Review of Lake Michigan Red Flags Analysis

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Abstract

The protocol for managing Chinook salmon in Lake Michigan has evolved into a two-step process. First, stocking policies are developed in a series of meetings that occur approximately every 5 years. Management agencies facilitate the meetings, which are designed to incorporate input from fishery stakeholders. Sophisticated risk assessment models and structured decision analysis techniques are used to support collaborative decision making. Second, after decisions are made and stocking policies are enacted, their performance is monitored annually. Managers and researchers around the lake collect data on the fishery and then share it through the Lake Michigan Committee structure of the Great Lake Fishery Commission (GLFC). The Red Flags Analysis (RFA) was developed as a way to organize and analyze that data. The primary purpose of RFA in the overall protocol is to identify problems in the fishery that might justify more immediate attention than would otherwise occur under the 5-year stocking policy development cycle. In the first section of this report, I present a detailed description of RFA and give a brief history of its use from 1997 through 2011. In the second section of this report, I critically review the analytical procedures used in RFA and reexamine its role in the overall management protocol.

The Lake Michigan Salmonid Working Group (SWG) developed and uses RFA. They created a list of biological indicators for gauging the population sizes and conditions of Chinook salmon and alewives, their primary prey. A time series of indicator data is maintained, and measurements from the current and past 5 years are compared to historical values. Indicator data are updated annually and are stored and analyzed in an MS Excel® workbook that covers the period 1985 to present. RFA measures the health of the system by tallying the number of potential biological problems found in indicator measurements. Potential problems are symbolically represented as red flags. Indicator values are considered to be of concern when recent values substantially deviate or trend away from the mean of the time series. The basic assumption is that extreme values or developing trends could be a sign of trouble in the system. The suitability of an indicator value for the current year is judged based on its relative rank within the historic range of values. Two decision rules are used to determine if red flags should be triggered. The *Level I* rule is designed to detect relatively large, immediate changes in indicator values. A red flag is triggered in *Level I* when an indicator value for the current year is either lower than the 20th or higher than the 80th percentile of the distribution of all values in the time series for that indicator. The *Level II* rule is designed to detect emerging trends in indicator values. A red flag is triggered in *Level II* when indicator values in three of the last five years are lower than the 40th or higher than the 60th percentile of the distribution of all values in the time series. Red flags are accumulated for the entire list of primary indicators. SWG has judged that when 50% or more of the indicators trigger red flags under either level, the system could be experiencing major problems. In which case, SWG reports to the Lake Michigan Technical Committee (LMTC) that they should make a more extensive review of the situation and consider recommending changes in management policy to the Lake Michigan Committee (LMC).

From 2004 through 2006, RFA seemed to be providing reasonable guidance for managers. However, from 2007 through 2010, RFA results were mostly contrary to expectations, and some biologists and managers began to question the validity of the approach. Results for the two decision rules were inconsistent. Under *Level I*, results were in the acceptable range (< 50% red flags triggered) for 2 of 3 years. But under *Level II*, results were far outside the acceptable range every year; about 90% of the red flags were triggered. Under the RFA rules a more extensive review should have been conducted and a change in management policy should have been considered as early as 2008 when SWG reported the results of the 2007 RFA to LMTC. But the perception of many biologists and anglers was that the Chinook salmon fishery was thriving. So consensus for management action could not be reached in the LMTC or LMC after review of biological data and considerable debate. Instead, a number of reasons were proposed as to why results of RFA might have been incorrect, and this review of the RFA methodology was suggested.

In my review, I identified a number of problems in the analytical procedures. Chief among them is that the methods do not do not allow for flexible and explicit definition of objectives for the biological indicators. Instead, the rules under *Levels I* and *II* imply that the management objective for each indicator is to maintain its value within a specified range around the mean of its historic values. This implicit definition of objectives constrains management flexibility by discouraging activities that could make beneficial changes in the system,

such as trying to increase the percent wild Chinook salmon above historic levels. In addition, I think RFA suffers from mission creep. That is, managers continue to make new demands on the procedure, which has resulted in expansion of the scope and objectives of RFA. SWG has not been able to keep pace in modifying RFA to address these new demands. My primary conclusion is that RFA is worth continuing. The analytical problems I found can be fixed and the procedures can be modified to satisfy new demands. If proper revisions are made, the procedure can play an important role in the overall management protocol – not only to monitor for developing problems in the fishery but also to more directly evaluate the success of the 5-year stocking policy in achieving its objectives. Eight major recommendations for revising RFA are offered: 1) clarify objectives; 2) modify the analysis to more directly address all objectives; 3) devise a more detailed interpretation of the Lake Michigan Salmonine Objectives, if they are to be evaluated; 4) abandon the use of percentiles and replace them with target and limit reference points to measure management success and trigger management action; 5) make use of data from the recent collapse of alewife and Chinook salmon in Lake Huron to help develop limit reference points; 6) revise the list of biological indicators to focus more on alewife; 7) develop new, quantitative metrics to better evaluate success of stocking policies; and 8) link indicators with a projection model to predict conditions a few years ahead. I developed two prototype analyses to illustrate how my recommendations could be implemented, but I think the final revisions should be made collaboratively by a task group with representation from the management agencies. If some or all of my recommendations are endorsed, the prototypes can be used to guide the revisions. The prototypes are stored as MS Excel® spreadsheets and can be obtained by contacting me or the Quantitative Fisheries Center.

Section 1: A Description of the Red Flags Analysis and Its Use from 1997 to 2011

The purpose of this section is to give a brief history of the Red Flags Analysis (RFA) and to document the current procedures and recent results of the analysis. To accomplish this task, I consulted with many of the biologists involved with RFA, reviewed Great Lakes Fishery Commission (GLFC) and management agency documents, and examined the spreadsheet containing the entire set of biological indicators and indicator values upon which RFA is based.

RFA was developed as an annual evaluation procedure to help monitor and communicate the progress of Chinook salmon stocking policies in Lake Michigan. Since the late 1990s, stocking policies were developed through a collaborative process designed to incorporate input from angling groups and the general public. Policy development was facilitated by management agencies and required a great deal of time and effort from everyone involved. Sophisticated mathematical modeling analyses (Szalai 2003) and structured decision analysis (Jones et al 2008) have been used to support this process. The agencies and stakeholders agreed to conducting these major policy reviews in 5-year intervals (Holey and Trudeau 2005; Claramunt et al. 2008; Wesley 2011). RFA was intended as an interim monitor on the 5-year stocking policy.

RFA has evolved over the years. It started in 1997 as a public presentation developed by Michigan Department of Natural Resources (MDNR) biologist Jory Jonas and United States Fisheries and Wildlife (USFWS) biologist Rob Elliott. At the time, a consensus had developed among biologists working on Lake Michigan that too many Chinook salmon were being stocked. The RFA presentation helped explain the problem to stakeholders and the general public and was a positive factor leading to the first cut in stocking rates in 1999. Since then, RFA was further developed and applied on a more lake-wide basis by committees under sponsorship of the GLFC. A Salmonid Working Group (SWG) was established under the Lake Michigan Technical Committee (LMTC). The SWG was charged to annually evaluate the health of Chinook salmon, identify potential treats to predator-prey balance, and make management recommendations for the LMTC and the Lake Michigan Committee (LMC). The SWG expanded and updated the original RFA and now uses it as the primary tool to achieve their mandate (Claramunt et al. 2008).

RFA has developed into a pseudo-monitoring program. I use the term "pseudo" because RFA is not a monitoring program in the traditional sense. No data are collected and maintained specifically for RFA. Each management agency monitors the Chinook salmon fishery within its jurisdictional waters, collecting data for its own use, such as number stocked, harvested, and returning to spawn. In addition, federal agencies conduct annual surveys to estimate forage fish abundance and federal, state, tribal, and university researchers periodically collect data during various other research studies. One of the key objectives of RFA is to assemble and organize relevant data from lake wide sources and to make them available for a quick, annual evaluation of the status of the Chinook salmon population and the predator-prey balance in the lake. Other objectives of RFA will be discussed later in Section 2 of this report.

Management Protocol for RFA

RFA is conducted annually. By early March of each year, SWG solicits and organizes data and conducts the analysis. By the end of the second week of March, SWG reports results to the LMTC. By the annual LMC meetings at the end of March, the LMTC considers results and determines whether or not they warrant recommending changes in management policies. If so, the LMTC makes recommendations to the LMC. During their March meeting, the LMC decides what, if any, action to take. Throughout the year, management agencies share the results of the analysis with constituent groups and general public to keep them abreast of the status of Chinook salmon and the predator-prey balance in the lake.

Methods of RFA

Indicators – The SWG members created a series of biological indicators for gauging the population sizes and conditions of Chinook salmon and alewives, their primary prey. A time series of indicator data is maintained, and measurements from the current and past 5 years are compared to historical values. Indicator data are updated annually and are stored and analyzed in an MS Excel® workbook that covers the period 1985 to present. Thus, the historical values from 1985 to the year prior to that in which the RFA is conducted are the basis for comparing and judging the appropriateness of the current year's indicator value.

Data from every source are not available every year. Availability varies for many reasons, such as budget shortfalls or changes in work and research priorities. To help compensate for missing records and to provide a biologically meaningful framework, data have been classified into six major categories (Claramunt et al. 2010). Each year, up to three of the data sets in each category are selected as biological indicators to represent the current conditions in the category. Indicators are selected based on recent availability of data and biological significance. Some indicators in each category are considered primary indicators because of their consistent availability and important biological meaning. A description of each category and a list of primary indicators are presented in Table 1.

In addition to primary indicators, each category has a list of auxiliary indicators and supplementary data (Table 2). Some auxiliary indicators or supplementary data are used to calculate primary indicators, and some auxiliary indicators have been used as substitutes for primary indicators in years when data for the primary indicator are not available. Also, auxiliary indicators or supplementary data might be examined to help interpret results of the primary analysis.

The main focus of RFA has been to monitor Chinook salmon and alewife populations, but in 2008 the LMC charged SWG to broaden the procedure to help monitor the status of other salmonine fisheries. This prompted SWG to add the "System Integrity" category and the "Proportion of harvest that is not Chinook salmon" indicator (Table 1). In addition, Claramunt et al. (2010) suggested incorporating additional indicators in the future, such as indicators to monitor trends in the harvest, growth, age structure, abundance, and egg thiamine levels of coho and lake trout populations, but to date no other indicators have been used.

I give a brief description of each of the primary indicators (Table 1) and present time series graphs of their values. In the *Abundance* category, the first indicator is the estimated Chinook salmon catch rate from the Michigan charter boat fishery (Figure 1 – top panel). It is assumed that this catch rate is proportional to abundance. The State of Michigan requires operators of charter boats to make annual reports documenting their hours of fishing effort and numbers of each species caught (Rakoczy and Wesander 2006). The catch per hour calculated from these reports is generally considered one of the better indices of Chinook salmon population abundance. Most charter boat operators are knowledgeable fishers who spend a significant amount of time trying to put their clients in a position to catch salmon and who are capable in identifying different species of trout and salmon. Charter boat catch data have been published in MDNR Fisheries Division Technical Reports from 1986 through 2001, but data from 2002 to present is available only in MDNR files. This indicator is estimated for Michigan waters only. Values ranged from 0.04 to 0.30 fish per hour from 1985 through 2010.

The second indicator in the *Abundance* category is a measure of angler success rate from the Michigan charter boat fishery (Figure 1 – middle panel). Angler success rate is assumed proportional to Chinook abundance. Success is measured as the percent of all anglers catching 3 or more Chinook salmon. It is measured for Michigan waters only. Values ranged from 0.4 to 29.5% from 1985 through 2010.

The third indicator in the *Abundance* category is a count of the number of Chinook salmon returning to Michigan weirs to spawn (Figure 1 – bottom panel). It assumes that the number of mature fish returning to spawn in a given year is proportional to overall Chinook abundance. The State of Michigan counts salmon returns at weirs located on the Little Manistee River (LMRW), Platte River (PRW), Boardman River (BRW), and Medusa Creek (MCW). These weirs are also primary stocking sites for Chinook salmon smolts. Weir operations are managed by MDNR and most counts are from unpublished data from MDNR files, although examples of counts for 1990 are reported by Hay (1992). Values ranged from 13,600 to 55,800 Chinook salmon from 1985 through 2010.

The first indicator in the *Recruitment* category is an estimate of the percent of age-1 Chinook salmon that are wild as determined from oxytetracycline (OTC) marking operations (Figure 2 – top panel). In years when all hatchery fish are marked with OTC, all unmarked fish are assumed wild (i.e. from natural reproduction). OTC operations are managed by MDNR and most of these estimates are from unpublished data from MDNR files, although examples of these estimates for 1992-93 are reported by Hesse (1996). The proportion wild at age 1 is considered the best indicator of the amount of natural reproduction in Lake Michigan. Samples for calculating this indicator were collected only from Michigan waters prior to 2000, but samples have been collected lake wide since then. Values ranged from 21.5 to 65.8% between 1985 and 2010, but values were not estimated every year.

The second indicator in the *Recruitment* category is an estimate of total annual smolt abundance for Chinook salmon (Figure 2 – middle panel). Smolts are age-0 fish recruiting to the Chinook salmon lake population. The assumption is that smolt abundance helps determine the future abundance of adults. Total smolt abundance is the sum of the number stocked and number spawned naturally. Management agencies report the number stocked annually (USFWS 2011). The number spawned naturally is either estimated from the percent unmarked at age 1 from the first *Recruitment* indicator or from values estimated by various authors and methods (Jonas et al 2008). Values ranged from 6.2- to 11.1-million smolts between 1985 and 2010.

The third indicator in the *Recruitment* category is an estimate of the age-1 Chinook salmon abundance (Figure 2 – bottom panel). Age 1 is when Chinook salmon begin to recruit to the fishery. The assumption is similar to that of the smolt abundance indicator, that age-1 abundance helps determine the future abundance of adults. However, age-1 abundance is estimated in a different way. A regression model derived by Warner et al. (2008) is used which relates the year-class strength of alewives in one year to the abundance of age-1 Chinook salmon the next year. Density of age-0 alewives is estimated from the annual acoustic survey conducted by the US Geological Survey, Great Lakes Science Center (USGS-GLSC). Results of the acoustic survey are used as an indicator for the *Prey Fish Abundance* category which is described below. Values ranged from 750,000 to 3,990,000 age-1 Chinook salmon between 1985 and 2010, but values were not estimated every year.

The first indicator in the *Growth* category is an estimate of the average weight of an age-2 Chinook salmon caught in the fishery during June and July (Figure 3 – top panel). It is based on fish sampled in MDNR's general angler survey (Lockwood et al 1999). The assumption is that the average weight at age 2 is a measure of food availability and growth conditions for the year. Lower average weights could mean there are too many salmon for the available food supply (alewives). Higher average weights could mean there are too many alewives. It is measured for Michigan waters only. Values ranged from 1,842 to 5,021 grams between 1985 and 2010.

The second indicator in the *Growth* category is an estimate of the average weight of a female, age-3 Chinook salmon sampled at Strawberry Creek Weir (SCW) in Wisconsin (Figure 3 – middle panel). The assumption and meaning are the same as for the first *Growth* indicator but this second indicator is measured in a different way and a different location on the lake. In addition, measuring the weight of prime, spawning-age females could provide some information on egg production potential of the Chinook salmon population. Values ranged from 4,870 to 9,900 grams between 1985 and 2010.

The third indicator in the *Growth* category is an estimate of the weight of a 30-inch salmon returning to the Strawberry Creek weir in Wisconsin (Figure 3 – bottom panel). This indicator is sometimes referred to as the "standard weight of a 30-inch Chinook salmon." First, a linear regression is calculated from all fish measured for length and weight at the weir for a given year, and then the weight of a 30-inch fish is estimated from the regression equation. It provides one number (weight) from the regression which is considered a good measure of the overall condition factor in the larger population. The assumptions are the same as for the first two *Growth* indicators. Values ranged from 3,814 to 4,585 grams between 1985 and 2010.

The first indicator in the *Prey Fish Abundance* category is an estimate of total alewife biomass from the annual acoustic survey conducted by the USGS-GLSC with help from fisheries management agencies around the lake (Figure 4 – top panel). The acoustic survey is lake wide and has been described by Warner et al. (2008). The assumption is that alewives are the primary food of Chinook salmon and so alewife abundance affects their condition and health. More alewives mean more and/or larger Chinook salmon (Warner et al. (2008). Over 90% of the biomass estimated from this acoustic survey consists of age-0 alewives (Warner et al. (2008). Values ranged from 9.1 to 279.8 kilotonnes (kt) between 1985 and 2010, but values were not estimated every year.

The second indicator in the *Prey Fish Abundance* category is an estimate of the biomass of age-1 and older alewife from the annual bottom trawl survey conducted by the USGS-GLSC (Figure 4 – middle panel). The bottom trawl survey is lake wide and has been described by Madenjian et al. (2003, 2005, 2008). The assumption is the same as for the first indicator in *Prey Fish Abundance*. However, while acoustic gear is better at sampling all sizes of alewives, trawls primarily collect larger (4 inches and larger) fish. Alewives are not fully recruited to the bottom trawl until age 3 (Madenjian et al. 2005). Values ranged from 4.7 to 47.6 kt between 1985 and 2010

The third indicator in the *Prey Fish Abundance* category is an estimate of the mean length of an age-1 (jack) coho salmon at Michigan weirs (Figure 4 – bottom panel). The assumption is that the size of an age-1 coho is proportional to alewife abundance for a given year. Data are from MDNR files. Units of measure are millimeters (mm). Values ranged from 350 to 398 mm between 1985 and 2010, but values were not estimated every year.

The first indicator in the *Fish Health* category is a measure of the percent of Chinook salmon testing negative for clinical signs of bacterial kidney disease (BKD) at Michigan weirs (Figure 5 – top panel). MDNR has tested fish for BKD at various weirs annually since 1991, when this disease caused major Chinook salmon mortality in the lake (Nelson and Hnath 1990; Holey et al 1998). Females testing positive for BKD are culled, and their eggs are not used for hatchery rearing. The assumption regarding fish health in the RFA is that the incidence of BKD at the weirs is representative of the incidence in the lake. Values for this indicator ranged from 87.8 to 99.3 percent negative between 1991 and 2010.

The second indicator in the *Fish Health* category is an estimate of the egg thiamine concentration in Chinook salmon eggs (Figure 5 – middle panel). The assumption is that low egg thiamine levels could adversely affect natural reproduction. Low egg thiamine concentrations have been linked to early mortality syndrome (EMS) for a number of salmonids. EMS has been associated with diets high in alewives and smelt (Fitzsimons et al. 1999) and has been implicated in causing poor natural reproductive success in Great Lakes salmonids (Madenjian et al. 2008). While susceptibility varies by species, predators of alewives and smelt can be at risk of developing a thiamine deficiency, and hence EMS. Values ranged from 1.7 to 11.6 nanomoles per gram (nmol g^{-1}) between 2001 and 2010.

The first, and presently the only, indicator in the *System Integrity* category is the percent by weight of the lake-wide salmonine harvest that is not Chinook salmon (Figure 5 – bottom panel). The assumption is that, since Chinook salmon are the largest component of the salmonine community, the proportion of the harvest that is not Chinook salmon is reasonable a measure of the relative salmonine species composition. Systems with diverse species compositions have greater integrity and have a greater ability to withstand perturbations. Data for this indicator comes from harvest estimates made by management agencies around the lake. Values ranged from 14.6 to 71.7% between 1985 and 2010.

Triggers – RFA measures the health of the system by tallying the number of potential biological problems found in indicator measurements. Potential problems are symbolically represented as red flags. Indicator values are considered to be of concern when recent values substantially deviate or trend away from the range of historical values. The basic assumption is that extreme values or developing trends could be a sign of trouble in the system.

The suitability of an indicator value for the current year is judged based on its relative rank within the historic range of values. Two decision rules are used to determine if red flags should be triggered. The *Level I* rule is designed to detect relatively large, immediate changes in indicator values. A red flag is triggered in *Level I* when an indicator value for the current year is either lower than the 20th or higher than the 80th percentile of the distribution of all values in the time series for that indicator. The *Level II* rule is designed to detect emerging trends in indicator values. A red flag is triggered in *Level II* when indicator values in three of the last five years are lower than the 40th or higher than the 60th percentile of the distribution of all values in the time series.

Red flags are accumulated for the entire list of primary indicators. Table 3 shows an example of a completed analysis for 2010. For a given year, it is assumed that the greater the number of red flags triggered, the worse the health of the system. The SWG has judged that when 50% or more of the indicators trigger red flags under either level, the system could be experiencing major problems. In which case, the LMTC should make a more extensive review of the situation and possibly recommend management policy changes to the LMC.

Past Results of RFA

RFA 2004-2009 – The 2004 RFA was completed in March 2005. Results were interpreted as meaning potential problems might be developing in the predator-prey balance (Claramunt et al. 2008). Red flags were triggered for 42% and 8% of the indicators under *Level I* and *Level II*, respectively. Even though results for both decision rules were below the pre-defined 50% threshold, the 42% result for *Level I* was considered worrisome. Claramunt et al. (2008) evaluated the RFA result along with supplementary biological information and concluded that Chinook salmon harvest levels in 2004 were probably not sustainable. In particular, they worried that trends in Chinook salmon growth and survival were trending downward. Further discussion and analysis seemed to support their concern.

Later in 2005, a more extensive evaluation of stocking strategies and predator-prey balance was conducted, including use of population models, structured decision analysis, and public input (Jones et al. 2008). This evaluation lead to a decision to reduce annual stocking rates for Chinook salmon by 25% (Wesley 2011; Claramunt 2010). Then in March 2006, the results of the 2005 RFA seemed to provide additional support to that decision. The 50% RFA threshold for concern was exceeded for both *Level I* and *Level II* decision rules (Figure 6). The new stocking policy was first put into action in spring of 2006. The number of Chinook salmon stocked into Lake Michigan decreased from an average of 4.3 million per year in 2001-2005 to 3.1 million per year in 2006-2010 (USFWS 2011).

The 2006 RFA was the first to be conducted after stocking was reduced and results indicated that the cut in stocking was beginning to work as anticipated. The number of red flags triggered was below 50% for both *Level I* and *Level II* decision rules (Figure 6). Thus, the 2006 RFA seemed to show that the system was moving in the right direction.

However, from 2007-2009, RFA results were mostly contrary to expectations, and some biologists and managers began to question the validity of the approach. Results for the two decision rules were inconsistent

(Claramunt et al. 2012). Under *Level I*, results were in the acceptable range (< 50% red flags triggered) for 2 of 3 years. But under *Level II*, results were far outside the acceptable range every year; about 90% of the red flags were triggered (Figure 6). Theoretically, under the RFA rules a more extensive review should have been conducted and a change in management policy should have been considered as early as 2008 when the SWG reported the results of the 2007 RFA to the LMTC. But the perception of many biologists and anglers was that the Chinook salmon fishery was thriving. For example, angler catch (Figure 1 – top panel) and success rates (Figure 1 – middle panel) were at the highest levels ever recorded. So consensus for action could not be reached in the LMTC or LMC after review of biological data and considerable debate. Instead, a number of reasons were proposed as to why results of the *Level II* trend analysis might have been incorrect and a review of the RFA methodology was suggested (R. Claramunt, MDNR, personal communication).

RFA for 2010 – The most recent RFA available was for 2010. Randy Claramunt, then Chair of the SWG, presented the results at the LMC Meeting in Ypsilanti, Michigan in March 2011. His summary for the analysis is reproduced in Table 3 (Randy Claramunt, Michigan Department of Natural Resources, personal communication). Results showed that 46% of *Level I* and 87% of *Level II* indicators were triggered in 2010. Thus, the 50% threshold for *Level II* was exceeded for the fourth consecutive year.

The LMTC was concerned about the RFA results, but decided against recommending immediate management policy changes. An extensive 5-year evaluation of the stocking policy was already scheduled for 2011-2012 (Wesley 2011), so LMTC decided to wait and use the RFA results as one of multiple factors to consider in that analysis. At the same time, this review of RFA procedures was being conducted.

Summary of RFA Annual Procedures

1. During spring, summer, and early fall, management and research agencies collect Chinook salmon and alewife data.
2. During winter, SWG assembles data for relevant biological indicators into a spreadsheet and conducts the *Level I* and *Level II* analysis for primary indicators. The Red flags are triggered in *Level I* when the indicator value for the past year is either lower than the 20^{th} or higher than the 80^{th} percentile of the historical range. Red flags are triggered in *Level II* when indicator values in three of the last five years are lower than the 40^{th} or higher than the 60^{th} percentile of the historic range.
3. By early March, SWG accumulates the number of red flags triggered over the entire series of indicators and reports the results to LMTC. When 50% or more of the red flags are triggered it is assumed that there could be a problem in the predator-prey balance, so a more detailed biological review is recommended to LMTC.
4. If the review convinces the LMTC that a problem exists, they recommend to the LMC that an even more detailed biological review be conducted or that an immediate change in stocking rates or fishing regulations should be considered. The intent of this process is to annually monitor the fishery and to catch major problems that would justify short-circuiting the 5-year management policy review cycle.
5. Return to #1.

Section 2: Critical Review of RFA

The protocol for managing Chinook salmon in Lake Michigan has evolved into a two-step process. First, stocking policies are developed in a series of meetings which occur approximately every 5 years. Management agencies facilitate the meetings which are designed to incorporate input from fishery stakeholders. Sophisticated risk assessment models (Szalai 2003) and structured decision analysis techniques (Jones et al. 2008) are used to support collaborative decision making. Second, after decisions are made and stocking policies are put in place, their performance is monitored annually. Managers and researchers all around the lake collect data on the fishery and then share it through the LMC. RFA was developed as a way to organize and analyze that data. The intended purpose of RFA in the overall protocol is to identify problems in the fishery that might justify more immediate attention than would otherwise occur under the 5-year policy development cycle.

I critically reviewed the analytical procedures used in RFA and reexamined its role in the overall management protocol. I found a number of problems in the analytical procedures. In addition, I think RFA suffers from mission creep. That is, managers continue to make new demands on the procedure, which has resulted in expansion of the scope and objectives of RFA. The SWG, who developed and operates RFA, has been unable to keep pace in modifying RFA to address these new demands.

I think the RFA is worth continuing. The analytical problems I found can be fixed and the procedures can be modified to satisfy new demands. If proper revisions are made, the procedure can play an important role in the overall management protocol – not only to monitor for developing problems in the fishery but also to more directly evaluate the success of the 5-year stocking policy in achieving its objectives. I developed prototype analyses to illustrate how this can be done. Final revisions of RFA should be made collaboratively by a task group with representation from the management agencies. If some or all of my recommendations are endorsed, the prototypes can be used to guide the revisions. The prototypes are stored as MS- Excel® spreadsheets and can be obtained by contacting me or the Quantitative Fisheries Center.

Recommendation 1 – Clarify RFA Objectives

Any good management tool needs a well-defined purpose. Without clear obvjectives, there is no way to judge effectiveness of a management program. RFA could benefit by a clearer definition of objectives. I propose the following five objectives for RFA:

1. To annually assemble and organize relevant, lakewide data to assess the balance between salmonine predators (especially Chinook salmon) and planktivore prey (especially alewives).
2. To provide an easily understood framework for describing the status of the Chinook salmon fishery and the predator-prey balance to user groups and general public.
3. To assess progress in achieving the Salmonine Objectives for Lake Michigan (Eshenroder et al. 1995).
4. To identify developing problems in the Chinook salmon-alewife predator-prey balance in time to avert or minimize them by taking management action.
5. To assess progress in achieving management objectives for Chinook salmon stocking strategies set forth during the 5-year policy reviews.

Based on my discussions with managers, I think RFA is achieving objectives 1 and 2, so I gave no further attention to them in this review. I focused my critical review on determining how well RFA satisfies objectives 3 through 5.

Recommendation 2 – Modify Analysis to Directly Address All RFA Objectives

RFA *does* directly address Objective 4. This was the original purpose of RFA and was the primary guide for its design. However, the design can be improved by revising the triggering mechanism (see my Recommendation 4 below).

RFA *does not* directly address either Objective 3 or 5. Some of the data in RFA could be used to address them, but the current procedure falls short of doing so. Perhaps, these objectives represent new demands on RFA (i.e., mission creep). Or, perhaps they represent a misinterpretation or exaggeration of what RFA is really doing. Whatever the case, I think these are very important objectives that should be addressed either through RFA or another procedure. My first prototype was designed to satisfy Objective 3 based on proposals described below under Recommendation 3. My second prototype was designed to simultaneously satisfy both objectives 4 and 5 based on proposals described below under Recommendations 4 through 8.

Recommendation 3 – Devise a More Detailed Interpretation of the Salmonine Objectives

Calls for managers to reexamine and/or revise the FCOs for Lake Michigan have appeared in the last two Lake Michigan State of the Lake Reports (Jonas et al. 2005; Clapp and Horns 2008). In conducting this review, it has become clear to me that any analysis designed to quantitatively assess progress in achieving the FCOs would benefit from a more detailed interpretation of those objectives. However, the authors of the FCOs deliberately set broad harvest targets to allow future management flexibility. One way to add detail and clarity and yet continue to maintain that flexibility would be to devise a way to add clarifying amendments. Or alternatively, the agencies could simply agree, formally or informally, on more specific interpretations of these objectives to benefit quantitative assessment of management activities.

For example, in the FCOs, Eshenroder et al. (1995) suggested quantitative, near-term expectations for salmonine yields were 3.1 million kg of Chinook salmon, 1.1 million kg of lake trout, 0.7 million kg of coho salmon, 0.3 million kg of steelhead, and 0.2 million kg of brown trout. These expectations were developed from recreational fishing effort and yield experienced in the mid-1980s but fishing effort has declined considerably since then (Figure 7). As a consequence, it may be unreasonable to expect such high yields from the lower fishing effort. However, suppose, the agencies agreed that these near-term expectations were only meant to be accomplished under the fishing mortality rates of the mid-1980s. Such an agreement would be a reasonable interpretation of what was meant by the phrase “capable of sustaining” in the Salmonine Objective and would allow direct estimates of the current theoretical potential yield for each of the major salmonine populations through a simulation analysis.

As an illustration, the first prototype analysis I created uses the CONNECT model (Rutherford 1997; Lake Michigan Salmonine Stocking Task Group 1998) to make these simulations. Then, I treated the near-term yields as management targets and created an overall FCO Index of management success by summing the deviations between the model-estimated yields and the targets.

For the prototype analysis, I used the stocking rates for the five major salmonids from USFWS (2011). I used wild smolt production based on the estimated proportion of wild fish from oxytetracycline (OTC) analyses. These proportions were included in the RFA spreadsheet. For the other salmonines, I continued with the estimates for natural reproduction and growth used by Rutherford (1997). For 1966 through 1996, I used the Chinook salmon mortality rates estimated by Benjamin and Bence (2003). For 1997 to present, I used the fishing mortality rates estimated for the mid-1980s for all species, which was the interpretation of the FCOs I was assuming.

The CONNECT model produced the estimated harvests presented in Figure 8. The near-term yield targets are also plotted for comparison. The graphs show that the estimated potential yields for Chinook salmon and lake trout have moved closer to the FCO targets, especially since 2000. Estimated potential yields for steelhead and brown trout overshoot the targets, and estimated yields for coho salmon undershoot the target.

I also created an overall index of management success, the FCO Index, using the sum of the annual deviations between potential and target yields for all five salmonine populations. All these deviations are measured in pounds of fish, so it is reasonable to sum them into an overall index. Positive and negative deviations would cancel, so this index really measures how close the total estimated yield of salmonines is to the

12.1 million pounds suggested in the FCOs as the desired lake wide expectation. This index could be improved by adding some measure of species diversity, or perhaps, by weighting some species as more important than others. Nonetheless, I think the simple FCO Index I present here is sufficient for illustrative purposes.

Results of my FCO Index suggested that management actions, such as stocking policy changes and activities to combat bacterial kidney disease (BKD), between 1985 and 2011 were successful in moving the potential yields towards the Salmonine Objective targets (Figure 9). Deviations between model-estimated yields and target yields decreased over time as Chinook salmon stocking rates decreased and lake trout stocking rates increased. In other words, current stocking rates are producing a salmonine community in Lake Michigan that is fairly close to the one expressed in my assumed interpretation of the FCOs. The exception is that self-sustaining natural reproduction of lake trout has yet to be achieved.

Managers should be cautious about using the results of my FCO prototype analysis, because they are very preliminary. My main purpose for presenting the analysis was to illustrate a method for quantitatively assessing the FCOs. I did not do a rigorous job of updating the CONNECT model with information developed after 1996, the last year covered by Chinook salmon mortality estimates of Benjamin and Bence (2003).

My FCO prototype analysis does address Objective 3 but does not fit very well into the existing RFA format. It appears to be more of a separate, complimentary analysis. First, the FCO analysis contains no red flag triggers. And second, there is little need to conduct this FCO analysis every year unless major changes in stocking rates occur. It makes more sense to conduct the FCO analysis in conjunction with the major, 5-year stocking policy reviews. Then, the FCO Index could be used as one of the decision criteria for developing the longer-term stocking policies. Thus, I conclude that evaluating progress towards achieving FCOs (Objective 3) should be done along with the 5-year stocking policy review and should no longer be associated with RFA.

Recommendation 4 – Revise the RFA Triggering Mechanism

I found a substantial lack of confidence in the results of RFA among biologists, and I think there are two main reasons for it. First, there appears to be a general mistrust in the rules used to trigger red flags. The percentiles identified as triggers and the 50% rule are both based on subjective statistical judgments. Some biologists I contacted were skeptical of the idea that a major review of management policies could be triggered based on these subjective statistical criteria.

Second, RFA has triggered reviews when some biologists did not think it was warranted. A major policy review was conducted in 2005, stimulated in part by RFA. The review resulted in a cut in Chinook salmon stocking rates in 2006. In spite of the cut, RFA continued to trigger reviews every year from 2007 to 2010 (Figure 6). LMTC examined available biological evidence, but could not develop a consensus to recommend changing stocking rates again. Thus, the 2007-2010 RFA results did generate some re-examination, but did not short-cycle the 5-year stocking policy. Another stocking policy review began on schedule in 2011.

I think one of the main problems with RFA is that the statistical methods used implicitly define the mean of the time series for each biological indicator as the management objective for that indicator. That is, if enough indicator values exceed the prescribed percentile range, management action is triggered which would attempt to bring future indicator values back into the prescribed range. I think this implicit definition of objectives constrains management flexibility by discouraging actions that might make beneficial changes in the system, such as increasing the percent wild Chinook salmon above historic levels.

Managers should identify specific target and limit reference points for each biological indicator based on a combination of biological and sociological criteria. Target reference points would replace the mean of the time series as the management objective and limit reference points would replace the percentiles as the red flag triggers. There is substantial literature addressing the use of target and limit reference points in fisheries management, especially in marine fisheries (e.g. Leaman 1993; Caddy 1999). In general, target reference points identify the desired conditions to be achieved and limit reference points define the boundaries of safe biological conditions.

Using target reference points would add a new feature to RFA by replacing the de-facto management objectives (means of time series) with explicitly-defined objectives. And, these explicitly defined objectives are required to quantitatively assess progress towards achieving RFA Objective 5. Using limit reference points would not add any new features, but would simply replace one way of addressing Objective 4 with another. Thus, the new method I am recommending directly addresses both objectives 4 and 5, whereas the old method addressed only Objective 4.

Figure 10 illustrates the comparison between using statistical percentiles versus biological reference points. The top panel shows a plot of charter boat catch rates along with the *Level I* percentiles and the long-term mean (which I labeled as the "Target"). The middle panel shows the same catch rates along with explicitly-defined limit and target reference points. The difference between the two graphs is that the percentiles and target in the upper panel have different values (0.08, 0.25, and 0.16 for percentiles and target, respectively) than the limits and target in the middle panel (0.10, 0.30, and 0.22 for limits and target, respectively). The percentiles and target in the top panel are inflexible. They are defined by the statistical dispersion in the historical values. However, the limit and target reference points in the middle panel are completely flexible. They are defined by biological and sociological criteria. For example, in the middle panel I set the target for catch rates to be higher than the long-term average, which I think could be an appropriate management goal.

As a further illustration of the flexibility of limit and target reference points, I created a hypothetical example in the lower panel (Figure 10) to show that the target or management objective could be deliberately changed over time. In my example, I imitated a situation in which the management agencies decided to reduce the abundance of Chinook salmon in 2011 by reducing stocking rates. Because catch rates should be proportional to abundance it should follow that the catch rate target would be reduced, and ideally, the annual catch rate values would begin to cluster around the new target as shown.

I think the best way to define target reference points is to use the results of the risk assessment model during the 5-year decision analysis process. This model contains estimated values for many of the biological indicators used in RFA. Therefore, the model-estimated values for the chosen stocking policy might be useful starting points for defining indicator targets. This approach has the added benefit of creating another clear link between the decision analysis process and RFA. In addition, I think the risk assessment model would be useful in defining limit reference points, but there are other good ways to define limits.

Alewife and Chinook salmon populations collapsed in Lake Huron in 2004 and 2006, respectively (Johnson et al. 2010). I think the best way to define limit reference points for Lake Michigan would be to use data from Lake Huron immediately prior to these collapses. I think this idea is so important that I highlighted it below as one of my major recommendations.

Recommendation 5 – Study the Recent Collapse of Alewife and Chinook Salmon in Lake Huron

Learning from the recent collapse of alewife and Chinook salmon in Lake Huron in my opinion has not been sufficiently emphasized. Lake Huron biologists collected many of the same data and statistics as Lake Michigan biologists. Lake Michigan biologists should take a retrospective look that data to help identify biological indicators and limit reference points. For example, Johnson et al. (2007) presented a plot of Fulton's condition factors for Chinook salmon in Lake Huron, including estimates from 1996 to 2005 (page 27, Figure 7 in that report). Condition factors were 0.9 or less for several years just prior to the population collapse. It seems logical that condition factors as low as 0.9 should be avoided in Lake Michigan. I cannot think of a better way to identify indicators and limit reference points that might provide advanced warning of an alewife or Chinook salmon collapse in Lake Michigan.

Recommendation 6 – Revise the List of Biological Indicators to Focus More on Alewife

I recommend reducing the number of primary indicators for Chinook salmon and increasing them for alewives. Currently, 12 to 15 primary indicators are used to characterize the Chinook salmon population. Too often, data are not available for one of the primary indicators in a given year, so a substitute indicator is selected to replace it. While these substitutes are considered to be within the same biological category, this substitution process could lead to biases. The management agencies should identify fewer indicators and make a stronger commit to collecting them. For Chinook salmon, I would use four general indicator categories: abundance (an estimate of catch-per-effort); recruitment (an estimate of wild recruitment); condition (a condition factor); and mortality (a direct estimate of mortality rate or an indicator of healthy age structure). Table 4 gives specific recommendations for Chinook salmon indicators with comments on each.

Currently, only 3 primary indicators are used to characterize the alewife population. Considering recent concerns about "bottom-up effects" (Madenjian et al. 2002), it seems like a good idea to expand these. Also, alewife recruitment is probably the single most important factor driving the dynamics of the predator-prey system. When alewife recruitment failed in Lake Huron, the alewife population collapsed followed by the Chinook salmon population (Johnson et al. 2010). Recent research on alewife recruitment (e.g. Madenjian et al. 2005) could be helpful in developing recruitment indices. I would use the same four general indicator categories for alewife as for Chinook salmon: abundance, recruitment, condition, and mortality. Table 5 gives specific recommendations for alewife indictors with comments on each. It is important to recognize that my recommendations for alewife do not represent any change or increase in data collection. Data for all these suggested alewife indicators are already being collected by the United States Geological Survey (USGS).

Recommendation 7 – Develop New, Quantitative Metrics to Better Evaluate Success of Stocking Policies

The current RFA uses the percentage of the total number of red flags being triggered as a gauge for prompting a detailed biological review. When 50% or more are triggered under either *Levels I* or *II*, then a review is recommended. I suggest replacing that standard with new, quantitative metrics, Chinook Salmon and Alewife Indices, based on the deviations between the current year's indicator values and the target values defined under Recommendation 4. Set up in this way, these two indices would quantitatively estimate the success of the stocking strategy, and when viewed in combination with the limit reference point triggers and the projection model below, they should provide sufficient information for SWG biologists to make a biologically-informed decision as to whether or not to prompt a detailed review of the stocking policy.

I developed an example of a Chinook Salmon Index in my second prototype analysis, and an Alewife Index could be developed very easily using the same techniques. The calculations are as follows:

$$\text{Chinook Salmon Index} = \Sigma \text{ Relative deviations for all indicators,} \qquad (1)$$

where,

$$\text{Relative deviation for indicator i} = \left| \frac{(X_i - T_i)}{SD_i} \right| . \qquad (2)$$

and X_i is the annual value for indicator i, T_i is the target value for indicator i, and SD_i is the standard deviation of the indicator historical values. Biological indicators for Chinook salmon are estimated in different units of measure. Dividing by the standard deviation in equation (2) has the effect of standardizing annual deviations for each indicator and making it reasonable to sum them into an overall index of success as in equation (1). Also, I used an absolute value in equation (2) to prevent positive and negative deviations from canceling.

These equations would define a Chinook Salmon Index with the following characteristics. The index would equal zero when all biological indicator values equaled their target values, which would represent perfect management. The further the index is from zero, the poorer the management success. Consistently achieving a Chinook Salmon Index of zero would seem unlikely due to the complexity and variability of the system, but the relative size of the deviation from zero would seem a reasonable measure of the success of the current management policy. If desired, the SWG could also identify a value of this Chinook Salmon Index as a limit reference point that would trigger a red flag and a cause reevaluation of the management policy.

I used four biological indicators in my prototype example to help illustrate the Chinook Salmon Index. Abundance is represented by the Michigan charter boat catch rates. Recruitment is represented by total number of smolts. Condition is represented by standard weight of 30-inch fish at SCW. Mortality is represented by percent age-1 in Michigan creel survey. I calculated the Chinook Salmon Index for each year, 1985-2010 (Figure 11). Results suggest that the degree of management success was relatively poor in 1987-1997, probably as a result of the BKD problem, but has gradually improved since then.

Managers should be cautious about using the results of my Chinook Salmon Index. They are very preliminary. My main purpose for presenting the prototype analysis was to illustrate a method for quantitatively assessing the success of achieving the goals of the stocking policy (Objective 5).

Recommendation 8 – Link indicators with a Projection Model to Predict Conditions a Few Years Ahead

My final recommendation is to add a projection model, such as CONNECT, to the RFA. Another criticism I heard from managers was that the biological indicators in RFA are treated as independent events, when in fact many of them are linked or dependent on one another. I cannot think of a better way to link the indicators in a biologically meaningful way than to do it with a population model.

Also, most of the current indicators are diagnostic in nature. Their only predictive ability comes from their relationship with the limit reference points. That is, when their value is near or outside the range of the limit reference points, a problem is predicted. However, these kinds of predictions might only reveal problems after it is already too late to do anything about them. Population models for both Chinook salmon and alewives could help predict emerging problems three or four years into the future with reasonable reliability. This might give managers a little more time to react. All the necessary data needed to utilize projection models are already being collected.

Summary of Revised Procedures

1. Address Objective 3 by using the CONNECT model to calculate a FCO Index. Do not do this every year, but do it in conjunction with the 5-year stocking policy review. Use the FCO Index as one of the factors in determining the stocking policy.
2. Address Objectives 4 and 5 by conducting the new and improved RFA every year. An example of an annual summary table report for the new procedure is presented in Table 6.

In my opinion, a task group could convert my prototypes into working management tools in one or two series of workshops conducted over a period of about 6 to 8 months. In addition, if simple projection models are used, such as CONNECT, I think the management agency biologists would be fully capable of running the final product on their own, without the kind of special analytical expertise required in the decision analysis process.

A Final Comment

In 2008, the LMC asked the SWG to expand RFA to include biological indicators for salmonines other than Chinook salmon (Claramunt et al. 2010). The modifications I recommended for RFA *do not* do this. While my prototype for evaluating Objective 3 does treat all the major salmonines, it relies on a theoretical modeling analysis instead of biological indicators. My prototype for evaluating objectives 4 and 5 uses biological indicators, but focuses solely on Chinook salmon and its primary prey, alewife. If the LMC continues to think it would be beneficial to monitor the other salmonines with biological indicators, then I suggest doing so by adding two new objectives similar to 4 and 5 for each additional species. For example, substitute "steelhead" for "Chinook salmon" in objectives 4 and 5 and call them objectives 6 and 7. Then, a new biological indicator analysis could be developed to address the new steelhead objectives. I think it would take at least another year to complete such analyses for the other four major salmonines.

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Table 1 – Description of indicator categories and a list of primary indicators used in RFA.

Category	Biological basis	Ideal	Primary indicators
Abundance (Chinook salmon)	The abundance of Chinook salmon determines the quality of the fishery and predator foraging demand.	Should be consistent with Fish Community Objectives (Eshenroder et al. 1995). Should be at a sufficient level to maintain a good fishery and keep alewife abundance below nuisance levels. Should be low enough to allow healthy growth of all salmonines and to avoid forage base collapse.	1) Chinook salmon catch rates from Michigan charter boat fishery; 2) Angler success rates from Michigan charter boat fishery (trips catching 3 or more Chinook salmon); 3) Numbers of Chinook salmon returning to Michigan weirs.
Recruitment (Chinook salmon)	Chinook salmon recruit to the lake population as age-0 smolts, including both stocked and naturally reproduced fish. They recruit to the fishery at age 1. Recruitment determines future abundance and predator demand on forage base.	Should provide a consistent number of young fish from year to year to maintain population at desired abundance.	1) Proportion wild, age-1 Chinook salmon from OTC evaluations; 2) Total smolt abundance; 3) Age-1 Chinook salmon abundance as predicted from age-0 alewife (Warner et al. 2008).
Growth (Chinook salmon)	Growth and condition (weight at size) of Chinook salmon are proportional to food ration size, which is indicative of relative predator-prey abundances and growth rates of individual salmon.	Should be adequate to produce good numbers of large, healthy fish for harvest and to provide sufficient natural reproduction.	1) Average weight of Chinook salmon sampled from the Michigan fishery at age 2; 2) Average weight of female, age-3 Chinook salmon at Strawberry Creek Weir (SCW), Wisconsin; 3) Estimated weight of a 30-inch Chinook salmon at SCW from length-weight regression.
Prey fish abundance	Abundance of prey fish (especially alewives) affects growth, survival, and recruitment of Chinook salmon and other salmonines.	Should maintain a diversity of prey species with abundances matched to primary production and predator demands – consistent with Fish Community Objectives (Eshenroder et al. 1995).	1) Alewife biomass as estimated by annual acoustic survey; 2) Alewife biomass as estimated by annual bottom trawl survey; 3) Average length of jack coho salmon (age-1 males) at Michigan weirs (assumed proportional to forage abundance).

Table 1 – Description of indicator categories and a list of primary indicators used in RFA (continued).

Category	Biological basis	Ideal	Primary indicators
Fish health (Chinook salmon)	Disease status and other health issues affect growth, survival, and recruitment of Chinook salmon and other salmonines.	Adult Chinook salmon should have low incidence of BKD and eggs should have good thiamine levels.	1) Signs of disease at weirs (percent Chinook salmon returning to weirs testing negative for BKD); 2) Egg thiamine concentration;
System integrity[1] (other salmonines)	System integrity is usually defined as some measure of species composition or biological diversity. Systems with integrity have the ability to maintain their structure following perturbations.	There should be a diverse salmonine community with species composition as defined by the Fish Community Objectives (Eshenroder et al. 1995).	1) Percent of salmonine harvest that is not Chinook salmon;

[1]This is a new category created in 2009. Suggestions have been made to add indicators to this category. See text.

Table 2 – A list of auxiliary indicators and supplementary data assembled for RFA.

Category	**Auxiliary indicators and supplementary data**
Abundance (Chinook salmon)	1) Sport fishing harvest of Chinook salmon in pounds; 2) Creel catch per effort (CPE) (Michigan waters only); 3) All weir extractions (total weight); 4) All weir returns (Number of Chinook salmon); 5) Illinois fall harbor returns-CPE; 6) MDNR vessel assessments with gill nets; 7) Salmon trout targeted effort; 8) Modeled abundance from Chinook salmon Statistical Catch At Age analysis; 9) Angler Success (catch 3 or more).
Recruitment (Chinook salmon)	1) Number of Chinook salmon stocked; 2) Proportion wild age 2 – open water collections; 3) Proportion wild age 3 - open water collections; 4) Egg weight index; 5) Trapping / smolt collections from streams; 6) Estimated number of wild smolts.
Growth (Chinook salmon)	1) Average size in fishery harvest (weight); 2) Average size at weir harvest (weight); 3) Age 3 weight for Michigan creel survey; 4) Weight at age 3+(g) at Little Manistee River Weir (LMRW); 5) Weight at age 2+(g) at LMRW; 6) Female wt at age 2+(g) at SCW; 7) Vessel assessments (weight at age 2); 8) Vessel assessments (weight at age 3); 9) MDNR master angler entries from open lake not including tributaries; 10) MDNR master angler entries from open lake including tributaries; 11) Mean length of coho female (age 1.1) from MI weirs; 12) Mean length of coho female (age 1.1) from WI weirs; 13) Mean length of coho jacks from WI weir returns.
Prey fish abundance	1) Diet ration age 1 (vessel survey); 2) Diet ration age 2 (vessel survey); 3) Diet ration age 3 (vessel survey); 4) Diet ration age 1 - southeast (creel survey); 5) Diet ration age 2 - southeast (creel survey) 6) Diet ration age 3+ - southeast (creel survey); 7) Diet ration age 1 - northeast (creel survey); 8) Diet ration age 2 - northeast (creel survey); 9) Diet ration age 3+ - northeast (creel survey); 10) Total ration.

Table 2 – A list of auxiliary indicators and supplementary data assembled for RFA (continued).

Fish health (Chinook salmon)	1) Survey visual signs of BKD %; 2) Boardman River Weir, visual signs of BKD; 3) LMRW, visual signs of BKD; 4) Platte River Weir, visual signs of BKD; 5) Manistee River Weir, visual signs of BKD; 6) BKD incidence from FELISA test – MI weirs; 7) Coho age 1 lipid levels – spring; 8) Coho age 1 lipid levels – fall; 9) Coho age 2 lipid levels – spring; 10) Coho age 2 lipid levels – summer; 11) Coho age 2 lipid levels – fall; 12) Chinook lipid - fall weirs in WI; 13) Muscle plugs (% of fish>78%water) - spring; 14) Muscle plugs (% of fish>78%water) – fall.
System integrity and Other	1) Age composition of Chinook salmon at SCW; 2) Age composition of Chinook salmon in sport catch; 3) Percent Chinook salmon mature by age in sport catch; 4) Percent Chinook salmon mature in vessel survey; 5) Weight of Chinook salmon harvested by state in sport fishery; 6) Weight of lake trout harvested by state in sport fishery; 7) Weight of rainbow trout harvested by state in sport fishery; 8) Weight of brown trout harvested by state in sport fishery 9) Number of Chinook salmon harvested in Michigan sport fishery; 10) Average weight of a 3-year-old lake trout in management district MM3.

Table 3. – Variable categories (Variable), biological indicators (Index), and results of red flag triggering for Level I and II in RFA for 2010. "Yes" indicates a red flag was triggered and "No" indicates a red flag was not triggered. Table is courtesy of Randy Claramunt, MDNR.

Variable	Index	Level I	Level II
Abundance	Catch rate (charter)	Yes	Yes
	Angler success	No	Yes
	Weir returns (MI only)	Yes	Yes
Recruitment	Percent wild from OTC	Yes	Yes
	Total smolt abundance	Yes	Yes
	Age-1 abundance	Yes	Yes
Growth	Creel wt at age 2	No	Yes
	Weir wt at age 3	Yes	Yes
	Standard wt	No	Yes
Prey Fish Biomass	Acoustic	No	Yes
	Bottom trawl	Yes	Yes
	Coho length index (diet data?)	No	Yes
Ecosystem Health	Visual signs of disease	No	No
	Egg thiamine levels	No	No
	Salmonine composition	No	Yes

Table 4. – Summary of the recommended revisions of RFA indicators for **Chinook salmon**. A list of suggested indicators is given for each category. I recommend selecting only one or two indicators per category for the analysis, even though I listed more than two in some cases.

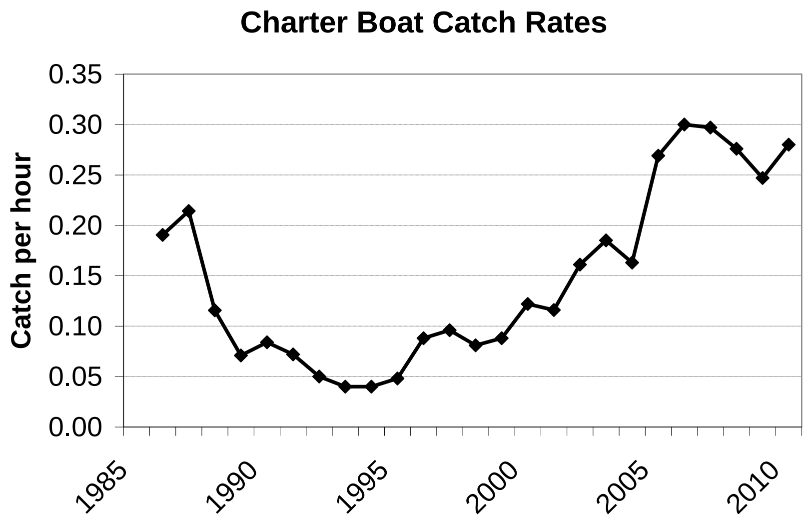
Category	**Suggested Indicators**	**Comments**
Abundance	1) Catch rates from Michigan charter boat fishery; Also consider: 2) Catch rates from May-July from angler survey on west side of lake.	Catch per hour from the fishery is probably the best abundance indicator available. The Michigan charter boat fishery is probably the most reliable source, but it only covers the east side of the lake. Catch rates from the west side of the lake would be another indicator worth considering. Many Chinook salmon are feeding on west side in May-July (Adlerstein et al. 2007).
Recruitment	1) Total smolt abundance; Also consider: 2) A migration rate indicator; 3) Age-1 Chinook salmon abundance as predicted from age-0 alewife; .	Total smolt abundance combines number stocked and estimated wild smolt production from OTC marking. If migration of fish from Lake Huron is determined to be a significant factor, then a migration rate indicator would be justified. Two possible migration indicators could be: "percent of fish stocked in Lake Huron recovered in Lake Michigan from CWT"; and "percent of wild fish recovered in Lake Michigan from Lake Huron tributaries based on otolith microchemistry analysis". Higher age-1 Chinook salmon abundance in years of high age-0 alewife abundance as predicted by Warner et al. (2008) could mean either higher survival within Lake Michigan, higher migration from Lake Huron, or both.
Condition (growth)	1) Estimated weight of a 30-inch fish at SCW from length-weight regression; Also consider: 2) Estimated weight of a 30-inch fish from length-weight regression in creel or from Michigan weirs.	The SCW length-weight regression provides a good index of body condition and growth for a given year. A similar measure from fish in creel or from Michigan weirs might be useful.
Mortality	1) Percent age-1 fish in Michigan creel. Also consider: 2) Return rates of stocked fish to creel at various ages.	Percent age-1 fish clearly showed the effects of BKD in the late 1980s and early 1990s. The percent age-1 increased as older fish were selectively killed by BKD. If stocked fish are marked, then return rates to creel could be estimated at various ages as indices of mortality for hatchery fish .

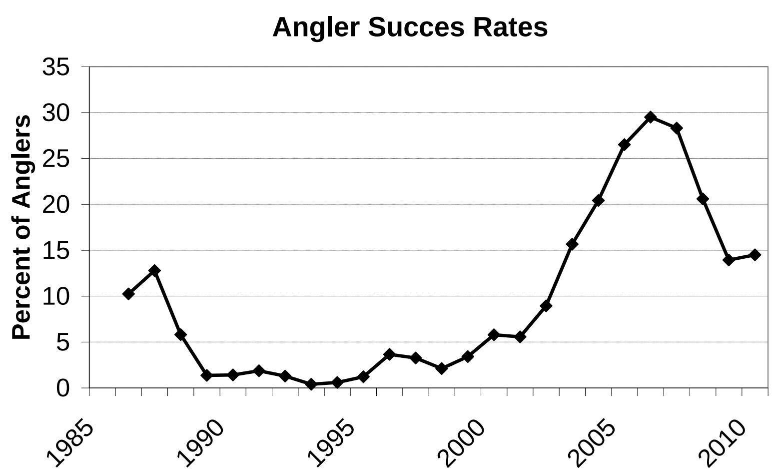
Table 5. – Summary of the recommended revisions of RFA indicators for **alewife**. A list of suggested indicators is given for each category. I recommend selecting only one or two indicators per category for the analysis, even though I listed more than two in some cases.

Category	**Suggested Indicators**	**Comments**
Abundance (adult standing stock)	1) Alewife biomass as estimated by annual USGS bottom trawl survey;	Size selectivity for bottom trawl is for larger, older fish, so biomass estimate is for adults. Age 3+ are fully recruited (Madenjian et al. 2006).
Recruitment	1) Alewife biomass as estimated by annual USGS acoustics survey; Also consider: 2) Recruitment predictions from a stock-recruitment relationship; .	Biomass estimates from acoustic survey is over 90% age-0 alewives (Warner et al 2008) representing current year's recruitment. The stock-recruitment relationship developed by Madenjian et al. (2005) predicts recruitment of age-3 alewife based on spring-summer water temperatures experienced at age 0, and an index of predation experienced from age 0 to 3. Thus, it predicts biomass of age-3 alewives 3 years hence.
Condition (growth)	1) Estimated weight of a 5- or 6-inch fish from length-weight regression calculated from bottom trawl samples; Also consider: 2) Fulton's condition factor as calculated by Madenjian et al. (2005); 3) An estimate of energy density, such as dry weight.	This gives a good index of condition and growth for a given year. An index of condition or energy density of alewife is one of the most important indicators to add to this analysis. It helps monitor bottom-up affects from changes occurring at lower trophic levels.
Mortality (age structure)	1) Devise an indicator of a healthy age structure.	The age structure of the population reflects both recruitment and mortality of year classes. A healthy population has multiple age groups represented and reasonable numbers of older fish.

Table 6. – Example of a summary of annual results for recommended new RFA. This table would replace currently used summary presented in Table 3. The variable X_i in the Deviations column is the annual value for indicator i.

Species	Indicator	Red Flags	Deviations	Projections
Chinook salmon	Abundance	Yes/No	X_1-$Target_1$	
	Recruitment	Yes/No	X_2-$Target_2$	
	Condition (growth)	Yes/No	X_3-$Target_3$	
	Mortality (age structure)	Yes/No	X_4-$Target_4$	
	Chinook Salmon Index		Value	
	Population model			Standing stock, Harvest, Predator demand.
Alewife	Abundance	Yes/No	X_5-$Target_5$	
	Recruitment	Yes/No	X_6-$Target_6$	
	Condition (growth)	Yes/No	X_7-$Target_7$	
	Mortality (age structure)	Yes/No	X_8-$Target_8$	
	Alewife Index		Value	
	Population model			Standing stock





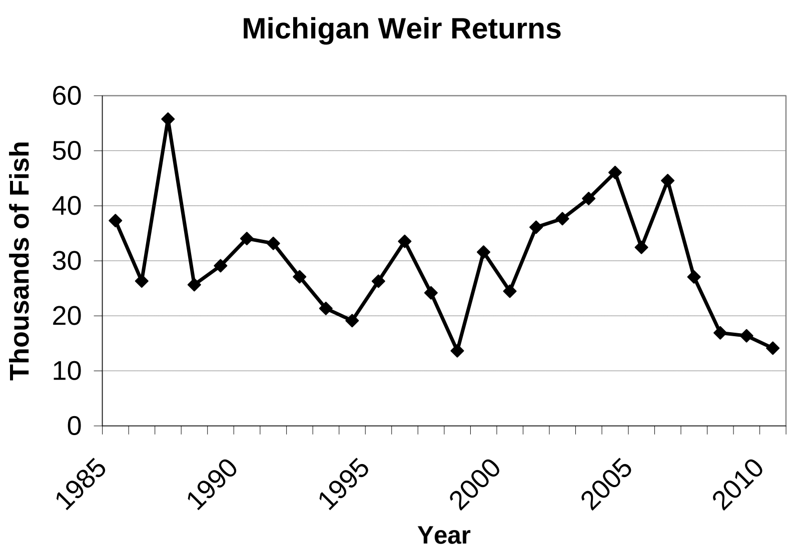


Figure 1. – Annual time series of biological indicators in Chinook salmon *Abundance* category.

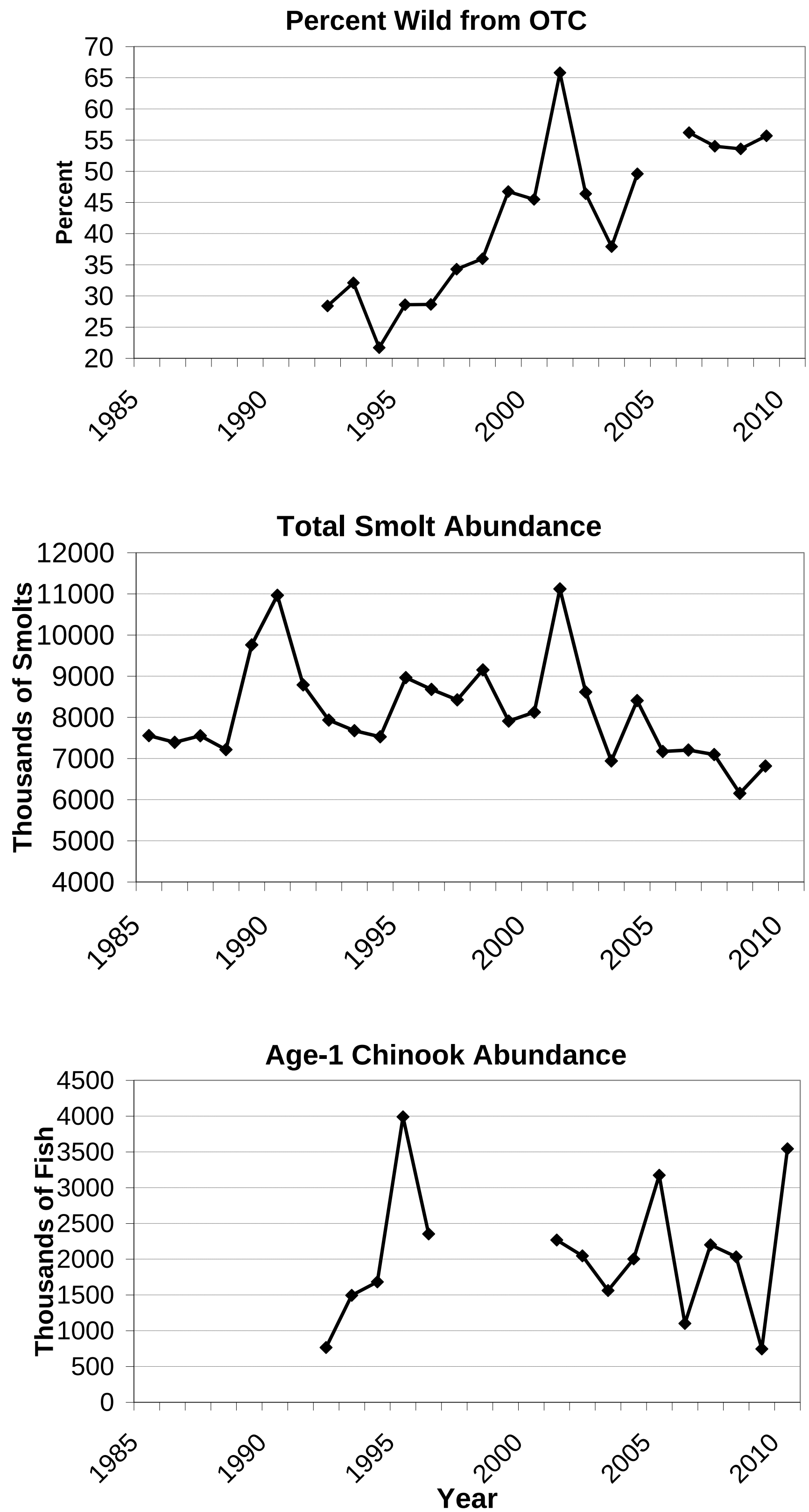
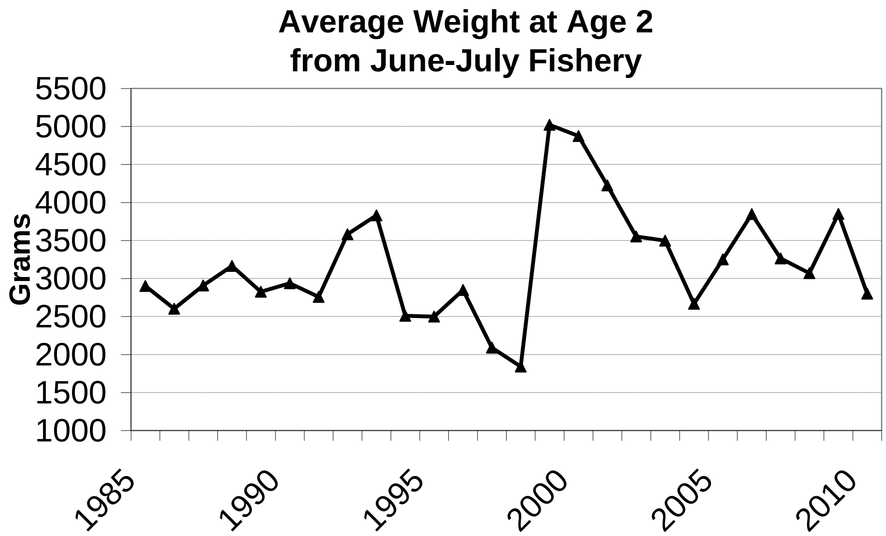
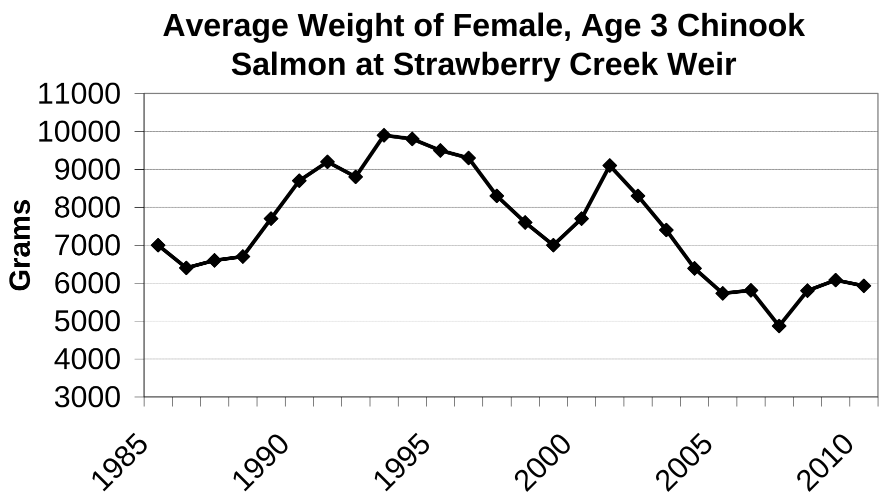


Figure 2. – Annual time series of biological indicators in Chinook salmon *Recruitment* category.





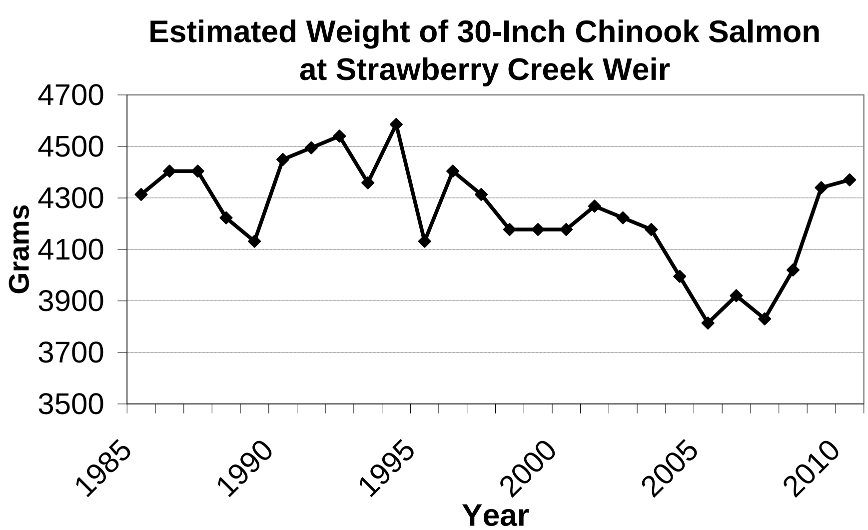


Figure 3. – Annual time series of biological indicators in Chinook salmon *Growth* category.

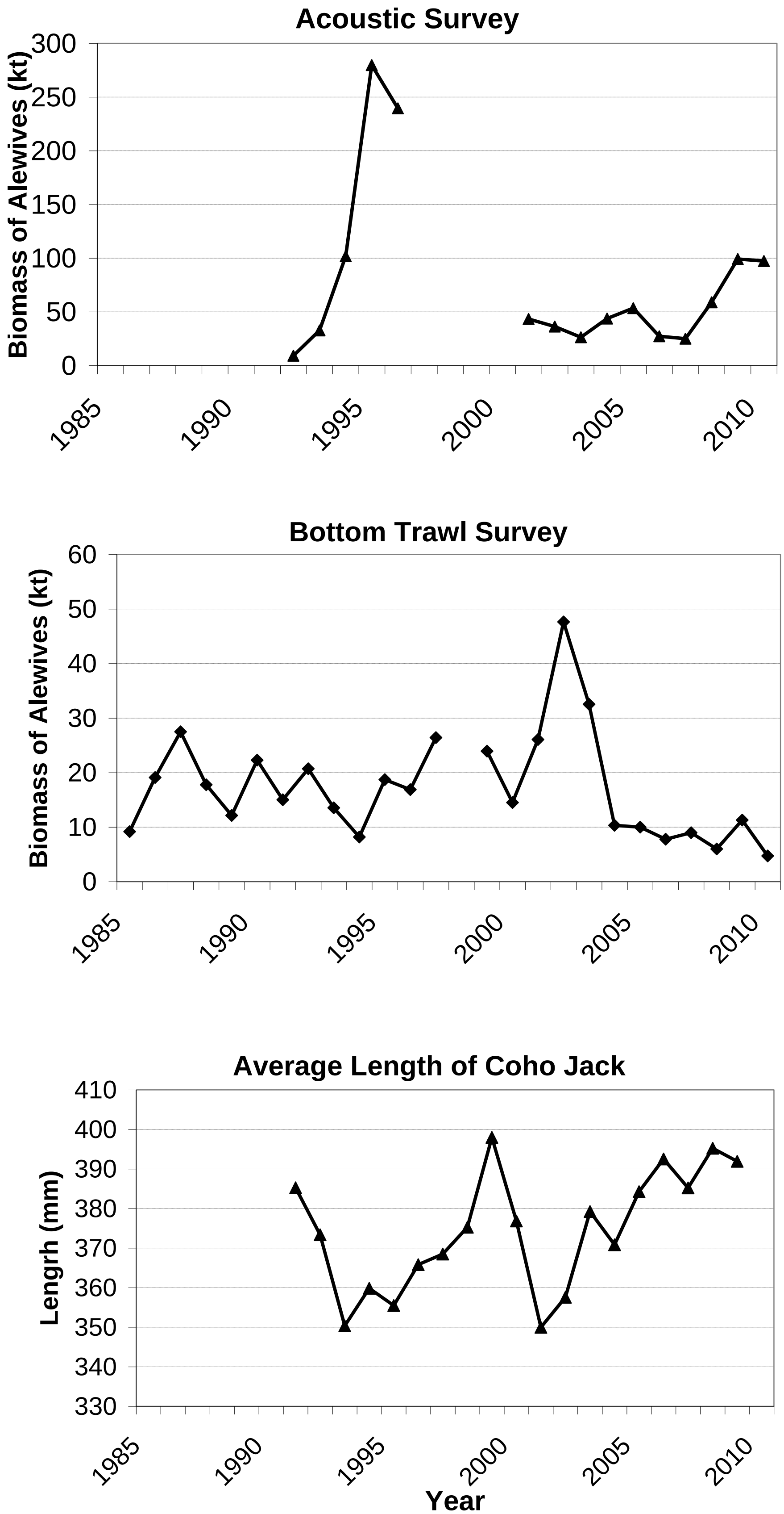


Figure 4. – Annual time series of biological indicators in *Prey Fish Abundance* category.

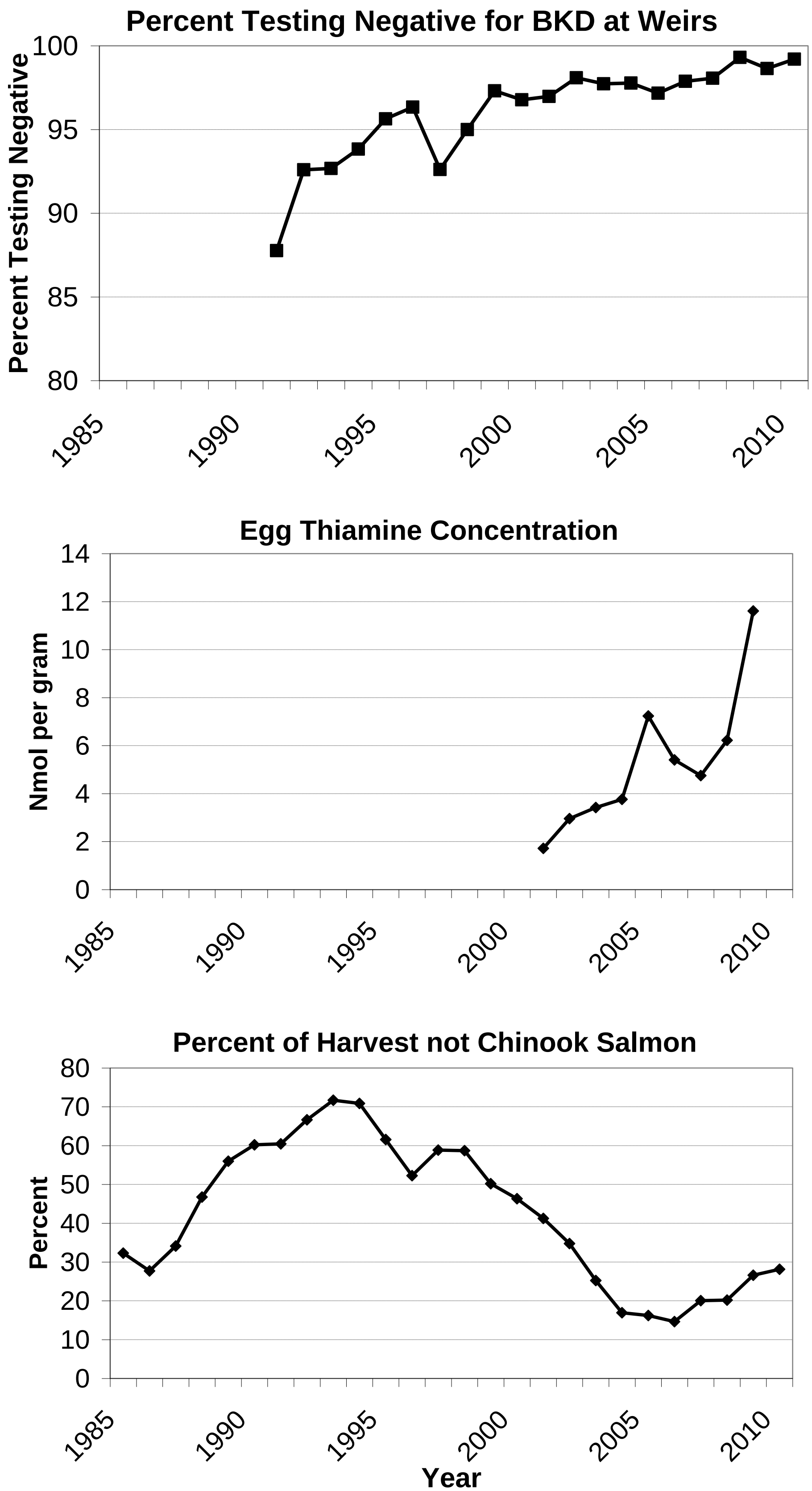


Figure 5. – Annual time series of biological indicators in *Fish Health and System Integrity* categories.

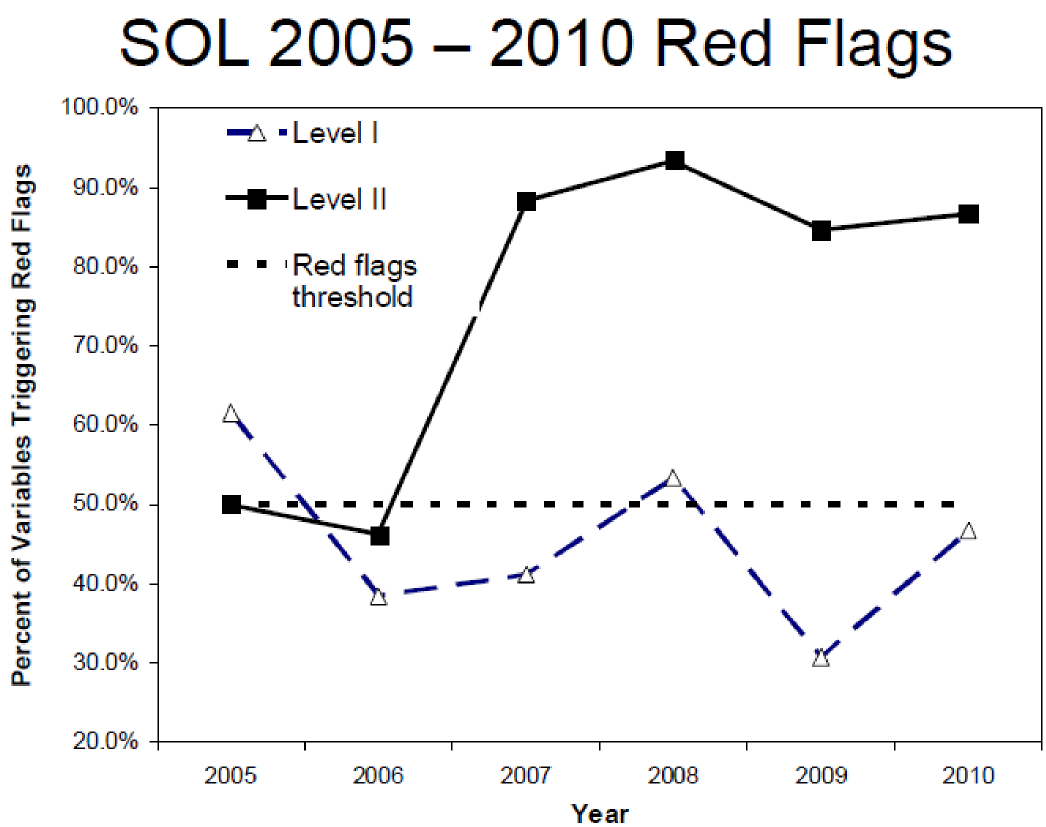


Figure 6. Time series of RFA results. Graph is courtesy of Randy Claramunt, MDNR.

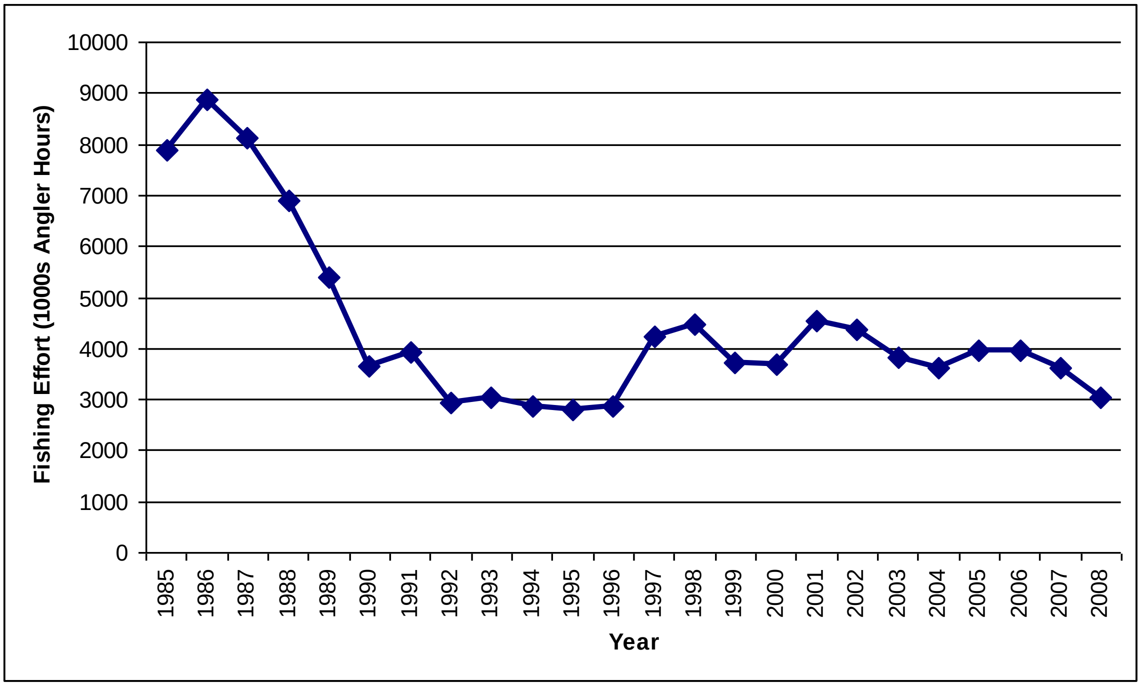


Figure 7. – Estimated lake wide, salmonid-targeted fishing effort for Lake Michigan from 1985-2008. Data are from the RFA spreadsheet developed by SWG.

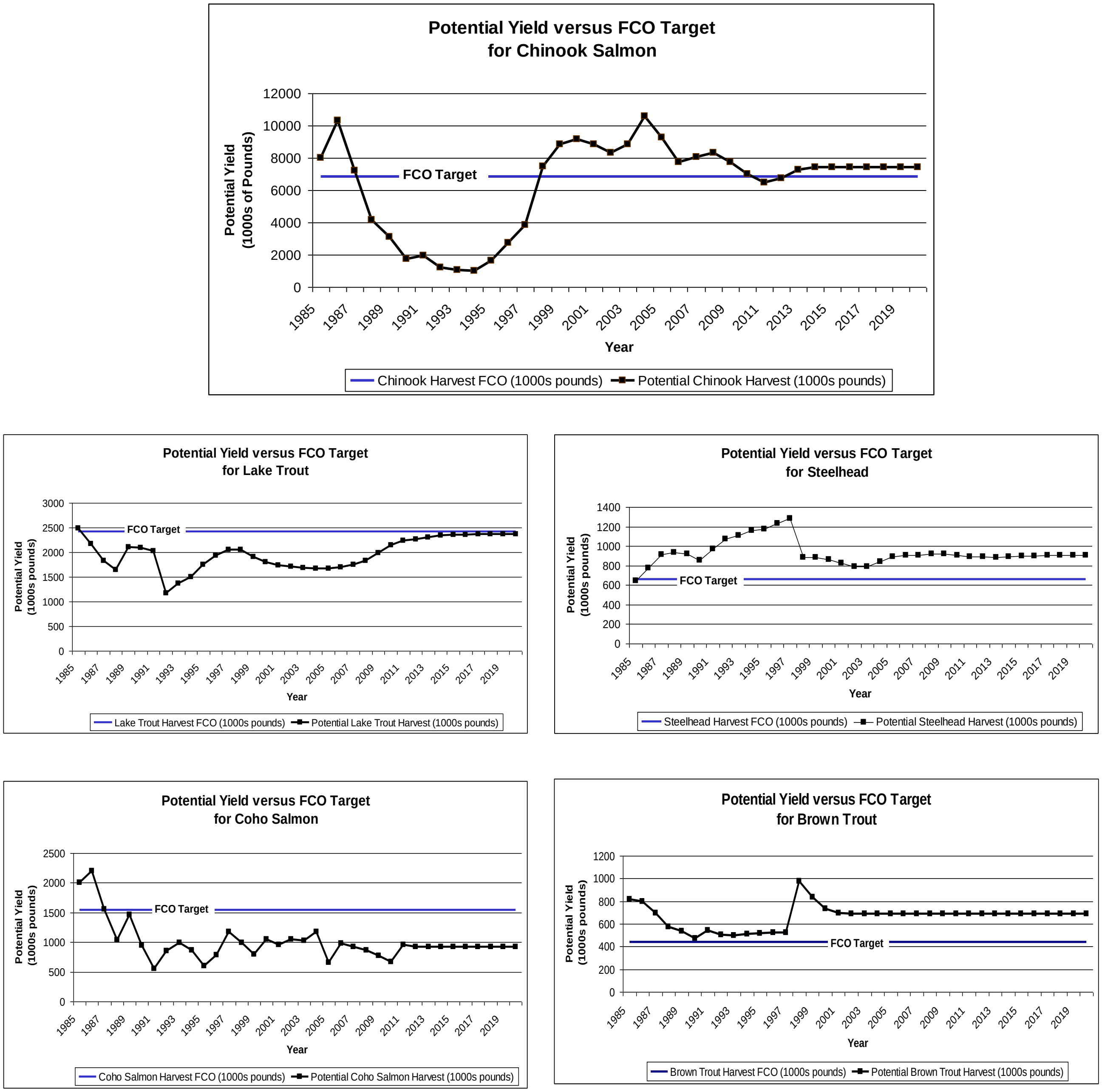


Figure 8. – Potential harvest over time as estimated by the CONNECT model using fishing mortality rates of the mid-1980s. The FCO Target lines are the expected near-term yields from Eshenroder et al. (1995). Projections into the future assume a continuation of current stocking rates.

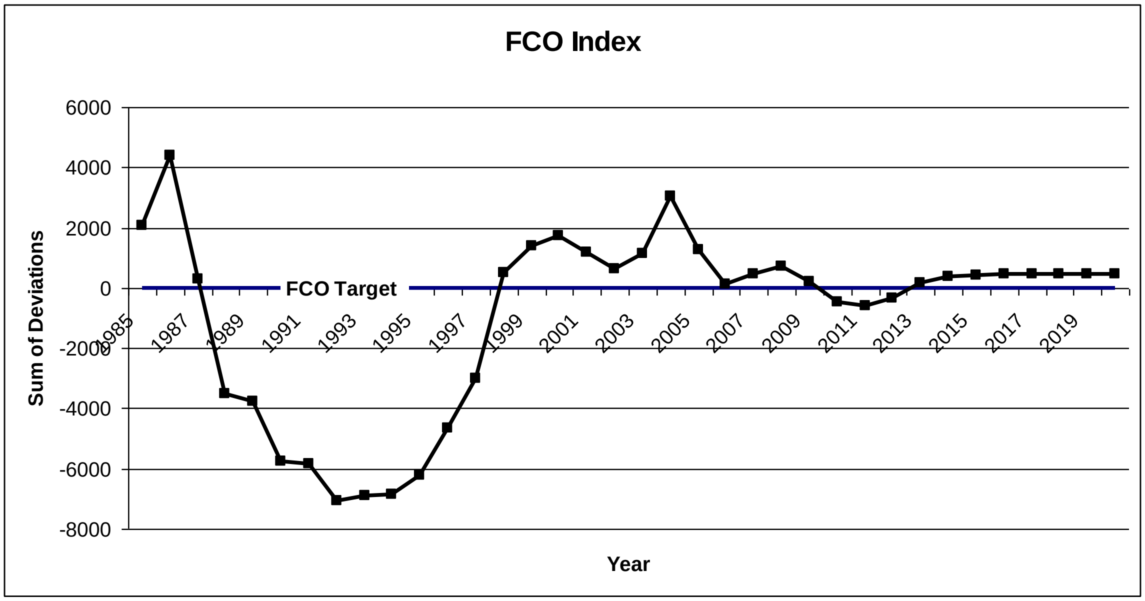


Figure 9 – FCO Index estimated from 1985 through 2010 based on actual stocking rates and from 2012 to 2020 based on a continuation of current stocking rates.

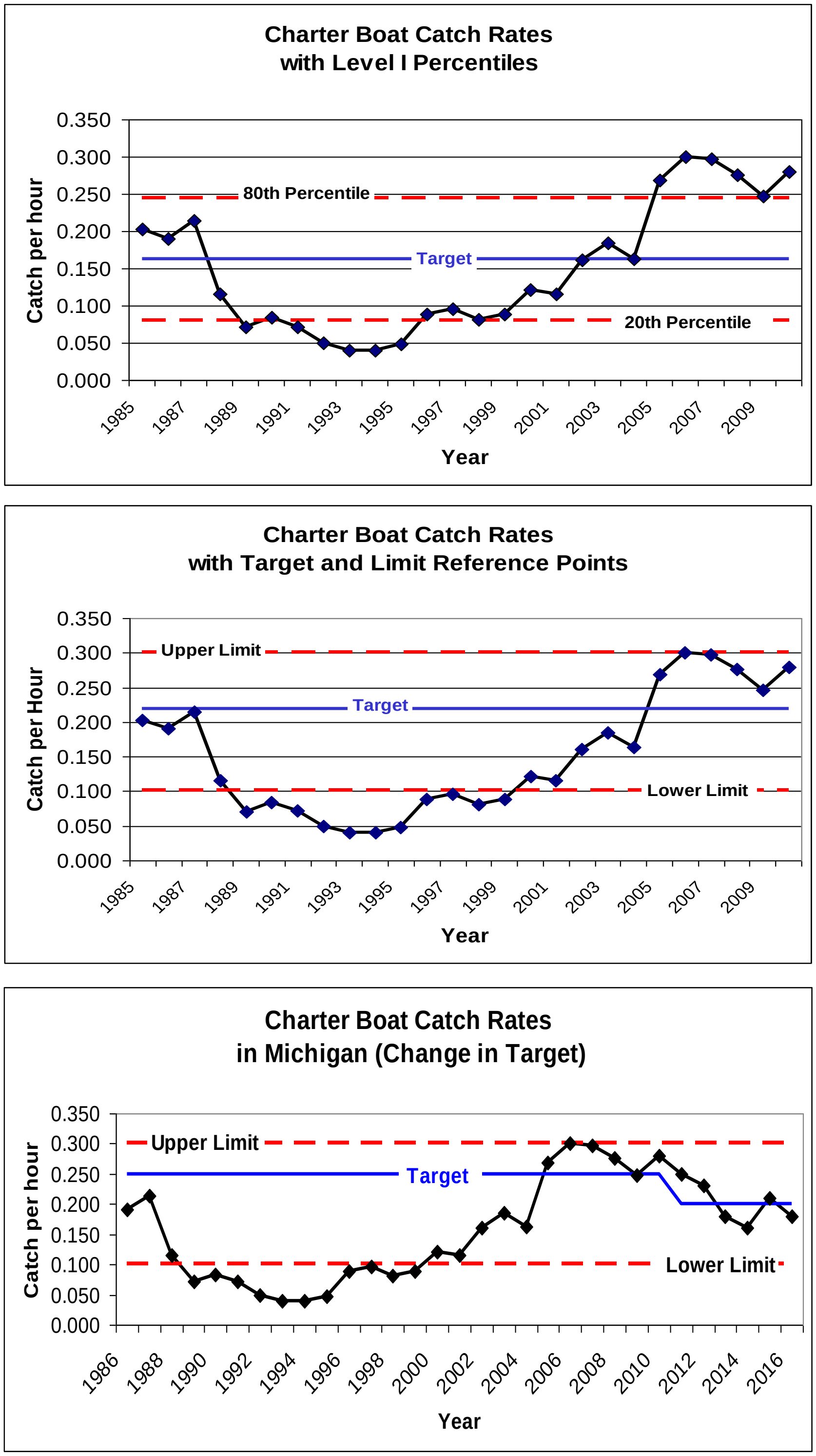


Figure 10. – The top panel shows charter boat catch rates with percentiles as are currently used. The middle panel shows an example of applying explicitly-defined limit and target reference points which are different from the percentiles. The bottom panel shows an example of applying a decision to change the management objective (target) after 2012. Catch per hour values beyond 2010 were created for illustration.

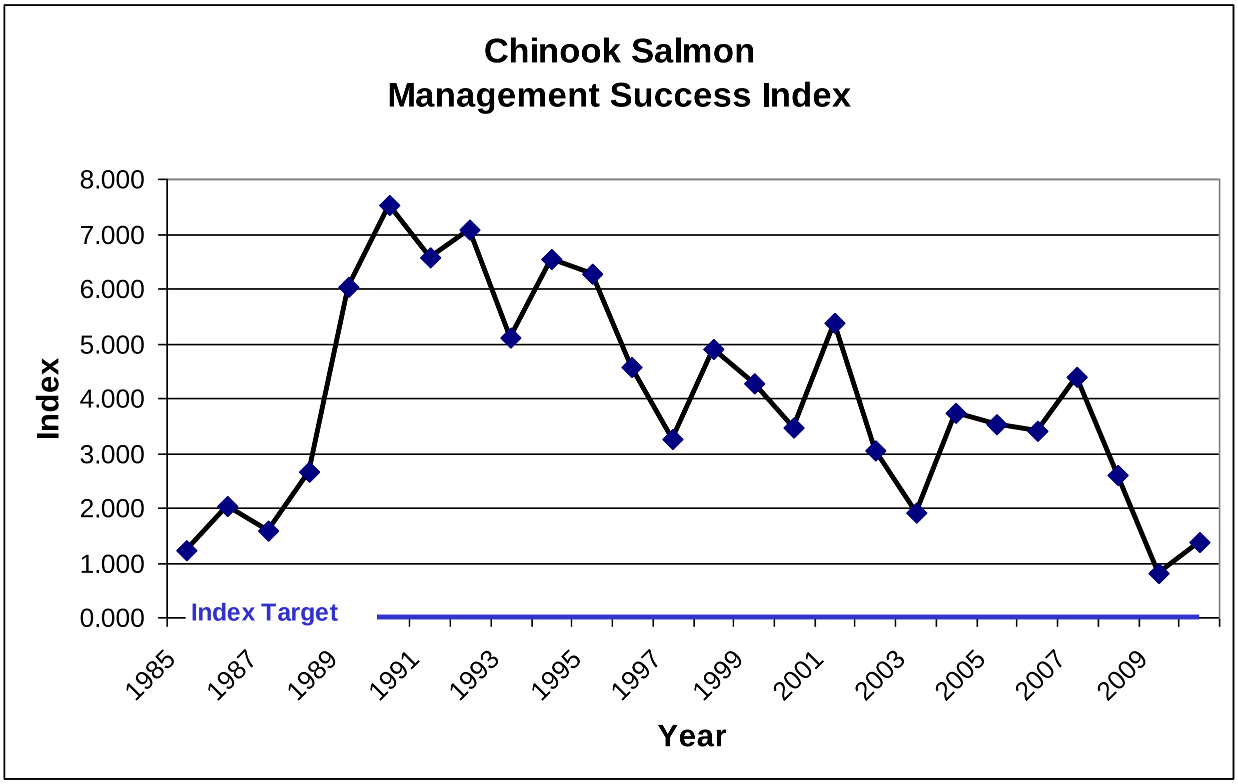


Figure 11. – Chinook Salmon Index calculated from example indicators for abundance, recruitment, condition, and mortality. Perfect management success is represented by the Index Target of zero.