturity-at-age for wild lake trout in MI-6 from 1978-2000. Data based on annual mean length-at-age data applied to a length-based logistic model for female maturity.

Spawning Stock
Spawning surveys have not been conducted in MI-6 since 1974. Peck (1979) reported spawner CPUEs in 1974 ranged from 0 to 305 fish/km with the percentage of wild lake trout ranging from 7 to 19.

Fishery

<u>Commercial fishery</u>
Tribal commercial harvest in MI-6 has been restricted to the region east of Grand Island (east of the north-south line forming the western boundary of grids: 934, 1034, 1134, 1234, 1334, 1434, 1534). Tribal harvest of lake trout has declined from the peak of 17,800 fish in 1977 to 5,200 fish in 2000 (Figure 94). Harvest of wild lake trout averaged 3,900 fish per year from 1976-2000, while the average annual harvest of hatchery fish was about 2,300. In most years, commercial lake trout harvest has been below 9,000 fish per year except in 1977-79 where total harvest was between 12,000 and 17,000 fish per year. The proportion of harvested fish that were wild has increased from about 20% in 1976 to 95% in 2000. Tribal gill-net effort declined from a peak of 1,100 km in 1978 to less than 310 km since 1995 (Figure 94). Effort data were not available for 1976 and 1977. The mean round weight of a harvested lake trout averaged 1.8 kg during 1978-2000 and has ranged from 1.5 to 3.1 kg.

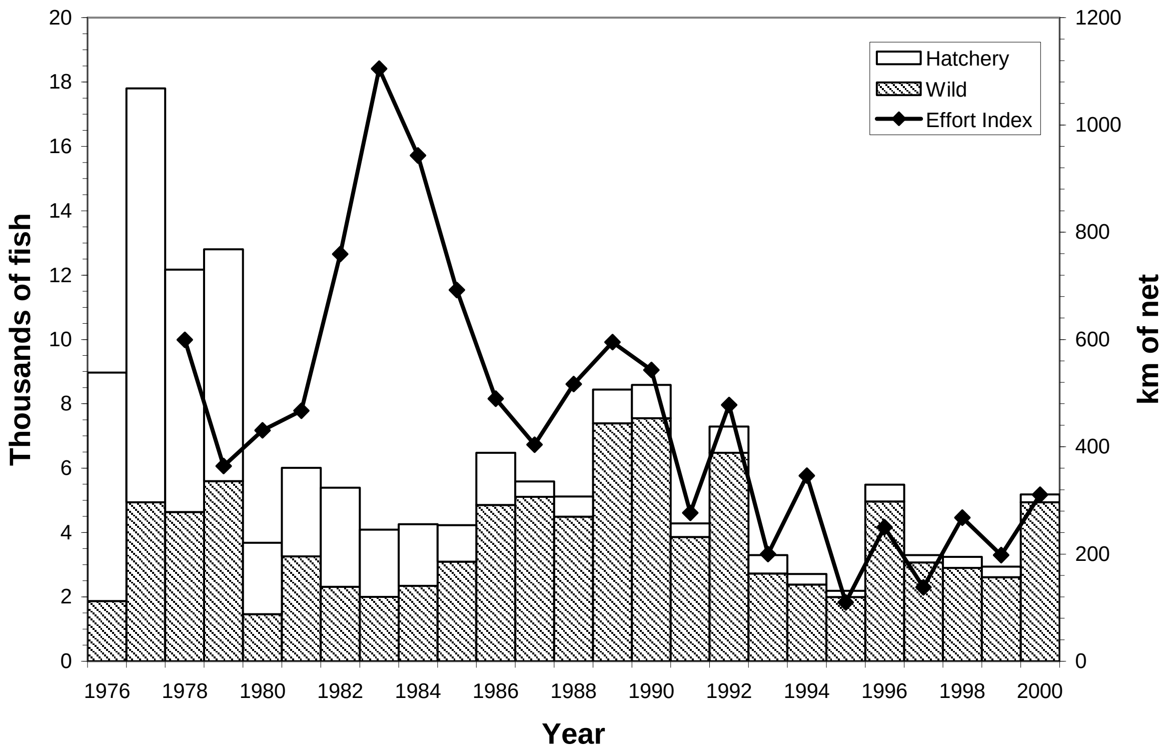


Figure 94. Tribal commercial large-mesh gill-net harvest and effort index for lake trout in MI-6. Data from the Chippewa Ottawa Resource Authority. Effort data were not available for 1976-1977.

<u>Recreational fishery</u>

Standardized creel surveys were not conducted prior to 1987 in MI-6. During 1987-2000, total wild lake trout recreational harvest has increased and averaged 3,900 fish per year, while harvest of hatchery fish has declined and averaged about 500 fish per year (Figure 95). The index of effort has declined from a peak of 72,000 angler hours in 1988 to 32,000 angler hours in 2000 (Figure 95). The annual mean weight of a harvest fish in the sport fishery averaged about 2 kg from 1987-2000 and ranged between 0.97 to 2.4 kg.

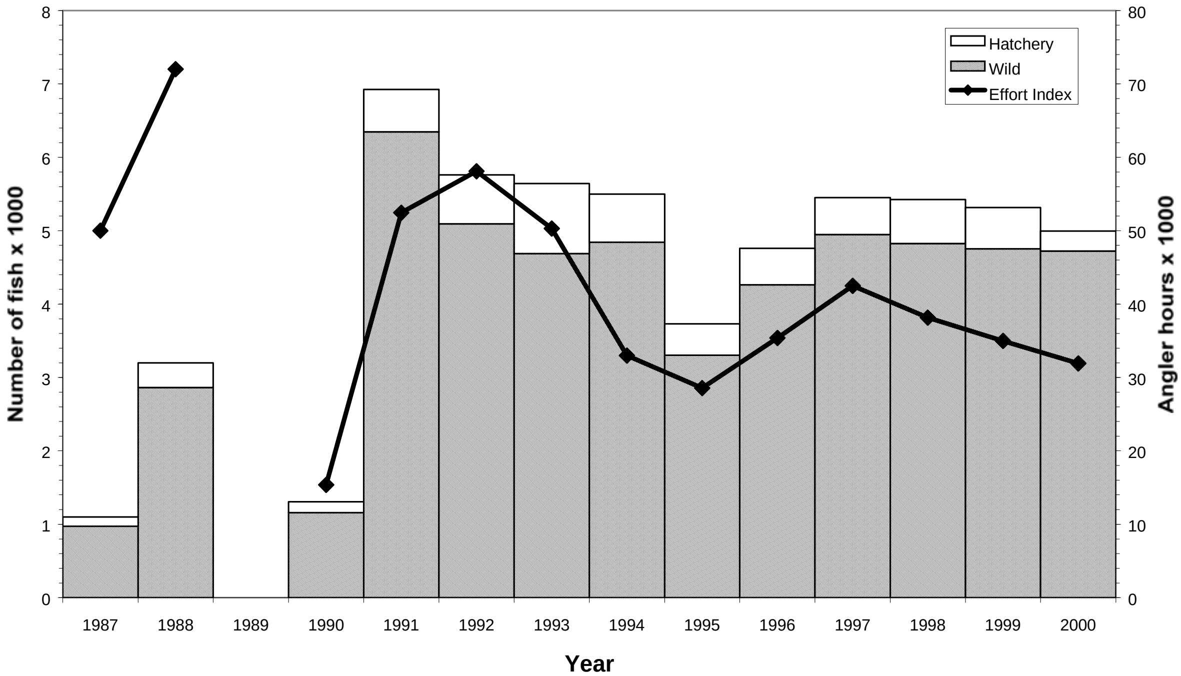


Figure 95. Sport harvest and index of effort for lake trout in MI-6. Data includes both charter boat and sport angler data. Data from Michigan Department of Natural Resources creel survey program and charter boat reports. No creel survey was conducted in 1989.

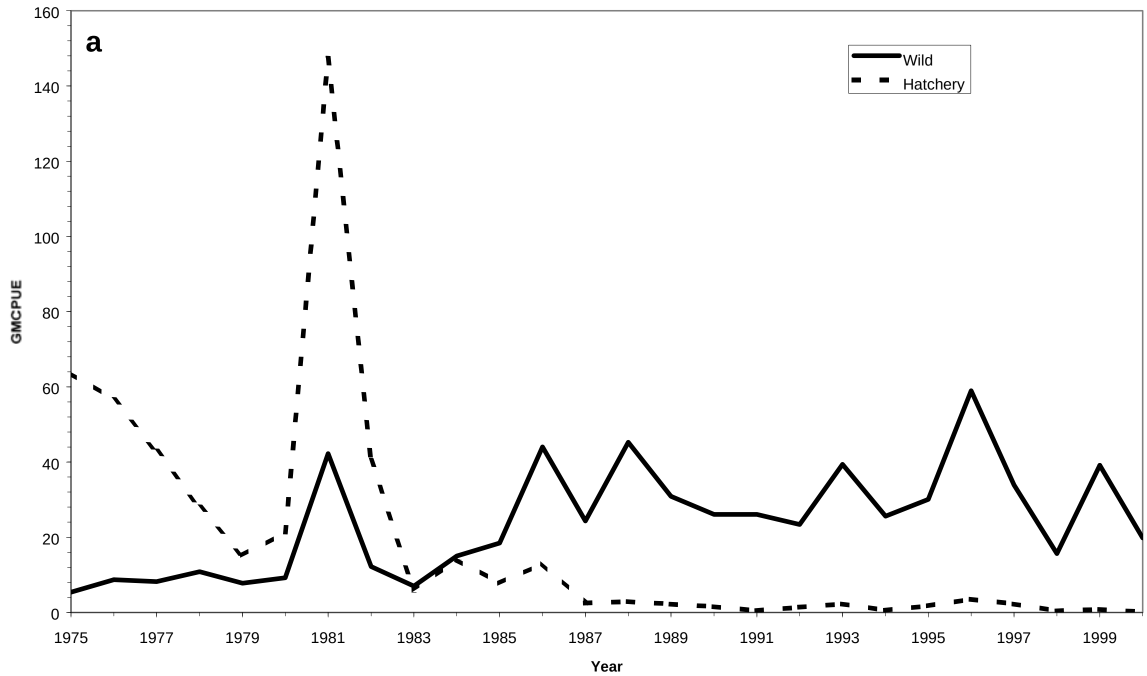
Population Surveys

<u>Spring survey</u>

The geometric mean CPUE of wild commercial-sized lake trout in MI-6 has increased from 7 fish/km in1983 to 19.8 fish/km in 2000 (Figure 96a). The average CPUE of wild lake trout during 1975-1984 was 12.7 fish/km and was 31.2 fish/km during 1991-2000. Average hatchery CPUE has declined 97% between the 1975-1984 and 1991-2000 time periods (Figure 96a). In recent years, hatchery fish have made up less than 10% of all the fish sampled in the spring survey. The transition from dominance by hatchery fish to wild fish began in 1985.

<u>Pre-recruit survey</u>

Relative abundance of wild pre-recruit lake trout in MI-6 declined 82% from 1987 to 1996 (Figure 96b). However, pre-recruit CPUE has increased during 1999-2000. Hatchery pre-recruit CPUE has been low and declining.



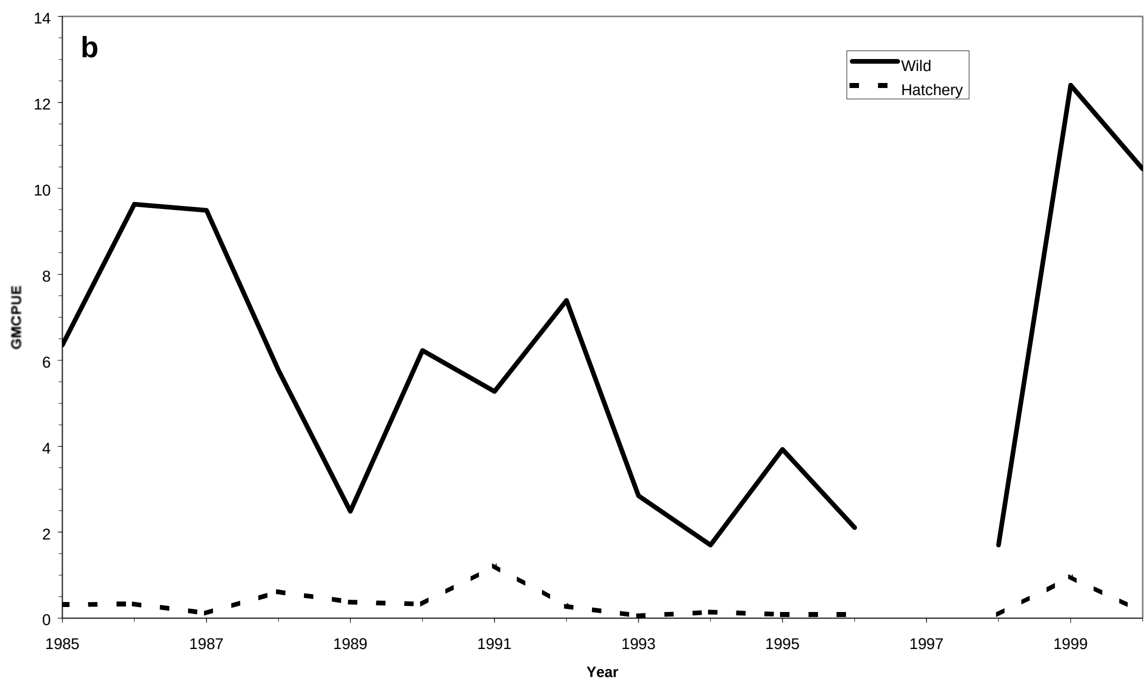


Figure 96. Index of relative abundance of lake trout in MI-6 from (a) the spring lake trout survey from 1975-2000 and (b) the pre-recruit survey from 1985-2000. No pre-recruit survey was conducted in 1997. Relative abundance index expressed as the geometric mean number of fish per km of net per night (GM CPUE) based on estimates from mixed model analysis.

Special Characteristics of MI-6 SCAA Model and Data

Commercial fishery

Biological sampling of tribal commercial harvest in MI-6 did not start until 1980. The mean weight of a harvested fish from the tribal commercial harvest was not measured in 1981-82, 1989, and 1993. Therefore, the mean weight of a harvested fish prior to 1980 was assumed to be equal to the mean value of the sampled years (1980, 1983-88, 1990-92, and 1994-2000), which was 1.82 kg. The commercial *F*s for all harvest years in the model (1978-2000) were estimated as model parameters, and commercial effort was de-emphasized in the model fitting process. The commercial $\log_e$-scale standard deviations (SD) for commercial harvest and effort were nominally set to 0.15.

Recreational fishery

Sport harvest data for MI-6 based on on-site standardized creel surveys were only available back to 1987. The 1987-98 recreational *F's* were estimated as individual model parameters. No creel data were available for 1989, so the *F* for 1989 was assumed to be equal to the average of 1988 and 1990 values. Since there were no reliable sport harvest data prior to 1987 in MI-6, the *F*s for 1978-86 were set equal to the estimated value for 1987. The $\log_e$ SD for harvest was 0.1613, while the $\log_e$ SD for effort was 0.0723.

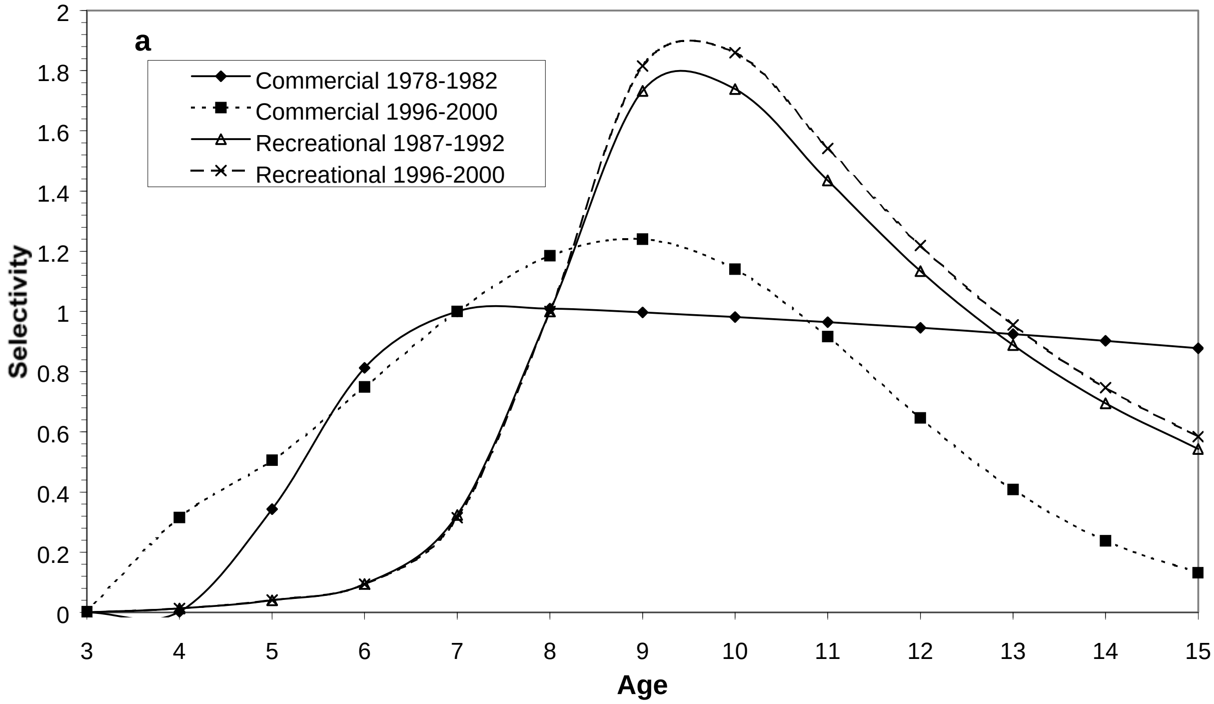
Other information

The prior estimate of *M* for MI-6 was based on using Pauly's equation with the following parameter values: temperature = 5^o C; L_∞ = 90 cm; K = 0.15; and SE = 0.057. The von Bertalanffy parameters were based on the average values from 1975-2000. The model's starting abundance of ages 12-15 lake trout in 1978 was set equal to the model's estimate for age 11. This was done because of unstable model convergence properties when these ages were estimated as individual parameters during earlier model runs. This is likely due to insufficient data in model for those cohorts.

Results of MI-6 SCAA Model

Selectivity

The commercial fishery selectivity pattern was estimated to be asymptotic in the early part of the time series (1978-1982) and was dome shaped during 1996-2000 (Figure 97). The commercial fishery had peak selectivity shifting from age 7 during 1978-1982 to age 9 during 1996-2000. Recreational fishery selectivity was dome shaped with peak selectivity between age 9 and 10. Spring survey selectivity was approximately asymptotic with peak selectivity at age 7 and 8 (Figure 97b). Pre-recruit survey selectivity was dome shaped with peak selectivity at age 5.



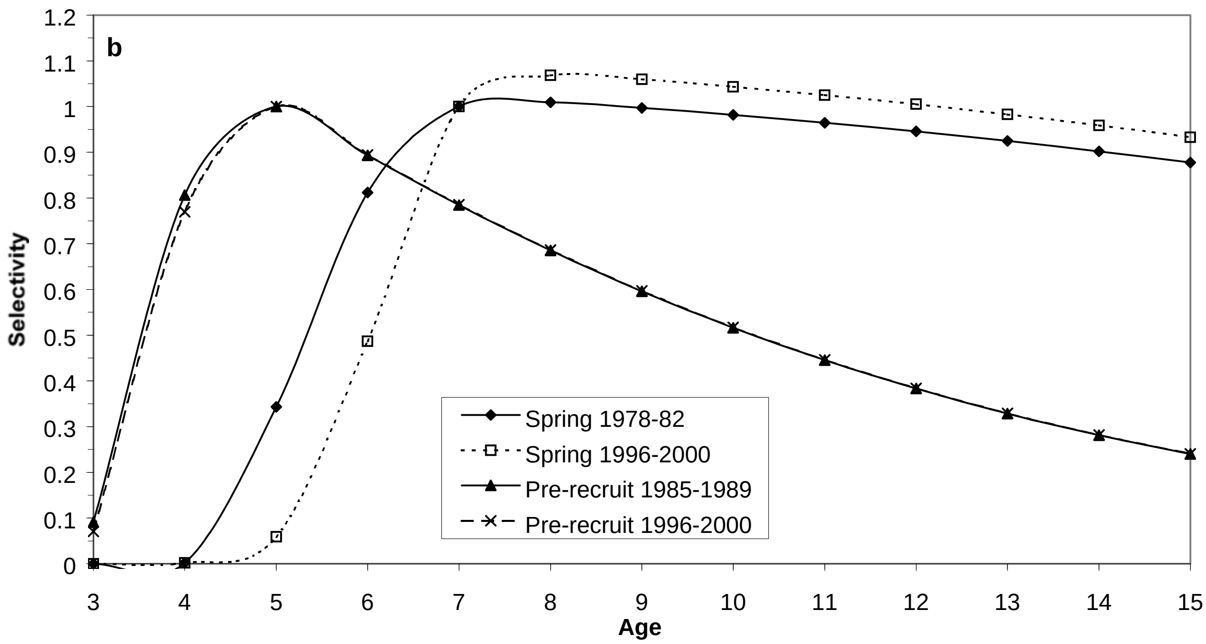


Figure 97. Selectivity patterns for wild lake trout in MI-6 estimated by statistical catch-at-age analysis: (a) commercial and recreational fisheries, and (b) spring and pre-recruit surveys. Pre-recruit surveys began in 1985. Selectivity patterns for all fisheries were assumed to be constant from 1994-2000 in the analysis.

<u>Fishing mortality (ages 6-11)</u>
Commercial fishing mortality has declined over time and has been lower than recreational fishing since 1991 (Figure 98). The average commercial fishing mortality rate during 1998-2000

was 0.07. Recreational fishing mortality rates increased over time and peaked in 1991 at 0.22. During 1998-2000, the average recreational fishing mortality rate was 0.13.

Sea lamprey-induced mortality (ages 6-11)

Sea lamprey mortality rates have declined from a peak of 0.44 in 1979 to an average of 0.12 during 1998-2000 (Figure 98). Sea lamprey mortality rates tend to peak about every four to five years and have changed up to five fold from one year to the next. These variations could be due to sea lamprey control treatment cycles.

Natural mortality

The SCAA model's estimate of background natural mortality for all ages was 0.173, which was nearly equal to the prior estimate of 0.175 from Pauly's equation. Natural mortality has been the dominant mortality source since 1992 (Figure 98).

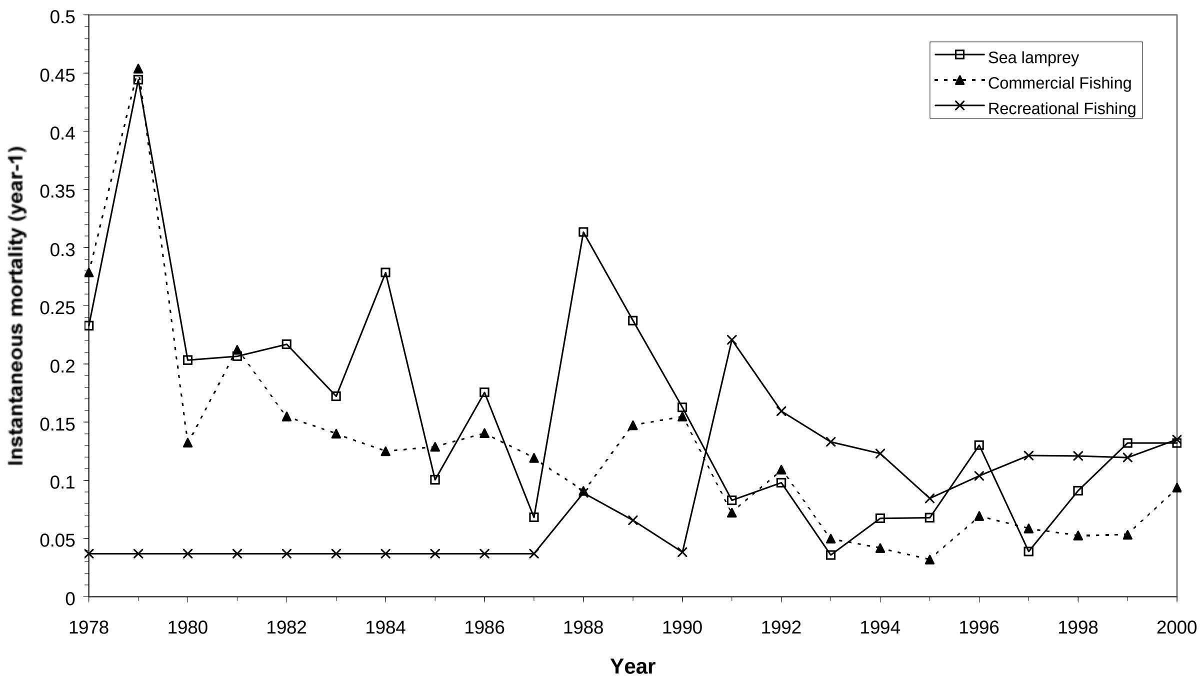


Figure 98. Average instantaneous mortality rates for ages 6-11 wild lake trout in MI-6. Fishing mortality rates were estimated by the statistical catch-at-age (SCAA) model. Commercial fishing mortality was based on a large-mesh gill-net fishery. Recreational fishing mortality rates were assumed constant from 1978-87.

Abundance

Total abundance (ages 3-15) increased from 114,000 fish in 1978 and peaked at 238,000 fish in 1988 (Figure 99a). Total abundance has averaged about 158,000 during 1998-2000. Recruitment at age 3 averaged 40,000 fish per year from 1991-2000 (Figure 99a). Total annual biomass peaked at 210,000 kg in 1994 and has declined to 147,000 kg in 2000 (Figure 99b). Spawning stock biomass has not increased since 1978 due to declines in growth and increased age at maturity, even though there were more fish in the population since the late 1980s. Despite the MI-6 SCAA model matching observed harvest, estimates of total stock size in MI-6 were not consistent with stock size estimates in adjacent management units (MI-5, MI-7). The spring survey CPUE values in MI-6 were about 70% of the values in MI-5 during 1991-2000. However, SCAA stock size estimates in MI-6 were about 15% of the MI-5 values. Although the MI-6 SCAA model is matching the major trends in observed data, it is likely that the overall scale of population size is underestimated.

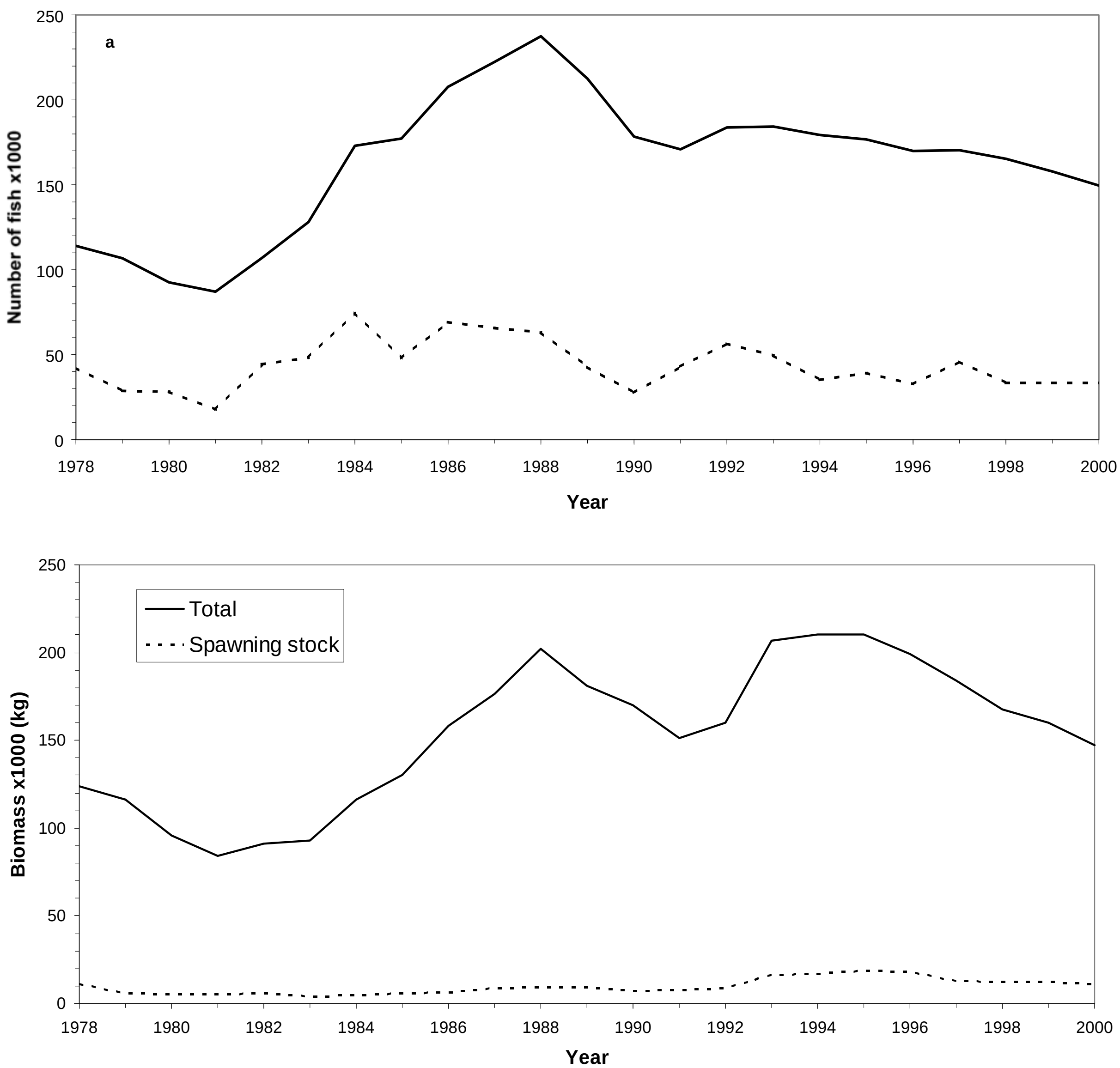


Figure 99. Statistical catch-at-age model estimates of wild lake trout abundance in MI-6. (a) Total abundance of ages 3 to15 fish (solid line) and recruitment at age 3 (dashed line). (b) Total biomass (solid line) and spawning stock biomass (dashed line).

Model fit

In general, there were no systematic patterns in residuals for fishery harvest (Figure 100). The greatest deviation between observed and predicted harvest was about 7% (730 fish) in the commercial fishery and 11% (720 fish) in the recreational fishery. The model's predicted values for spring survey CPUE were consistent with observed estimates (Figure 101a). Likewise, model estimates of pre-recruit survey CPUE were consistent with observed values, though the model estimates were consistently higher for 1993 to 1998 (Figure 101b). Observed CPUE estimates were more variable across time than SCAA model estimates. There were no major systematic patterns in residuals for fishery age compositions (Figure 102). However, the magnitude of the age composition residuals was modest for the commercial fishery data and deviations were twice that of the recreational residuals. The model tended to over-estimate the proportion of the youngest age (age 4) in most years for the spring survey age compositions (Figure 103a). This pattern in the residuals is likely due to a bias in the observed age compositions because inconsistent reporting of small fish in the spring surveys (see previous section titled: “Survey age composition” under “Special characteristics of wild lake trout statistical catch-at-age models and data”). No significant patterns in residuals were observed for the pre-recruit survey age compositions (Figure 103b).

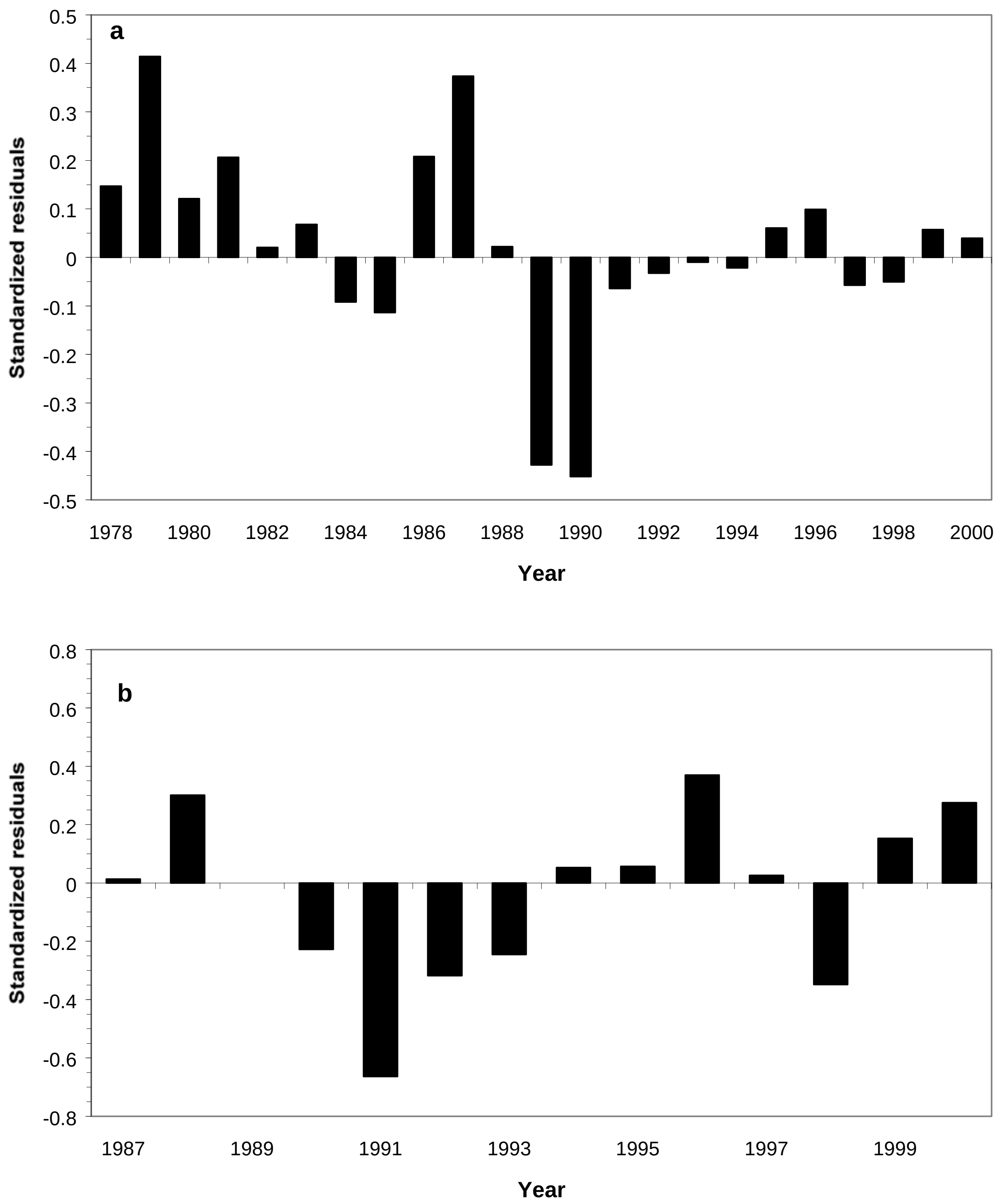


Figure 100. Standardized residuals for MI-6 wild lake trout harvest for (a) tribal commercial fishery, and (b) recreational fishery. Observed recreational harvest was not available for years prior to 1987. Standardized residuals calculated by: observed minus predicted divided by the estimated standard deviation.

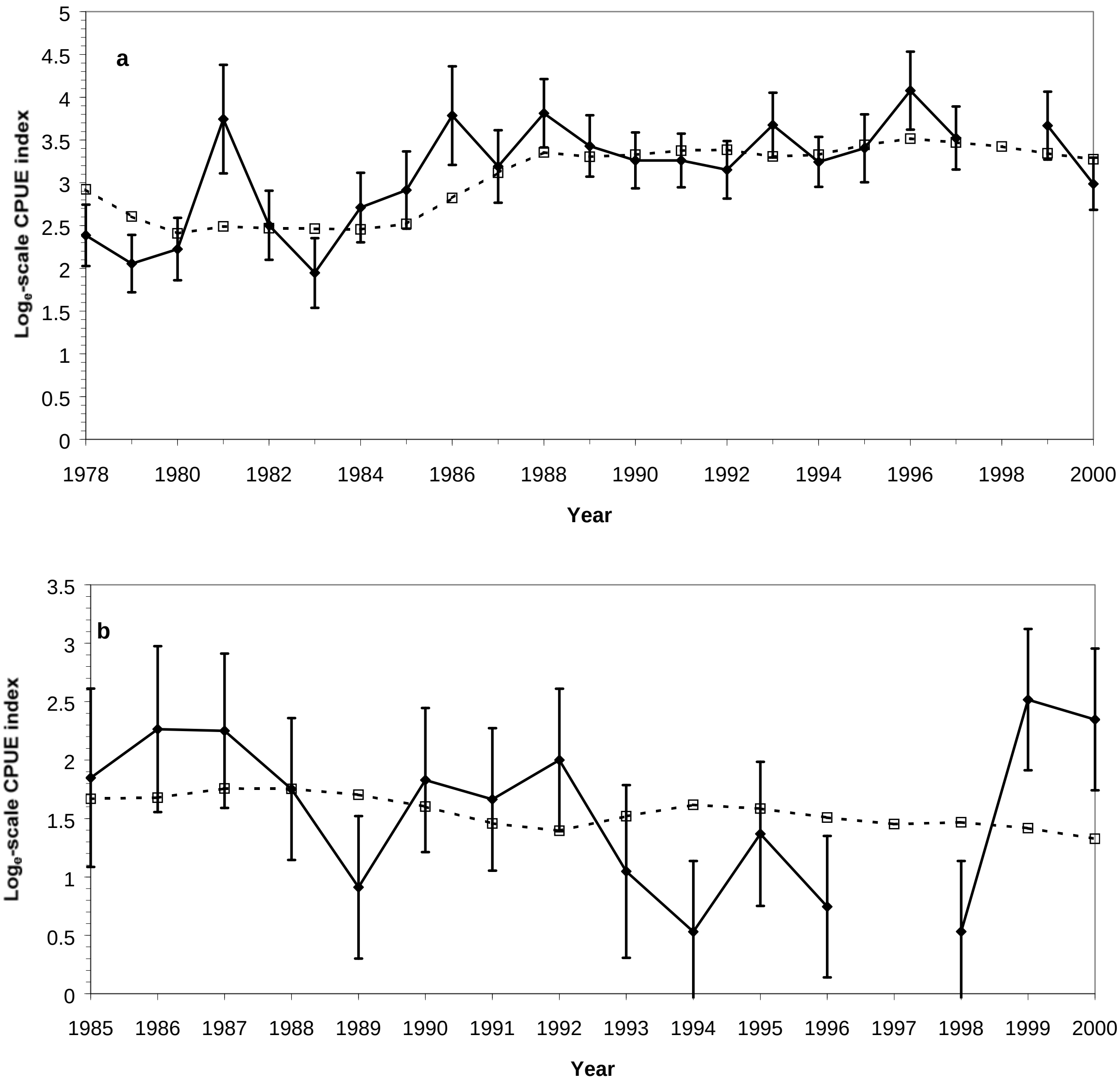


Figure 101. Comparison of MI-6 statistical catch-at-age model predictions to observed values for survey CPUE. (a) Spring survey. (b) Pre-recruit survey. Survey CPUE expressed as a $\log_e$-scale index. Error bars represent one standard error. Solid lines are observed values and dashed lines are model estimates. No pre-recruit survey was conducted in 1997. The observed 1998 spring survey CPUE was not used in the analysis because it was strongly biased and unrepresentative of lake trout relative abundance.

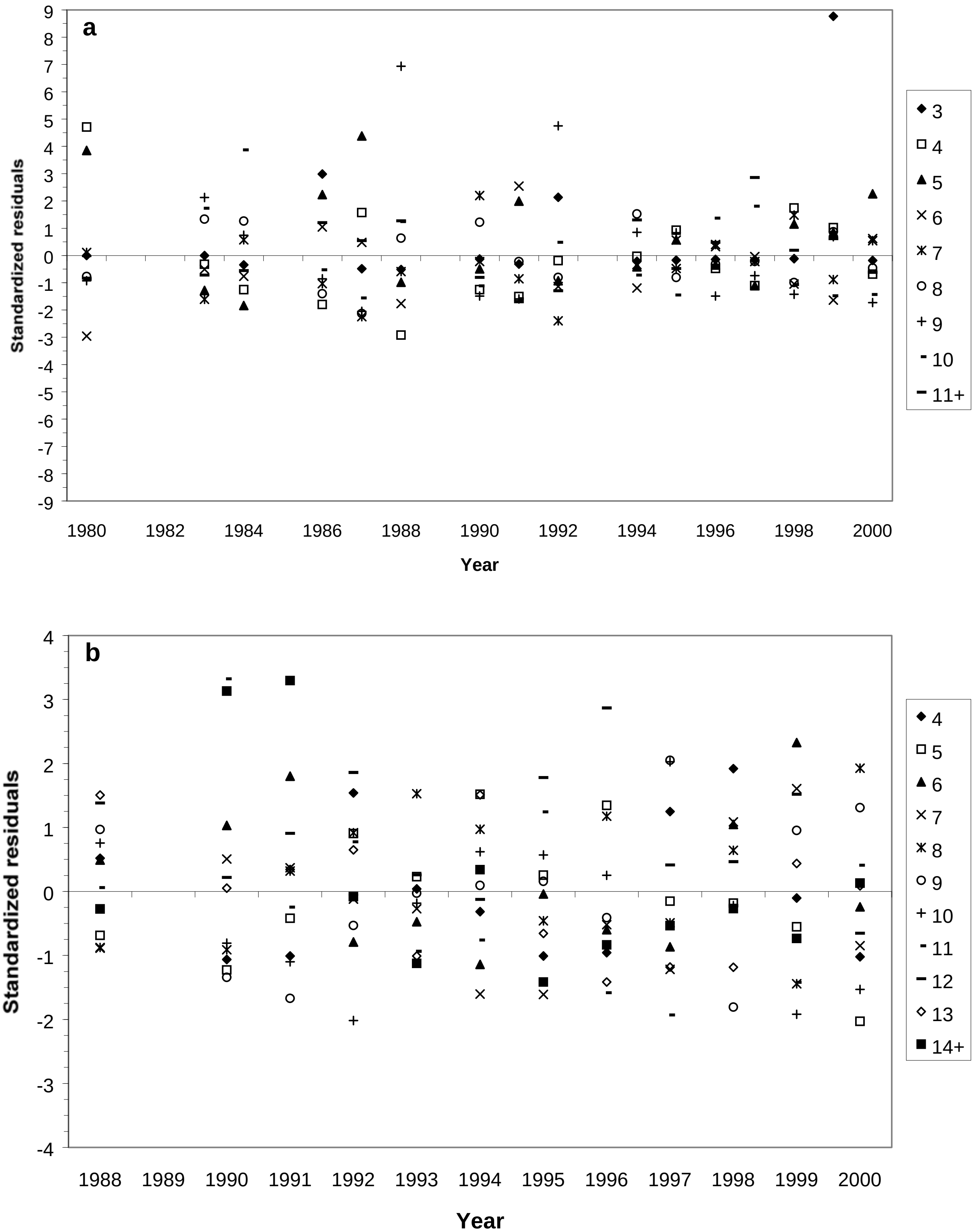


Figure 102. Standardized residuals for MI-6 wild lake trout age composition data from (a) tribal commercial fishery, and (b) recreational fishery. Observed recreational age compositions were not available in 1989 and prior to 1988. Standardized residuals calculated as observed minus predicted proportions at age divided by the estimated standard deviation.

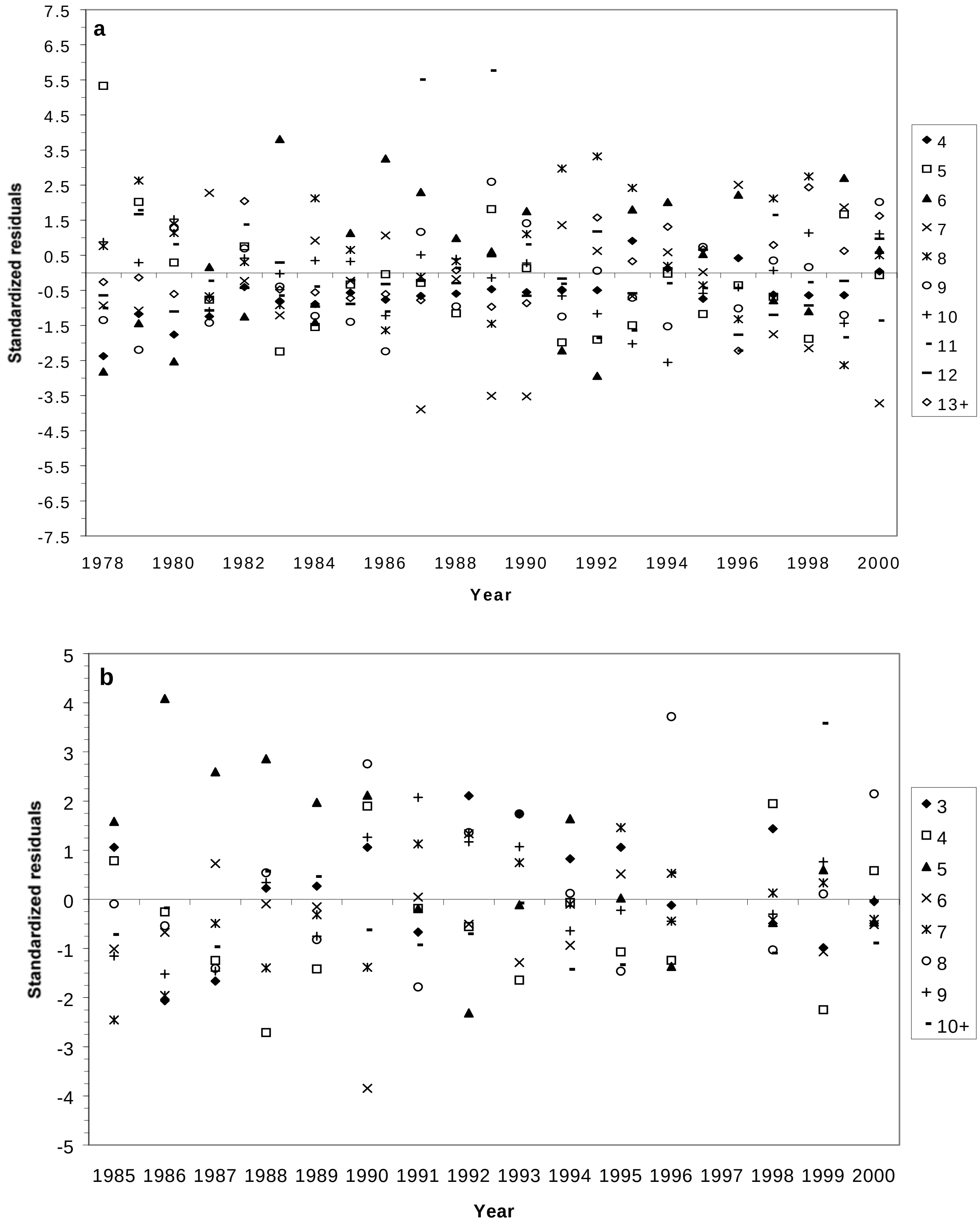


Figure 103. Standardized residuals for MI-6 wild lake trout age composition data from (a) spring survey, and (b) pre-recruit survey. The pre-recruit survey was not conducted in 1997. Standardized residuals calculated as observed minus predicted proportions at age divided by the estimated standard deviation.

Status Relative to Reference Point in MI-6

Mortality and SSBR
Based on recent model estimates (1998-2000), mortality rates were below the established target maximum, however current SSBR was lower than target SSBR. The average Z for ages 6-11 lake trout during 1998-2000 was 0.48 (range: 0.44-0.53), which is lower than the target maximum of 0.59 (A = 45%). The SSBR for 1998-2000 was 0.224 kg and SSBR target was 0.262 kg. Spawning potential ratio was 0.116. The highest mortality sources (excluding background natural mortality) during 1998-2000 were from recreational harvest and sea lamprey predation (see Figure 98).

Harvest and TAC
Recent combined fishery yield has averaged about 12,000 kg annually (1998-2000). Using the SCAA model results and following the requirements of the Consent Decree, the recommended lake trout yield limit (TAC) for MI-6 (1836 Treaty waters) for 2001 is 11,400 kg with 6,350 kg allocated to the recreational fishery and 5,050 kg for the tribal fishery. This yield limit includes an allowance for hatchery fish (9%). This yield limit does not include allowances for siscowets in the commercial fishery harvest. The commercial yield can actually be exceeded by 14% based on siscowet catch composition from commercial monitoring data.

Status of Lake Trout in MI-7

Growth
Wild lake trout weight data for MI-7 were measured only in 1986, 1989, 1991, 1994, and 1995-2000. Overall, mean length- and weight-at-age for wild lake trout have declined from 1975 to 2000 (Figure 104). Mean length-at-age 7 during 1995-2000 was about 7% lower than during 1975-1979. Mean weight at age 7 was 28% lower during 1995-2000 than during 1975-79. The β for wild lake trout has declined from 3.00 in 1986 to 2.98 in 2000 (Figure 104c). Although under-aging may have had an influence in trends in mean length- and weight-at-age, other sources of information indicate that the declines were real. The declining trend in growth may be due to intensified density-dependent effects, competition, and declines in forage fish abundance (Hansen 1990).

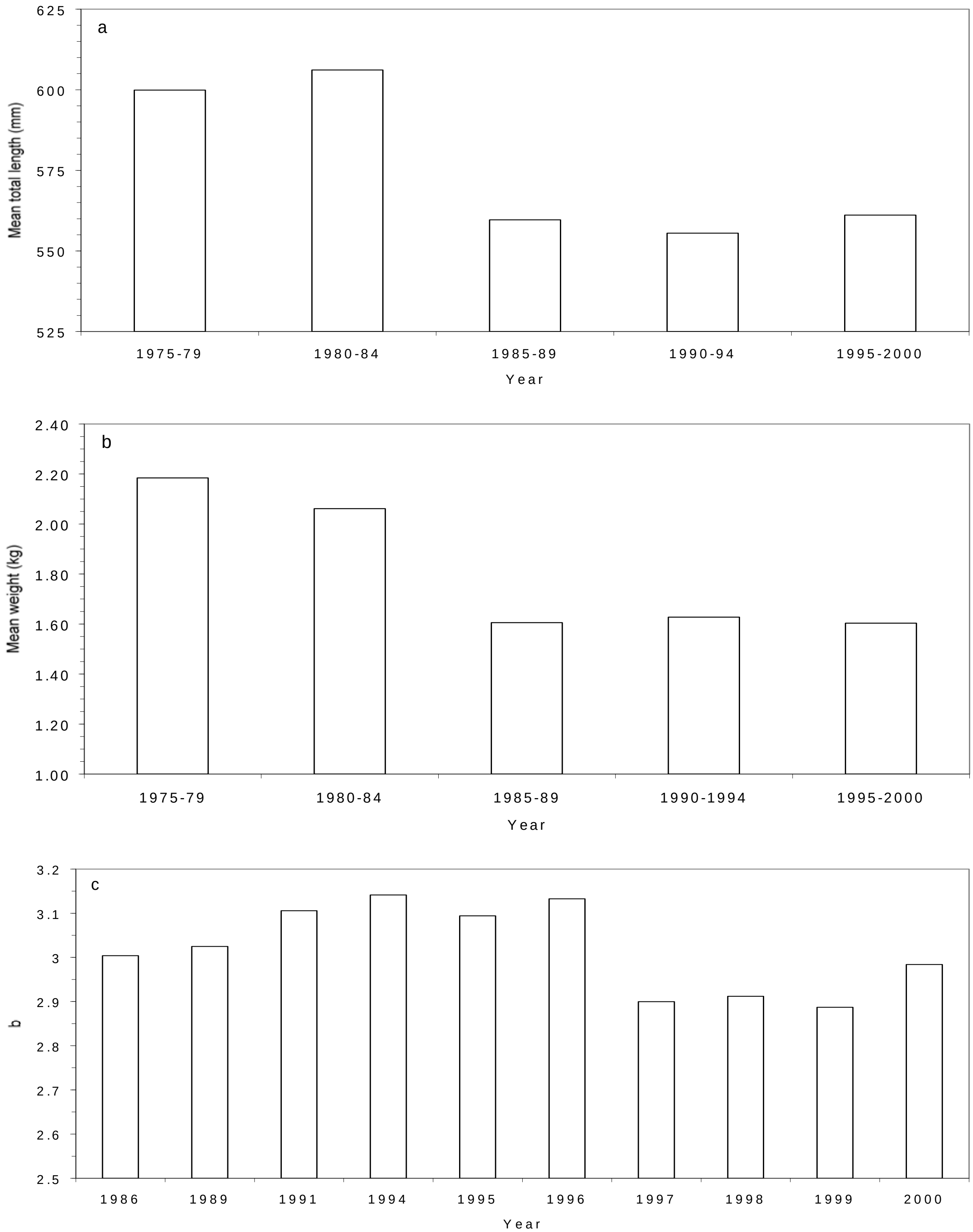


Figure 104. Growth of wild lake trout in MI-7 during 1975-2000 as indexed by (a) mean length of age 7; (b) mean weight of age 7; and (c) exponent from weight-length allometric growth model.

Maturity
Age at 50% maturity has increased from 1975 to 2000. The age at 50% maturity for wild lake trout was about age 8 during 1975-79 and increased to age 10 during 1995-2000 (Figure 105). The shift in maturation follows the trends in growth (length), since the maturity logistic model is length-based.

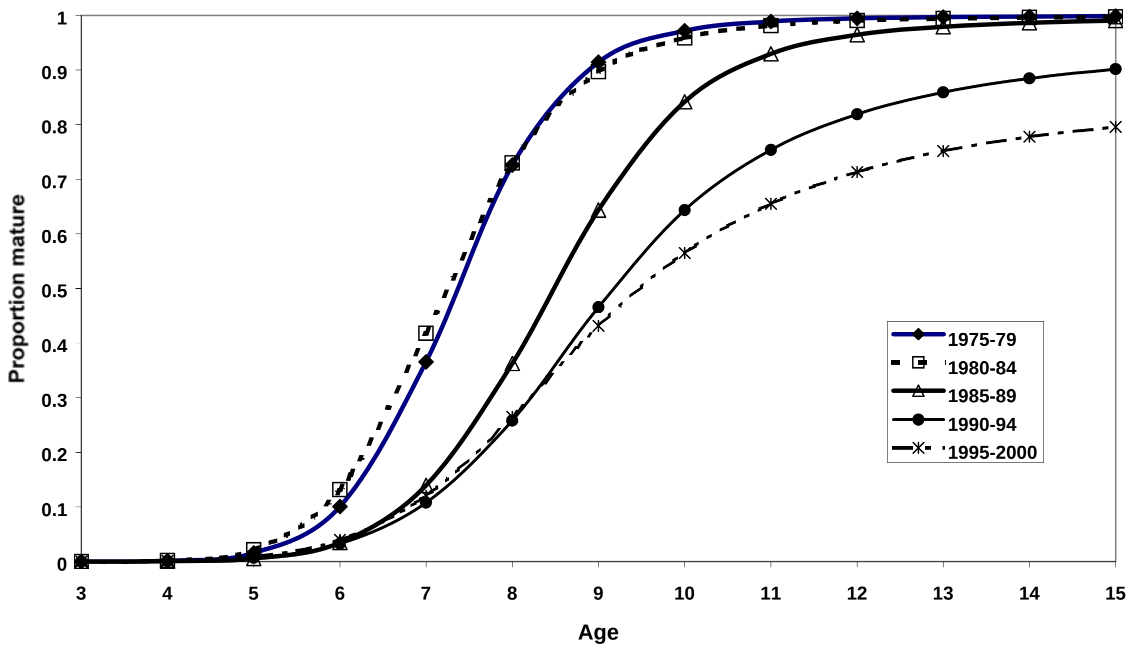


Figure 105. Female maturity-at-age for wild lake trout in MI-7 from 1975-2000. Data based on annual mean length-at-age data applied to a length-based logistic model for female maturity.

Spawning Stock
Spawning surveys have not been conducted in MI-7 since 1976. Peck (1979) reported spawner CPUEs in 1976 ranged from 7 to 26 fish/km with the percentage of wild lake trout ranging from 73 to 100.

Fishery

Commercial fishery
Tribal commercial harvest of lake trout has declined from the peak of 32,500 fish in 1985 to 4,900 fish in 1998 (Figure 106). However, harvest increased to 22,900 fish in 2000. Harvest of wild lake trout averaged 11,000 fish per year from 1976-2000, while the average annual harvest of hatchery fish was about 1,300. The proportion of harvested fish that were wild has increased from about 32% in 1976 to 94% in 2000. Tribal gill-net effort declined from a peak of 2,500 km in 1990 to 1,100 km in 2000 (Figure 106).

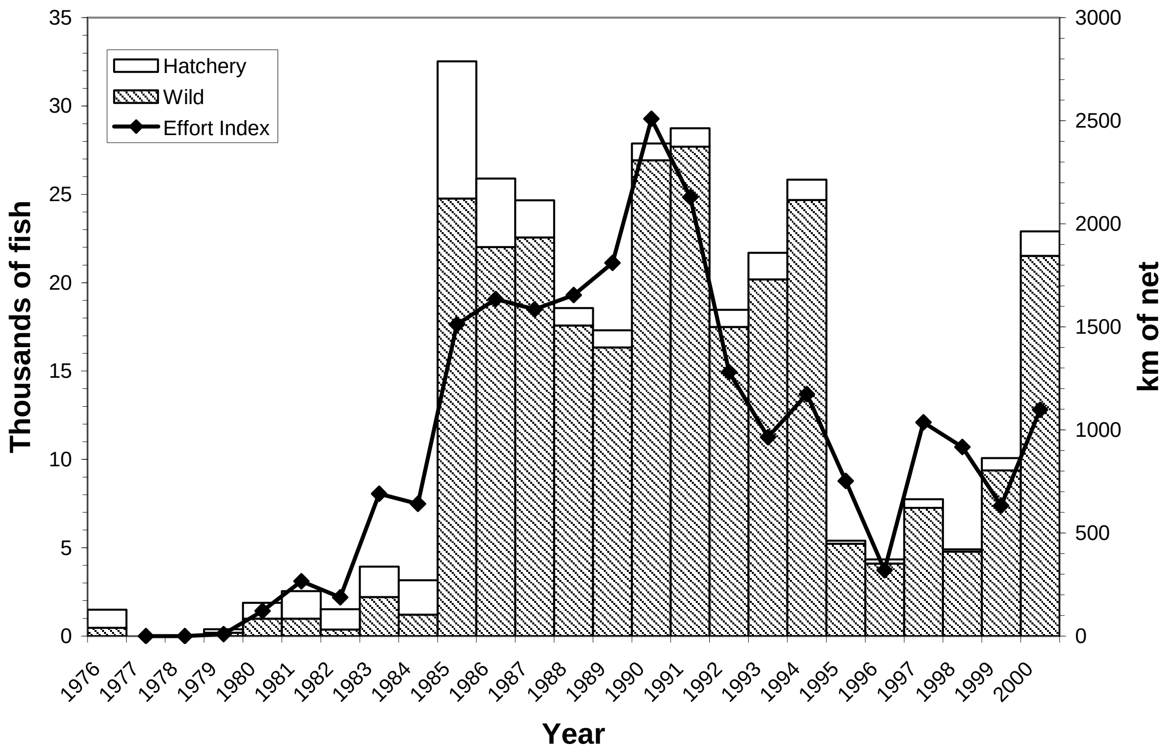


Figure 106. Tribal commercial large-mesh gill-net harvest and effort index for lake trout in MI-7. Data were from Chippewa Ottawa Resource Authority. Effort data were not available for 1976. There was no tribal harvest in 1977 and 1978.

Recreational fishery

Standardized creel surveys similar to ones conducted in other management units have not been conducted in MI-7, but there has been sport harvest. The SCAA models must have estimates of harvest in order to properly estimate parameters and mortality rates. The mail survey estimates of sport harvest and effort conducted for 1971-82 were biased and cannot be used. However, the proportional relationship of harvest and effort between management units may be unbiased. This relationship can be applied to years when there were reliable estimates of sport harvest and effort from standardized on-site creel surveys.

Sport harvest and effort index in MI-7 were estimated using the average sport CPUE and effort index ratio between MI-7 to MI-5 from the 1971-82 mail survey data (Peck and Schorfhaar 1991) applied to MI-5 sport harvest and effort during 1984-2000. The average CPUE ratio was 0.6772 and the average effort ratio was 0.2408. Total harvest in MI-7 (C_7) was calculated as $C_7 = C_5 * X * Y$, where C_5 was MI-5 sport harvest, X was the CPUE ratio, and Y was the effort index ratio. The sport effort index in MI-7 (E_7) was estimated by: $E_7 = Y * E_5$, where E_5 was the MI-5 sport effort index. This approach assumes that 1) there was a measurable relationship between sport harvest and effort in MI-7 to MI-5 from the mail survey, and 2) that the relationship applies to the recent time period, 1984-2000. As a consequence of this approach, the patterns in MI-7 harvest and effort index will be identical to the trends in MI-5. Data from MI-6 were not used for the ratios because there was no consistent pattern in harvest or effort between MI-6 and MI-7 in the mail survey data of 1970-82. Estimated sport harvest of wild lake trout in MI-7 averaged

1,800 fish per year from 1985-2000 (Figure 107). Estimated hatchery lake trout harvest averaged 200 fish per year.

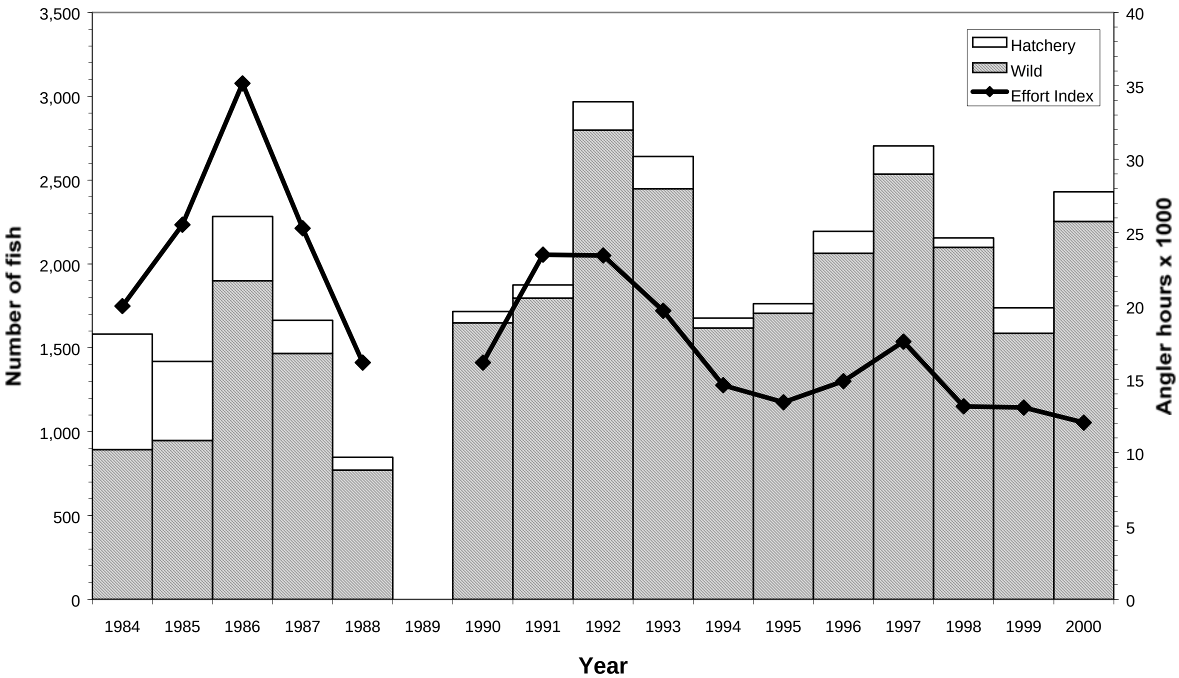


Figure 107. Estimated sport harvest and index of effort for lake trout in MI-7. Data estimated by applying the ratio of MI-7 to MI-5 sport effort and CPUE during 1970-82 to standardized creel survey data from MI-5 during 1985-2000.

Population Surveys

<u>Spring survey</u>
The geometric mean CPUE of wild commercial-sized lake trout in MI-7 has averaged 13.0 fish/km during 1975-2000 with no overall trend (Figure 109). Hatchery CPUE has declined 99% since 1975 (Figure 108). The transition from dominance by hatchery fish to wild fish began in 1984.

<u>Pre-recruit survey</u>
Wild pre-recruit lake trout CPUE has been without trend at an average of 4.2 fish/km during 1986-1998, and increased to 11.6 fish/km during 1999-2000 (Figure 108). Hatchery pre-recruit CPUE has been very low and averaged 0.05 fish/km during 1986-2000.

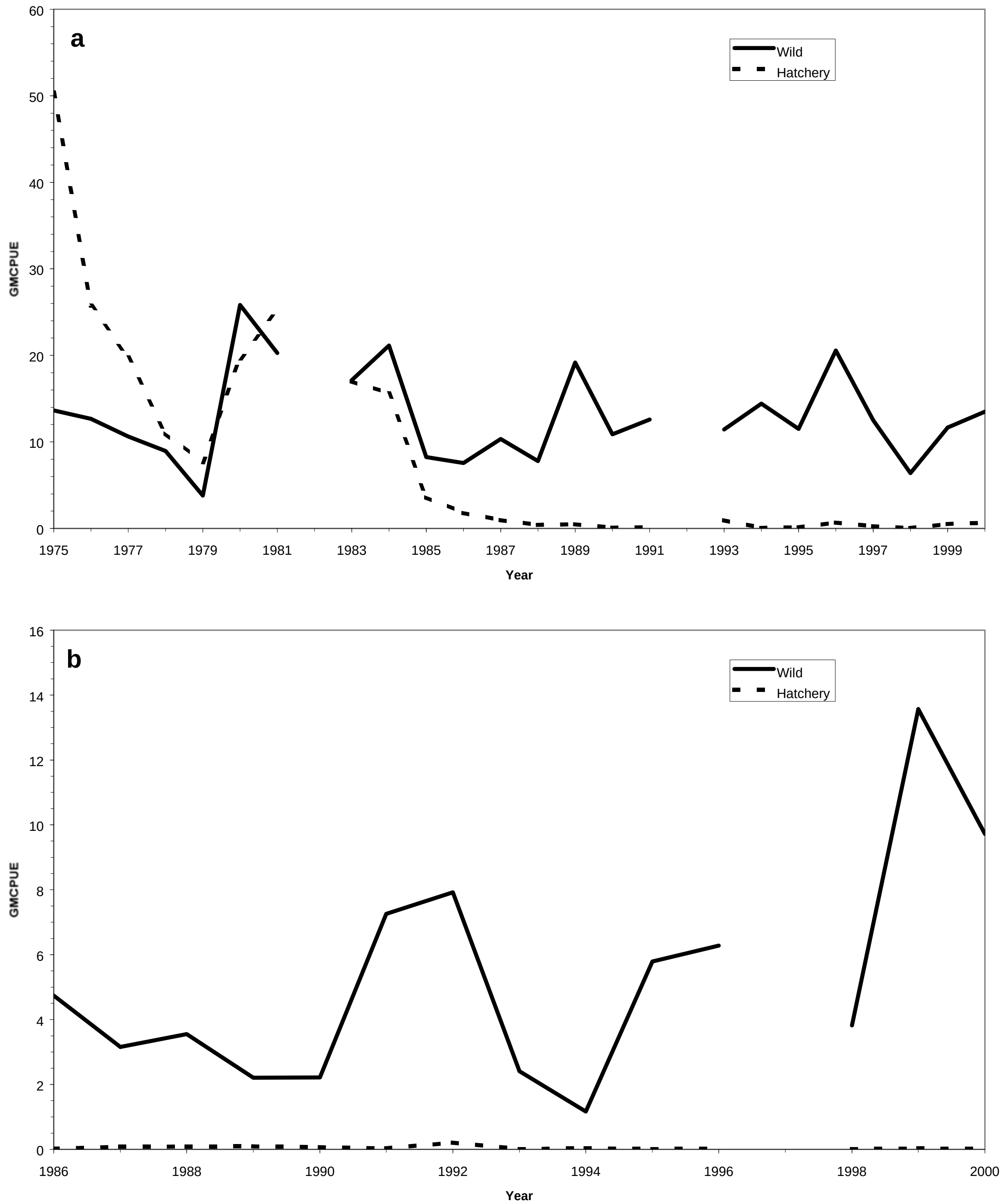


Figure 108. Index of relative abundance of lake trout in MI-7 from (a) the spring lake trout survey from 1975-2000 and (b) the pre-recruit survey from 1986-2000. No pre-recruit survey was conducted in 1997. Relative abundance index expressed as the geometric mean number of fish per km of net per night (GM CPUE) based on estimates from mixed model analysis. No spring survey data were available for 1982 and 1992.

Special Characteristics of MI-7 SCAA Model and Data

Commercial fishery
The commercial *F*s for 1980-2000 were estimated as model parameters. Individual fishing intensities were also estimated for each year from 1976-1979. This was because commercial harvest information was not available for 1975, no effort data were available for 1975-1976, and there was no tribal commercial harvest in 1977-1978. The fishing intensities were estimated for 1977-1978 to account for survey catch and state-licensed bycatch in trap and gill nets. There were uncertainties in the 1979 harvest and effort values, so the fishing intensity for 1979 was estimated as a model parameter.

Biological subsampling of tribal commercial harvest in MI-7 did not begin until 1980. The mean weight of a harvested fish from the tribal commercial harvest was not measured in 1980-1981, 1983, and 1996. Therefore, the mean weight of a harvested fish prior to 1980 and for the non-sampled years after 1979 were assumed to be equal to the mean value of the sampled years (1982, 1984-1995, and 1997-1998), which was 1.82 kg. Age composition data for tribal harvest were not collected until 1985, so the commercial age compositions and associated sample sizes for 1975-1984 were set equal to the values reported for the spring survey during the same years. This assumption was made because the spring survey gear specifications are similar to those of tribal gill nets. The commercial $\log_e$-scale standard deviations (SD) for commercial harvest and effort were nominally set to 0.15.

Recreational fishery
Sport harvest data for MI-7 were not estimated from on-site standardized creel surveys as described above. The sport harvest estimates from the ratio approach were treated as observed data in the SCAA model. Similarly, the age composition data from MI-6 were used as observed sport age compositions for MI-7. The $\log_e$ SDs for harvest and effort were also assumed to be equal to the values for MI-6.

Other information
The prior estimate of *M* for MI-7 was based on using Pauly's equation with the following parameter values: temperature = 5^o C; L_∞ = 79.7 cm; K = 0.20043; and SE = 0.057. The von Bertalanffy parameters were based on the average values from 1975-2000. The abundance of age 14 and 15 lake trout in 1975 was set equal to the model's estimate for age 13. This was done because of unstable model convergence properties when those two ages were estimated as individual parameters during earlier model runs. This is likely due to insufficient data in model for those cohorts

Results of MI-7 SCAA Model

Selectivity
As in the other management units, peak selectivity for all gears except the pre-recruit survey has shifted to older ages over time. Selectivity patterns for all fishing sources were dome shaped (Figure 109). Commercial fishery selectivity peaked at age 6 in 1975-1976 and shifted to age 10 in 1996-2000 (Figure 109a). Peak recreational selectivity was age 10 in all years. Spring survey peak selectivity was age 6 during 1975-1979 and shifted to age 8 during 1996-2000 (Figure

109b). The pre-recruit survey selectivity was broadly dome-shaped in all years with peak selectivity at ages 5 to 10 (Figure 109b).

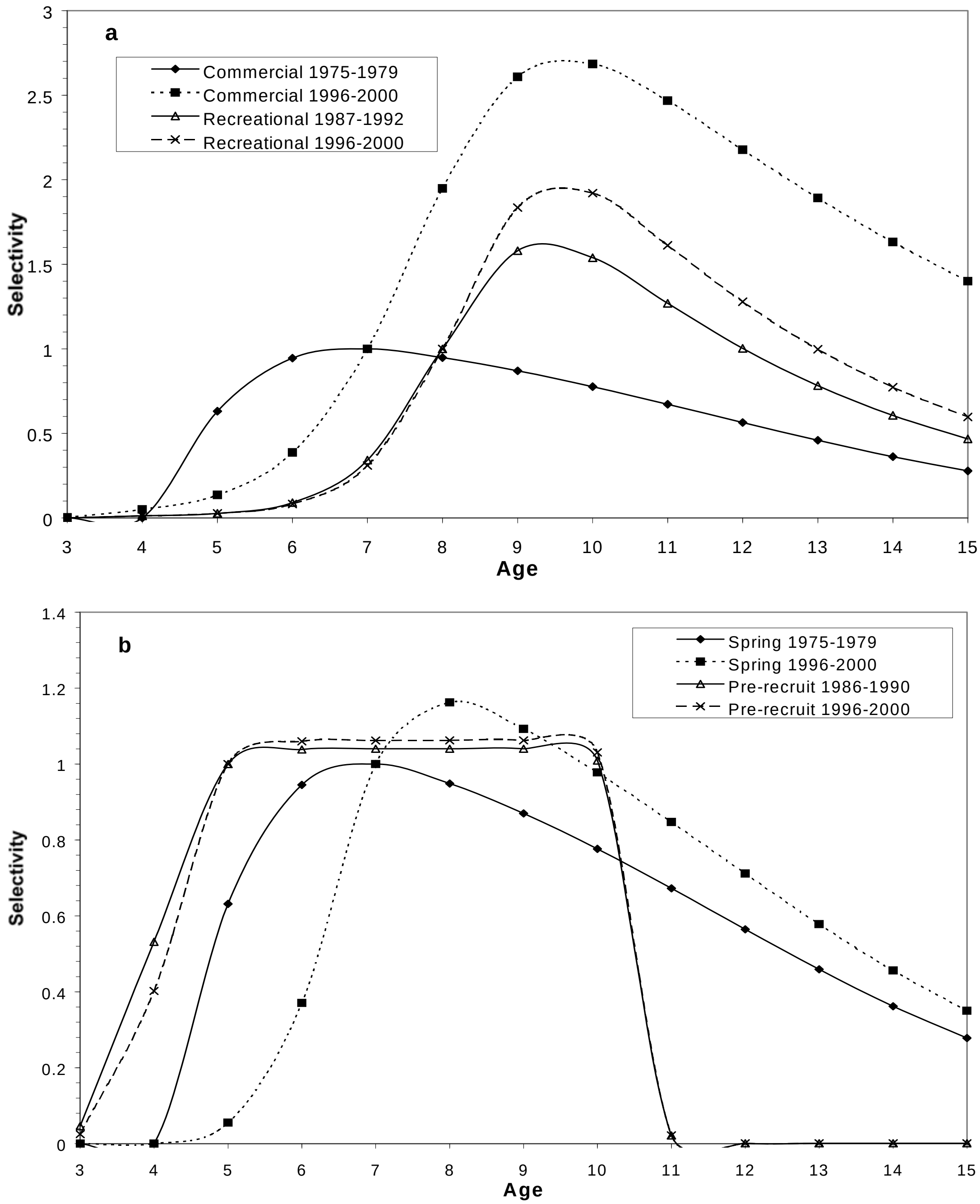


Figure 109. Selectivity patterns for wild lake trout in MI-7 estimated by statistical catch-at-age analysis: (a) commercial and recreational fisheries, and (b) spring and pre-recruit surveys. Pre-recruit surveys began in 1986. Selectivity patterns for all fisheries were assumed to be constant from 1994-2000 in the analysis. Recreational fishery selectivities prior to 1984 were assumed equal to 1984.

Fishing mortality (ages 6-11)
Commercial fishing mortality was higher than recreational fishing mortality between 1980 and 2000 (Figure 110). Commercial fishing mortality peaked at 0.24 in 1990 and has declined three-fold to 0.08 in 2000. There was no temporal trend in recreational fishing mortality which has averaged 0.014 during 1984-2000.

Sea lamprey-induced mortality (ages 6-11)
Sea lamprey-induced mortality has declined by 72% from the peak in 1979 at 0.47 to 0.13 in 2000 (Figure 110). Excluding background natural mortality, sea lamprey parasitism was the highest mortality source since 1995.

Natural mortality
The SCAA model's estimate of background natural mortality for all ages was 0.21, which did not deviate much from the prior estimate of 0.22. Natural mortality has been the dominant mortality source since 1991 for age 6 to 11 lake trout.

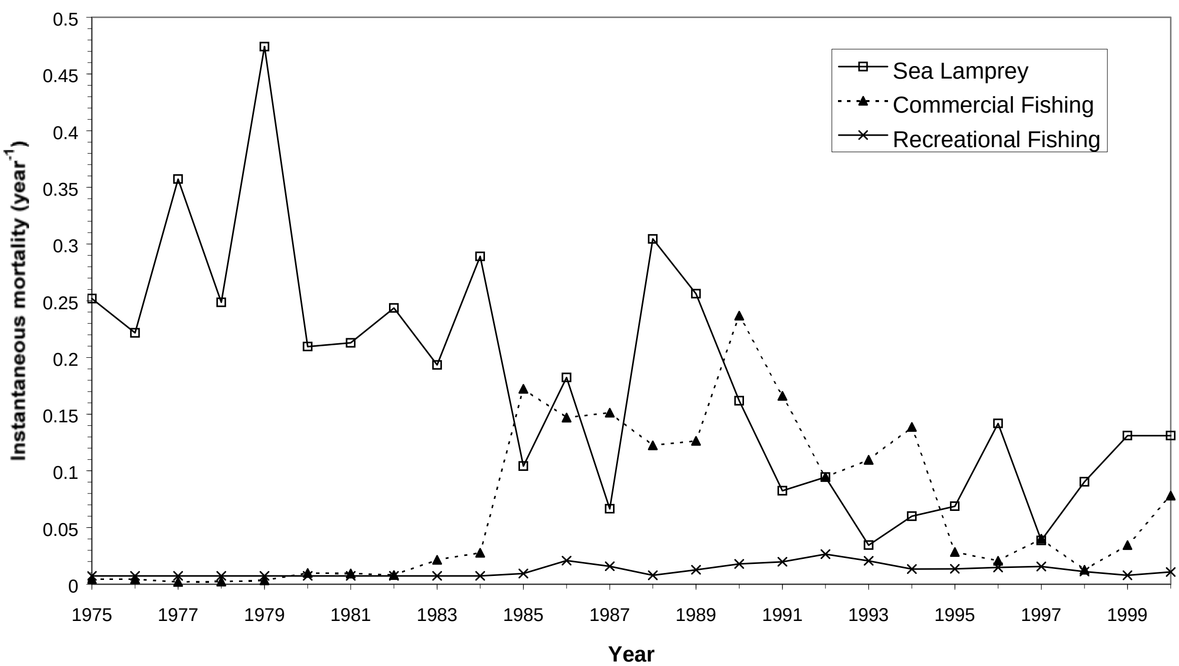


Figure 110. Average instantaneous mortality rates for ages 6-11 wild lake trout in MI-7. Fishing mortality rates were estimated by the statistical catch-at-age (SCAA) model. Commercial fishing mortality was based on a large-mesh gill net fishery. Recreational fishing mortality rates were assumed constant from 1975-83. Sea lamprey-induced mortality was estimated external to the SCAA model using a lake trout-sea lamprey functional response model.

Abundance
Estimated total abundance (ages 3-15) of wild lake trout has decreased from 600,000 fish in 1975 to 575,000 fish in 2000 (Figure 111a). Total abundance in MI-7 averaged 690,000 fish between 1975 and 2000 and ranged from 543,000 fish in 1981 to 911,000 fish in 1996. Recruitment at age 3 has averaged 180,000 fish per year during 1991 to 2000 and has declined since 1995. Total

biomass has declined from 1 million kg in 1975 to 820,000 kg in 2000 (Figure 111b). Spawning stock biomass has declined by 60% since 1975 (Figure 111b). This decrease in SSB was due to declines in growth and increased age at maturity.

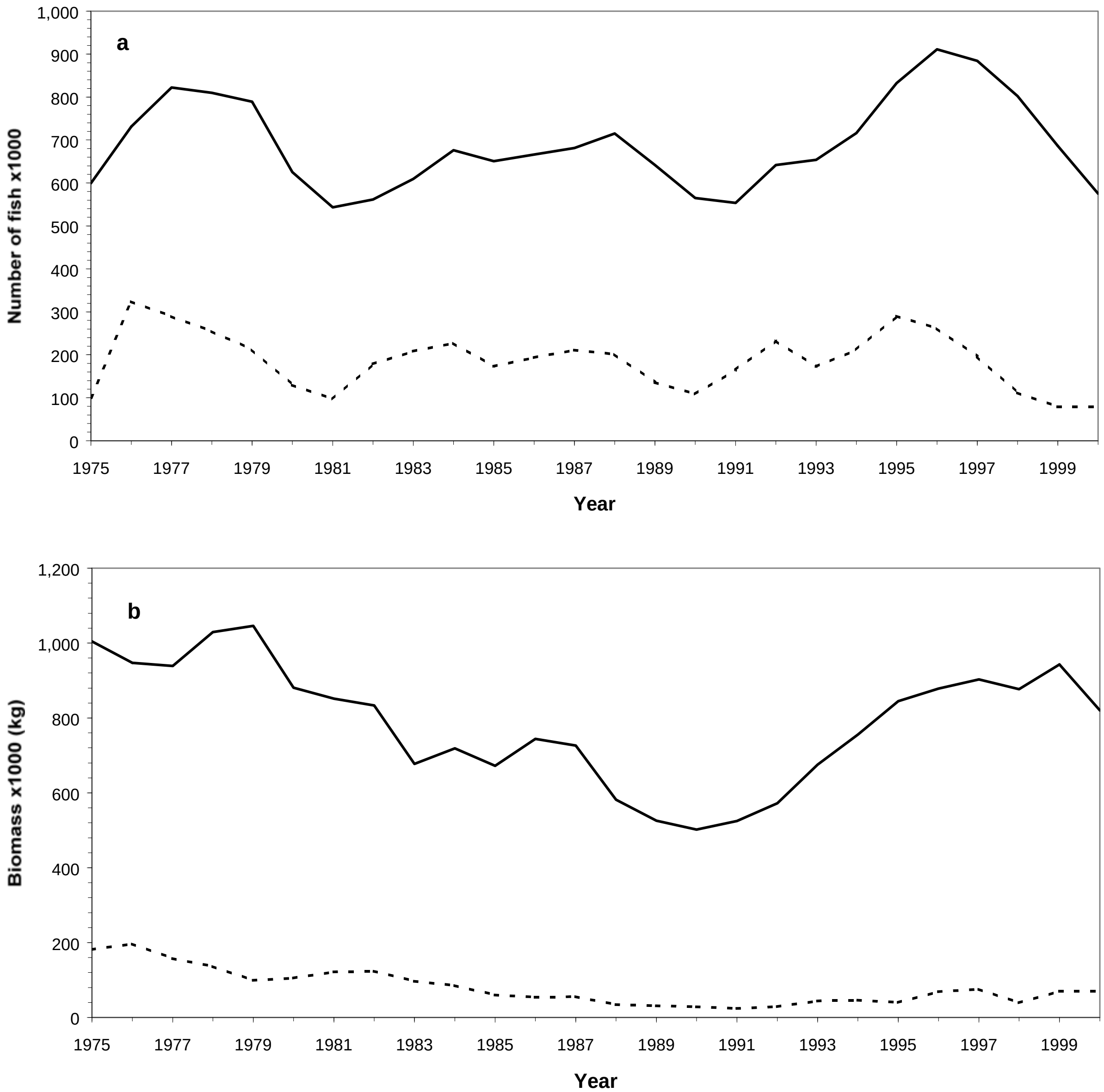


Figure 111. Statistical catch-at-age model estimates of wild lake trout abundance in MI-7. (a) Total abundance of ages 3-15 fish (solid line) and recruitment at age 3 (dashed line). (b) Total biomass (solid line) and spawning stock biomass (dashed line).

<u>Model fit</u>

Generally, model predictions were consistent with observed data. Overall, no sustained patterns in residuals were observed in commercial and recreational harvest data (Figure 112), though the model over-estimated commercial harvest during 1994-2000. The greatest difference between observed and predicted commercial harvest was 4.6% (1,376 fish) in 1994. There were no patterns in survey CPUE residuals (Figure 113). There were some systematic patterns in age composition residuals for fishery and survey data. The model over-estimated the proportion of age 3 and 4 fish in the fishery data in most years (Figure 114). Similarly, the model over-estimated the proportion of age 4 and 5 fish in the spring survey data and age 3 fish in the pre-recruit survey data (Figure 115). This pattern in the residuals is likely due to a bias in the age compositions because of minimum length limits (432 mm) in the commercial fishery resulting in discard of sub-legal fish and because of under-reporting of fish <432 mm in the spring surveys (see previous section titled: "Survey age composition" under "Special characteristics of wild lake trout statistical catch-at-age models and data"). Other factors that may explain the pattern in commercial age composition residuals of young ages include under-sampling of small fish in the commercial monitoring program, and commercial fishers selecting for larger fish and discarding small fish in order to optimize harvest and revenue.

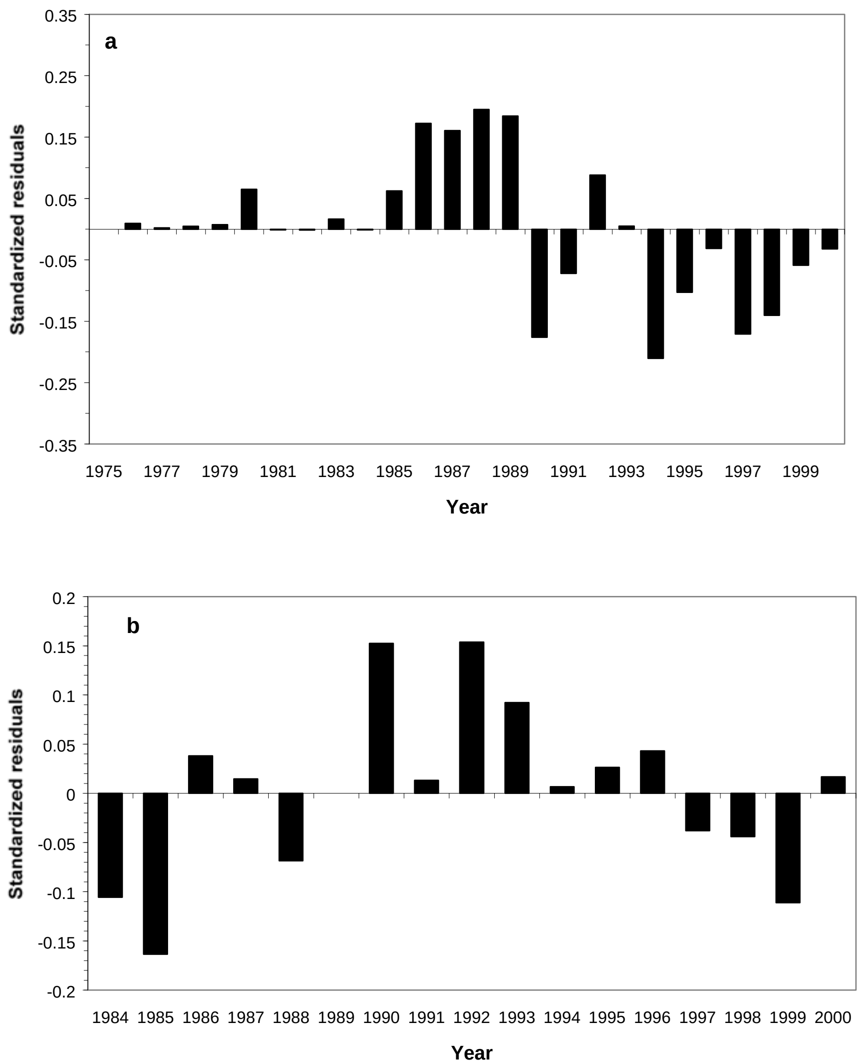


Figure 112. Standardized residuals for MI-7 wild lake trout harvest from (a) tribal commercial fishery, and (b) recreational fishery. Observed recreational harvest was not available in 1989 and prior to 1984. Standardized residuals calculated by: observed minus predicted divided by the estimated standard deviation.

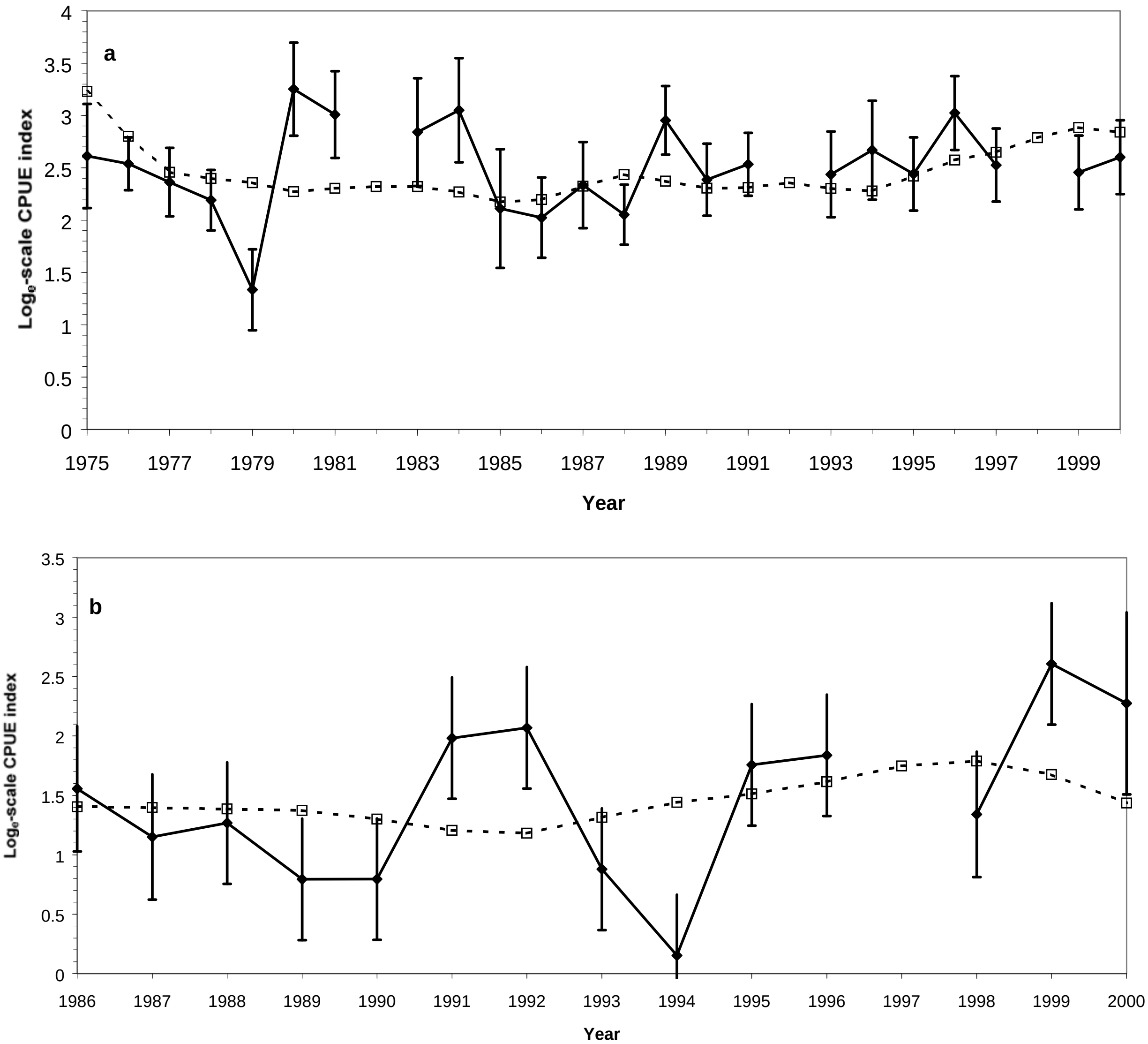


Figure 113. Comparison of MI-7 statistical catch-at-age model predictions to observed values for survey CPUE. (a) Spring survey. (b) Pre-recruit survey. Survey CPUE expressed as a $\log_e$-scale index. Error bars represent one standard error. Solid lines are observed values and dashed lines are model estimates. No pre-recruit survey was conducted in 1997. The observed 1998 spring survey CPUE was used in the analysis because it was strongly biased and unrepresentative of lake trout relative abundance. No data were available for the spring survey in 1982 and 1992.

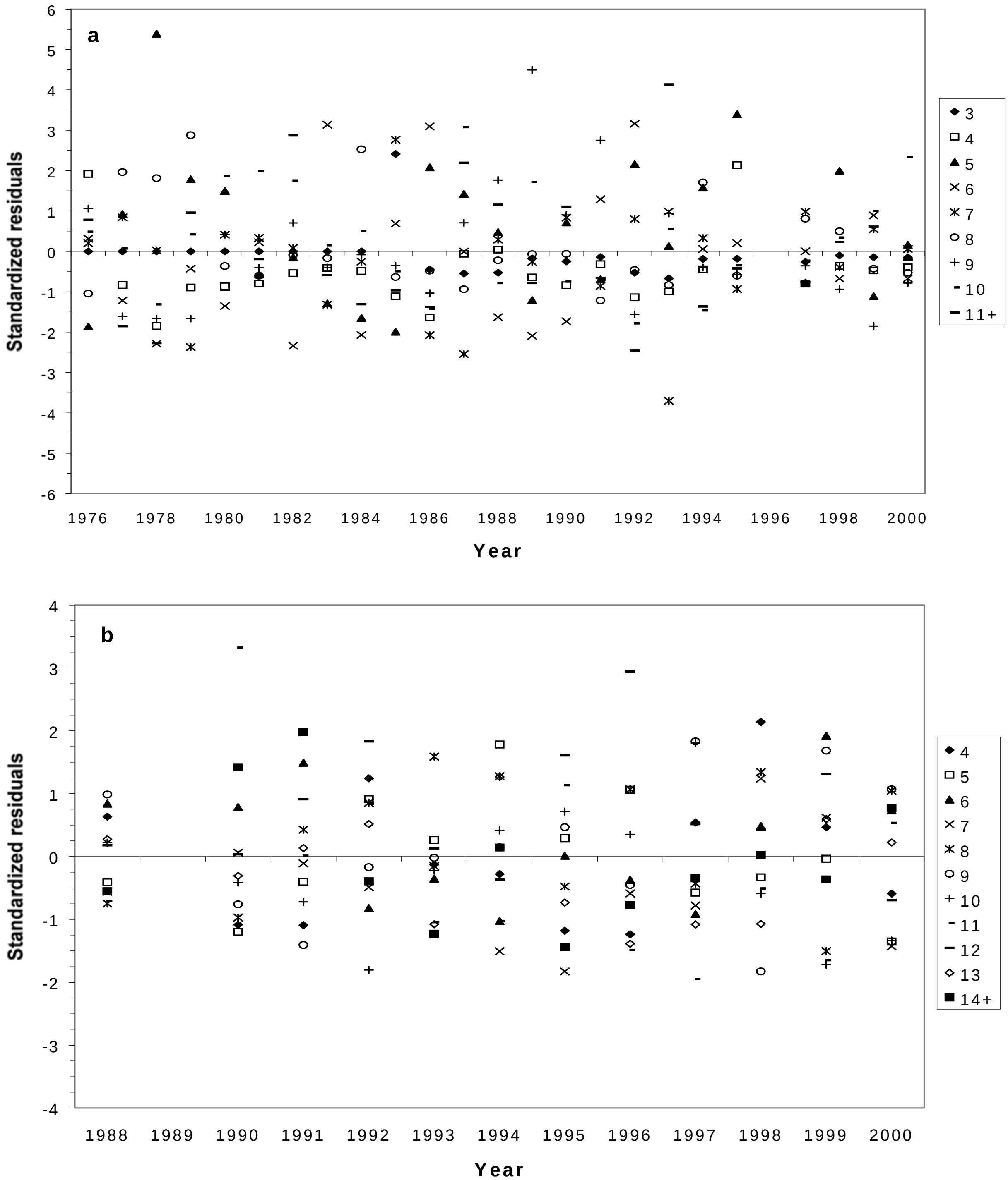


Figure 114. Standardized residuals for MI-7 wild lake trout age composition data from (a) tribal commercial fishery, and (b) recreational fishery. Observed recreational age compositions were not available in 1989 and prior to 1988. Standardized residuals calculated as observed minus predicted proportions at age divided by the estimated standard deviation.

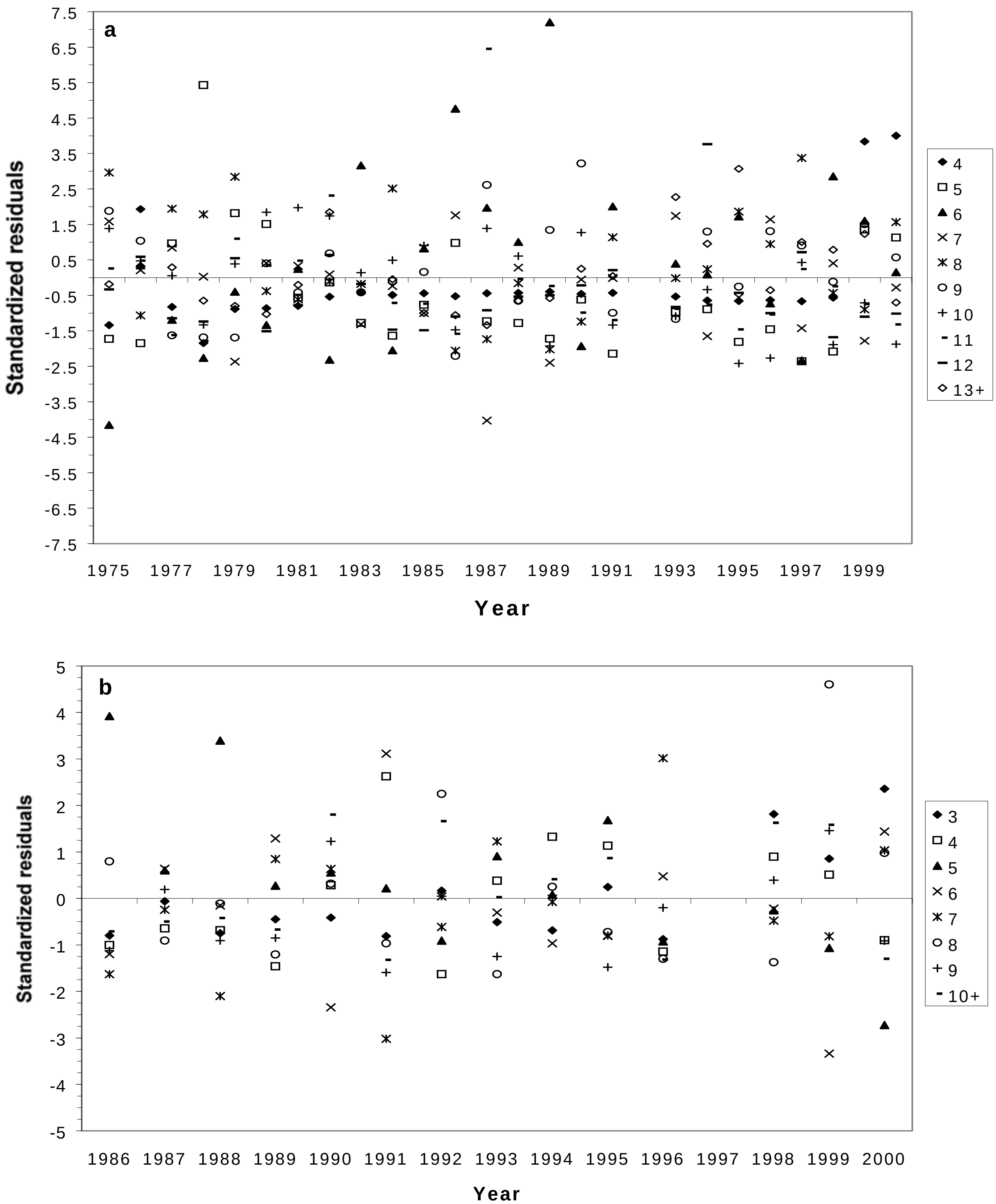


Figure 115. Standardized residuals for MI-7 wild lake trout age composition data from (a) spring survey, and (b) pre-recruit survey. The pre-recruit survey was not conducted in 1997. Standardized residuals calculated as observed minus predicted proportions at age divided by the estimated standard deviation

Status Relative to Reference Point in MI-7

<u>Mortality and SSBR</u>

Based on recent model estimates (1998-2000), mortality rates were below the established target maximum and SSBR was greater than the target. The average *Z* for age 7 and older lake trout during 1998-2000 was 0.38 (range: 0.32-0.43). The SSBR was 0.268 kg while SSBR_T was 0.219 kg. Spawning potential ratio was 0.288. The highest mortality source (excluding background natural mortality) since 1995 was sea lamprey predation (see Figure 110) with sea lamprey mortality rates averaging 0.118 for ages 6-11 during 1998-2000.

<u>Harvest and TAC</u>

Recent combined fishery yield has averaged about 19,400 kg annually (1998-2000). Using the SCAA model results and following the requirements of the Consent Decree, the recommended lake trout yield limit (TAC) for MI-7 for 2001 is 63,000 kg with 18,900 kg allocated to the recreational fishery and 44,100 kg for the tribal fishery. This yield limit includes an allowance for hatchery fish (6%). This yield limit does not include allowances for siscowets in the commercial fishery harvest. The commercial yield can actually be exceeded by 35% based on siscowet catch composition from commercial monitoring data.

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Appendix

The appendix for this document includes the SCAA model files, including data (.dat), model code (.tpl), and stocking (xx stock.dat). It can be found alongside this document on the Michigan Department of Natural Resources website (http://www.michigan.gov/greatlakesconsentdecree**)**. It is also available on the Michigan State University Quantitative Fisheries Center's ftp site (ftp://glpd.fw.msu.edu/MSCFTP/) and was distributed with this document to the TFC, Parties to the Consent Decree, and Amici Curiae.