Lake Erie
Walleye Management Plan
2015-2019

Lake Erie Committee
Great Lakes Fishery Commission

October 2015

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Section 1. Introduction

This document is an update and revision of the original Lake Erie Walleye Management Plan (Locke et al. 2005). It presents a brief recent history of Walleye (*Sander vitreus*) management on Lake Erie, the current status of this important species, fishery and fish population objectives, and management tools for the Lake Erie Committee to use to ensure that the objectives are met. Appendix A details previous strategies employed by the Lake Erie Committee and Walleye Task Group to manage Walleye since the 1970s, and Appendix B provides a glossary of abbreviations used throughout this document.

This document includes detailed information on the formation of the Lake Erie Percid Management Advisory Group (LEPMAG) and the new Walleye Harvest Control Rule strategy it helped develop. This revised Plan will guide Lake Erie Walleye management in the near future and will be evaluated after five years to determine if it is meeting the Lake Erie Fish Community Goals and Objectives (FCGO) for Lake Erie (Ryan et al. 2003) as well as the objectives established by LEPMAG.

1.1 Lake Erie Fisheries Management through the Lake Erie Committee

The Lake Erie Committee (LEC) is a bi-national committee of state and provincial fisheries agencies operating under the auspices of the Great Lakes Fishery Commission (GLFC) and guided by the Joint Strategic Plan (JSP) for Management of Great Lakes Fisheries to cooperatively manage fish communities and fisheries in Lake Erie. The LEC agencies include the Michigan Department of Natural Resources (MDNR), the New York State Department of Environmental Conservation (NYSDEC), the Ohio Department of Natural Resources (ODNR), Ontario Ministry of Natural Resources and Forestry (OMNRF), and the Pennsylvania Fish and Boat Commission (PFBC). The LEC has developed Fish Community Goals and Objectives (FCGOs; Ryan et al. 2003) to guide management of the internationally shared fishery resources. To advise the LEC, staff members from each agency participate in six sub-committees, or task groups, that have a particular area of shared interest: the Habitat Task Group (HTG), Forage Task Group (FTG), Walleye Task Group (WTG), Yellow Perch Task Group (YPTG), Coldwater Task Group (CWTG), and Standing Technical Committee (STC).

The Lake Erie fishery is composed of a number of species that are highly sought after by commercial and recreational fisheries, including Walleye. This species is of enormous economic importance to all LEC jurisdictions; therefore, it is imperative that management objectives for this species focus on the sustainability of the population and maximizing social and economic benefits for all jurisdictions through a fair, transparent, and biologically justified process. In order to achieve this, managers require a decision making process that has clear objectives, both for the fish population and the harvests associated with it, and robust systems and processes in place to make informed decisions. These objectives need to be supported by a management regime that will ensure that resource sustainability is maintained, that the Walleye population continues to support fisheries of a high quality, and is in keeping with the LEC's FCGOs for Lake Erie.

1.2 Fish-Community Goals and Objectives Relevant to Walleye

The Fish-Community Goals and Objectives for Lake Erie (Ryan et al. 2003) guide fishery management for all LEC agencies. As a terminal predator, Walleye are a key component of the Lake Erie ecosystem, and management of this species must take this into consideration. The following are the relevant goal and objectives directly pertinent to Walleye, with respect to understanding all the aspects of the fish community.

Relevant Goal

- *Secure a balanced, predominantly cool-water fish community with Walleye as a key predator in the western basin, central basin, and the nearshore waters of the eastern basin, characterized by self-sustaining indigenous and naturalized species that occupy diverse habitats, provide valuable fisheries, and reflect a healthy ecosystem.*

The extent to which this goal is achieved is largely dependent on the environmental health of Lake Erie, including the status of the entire fish community, the quality of the habitat, and abiotic factors, such as nutrient levels and water temperatures. The numbers of Walleye required to achieve this goal are greatly dependent on annual and spatial variations in prey distribution. Moreover, some feedback is expected since the characteristics of the prey fish community will act in concert with habitat variability and abiotic factors, thereby changing the carrying capacity for Walleye. This is additionally complicated if one considers that Walleye share their thermal niche with several other species such as White Bass and Smallmouth Bass, and have seasonal niche overlap to some extent with other species such as Steelhead and Lake Trout, whose abundance is controlled by other factors (e.g., different environmental conditions, food web factors, or stocking). Provided that Walleye abundance does not decline below levels that are sustainable, and a diverse stock structure is maintained, this objective will continue to be achieved.

Relevant Objectives

- *Provide sustainable harvest of Walleye for all areas of the lake*

Provided that the goal of maintaining Walleye as a key predator is upheld, and that sustainable levels of fishing mortality are maintained, Walleye population abundances should be kept above the drastic low population levels and poor fishery performance that prompted additional management actions like the Coordinated Percid Management Strategy (CPMS) in 2001.

- *Genetic diversity – maintain and promote genetic diversity by identifying, rehabilitating, conserving, and/or protecting locally adapted stocks.*

Several research projects have been performed in partnership with the LEC and its member agencies. These projects include documentation and description of discrete stocks (i.e., a unit capable of independent exploitation or management) of Walleye, based on genetic or other biometric attributes, and investigating migratory behaviour. Work still continues on developing a viable mixed-stock model for Walleye in areas outside the Total Allowable Catch (TAC) area (i.e., eastern basin). There is always the potential that smaller stocks, or sub-stocks, within the

Lake Erie Walleye population can be disproportionately overfished. This is particularly the case if fisheries are exploiting stocks during spawning or staging for spawning. Improved understanding of the effects of spring fisheries is necessary to ensure that exploitation does not impinge on population sustainability or fishery objectives.

1.3 Lake Erie Walleye Assessment and Quota Management

For the purposes of Walleye population assessment and management, Lake Erie is divided into five Management Units (MUs); MU 1 includes the western basin of Lake Erie, MUs 2 and 3 cover the central basin of Lake Erie, MU 4 covers the Pennsylvania Ridge area and the areas surrounding Long Point Bay and Presque Isle as the lake transitions between the central and eastern basins, and MU 5 covers the eastern basin (Figure 1.1).

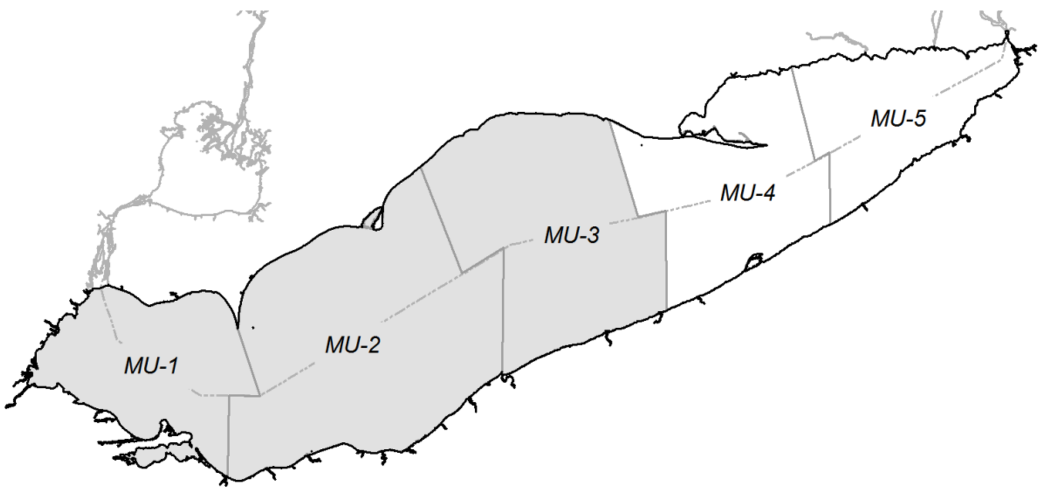

Figure 1.1. Management Units (MUs) for Lake Erie Walleye. Shaded area in MUs 1-3 represents the water area for annual Total Allowable Catch (TAC) determination.

A variety of both fishery-dependent and fishery-independent surveys are conducted annually throughout Lake Erie (Table 1.1). Survey data (i.e., from MUs 1-3) are used in a stock assessment model to estimate population abundance and develop a Recommended Allowable Harvest (RAH). Although the model used assumes that information collected from fisheries and surveys track the same cohorts through time, studies have shown the Walleye resource in the eastern basin during harvest season is a mixture of Walleye sub-populations from both the western and eastern basins (Einhouse and MacDougall 2010). More recently, Zhao et al. (2011) estimated that about 90% of all Walleye harvested in the eastern basin were seasonal migrants from the western basin. These studies suggest that catch-at-age information cannot track the same cohort of Walleye from year-to-year in the eastern basin, and the core assumption of tracking cohorts in a cohort-based model is likely violated. Given regional differences in productivity, recruitment dynamics, stock composition, and socioeconomic considerations, the Walleye RAH on which the TAC is based only encompasses Lake Erie MUs 1-3. This Plan only considers the Walleye TAC in MUs 1-3.

Table 1.1. A listing of Lake Erie Walleye assessment surveys, 1978-2013.

Survey type	Variables	Jurisdiction	Time-series
Commercial gill net monitoring	Harvest, effort, and age structure	Ontario	1978 - 2013
Partnership gill net survey	Catch-per-effort and age structure	Ontario	1989 – 2013
Fall gill net assessment	Catch-per-effort and age structure	Michigan and Ohio	1978 – 2013
Fall gill net assessment	Catch-per-effort and age structure	New York	1981 - 2013
Young-of-year trawling survey	Catch-per-effort	Ontario and Ohio	1988 - 2013
Sport fishing survey	Harvest, effort, and age structure	Ohio	1978 – 2013
Sport fishing survey	Harvest, effort, and age structure	Michigan	1986 – 2013
Sport fishing survey	Harvest, effort, and age structure	New York	1988 - 2013
Sport fishing survey	Harvest, effort, and age structure	Pennsylvania	1996 - 2013

1.4 Lake Erie Walleye Harvest Strategies

Following a 1970 harvest moratorium, due to the discovery of mercury levels exceeding consumption standards, international Walleye quotas were introduced in 1976 for Lake Erie Walleye (Hatch et al. 1987). Over the past 37 years, the Walleye Task Group and the LEC have used a number of different techniques, models and harvest strategies as outlined in Table 1.2. These adjustments over time reflect the current state of knowledge and fisheries management practices for that time period. For example, in the late 1970s, the Walleye Task Group estimated Walleye abundance by sequential projection, using fishery harvest data, estimated mortality rates (assumed natural mortality, M=0.218), and U.S. Fish and Wildlife Service western basin young-of-the-year trawl indices (WTG 1979). The safe harvest level (i.e., TAC) was initially derived from Gulland (1971) based on $½*(B_0)*(M)$, where B_0 and M are biomass and natural mortality at carrying capacity (Hatch et al. 1987). Please refer to Appendix A for a more in-depth description of the history of Walleye harvest strategies on Lake Erie.

By the early 1980's the WTG started adjusting the fishing rates to better align with the fishing harvest and estimates in Walleye abundance. Towards the end of the 1980's, amidst concerns that the current techniques were underestimating year class strength, the WTG began using catch-at-age modeling programs (Table 1.2). By 1990, the WTG had revised the population model and harvest rule, and had replaced the sequential projection method with the new CAGEAN methodology.

Over the next decade (1990-2000), the LEC and WTG used a CAGEAN-based and optimal fishing mortality, F_{opt}, policy to determine annual TAC's (WTG 1990). This assessment and allocation process continued until 1998, when the method of scaling F_{opt} was changed so that individual age groups would not be fished at rates higher than the targeted level (WTG 1998)

By 2000, the downward trends observed in the fishery surveys (i.e., independent and dependent surveys), low levels of recruitment, and environmental changes suggesting continuation of these trends were major concerns for the LEC. There was also additional concern over the retrospective patterns in the population model (i.e., virtual population analysis or CAGEAN) used to estimate Walleye abundance. In an attempt to stop this decline and to restore the state of the Walleye population to a favorable condition, the LEC initiated the Coordinated Percid Management Strategy (CPMS) for three years, from 2001-2003. During this time period, TAC was set at 3.4 million fish and WTG explored moving to state-of-the-art population modeling techniques such as Auto Differentiation Model Builder (ADMB) Statistical Catch-at-Age software (Quinn and Deriso 1999).

In 2005, the first Lake Erie Walleye Management Plan (WMP; Locke et al. 2005) was adopted with the key components establishing sustainability and defining fishery quality objectives that the LEC employed as a basis for Walleye management. The Plan identified limits and uncertainties on Walleye management as well as sustainability thresholds. It also recognized the Fish-Community Goals and Objectives for Lake Erie, which indicate that a sufficient number of Walleye need to be present to act as a keystone predator and also allow stakeholders to realize a broad distribution of benefits throughout the lake (Ryan et al. 2003).

Table 1.2. Models used for estimating Lake Erie Walleye population parameters.

Year	*Walleye Abundance*	*Exploitation Rate*	*Reference*
1976	sequential projection model	½*(B0)*(M)	Gulland 1971 and Hatch et al. 1987
1977-1979	sequential projection model	F=0.10	Gulland 1970
1980	sequential projection model	F=0.20	
1981-1983	sequential projection model	F=0.285	
1984	sequential projection model	target fishing mortality rates were conditional on three categories of Walleye abundance	Hatch et al. 1987
1988-1989	sequential projection model and two catch-at-age models (CAGEAN and RECQUEST)	F=0.285	WTG 1989
1990-1998	CAGEAN	$F_{opt} = 0.326$	WTG 1997
1998-2000	CAGEAN	$F_{age} = F_{opt} * s_{(age)}$	WTG 1998
2001-2003	Coordinated Percid Management Strategy (CPMS)	the annual total allowable catch (TAC) was set at no more than 3.4 million Walleye	LEC 2004
2004	Coordinated Percid Management Strategy (CPMS)	30% below the CPMS level in response to further declines in estimated Walleye biomass.	LEC 2004
2005-2012	Auto Differentiation Model Builder (ADMB) Statistical Catch at Age	Sliding-F policy based on Walleye abundance	Quinn and Deriso 2001 & WMP: Locke et al. 2005.

Section 2. Performance of Lake Erie Walleye, WMP, and the LEC: 2005-2012

2.1 Lake Erie Walleye Population

During the timeframe of the first Walleye Management Plan, the Lake Erie Walleye population enjoyed a solid recovery based on the large 2003 cohort (WTG 2005). This 2003 year class was one of the strongest observed historically. The abundance of age-2 and older Walleye increased to over 40 million fish in 2005. In subsequent years, estimates of abundance for this year of strong recruitment increased (Table 2.1). By 2007, without another strong cohort to buoy the population, Walleye abundance began to slip, and by 2009 the population was again below an estimated 20 million fish (Table 2.1). The influence of a moderate 2007 cohort contributed to a slight recovery in the population (WTG 2008; Table 2.1). By 2012, with the recruitment of another moderate 2010 cohort, the abundance estimates were in the 25-30 million fish range. The lack of strong cohorts, and even infrequent moderate ones, has caused the Walleye population to remain in the range of either the low end of a maintenance fishery or a lower quality fishery status.

2.2 Lake Erie Walleye Fisheries

The fisheries responded positively to the recruitment of the strong 2003 cohort and associated increase in TAC. The Ontario commercial gillnet fishery in the west (MU1) and central basins (MUs 2&3) peaked in 2006 at 3.466 million fish harvested; the Ohio and Michigan sport fishery peaked a year later with 2.327 million fish harvested (WTG 2014). Fisheries declined due to the lack of strong recruitment, an aging 2003 cohort, and lower TACs; since 2009 the Ontario gillnet fishery and Ohio and Michigan sport fishery have each harvested 1.4 million fish or less annually. Commercial effort during this time period peaked in 2005, bottomed out in 2010, and rebounded to recently-observed average levels by 2013. Sport fishing effort peaked in 2007, but reached a low level in 2011, the likes of which have not been observed since 1976. This was primarily due to consistently poor weather and lake conditions, combined with lower Walleye abundance. Angler effort has rebounded since that low, but remains just below the short-term average (WTG 2014). Eastern basin fisheries also flourished during the early part of this time period as local and migratory fish were available to fisheries there.

Table 2.1. Lake Erie Walleye population estimates, RAHs, TACs and TAC area harvest for 2005-2012 by year of reporting. Past abundance estimates changed due to the addition of data annually and to changes in the statistical catch-at-age analysis model configurations.

	Estimates of Ages 2-7+ Walleye from ADMB (millions of fish)									Millions of Fish		
RAH Year	2005	2006	2007	2008	2009	2010	2011	2012		mean RAH	TAC	Harvest
2005	42.427									5.815	5.815	3.646
2006	62.882	46.129								9.886	9.886	5.669
2007	58.584	38.971	29.871							5.360	5.360	4.486
2008	64.796	43.974	37.597	22.652						3.594	3.594	2.778
2009	58.728	38.898	27.259	17.178	18.420					1.558	2.450	2.157
2010	68.316	46.180	31.927	20.599	39.243	30.279				2.429	2.220	1.997
2011	78.571	53.922	37.573	24.757	34.134	26.697	21.243			2.919	2.919	1.691
2012	82.950	57.038	39.982	26.422	33.717	30.525	24.255	26.132		3.487	3.487	2.364

2.3 Lake Erie Walleye Assessment

Standard survey gears were used in Ontario, Ohio, and Michigan to assess the population of ages 2 and older Walleye across the Lake Erie TAC Area (Figure 1.1). Ontario used a lake-wide Partnership fall index gill net survey program at stratified random sites, while Michigan used fall gill nets at index stations, and Ohio used fall gill nets at stratified random sites across the western and central basins. Ohio and Ontario assessed the age-0 hatch each year by combining data from August trawl surveys performed across the western basin. These data were calculated in catch per hectare, and fishery gear performance correction factors were employed to account for the difference in gear and deployment methods according to Tyson et al. 2006. All of these data, and the previously described harvest assessment data were used to inform the ADMB catch-at-age models for population estimates and age-2 recruitment using a standard regression method between age-0 trawl values and age-2 population estimates (WTG 2005). A Blue Ribbon Panel was convened in 2004-2005 to insure that all best management practices were being used to assess the performance of the fisheries and the status of the Lake Erie percid populations (Lester et al. 2005), and the STC directed and assisted the task groups with implementation strategies (STC 2006).

Ontario, New York, and Pennsylvania assess juvenile and adult Walleye in the waters of Lake Erie's eastern basin through fisheries, gill net, and trawl assessment surveys. These data are collected and are being applied to the development of an interim ADMB catch-at-age population model for eastern basin stocks, but these outputs are not used to generate an RAH range for eastern basin Walleye.

2.4 Lake Erie Walleye Population Models

The Walleye statistical catch-at-age (SCAA) population estimates of ages 2-7+ Walleye for the western and central basins combined were generated annually with fishery and assessment survey data using ADMB software (Table 2.1). For the purpose of clarity, the SCAA models described here are those used to generate the RAH for the western and central basin "quota zone" (i.e., MUs 1-3) for the next given year. The actual SCAA model employed uses data from 1978 to the latest (last) year available for fisheries and assessment surveys. Model calculations allowed estimation of abundance, biomass, and fisheries rate functions through the last year that fishery and assessment data is available. Recruitment estimates of incoming age-2 fish to project abundance and projected selectivity and fishing mortality at age for the upcoming year were then incorporated to determine RAH.

As a side note, there is typically some confusion on the year determination for the model "version" based on the last year of data input or when the model was actually run to calculate RAH (as the model is typically run the following winter after all data is assembled). In the year designation for models, the model year was defined as the last year of data in the data set, rather than the year (winter) the model was actually run.

The catch-at-age model employed in 2005 used natural-log transformed catch and effort data to estimate the abundance-at-age of fish. The solution of the catch-at-age equation was obtained using non-linear sum of squares and a penalized, concentrated likelihood objective function. In the catch-at-age model, population estimates are derived by minimizing an objective function weighted by data sources including fishery effort, fishery catch, and survey catch rates; these data weighting factors are designated as lambdas. From 2001 until 2009, the lambdas (survey and fishery weighting factors) of effort data in the model were calculated by the ratio of the variance of observed log-catch to log-effort. Weightings of fishery catch and survey catch rates were solved iteratively until convergence occurred. While lambdas within similar parameter groups (i.e., effort, catch, and survey) were solved and weighted accordingly, the groups themselves were given equal weight (i.e., there was at least one effort, catch, and survey lambda that received the maximum value of 1.0).

Other modifications to the model were made in 2007. Specifically, the Ohio and Michigan sport effort and harvest-at-age datasets were separated. Historically, harvest-at-age and effort datasets for Ohio and Michigan sport fisheries were combined given the similarity of the survey type. After closer inspection, these data sources were separated because there were significant differences in the duration of sport angler surveys, differences in coefficients of variation around sport harvest and effort estimates, and differences in creel survey methodology, administration, and biological sampling efforts. Additionally, in 2007, a new selectivity time block was added for the sport fisheries to account for the implementation of a 15-inch minimum size limit that took effect three years prior.

This same model was used again in 2008 with updated data sets, but a decrease in cohort abundance from estimates the year prior in subsequent model runs was noticed to persist (WTG 2008). This “creeping down” result is due to a high estimate being generated for a cohort as it enters the fishery, then as more data becomes available for the cohort through time, the estimate ranges decline. This can be quite problematic when harvest decisions are made based on overinflated estimates that track lower when re-estimated over time. In 2009, and continuing through 2012, difficulties with estimates of early-entry cohorts and creeping down led to the use of regression estimates to determine cohort abundance for age 2s and age 3s instead of the first ADMB estimate.

In time for the 2010 RAH determination and WTG Report, a technical working group comprised of members from the WTG and the Quantitative Fisheries Center (QFC) at Michigan State University, implemented a method for determining lambdas based on an expert opinion approach for evaluating potential sources of bias in data sets that could negatively influence model performance. WTG members supplied background materials for each data source to the working group to facilitate completion of lambda spreadsheet templates. Expert opinions were expressed in a spreadsheet template by evaluating possible sources of bias pertaining to all nine data sources used in the west-central SCAA model. The perceived magnitude of bias in each data set was ranked according to factors associated with spatial, temporal, sampling, modeling assumptions, and fishing methodology. These qualitative selections linked to numeric values were then weighted by the relative importance assigned to each factor, resulting in SCAA model lambda configurations determined by eleven individual WTG members. These values were averaged to determine the final lambdas for use in the 2009 model.

Catchability was estimated in the 2005-2012 SCAA models using time blocks, which set catchability over a specified period of years. Time blocks were set for each gear, based on changes noted in fishery equipment and performance, abiotic variables, and fishery regulations. Time blocks were evaluated by assessing residuals in the model outputs. The alternative, allowing constrained catchability to vary from year to year using a random walk, was also explored by the QFC and WTG modelers. The desire to address potential model changes in estimating selectivity, catchability, the age-2 and age-3 cohort abundance, and other model parameter estimates were incorporated into the 2013 models and the next revision of the WMP and the LEPMAG process, as described in Section 3, below.

2.5 The 2009 Review of the Walleye Management Plan

As recommended by the LEC, a draft review of the WMP was implemented in 2009 by the Lake Erie Standing Technical Committee (STC) with help from the Walleye Task Group (WTG). The review contained background information on the 2005 WMP, a review of Walleye stocks over the 5-year review period (2005-2009), and an evaluation of the performance of the WMP. Conclusions from the review were that the WMP performance varied. While some fishery catch rate objectives were achieved (commercial catch rates), others, like angler catch rates, were not. Other issues, such as instability in harvest and TAC due in part to recruitment patterns, caused concern for fisheries managers and stakeholders. While a final report and formal adoption of the review recommendations were never completed, there were action items that were considered by the LEC and WTG. Management strategies under consideration included the incorporation of auxiliary information into the harvest strategy, the development of a Decision Table for TACs, the consideration of alternate exploitation policies, the use of population thresholds of Walleye ages three and older for establishing fishery objectives, and consideration of alternate processes to hear and address stakeholder concerns and opportunities for participation.

Section 3. Stakeholder Involvement

The task groups are responsible for implementing assessment activities, population modeling, and providing a biologically supported range of safe harvest levels to the LEC. Other factors, including social and economic concerns, are inherently a part of the decision-making process for managing the Lake Erie Walleye resource. To provide an opportunity for stakeholders to provide input on social and economic concerns, the Lake Erie Committee has historically solicited formal stakeholder commentary during the Lake Erie Committee meetings. Although useful, the above process used for soliciting stakeholder input was not very effective because information provided by stakeholders was not formally incorporated into the decision-making process. The LEC recognized that the lack of structured input into Walleye management decisions from stakeholders was a deficiency and began to consider other mechanisms to include stakeholder input into the Walleye and Yellow Perch management process. The LEC also wanted to improve transparency and develop a structured and science-based approach to setting annual TAC levels for Walleye and Yellow Perch.

In an initial attempt to incorporate social and economic considerations into the process, the LEC formed a Human Dimensions Task Group (HDTG). The charges assigned to the HDTG were: (1) develop a set of fishery indicator metrics; (2) assess the socioeconomic aspects of recreational and commercial fisheries on Lake Erie; (3) simulate fishery responses to potential fish population and management actions; and (4) report on the indicator metrics, socioeconomic and business status of Lake Erie fisheries to the LEC and the public (STC 2009). No members were assigned to this task group at that time.

By the 2010-2011 LEC reporting cycle, the HDTG was populated by agency representatives from Ohio, Ontario, and Pennsylvania. Additional members included economic experts from the University of Guelph, Brock University, the Ohio State University, and Michigan State University. One meeting of the HDTG was held in January 2011 in consultation with the LEC. During this meeting, it was recognized that participation of the academic contingent could not continue without some monetary project support. This relegated the HDTG to an indeterminate status during the 2011-2012 cycle. Due to funding and resource issues, and a change in direction by LEC to explore a more efficient method of capturing and incorporating stakeholder and socioeconomic information into its management process, the HDTG was dissolved by the end of the 2012-2013 LEC cycle.

Concurrent with the communications with the HDTG, the LEC began consultation with Dr. Michael Jones at Michigan State University's Quantitative Fisheries Center (QFC), who had experience in working with stakeholder groups as related to Structured Decision Making (SDM) in fisheries management. In light of these discussions, the LEC requested that the QFC, in conjunction with the GLFC, facilitate a stakeholder's workshop to discuss a new approach to stakeholder input into Lake Erie Walleye management.

3.1 The Lake Erie Percid Management Advisory Group Structure and Process

The first stakeholder's workshop was held in November 2010. The facilitators opened the meeting by defining issues in a "management process" and introduced the structured decision making process components, including Decision Analysis (DA) and a Management Strategy Evaluation (MSE). The primary purpose of this meeting was to: (1) identify and refine common management objectives; (2) discuss the management options for attaining these objectives; and (3) identify critical uncertainties in management of percid stocks. At the conclusion of this meeting, stakeholders expressed a strong desire to be apprised of the technical aspects of the assessment models and requested the opportunity to review and comment on any management decisions before final adoption by the LEC. This initial workshop was the precursor to the Lake Erie Percid Management Advisory Group (LEPMAG).

Following the March 2011 LEC meetings, a second stakeholder workshop was scheduled for July 2011. It was during this workshop that LEPMAG was formalized. The group began by drafting a Vision Statement and a Terms of Reference document describing the background, purpose, guiding principles, and objectives of LEPMAG. The Terms of Reference also defined structure, membership and the roles and responsibilities of the participants. The LEPMAG's July 2011 Vision Statement reads: *Lake Erie percid fisheries will be transparently managed using sound science and partnerships to achieve stable and sustainable harvests from shared stocks providing broad and equitable benefits for all jurisdictions*. The following is a summary of the parties involved in the LEPMAG and their roles and responsibilities in the process:

Facilitators

The Lake Erie Percid Management Advisory Group is facilitated by the QFC and a senior Research Biologist from the GLFC. Dr. Michael Jones has directed the facilitation process with a team composed of modelers and decision process experts to guide the LEPMAG through the MSE process. In addition to developing the framework for the LEPMAG, the facilitators were responsible for implementing suggested revisions to the assessment models and for the development of the MSE models that evaluated Harvest Control Rules (HCRs). The facilitators also provided an analysis of various harvest control rules applying a range of fishing mortality rates within a range of limit reference points. Each of these scenarios was accompanied with a range of trade-off analyses.

Lake Erie Committee and Standing Technical Committee

Members of the LEC (one representative of each Lake Erie state or provincial agency) and their designated agency representative to the LEC's Standing Technical Committee participated in the LEPMAG process. A representative from the GLFC was at each meeting to record notes, oversee the process to meet the stated goals and objectives, and assist in logistics and discussions.

Stakeholders

Stakeholders were appointed to LEPMAG by the LEC agency representative from their respective jurisdiction. Each agency developed a list of stakeholders that would best represent the fishing interests of their respective jurisdictions. Stakeholders represented both commercial and recreational fishing interests. Most stakeholders were affiliated with organized groups with diverse philosophies on the management of Lake Erie's percid resources. Representatives included commercial gill net and trap net fishermen, fish processing operations, charter boat operators, and organized recreational fishing associations. The LEPMAG members from some jurisdictions were GLFC advisors or state Sea Grant personnel. The role of stakeholders in the LEPMAG process is to provide recommendations or options on harvest policies; provide input on fishery performance metrics that helped inform the MSE; consider and comment on the social and economic impacts of a TAC or the TAC-setting process; inform others in their constituency of LEPMAG progress; and recognize/respect LEC members' statutory responsibility to regulate percid harvest.

Technical Review Panel

After several LEPMAG workshops and the identification of the critical uncertainties, it was realized that several issues would be best addressed by an independent scientific group of experts referred to as the Technical Review Panel (TRP), so as to be as objective as possible while maintaining an open dialog on the uncertainties in the assessment model and supporting datasets. This also ensured that the latest (most current and peer-reviewed) population modeling and management techniques would be applied in managing Lake Erie percids. As part of the Walleye MSE, the panel of technical experts was convened by the LEC and by LEPMAG members to populate a TRP. The TRP reviewed unresolved issues associated with the model simulations and provided their recommendations to the QFC. After review and consideration, adoption of TRP recommendations to the LEC was at the discretion of LEPMAG.

Walleye Task Group

Members of WTG were included as resource participants for the LEPMAG process. The QFC and LEC needed the institutional knowledge and technical expertise of the WTG for guidance, advice and evaluation of the proposed changes. Additionally, the task group would be responsible for providing data and implementing any changes resulting from the LEPMAG process and task group members needed a clear understanding of proposed changes.

LEC Decision Making

The LEPMAG was proposed and conceived by unanimous agreement among LEC members to establish a process for increased stakeholder engagement in percid management planning. As per the Terms of Reference for the LEPMAG, the LEC committed to explicit consideration of all recommendations from the LEPMAG, to be transparent and accountable for TAC decisions, and to consult with the LEPMAG in an evaluation of outcomes. To this end, the LEC holds the final authority regarding decisions after considering the LEPMAG recommendations.

3.2 Fishery Objectives

After the framework for LEPMAG was finalized, the group began to more closely examine the specifics of Lake Erie Walleye management. The goals and objectives were defined early in the process, and it was recognized that examining fishery trade-offs would be useful to help members achieve consensus about the most appropriate harvest strategy for Walleye. LEPMAG objectives for the Walleye fishery included: sustainability and stabilization of the fishery, economic viability of commercial industry, reversal of the recent downward trend in abundance, explicit and balanced handling of risk and uncertainty, defined performance measures, a broad distribution of population benefits lake-wide, and a more transparent management process. Through the series of LEPMAG meetings, discussions were held with stakeholders regarding these fishery objectives. In order to achieve these objectives, LEPMAG committed to two specific tasks, which included assistance and input on population model revisions and refinements (both assessment and prospective models), and assistance and input on development of fishery performance metrics for evaluating and selecting the most appropriate harvest strategy for Walleye through the Management Strategy Evaluation (MSE).

3.3 Population Model Revisions and Refinement

As the MSE process progressed, there were several considerations and associated trade-offs reviewed by the LEPMAG towards the development of the next Walleye population SCAA model in this new WMP for Lake Erie.

Stakeholders were provided a range of alternatives to consider in moving forward on a new management strategy for Lake Erie Walleye. Options specific to the SCAA model that would be initially addressed included changes to catchability (random walk vs. fixed time blocked), selectivity (estimated for all data sources within the model across all ages vs. fixed), treatment of catch-at-age data model-fitting (multinomial distribution vs. lognormal distribution), and using an integrated modeling approach to estimate incoming age-2 recruits (vs. estimating recruitment outside the model via the age-0 trawl regression method). Other model developments may be more complex (requiring additional/pending research) and are to be addressed within the next WMP cycle (see Section 4.5).

3.4 Management Strategy Evaluation

One of the initial topics explained to the LEPMAG was the application of a Management Strategy Evaluation, or MSE. This concept is one of several structured decision making tools used to guide management decisions. The process of conducting a MSE entailed construction of a model of the entire management and assessment process, to account for the uncertainties in information gathering and implementation as well as "system uncertainties," culminating in an evaluation of the performance of alternate management procedures. This was the basis for the LEPMAG process.

The LEPMAG was next exposed to a structured decision making process called *FishSmart* (Ihde et al. 2011), which was used for consensus building in facilitated workshops. Dr. Michael Wilberg from the University of Maryland, Center for Environmental Science, attended a LEPMAG meeting and provided background information on the collaborative process used to manage the King Mackerel fishery on the southeast United States coast. *FishSmart* incorporated a decision analysis framework in which stakeholders could compare the consequences of alternative management options with trends in the King Mackerel population and the fisheries. Specifically, the *FishSmart* process brought together commercial and recreational user groups of this fishery to develop consensus building techniques that ultimately resulted in agreement for a recommendation of more conservative regulations.

The LEPMAG Walleye MSE was primarily a two-part process: (1) a review of the population model and associated fishery and assessment data and (2) development of a Harvest Control Rule (HCR). Evaluation of the Walleye assessment model resulted in an updated model that included: (1) estimating selectivity for all data sets across all ages within the model without the assumptions of known selectivity at age; (2) integrating age-0 trawl survey data into the ADMB model; (3) using a multinomial distribution for the age composition data; and (4) allowing catchability to vary from year to year with constraints, using a random walk for fishery and survey data including the age-0 trawl survey.

LEPMAG developed a series of fishery performance metrics, informed by historical performance and socioeconomic factors and needs of the individual fisheries sectors. The process ultimately resulted in the definition of acceptable fishery performance criteria across fisheries. For the Management Strategy Evaluation, a recreational catch rate of 0.4 fish per angler-hour (f/hr) and an annual commercial yield of 4 million pounds of Walleye were defined as suitable benchmarks for evaluating fishery performance, below which there was perceived to be increased economic risk. The Management Strategy Evaluation process' benchmark reference points, fishery thresholds, simulation model results, the Harvest Control Rule chosen, and future LEC implementation to determine annual RAHs and TACs are all discussed in Section 4.

The adoption of an updated assessment model and the MSE harvest control rule was discussed at the September 2013 LEPMAG meeting and was accepted by a majority of those stakeholders that were in attendance. In consideration of LEPMAG recommendations, the LEC formally adopted a new HCR, which was first applied during the 2014 TAC-setting process for Lake Erie Walleye.

Section 4. Reference Points and Exploitation Policies

In managing a fishery as dynamic as that observed for Lake Erie Walleye, there are many components that must be evaluated simultaneously. Fisheries must be assessed throughout the fishing year: reporting catch, effort, size distribution at harvest, and age-specific harvest information. Independent surveys of recruitment, age, growth, and mortality must be completed. Individual jurisdictional agencies manage their fisheries, fishing effort, and harvest by regulations to ensure that quota is not exceeded and fish populations are not overexploited.

4.1 Target and Limit Reference Points

Scientific fisheries literature covers a wide spectrum of techniques employed to set and adjust fishing mortality schedules based on population abundance and biomass trends. While nearly all of these reference points deal with ocean or coastal fish species, their techniques in simulations and modeling are appropriate for Lake Erie fish populations and fisheries. An overarching principle in the international management of harvested fish species is the Precautionary Approach (FAO 1995). This management doctrine describes a process for sustainably managing fisheries by defining a feedback harvest control rule that adjusts fishing mortality in a defined fashion as populations fall below a predetermined level. FAO (1995) guidelines for this approach advocate a detailed management process that includes data collection, research, enforcement, and policy review. While the GLFC and LEC do not make specific reference to the Precautionary Approach in their management of percid fisheries, the concepts, process and outcomes are consistent with recent and current LEC quota management actions.

Fisheries managers define levels of fishery harvest, or exploitation, and rate functions of fishing mortality, as *targets* of some maximum or optimum level derived by calculations or estimates of theoretical biological and fishery parameters. These fisheries targets are set to allow an appropriate level of harvest (fishing mortality across specific ages of fish) that will satisfy the diverse group of fishers and maintain enough standing stock for producing satisfactory fishable populations, the potential for adequate recruitment into the future, and rapid recovery should stocks become depleted (Babcock et al. 2007).

One of the most recognized fishery harvest strategies in use or discussed is Maximum Sustainable Yield or MSY. Developed in the mid-1900s (Thompson and Bell 1934, Graham 1935, Schaefer 1954), MSY is a maximum fishing mortality rate developed with available biological, growth, and fishery parameters. MSY as a fisheries policy has undergone periods of favor and disdain (Hilborn 2002, Mace and Sissenwine 2002). Problematic in its application, the target fishing rate associated with MSY, or F_{MSY}, can lead to overexploitation if factors such as uncertainty (error), risk, model change, and ecosystem change are not taken into account. Also, many of these estimated parameters have wide error bounds in the precision of their latest estimates, which can lead to inherent dangers in setting (or exceeding) target fishing rates (Beddington and May 1977, Larkin 1977, Sissenwine 1978).

Researchers and managers have called for F_{MSY} to be identified as a fishing mortality rate upper limit in the process of setting appropriate management strategies and harvest control rules (Thompson 1950, Chapman et al. 1962, Sissenwine 1978, Mace and Sissenwine 1989, Angel et al. 1994, Mace 1994, Myers et al. 1994, Larkin 1997, ICCAT 2000, Hayes 2000, Mace and Sissenwine 2002, Caddy 2004, and Babcock et al. 2007). Researchers have suggested that reducing fishing mortality below F_{MSY} would be best for sustainable ecosystems (Mace and Sissenwine 2002, Shelton and Sinclair 2008). Other harvest policies, formulated in response as alternatives to MSY, define F as a proportion or percentage based on standing or unfished abundance or biomass or biological parameters such as spawner-per-recruit dynamics of the stock (Clark 1991, Mace and Sissenwine 1993, Mace 1994, Overholtz 1999, Clark and Hare 2004).

Also, a cornerstone in the process for managing fisheries and exploited fish populations is the concept of adjusting fishing rates as populations fall below a recognized threshold value. Conversely, managers can define population goals or benchmarks for healthy populations or restored populations (Shelton and Sinclair 2008). These *biological reference points* (BRPs) are in common use in fisheries management (Sissenwine 1978, Mace and Sissenwine 1989, Angel et al. 1994, Mace 1994, Myers et al. 1994, Larkin 1997, ICCAT 2000, Hayes 2000, Mace and Sissenwine 2002, Caddy 2002, 2004, Babcock et al. 2007, Shelton and Sinclair 2008). These thresholds can be targets or limits (Mace 1994), and define when changes in fisheries harvest policy may be warranted. Key components of these reference points are estimates of past, current, or future (simulated) abundance, biomass and hypothetical unfished or "virgin" abundance, biomass, or spawning stock biomass (referred to as N_0, B_0, and SSB_0, respectively). These estimates are generated by statistical population models including future simulations based on best available relationships of the stock-recruitment and density dependency relationships. Population models and parameters, abundance and biomass, when defined as benchmark limits or thresholds, need to incorporate measures of uncertainty and risk (Walters and Punt 1994, ICCAT 2000, DeRoos and Persson 2002, Mace and Sissenwine 2002, Gibson and Myers 2004, Zhang and Megrey 2006, Jiao et al. 2009, and Ying et al. 2011).

The LEC and the WTG use fishery-dependent surveys, fishery-independent surveys, and population model information, and address stakeholder input, to determine an annual Walleye TAC. Setting fishing policy, determining optimal fishing effort, and projecting fishing mortality are outcomes based on an assessment of current conditions, applying the latest modeling techniques, and employing the applicable fishing policy as specified in this WMP. Derivations of decision criteria for appropriate harvest control rules are based on historic and emerging fisheries management theory; there is no "one-size-fits-all" recognized fisheries management policy or static procedure for estimating population status and calculating optimum yield. The LEC and WTG employ the latest robust scientific methods to identify critical and satisfactory population levels and acceptable fishing mortality rates in order to maintain the potential sustainability of Lake Erie Walleye populations and fisheries under a variety of biotic and abiotic conditions and uncertainties.

Managers and biologists on the LEC and WTG recognize that low population abundance levels and spatial structuring may lead to circumstances where recruitment may be affected and regional Walleye fisheries cannot be sustained; thus, management actions which further constrain fisheries may be necessary to protect spawning stock biomass. These population thresholds represent *limit reference points* that determine when a change in fishing policy is warranted and implemented. The combination of defining *fishing mortality targets* and population thresholds or *limit reference points* for Lake Erie Walleye is the basis of our management exercise in this version of the Walleye Management Plan (Figure 4.1).

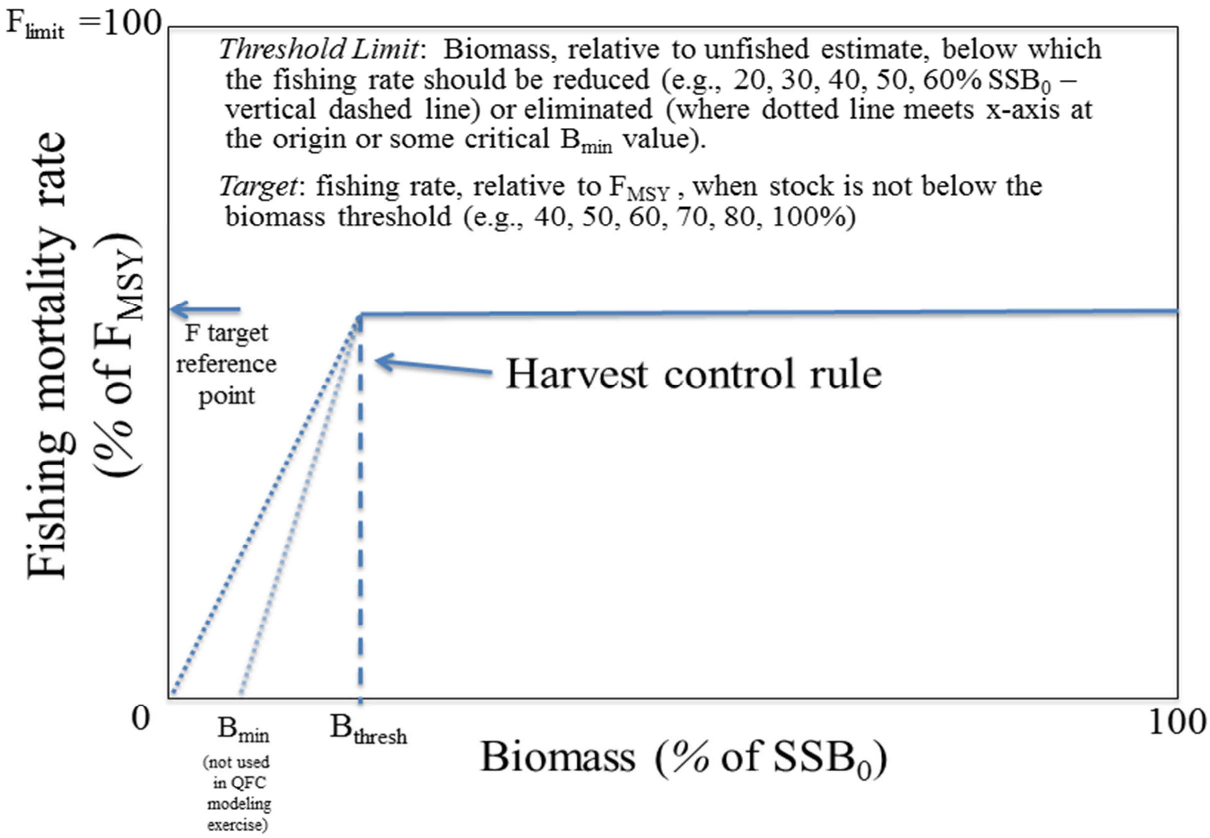

Figure 4.1. An example illustration of a harvest control rule with biological reference points and fishery targets and limits as employed in the LEPMAG MSE process.

Early implementation of Lake Erie Walleye harvest control rules involved setting a fishing rate F policy and calculating RAH by altering fishing mortality based on estimates of the Walleye population, biological parameters such as unfished virgin biomass (B_0), von Bertalanffy growth parameters, and calculations of F_{opt}. During the years of CPMS, the LEC set harvest levels at fixed values (3.4 and 2.4 million fish) during a period of low recruitment, model uncertainty, following higher levels of fishing mortality.

The first iteration of the Lake Erie WMP set appropriate harvest strategies after completion of a QFC-WTG Decision Analysis exercise that incorporated various model recruitment and harvest scenarios. The harvest management policy adopted by the LEC in the first WMP (Locke et al. 2005) was a sliding F-scale that has a feedback, or state-dependent approach, and varied targeted fishing mortality rate based on population abundance (see Figure 1.2).

While these previous methods incorporated fishery *target F levels* and *biological limit reference points* in the decision-making process, a few stakeholders were dissatisfied with the strategy adopted and stated that more efforts needed to be devoted to examining limit reference points, target levels, stock-recruit and virtual population models, and the uncertainties around their estimates.

In the analysis guided by the LEPMAG process, the QFC presented a range of MSY fishing mortality rates as their fisheries target and limit scenarios, as these could be modeled with ADMB SCAA software simulation programs and the WTG data. They developed biological and fishery reference points to measure population benchmarks and thresholds that when crossed would represent diminished fishery performance and undesirable outcomes.

QFC model runs were comprised of current WTG ADMB model components of fishery and survey catch, effort, age distributions, numbers of aged fish, natural mortality (M), lambda weighting factors, and weight- and maturity-at-age. The model incorporated random walk catchability, model-estimated selectivity for all ages and gears, multinomial distributions for model fitting of age data, and an integrated age-0 regression method for estimating incoming recruitment. Also in a separate stock-recruitment ADMB model, estimates of recruitment, spawner biomass, weight- and maturity-at-age, selectivity and M were used to generate SSB_0, MSY, and F_{MSY} parameter estimates and associated error bounds. The first ADMB model would inform parameters in the second ADMB model, which would then inform parameters that would go back into a modified version of the first ADMB model for (future) Walleye population simulation projections. QFC modelers could vary harvest control rules at this point by defining different fishery targets and biological limit reference points and summarize outcomes and performance metrics generated from the simulations. From these 250 simulations, the QFC modelers generated box plots that showed population or fishery performance over a suite of fishing (F_{target} ranging from 40% to 100% of F_{MSY} by 20% increments) and/or parameter conditions in short-term (3-year) and longer-term (25-year) projections. For detailed descriptions of model components and simulations, see Jones et al. (2014, *in review*).

4.1.1 Target Fishing Mortality; F as a percentage of F_{MSY}

The QFC presented a number of different scenarios for assessing a target fishing mortality in the harvest control rule model process for adaptation in the latest WMP. They incorporated a series of ADMB model runs that determined a measure of stock-recruitment and reference spawning stock biomass. They also determined Maximum Sustainable Yield (MSY) - not as a fishery target, but as a limit not to be exceeded (as in Mace and Sissenwine 2002) - the fishing mortality at MSY, F_{MSY}, and the uncertainty around that estimate. From that step, fishing mortality was capped at some proportional level of F_{MSY}; $F_{\%MSY}$ values of F_{max} tested were 40, 50, 60, 70, 80 and (at a later date) 100 percent of F_{MSY}. Then the model simulations were run, and observations and outcomes to population and fishery metrics were reported under various target F values. Similar to previous WTG models methods, the target F value for full vulnerability and selectivity was equal to the chosen $F_{(\%MSY)}$ and other F_{age} values were scaled by the selectivity at that age (i.e., $F_{age}=F_{\%MSY}*sel_{age}$).

4.1.2 Limit Reference Points; $\%SSB_0$

The QFC examined several limit reference points to explore where a threshold would be set that, when crossed as populations decline, determined a change in fishing mortality within the harvest control rule similar to the sliding-F rule previously employed. These reference points were based on the ADMB population model runs, population maturity information, and stock-recruitment estimation. From these data, an ADMB model was built and run to estimate the virgin (unfished) spawning stock biomass SSB_0 , and uncertainty estimates around that value. The QFC considered a range of options beginning with a benchmark reference point of 20% of the virgin spawning stock biomass, or 20%SSB_0. This reference point was recognized as a point at which other fisheries were further controlled by reducing F (Mace and Sissenwine 1989, Mace 1994, New Zealand Ministry of Fisheries 2007). The reference point was then varied at 20, 30, and 40 percent of SSB_0 , while fishing mortality was varied under a range of proportions of F_{MSY} as specified above, and performance outcomes of Walleye populations and fishery performance metrics were tracked. While there are references that refer to fishery closure at levels below 10% of SSB_0 (Mace and Sissenwine 2002, New Zealand Ministry of Fisheries 2007), this metric was not evaluated or reported on by the QFC to LEPMAG. The data and results are still available should more documentation on this metric be warranted.

4.1.3 P- A Measure of Risk*

Based upon recommendations from LEPMAG, the QFC presented a probabilistic control rule to the harvest policy scenarios to determine the risk of falling below the SSB_0 limit reference point in the year following TAC implementation at the harvest policy fishing rate. Prager et al. (2003) describes this probability-based approach as a method to incorporate a measure of uncertainty in the derivation of *target* reference points compared to corresponding *limit* reference points, based on fishing mortality and/or biomass. This probabilistic risk value, known as P*, is defined *a priori*, in advance of the model runs, as an input value, and P* represents our risk tolerance for management decisions that would result in the probability of the estimated SSB being less than our determined limit value; for example, the probability of SSB slipping below the estimated *x*% of SSB_0. Higher values of P* represent more risk-prone decisions, while lower values of P* represent more risk-averse decisions. The probabilistic control rule exercise, applied to the Lake Erie Walleye model, assumes full fishing of the TAC in the upcoming year (*t+1)* and estimates via regression age-2 recruitment in year *t+2* of the model. SSB, SSB_0 , and F_{MSY} were determined and varied in the stock-recruitment model step as described above. Ranges of P* examined in the models were P*= 0.05, 0.15, 0.25, 0.30 and 0.50; with potential risk increasing with increasing P* values. Model runs were completed under the range of P* values presented, and model runs were also completed without employing the probabilistic control rule P*, to determine its relative effect on the overall HCR/TAC management decision process.

4.1.4 Annual TAC Change Constraints

During the initial evaluation of the 2005 Walleye Management Plan performance, and the LEPMAG process, stakeholders and managers identified that they wanted to pursue a harvest strategy that incorporated some stability in Walleye TAC from one year to the next. Stakeholders expressed this interest as a way to assure market supply of their product and protect their market share from outside interests, as well as reduce uncertainty around inter-annual changes in recreational fisheries bag limits. This stability would benefit not only commercial fishing operations, but charter boat operations that sell fishing trips in future seasons. The population models were run as above with varying $F_{\%MSY}$, %SSB_0 and P* specifications, then

TAC changes projected for the upcoming fishing year were constrained to vary by no more than 10%, 20%, or not constrained at all (as is the current process). Again, simulation model runs and HCR/TAC outcomes were summarized as to the effect of implementing variations of this constraint. In the MSE modelling process, the QFC addressed a LEPMAG comment regarding the inequity and lag caused by a 20% TAC reduction followed by 20% increase in TAC, which results in landing at a TAC that was not the same as the original value. The QFC slightly modified the percentage change to account for this event. In actual application, this concept has yet to be addressed.

4.2 MSE Results and the Harvest Control Rule

The QFC presented model results and performance outcomes to the LEPMAG, the STC, and the WTG (see Jones et al. 2014, *in review,* for further details). Model runs were completed for 250 simulations of 25-year time horizons. Distribution and mean results were recorded. As the summary graphic box-plots presents ranges and distributions associated with average outcomes and medians-of-means, much of the variability observed in the models was dampened (Figure 4.2). Biological thresholds and limits were still crossed in all models; they only represented a small fraction of occurrences based on the tendency to rebuild the population through the stock-recruit function feedback loop.

LEPMAG members reviewed the model outputs and the performance of the metrics against various Walleye population and fisheries indicators, such as abundance, biomass, recruitment, commercial yield and angler catch rates. Short-term and long-term model projections were presented, as well as a graphic of trade-offs between the probability of angler CPE not achieving a benchmark of 0.4 f/hr and the probability of commercial fisheries not achieving an annual harvest of 4 million pounds under a variety of target F, threshold SSB, and P* conditions (Figure 4.3; see also Jones et al. 2014, *in review*). In each simulation, the proportion of years out of the 25 where the values fell below the fishery benchmark was calculated. Then the mean of those proportions was calculated for the 250 simulations. The resultant mean probability for that fishery target F and threshold SSB for each fishery was represented on the plot (Figure 4.3).

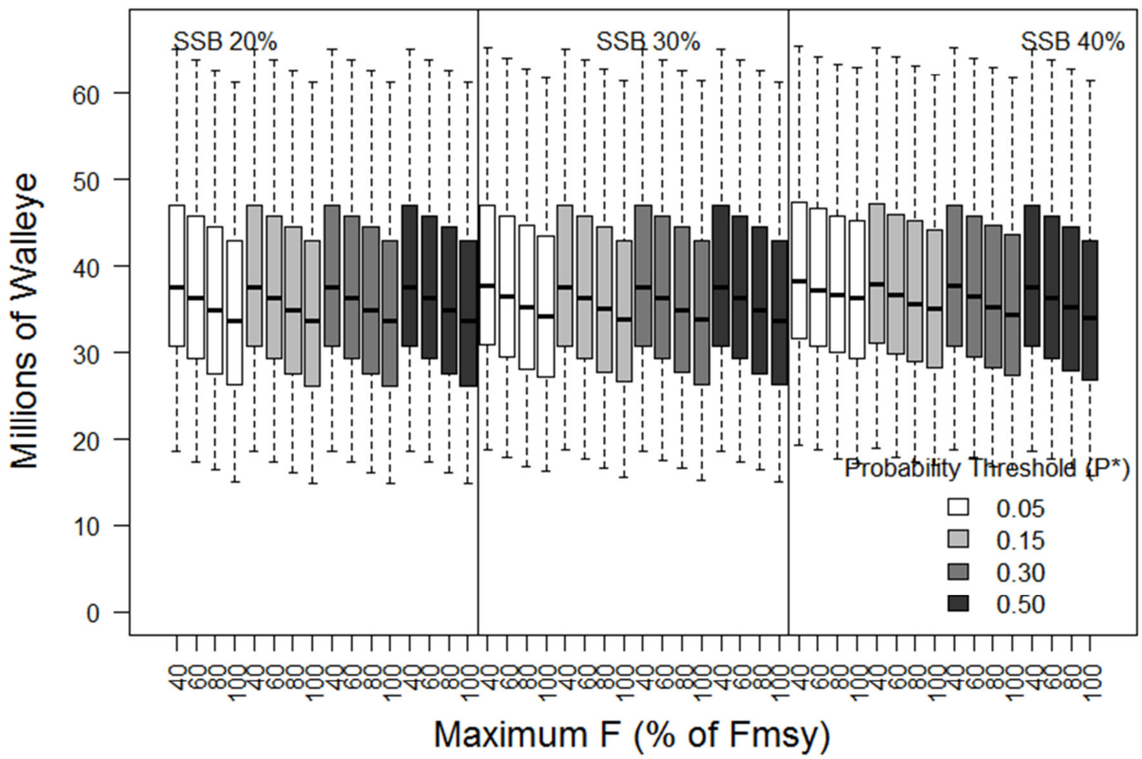

Figure 4.2. Box and whisker plots of mean abundance of Walleye ages 2-7+ in the Management Strategy Evaluation simulation results under varying fishing rates (% of F_{MSY}), biological limit reference points (SSB %), and risk probability threshold (P*) criteria. The dark horizontal line in the box represents the 50^{th} percentile (i.e., the median of mean values).

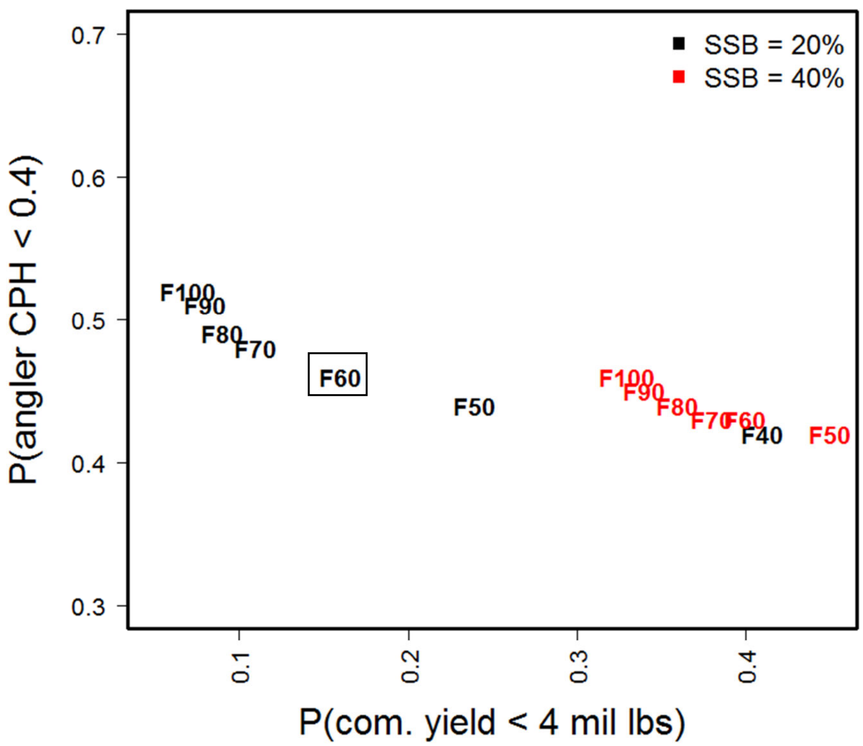

Figure 4.3. Comparison of fisheries performance against fisheries objectives under varying fishing policies and biomass thresholds. Boxed value represents chosen Harvest Control Rule.

The QFC presented these results to the LEPMAG and circulated surveys to ascertain the range of stakeholder preferences for the fisheries performance benchmarks, target F, limit reference point thresholds, and risk factors. The QFC discussed with the stakeholders various HCR MSE outcomes and the preferences that LEPMAG participants desired. At the October 2013 LEPMAG meeting, the QFC and stakeholders determined what HCR all participants would deem adequate (i.e., what they could "live with") to meet their needs. This process helped stakeholders realize relative risks and trade-offs for various stakeholder sectors and set a course of action for the recommended management strategies for implementing the latest WMP Harvest Control Rule (HCR). Based upon the MSE, the LEPMAG recommended an HCR that included:

- *Target Fishing Mortality* at **60%** of the Maximum Sustainable Yield ($F_{60\%MSY}$) ;
- Threshold *Limit Reference Point* of **20%** of the Unfished Spawning Stock Biomass (20%SSB_0);
- Probabilistic Control Rule, P*= **0.05** ;
- A limitation on the annual change in TAC of $\pm$**20%**.

After further deliberation, the LEC adopted the recommended HCR advanced by LEPMAG in March, 2014.

4.3 Determining Annual RAHs and TACs Using the HCR

In implementing this Walleye Management Plan, the Walleye Task Group (WTG) will utilize the updated Statistical Catch at Age models (SCAA) developed and recommended through

LEPMAG to produce an annual Recommended Allowable Harvest (RAH) based upon the Plan's Harvest Control Rules (HCR). On an annual basis, the WTG will collect and update the interagency fisheries and assessment databases utilized in the SCAA.

An initial run of the SCAA will include the updated fisheries and assessment databases, but will utilize the Biological Reference Point Estimates (SSB_0 and F_{msy}) from the year prior. Following this step, the WTG will re-estimate the Spawner-Recruit model (using parameter estimates from the latest model run) and estimate updated values of SSB_0 and F_{msy}. These new values of SSB_0 and F_{msy} will be used to generate the RAH mean, RAH range ($\pm$ one standard error of the RAH estimate), and the $\pm$20% bounds from the previous year's Total Allowable Catch (TAC) for consideration by the LEC as it deliberates about the TAC for the current year.

The WTG will provide the above information to the LEC and stakeholders in presentations and reports leading up to and during the annual meeting. The LEC will solicit additional information from stakeholders regarding social and economic factors for the TAC decision-making process. After this, the LEC will meet at the annual meeting and will utilize the information provided by the WTG (RAH mean, RAH range, and 20% bounds).

1) If the RAH mean is within the $\pm$20% bounds of the previous year's TAC, the LEC will establish the TAC at the RAH mean (but see part 3).
2) If the RAH mean is outside of $\pm$20% bounds of the previous year's TAC, the LEC will establish a TAC at $\pm$20% of the previous year's TAC. For example, if the mean RAH exceeds the previous year's TAC by greater than 20%, the TAC would be set at the previous year's TAC plus 20%. The reverse would be true if the Mean RAH was more than 20% below the previous year's TAC: resulting in a TAC set at last year's TAC minus 20%.
3) The LEC will provide rationale for any TAC that differs from the RAH mean but remains consistent with the harvest control rules during the TAC announcement. The LEC will endeavor to implement the RAH mean at all times, but reserves the right to deviate (while staying within the 20% HCR) from the RAH mean if there is a compelling social or economic rationale to do so. The LEC will use the RAH range to guide this decision, and will typically work within it. If the LEC chooses this option, strong justification will be provided to stakeholders and the WTG, based on social and/or economic information.

4.4 Deviating from the WMP Harvest Control Rule

The Walleye Management Plan's Harvest Control Rules reflect the diverse values and concerns, of Lake Erie stakeholders and were designed to ensure that fishery performance and stock sustainability objectives will be met well into the future. During the five-year implementation of the WMP, the LEC intends to implement the plan's HCRs. Deviation from the HCR (e.g. setting a TAC outside of the 20% constraint) will only be considered in cases when the sustainability of the walleye population will be compromised if this action is not taken. If this action is taken, the rationale will be fully articulated to stakeholders and the public.

4.5 Areas of Needed Research and Continued Investigation

While fisheries operate, assessments are completed, annual TACs are set, and fishery quotas are distributed, more research on Lake Erie Walleye needs to be done. The LEC, STC, WTG, and allied researchers must assess the contribution of eastern basin and connecting channels' Walleye stocks and fisheries to pursue the holistic management of Lake Erie Walleye. LEPMAG, LEC, QFC, and WTG members have identified specific topics that need to be explored during the next cycle of the WMP:

- All parties recognize the importance of pursuing a more integrated approach to assessment and management of Walleye lake-wide, and recommend exploration of eastern basin Walleye datasets to achieve a broader-based approach to Walleye assessment and management in the eastern basin (and lake-wide). Assessing migratory fish stocks and fishers, changing abiotic and biotic factors, and their uncertainties will be important areas of research during this current WMP time step.
- Also of great importance to the managers, fisheries biologists, and researchers is determining whether estimates of natural mortality (M) are time- and/or age- varying, their uncertainties, and incorporating these findings into the SCAA models for Lake Erie Walleye.
- Continued investigations should be forthcoming on incorporating appropriate estimators for age-2 recruitment based on multiple regressions of independent or conjoined assessment surveys. One drawback has already been revealed in this review process for inclusion of potential surveys to predict age-2 Walleye recruitment: if P* is a valuable metric in the WMP process, then no surveys that include an age-2:age-1 regression can be used, because there is no way to calculate or predict an age-1 survey estimate in time *t+2* (two years from the present, which is used as a time factor in evaluating P*) because spawning of that cohort has yet to occur. Thus, we are currently restricted to assessments that use age-0 survey indices to predict age-2 recruitment two years hence.

Another consideration in the process of setting sustainable fisheries management policies has been fisheries certification, under the Marine Stewardship Council's (MSC) eco-certification or eco-labelling process (FAO 1995, Shelton and Sinclair 2008, and MSC 2010). This process defines the fishery as being sustainably managed and certifies the fisheries as employing best sustainable practices, and allows the fishery to market and label their product for a competitive advantage. The Lake Erie commercial fisheries stand to benefit from certifying their fisheries in the MSC process, and continued LEPMAG communications, definition of LEC fisheries policies, and implementation of management plans will aid in this endeavor.

Section 5. WMP Evaluation and Review

An evaluation of this WMP relative to its objectives will be best performed after a sufficient time period has passed. The simulation model and harvest control rule were developed based upon average performance simulated over a long time horizon, and utilized means to smooth out annual variability. In contrast, the annual Walleye population abundance model and TAC-setting process occurs on a much shorter time scale, and is driven by stochastic, and often highly variable, recruitment events. Therefore, an acceptable measure of success incorporates both of these time frames of information in evaluating performance.

As indicated in this Plan, key objectives identified by LEPMAG relate to performance of the fisheries: namely, the stability of the TACs, catch rates of the sport fishery, and harvest of the commercial fishery. If the WMP exploitation policy works as it is intended, these metrics should be achieved, with variance from initial RAHs driven primarily by short-term annual fluctuations. Managers and stakeholders are well aware that recruitment patterns will largely dictate the direction of the Walleye population and fisheries in Lake Erie. Any dramatic shift from this current state will be driven primarily by changes in carrying capacity or other major ecosystem change(s). Because these changes typically occur over a span of years, the effect of the WMP cannot be understood without the benefit of allowing those years to pass. Therefore, the true test of the policy will be to examine whether these objectives are met on average and over time.

The previous Walleye Management Plan's (Locke et al. 2005) review period of five years will continue to be used for this Plan. The LEC may decide to adjust the review period for various reasons. For example, exceptional circumstances, or the need to incorporate new information, changing objectives or models as previously described, may lead to a decision to either shorten or lengthen this period. Given no further changes in the HCR, the WTG should be responsible for preparing a status report evaluating the performance of the current WMP commencing at the end of this Plan Cycle (2015-2019).

The scope and nature of the next review will be determined by the LEC, but it should be conducted with the consultation and involvement of the WTG and LEPMAG. Overall, the purpose of the review is to track the Plan's progress and measure achievement of the Plan's objectives. It may consist of evaluation of or reporting on:

- Plan performance over the review period;
- Performance of Harvest Control Rules;
- Maintenance or updates to fishery objectives;
- Proposed changes to the assessment model;
- Any exceptional circumstances that have been identified over the review period;
- Impacts of long-term exploitation policy implementation on population abundance during the review period.

Advances in scientific and/or modeling techniques and in implementing fishery management policies are possible during the course of the next time step. If there are significant improvements or changes in the biology, ecology, statistical techniques, or management procedures that can be embarked upon by the LEC, WTG, STC, LEPMAG, and the QFC to improve the Lake Erie Walleye population models or harvest control rules (re-defining biological thresholds) or that significantly alter management direction (affecting fishery F targets or assessment of risk), then they should be addressed at the earliest convenient opportunity. Unless decided otherwise, a new MSE would usually be performed to recommend to the LEC and LEPMAG any necessary changes to the Plan based on the review. The next iteration of the WMP would commence upon completion of the performance review of this WMP.

Section 6. Conclusion

This plan for Lake Erie Walleye management is a revision of the initial 2005 Walleye Management Plan that uses the best information available to understand and interpret the status of the Walleye population, and includes analysis of the past performance of both the fisheries and the populations under wide range of environmental conditions and exploitation rates.

Key to this revision of the initial WMP is the LEPMAG process, which has included management agencies and stakeholder representatives in a facilitated cooperative and collaborative process toward management of a sustainable and economically viable Lake Erie Walleye fishery. This included not only evaluating scientific assessment methods, but setting specific fishery objectives, the use of MSE in risk-based evaluation of options, and development of harvest control rules in a consensus-based manner. The success of this process is reflected in this plan, and it forges a commitment to continue the process of interaction through LEPMAG for additional recommendations, evaluations, and management actions during implementation.

The LEC intends to continue stakeholder engagement beyond WMP development and implementation in the future management of Lake Erie fisheries, including engagement in plan reviews and revisions. LEPMAG's objectives also include active participation through consultation and evaluation of Lake Erie Yellow Perch Management Plan development, as well, which is underway as this WMP reaches completion. LEPMAG participants also wanted percid task groups to define specific fisheries performance objectives in order to facilitate evaluation and recommendations surrounding the MSE process. Developing specific metrics would allow quantifiable determination of risks and trade-offs associated with differing model configurations and Harvest Control Rules (HCR).

This plan is a living document, and both LEC and LEPMAG recognize that changes and revisions to strengthen all of these processes and components are dynamic and ongoing and will be guided by the evaluation of the Walleye population and fishery performance by the LEC and its task groups. Future improvements to the model and management processes will be evaluated and incorporated as outlined in this plan and as we proceed through the five-year plan period as described in Section 4.4.

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Appendix A. Historic Lake Erie Walleye Harvest Strategies

A.1. Initial Quota and TAC Strategies

Following a 1970 harvest moratorium, due to the discovery of mercury levels exceeding consumption standards, international Walleye quotas were introduced in 1976 for Lake Erie Walleye (Hatch et al. 1987). Initially, the Walleye Task Group estimated Walleye abundance by sequential projection using harvest data and estimated mortality rates (assumed natural mortality M=0.218) and U.S. Fish and Wildlife Service western basin young-of-the-year trawl indices (WTG 1979). The initial safe harvest level (i.e., TAC) was initially derived from Gulland (1971) based on ½*(B_0)*(M) where B_0 and M are biomass and natural mortality at carrying capacity (Hatch et al. 1987).

In 1977 and 1978, the WTG used Gulland's (1970) approach to derive the TAC. This method calculated the maximum yield as derived from B_0 using two ratios. The first ratio was the size at first capture to maximum size, and the second ratio was that of natural mortality to growth (Hatch et al. 1987). After the TAC was exceeded in 1979, the target fishing rate (F=0.10) was doubled (F=0.20) in 1980 (Hatch et al. 1987). In 1981, the target fishing rate was increased to a level at which the 1980 TAC would have approximated the 1980 harvest (F=0.285) and that rate was maintained from 1981-1983 (Hatch et al. 1987). In 1984, target fishing mortality rates were conditional on three categories of Walleye abundance (Hatch et al. 1987):

• Category (1): 40-50 million fish in two successive years:		F=0.285
• Category (2): > 50 million in two successive years:		F=0.285+
• Category (3): < 20 million fish in two successive years:		
For any one year:	15-20 million:	F=0.20
	10-15 million:	F=0.15
	<10 million:	F=0.10.

In 1985 and 1986, the Category 3 condition was not in force as various methods were being used to estimate abundance. In 1986, the 1982 year class was considered to be underestimated by the sequential projection model, and was adjusted upwards in proportion with fishery catch rates with F=0.285 (WTG 1985, 1986). In 1988, the WTG expressed concern that the YOY index and sequential projection modeling were not accurately describing recruitment or the resulting age composition of the fishable stock. In 1988 and 1989, population estimates were derived using the original sequential modeling process and two statistical catch at age population modeling programs, CAGEAN and RECQUEST, with CAGEAN producing the estimates which were subsequently accepted that year as they best tracked the results observed in the fisheries and surveys (WTG 1988). A constant natural mortality rate (M=0.218) was assumed and selectivity was not part of the model (WTG 1989). However, the WTG favored a strategy that incorporated yearling gill net indices and a revised, stratified-random sampling in the western and central basins to estimate age-2 recruitment. In a revised population model and harvest rule, CAGEAN methodology was chosen over RECQUEST, with average annual exploitation rates applied for the TAC (WTG 1989, 1990).

A.2. Implementing an F_{opt} Strategy (1990-2000)

The LEC and the WTG have employed a number of "benchmark" criteria in the past to determine sustainable population and harvest levels that support adequate recruitment and a broad distribution of benefits to various fisheries across the lake. The LEC and WTG used a procedure that calculated an optimal fishing mortality, F_{opt}, based on a yield per recruit model of Lake Erie (western and central basins) Walleye age, abundance, von Bertalanffy growth parameters, and fishery selectivity at age.

In 1990, the WTG used the existing CAGEAN-based TAC approach over an alternative Beverton-Holt yield per recruit method (WTG 1990). In 1991, the Walleye tag recapture program suggested M=0.38, but a value of two standard errors below this estimate was adopted (M=0.32) due to uncertainty around the estimate of M. The WTG also continued the use of CAGEAN.

From 1990-1998, the desired harvest strategy, used in conjunction with a yield-per-recruit model, was to optimize the return in weight-per-recruit. The optimum harvest rate, F_{opt}, was determined by growth rate versus natural mortality rate. For temperate waters, F_{opt} was modified to $F_{0.1}$, which corresponds to 10% of the rate of increase in yield per recruit, which can be obtained by increasing F (fishing mortality) at low levels of fishing. Each year, the WTG determined von Bertalanffy growth parameters and updated F_{opt} calculations and outputs. The Beverton-Holt yield-per-recruit approach was used to generate an F_{opt} of 0.326 for calculating the RAH in 1991. F_{opt} was scaled such that more vulnerable age groups would be fished above the target fishing rate, while less vulnerable (younger) fish would be fished below the target rate (WTG 1991). Although F_{opt} was equal to 0.326, the true targeted fishing mortality rate was approximately 0.4 after scaling (WTG 1997).

This assessment and allocation process continued until 1998, when the method of scaling F_{opt} was changed so that individual age groups would not be fished at rates higher than the targeted level. Fishing mortality by age (F_{age}) was equal to F_{opt} (not greater) and for those ages where full recruitment was not attained, F_{age} was calculated by the equation: $F_{age} = F_{opt} * s_{(age)}$, where $s_{(age)}$ is the selectivity for that age. Selectivity at a specific age was calculated from the last year of the statistical-catch-at-age (SCAA) model run (or a similar year's conditions in SCAA model runs if the new year was expected to differ significantly from the previous year's fishery), based on the ratio of F for that age to F for the age of full recruitment. This method produced a more conservative estimate of F_{age}, and resulted in a lower estimate of projected harvest at age and RAH than the previous method. From this time on, the WTG did not recommend an F value for any age group that was higher than F_{opt}. In 1998, the task group assumed a lower M=0.25 based on alternative analyses (this reduced F_{opt} to 0.259), but M=0.32 was reinstated in 1999 and 2000 after additional considerations, with F_{opt} = 0.326.

A.3. Coordinated Percid Management Strategy (2001 – 2003)

By 2000, the downward trends observed in the fishery surveys (i.e., independent and dependent surveys), low levels of recruitment, and environmental changes suggesting continuation of these trends were major concerns for the LEC. There was also additional concern over the retrospective patterns in the population model (i.e., virtual population analysis or CAGEAN) used to estimate Walleye abundance. Specifically, the model may have been overestimating age-specific abundance in the early iterations (as cohorts entered the fishery). In an attempt to stop this decline and to restore the state of the Walleye population to a favorable condition, the LEC initiated the Coordinated Percid Management Strategy (CPMS) for three years, from 2001-2003. The objectives of CPMS were to: (1) reverse declines and rebuild percid stocks to achieve a broad distribution of benefits throughout the lake, and (2) improve approaches used to estimate percid abundance and determine sustainable harvest levels (LEC 2004). During the three years of the CPMS (2001-2003), the annual total allowable catch (TAC) was set at no more than 3.4 million Walleye. To ensure that the lake-wide TAC was not exceeded, each LEC agency took steps to decrease Walleye harvest. The specific actions of each agency to achieve this end are listed in the CPMS document (LEC 2004). In addition, agencies implemented changes to the fisheries that affected timing of harvest, such as reduced commercial allocations and reduced sport fish daily bag limits during the springtime, to reduce fishing pressure on segregated spawning stocks.

In 2003, the CPMS was evaluated to determine if the strategy met the intended objectives. The first objective, *to reverse declines and rebuild percid stocks to achieve a broad distribution of benefits throughout the lake,* was only partially achieved. Implementation of the CPMS three-year strategy and changes to harvest levels were enough to stop the decline in Walleye abundance. Unfortunately, year class failures prior to and during the CPMS time frame prevented Walleye stocks from increasing in abundance. In 2004, the TAC was set 30% below the CPMS level in response to further declines in estimated Walleye biomass.

The second objective of the CPMS, *to improve approaches used to estimate percid abundance and determine sustainable harvest levels,* was achieved to the satisfaction of the LEC. Specifically, concurrent with the CPMS process, Auto Differentiation Model Builder (ADMB) Statistical Catch at Age software using the C++ programming language was introduced in 2001 (Quinn and Deriso 1999). This model accepted data series from multiple assessment surveys (CAGEAN did not) and offered greater programming flexibility. An independent technical assessment model review was conducted in 2001 and the reviewers endorsed the new stock assessment model as an improvement over the former (i.e., CAGEAN) modelling approach (Myers and Bence 2001). Reliance on additional information sources and up-to-date fish population models is imperative to understanding fish stock status. By moving to state-of-the-art population modeling techniques, and having them independently reviewed by fisheries modeling experts, the LEC was able to better understand Walleye stock status.

A.4. The 2005 Walleye Management Plan

The first Lake Erie Walleye Management Plan, which was drafted during 2004 and early 2005, documented past Walleye management actions in Lake Erie (Locke et al. 2005). The plan identified limits and uncertainties on Walleye management as well as sustainability thresholds. It also recognized the Fish-Community Goals and Objectives for Lake Erie, which indicate that a sufficient number of Walleye need to be present to act as a keystone predator and also allow stakeholders to realize a broad distribution of benefits throughout the lake (Ryan et al. 2003).

In 2005, the Lake Erie Walleye Management Plan (WMP; Locke et al. 2005) was adopted with the key components establishing sustainability and defining fishery quality objectives that the LEC employed as a basis for Walleye management. The plan's initial focus was on the Western and Central Basin Walleye spawning stocks as these are the primary populations that provide the most benefit to users throughout Lake Erie. While the WMP formed the basis for future management of the Walleye resources in the lake, it was also meant to be dynamic, to continue to evolve with advances in science, assessment, and knowledge, and to be transparent and straightforward in the TAC-setting process so that stakeholders could see how management decisions were made and knew what to expect at given population levels and fishery performance.

The 2005 WMP had two main components. The first component was comprised of population objectives that defined the fishery quality characteristics that the LEC identified for the Lake Erie Walleye population. These objectives were: 1) to maintain Walleye catch rates at average or better levels; and 2) to maintain both sport and commercial harvest at average or better levels, using the time period of 1978 through 2004 for reference data. Additionally, the age and size structure in the Walleye population at-large needed to be sufficient to promote migration of Walleye towards the eastern basin, provide diverse fishing opportunities to anglers, and provide sufficient numbers of commercially-desirable fish. In general, these objectives should be achieved when the population size was between 26 and 40 million age-2 and older Walleye (ages 2+; based models in use by the WTG at that time). Reliance on a single year class to support fisheries was considered an undesirable state for management, although it was recognized that Walleye year class strength fluctuates irrespective of spawner biomass.

The second component of the WMP was to develop an exploitation policy for age 2+ Walleye that was designed to help meet these fishery and population objectives while at the same time recognizing the economic importance of the Walleye fishery to stakeholders. Following completion of a Decision Analysis exercise (Peterman and Anderson 1999, Wright et al. 2005) between researchers at Michigan State University and the WTG that incorporated various model recruitment and harvest scenarios, the sliding-F policy was developed and adopted by the LEC (Figure A.1; Locke et al. 2005).

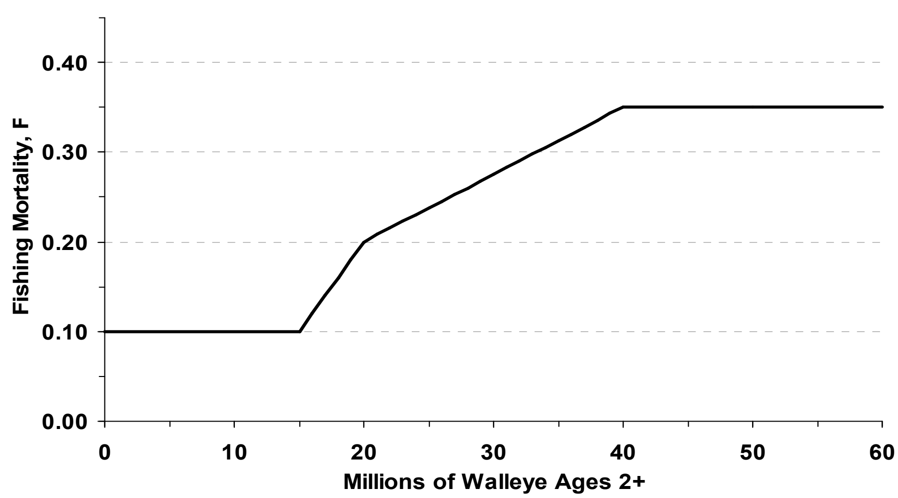

Figure A.1. The LEC sliding-F exploitation policy established in the 2005 Lake Erie Walleye Management Plan (Locke et al. 2005) for Walleye management in Lake Erie.

The fishing mortality, F, was calculated for ages 2 through 7+ individually; F-at-age was calculated to determine RAH by multiplying target F by the resultant combined gear selectivity-at-age observed in the previous year, which was derived from ratios of total fishing mortality at age. F_{age} and ultimately exploitation (*u*) was multiplied by the estimated number at age (with uncertainty to provide minimum and maximum bounds) to calculate the RAH and an associated RAH range. Ultimately, the sliding-F exploitation policy was designed to achieve four things: 1) ensure the sustainability of the Walleye population; 2) help to maintain Walleye within the maintenance thresholds established by the LEC; 3) allow user groups to take advantage of large Walleye populations; and 4) be simple to understand and reliable for determining RAH calculations.

Within the WMP was the recommendation that the actions, and outcomes of these actions, be reviewed on a five-year basis in order to measure the success of the plan and evaluate its objectives. Recommendations within this review include: 1) review the overall status of the Walleye population relative to changes in carrying capacity; 2) evaluate the impact of long-term exploitation policy implementation on population abundance and demographic attributes; and 3) determine if the exploitation policy is working as it was intended to in the Plan. If necessary, the review was to include recommendations on improvements to the WMP to achieve its objectives.

Appendix B. Glossary of abbreviations used in the Walleye Management Plan.

Abbreviation	Definition
ADMB	Auto Differentiation Model Builder
CPMS	Coordinated Percid Management Strategy
CWTG	Coldwater Task Group
DA	Decision Analysis
F	Fishing Mortality
FCGO	Fish Community Goals and Objectives
FTG	Forage Task Group
GLFC	Great Lakes Fishery Commission
HCR	Harvest Control Rule
HDTG	Human Dimensions Task Group
HTG	Habitat Task Group
JSP	Joint Strategic Plan for Management of Great Lakes Fisheries
LEC	Lake Erie Committee
LEPMAG	Lake Erie Percid Management Advisory Group
M	Natural Mortality
MDNR	Michigan Department of Natural Resources
MSE	Management Strategy Evaluation
MSY	Maximum Sustainable Yield
NYSDEC	New York State Department of Environmental Conservation
ODNR	Ohio Department of Natural Resources
OMNRF	Ontario Ministry of Natural Resources and Forestry
P*	Probabilistic risk
PFBC	Pennsylvania Fish and Boat Commission
QFC	Quantitative Fisheries Center at Michigan State University
RAH	Recommended Allowable Harvest
SCAA	Statistical Catch-At-Age (model)
SDM	Structured Decision Making
SSB	Spawning Stock Biomass
STC	Standing Technical Committee
TAC	Total Allowable Catch
TRP	Technical Review Panel
u	Exploitation
WMP	Walleye Management Plan
WTG	Walleye Task Group
YPTG	Yellow Perch Task Group