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Evaluating Strategies for Managing Yellow Perch Sport Harvest in New York's Portion of Lake Erie

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Evaluating Strategies for Managing Yellow Perch Sport Harvest in New York's Portion of Lake Erie

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Executive Summary

Interjurisdictional commercial and recreational yellow perch harvest in Lake Erie is managed through an annual quota setting process based on formal stock assessment. New York (NY) has been uncomfortably close to its recreational quota on a few occasions, suggesting NY yellow perch fisheries have the capacity to exceed quota. This analysis was conducted to determine whether we can forecast situations under which the yellow perch quota in the NY waters of Lake Erie could be exceeded, and prescribe management actions that could be implemented to prevent that from happening. We tested several model-based methods for projecting yellow perch harvest based on previous and current years' fishery independent and fishery dependent data. We also simulated the effect of changing harvest regulations and angler behavior on total yellow perch harvest across a range fishery conditions.

Models that predicted harvest prior to the start of the fishing season performed poorly as predictors of future harvest, and in many cases, failed to predict the directionality of changing annual harvest. Models that used the current year's May and June harvest to predict total harvest in the rest of the year had better performance and could successfully predict the direction of harvest as well as whether the harvest would remain under quota. The large amount of uncertainty surrounding model-based harvest projections may limit the utility of these models as a tool to drive regulation changes. The ability to moderate harvest using daily creel limits was strongly positively related to the overall level of harvest. As stock size and angler success increase, reductions in daily limits are more effective at reducing harvest because proportionally more anglers can achieve a limit. However, our ability to make meaningful harvest reductions with regulation changes is limited because most anglers achieve only modest harvest levels even in years with exceptionally high stock size and angler success (i.e. catch per hour).

Thinking through the decision-making process helped identify many challenges associated with actively managing for quota compliance in a largely recreational fishery. In most situations, the opportunity cost of acting and being wrong would likely outweigh the benefit of taking actions to stay under quota. This analysis indicates that NY's ability to predict when we will exceed quota and then prevent quota from being exceeded using preemptive regulatory changes is limited. Given these limitations, the strength of this approach is more in advanced notification and increased understanding rather than regulatory action. Still, the ability to inform our Lake Erie partners in years that there is potential for NY to exceed quota and to quantify the potential management actions necessary to achieve quota compliance is the only responsible way to proceed within the current management structure. The chief benefit of this research is that it provides us with a scientific basis that underlies our current regulatory framework and upon which future decisions can be based.

Management conclusions:

1. Understanding how fisheries and regulatory tools perform over a range of population conditions allows us to pursue more informed regulatory decision-making and effectively communicate those decisions based on available science.
2. The high uncertainty associated with projecting harvest and the drastic cuts in daily limit that would be necessary to avoid exceeding quota likely means that projecting harvest is an exercise in advanced notice rather than emergency actions.
3. Adopting an "emergency" regulatory action of reducing daily limits with the objective of remaining compliant with quota decisions only seems effective when fishing quality is exceptional and stocks are at high levels, which will likely seem counter-intuitive to the angling community.

Rationale

Commercial and recreational yellow perch (*Perca flavescens*) harvest in Lake Erie is managed through an annual quota setting process that is based on formal stock assessment (YPTG 2017). Total allowable catch (TAC) limits for Lake Erie yellow perch are announced each March as a consensus decision of five jurisdictions representing the Great Lakes Fishery Commission's (GLFC's) Lake Erie Committee (LEC). These TAC limits are used to establish harvest quotas for all Lake Erie jurisdictions. Annual harvest quotas for commercial fisheries in Ontario (ON), Pennsylvania (PA), and Ohio (OH), and sport harvest daily limits in PA, and OH are adaptively changed (if necessary) to comply with the quota decision. Unlike most other Lake Erie jurisdictions, NY's regulatory mechanism to swiftly adopt new rule making is an "emergency regulation". Although NY has not yet exercised this option for Lake Erie yellow perch, or exceeded quota, we have been uncomfortably close to quota on a few occasions, which suggests NY yellow perch fisheries have the capacity to exceed quota. This discomfort has compelled us to consider how we can determine if we are likely to exceed quota and what actions, if any, could be taken to prevent NY from exceeding quota. This report evaluates methods for projecting the total annual harvest of yellow perch in the NY waters of Lake Erie, and the efficacy of adaptively reducing daily creel limits (hereafter "limits") to constrain harvest, when necessary. The overall goal of this work is to develop a better understanding of, and scientific basis for, regulating yellow perch recreational harvest in NY's portion of Lake Erie to remain compliant with annual quota decisions.

Introduction

Recreational fisheries for yellow perch are largely self-regulating, meaning that fishing effort is positively correlated with fishing quality and/or abundance (Pereira and Hansen 2003). When strong self-regulation is present, protecting spawning stock biomass can often be achieved through reasonable daily limits because anglers stop fishing as adult abundance and fishing quality declines. Commercial fisheries are not usually self-regulating. As adult abundance declines a commercial fleet may increase fishing effort to achieve profit-oriented goals. Lake Erie yellow perch fisheries include commercial trap netters (NY, PA, OH) and gillnetters (ON), plus charter and recreational anglers in all jurisdictions. On a lakewide scale, these groups harvest millions of pounds each year (2016: 7.2 million lbs.). Thus, Lake Erie yellow perch must be managed as a largescale commercial fishery, with a stock assessment, harvest policy, and quota setting procedures.

Effective management of large scale commercial fisheries typically involves a quota management approach with accompanying mandatory harvest reporting, and a mechanism to ensure quota compliance. However, quota style fisheries management applied to recreational fisheries is problematic because measuring and controlling harvest is difficult and there is no real-time mechanism to identify if or when quota is being approached or exceeded. In Lake Erie, stock assessments and annual yellow perch quotas are applied to four management units and then to jurisdictions within each of those units. As a result, annual quotas apply to the recreational and commercial fisheries within each management unit and jurisdiction. Fishery self-regulation does not necessarily prevent a recreational fishery from exceeding agreed upon quotas. For example, in 2016 a combination of good weather, very high catch per hour (CPE), and positive media reports, caused high angler effort resulting in a yellow perch harvest 1.9 times the quota for the MI waters of Lake Erie (YPTG 2017).

Yellow perch quotas in Lake Erie increase and decrease primarily in response to yellow perch abundance estimates based on annual stock assessments. However, sometimes quotas are changed more gradually than stock assessment results would warrant to foster fishery stability, and in recognition of uncertainties, risk, or socioeconomic factors. Occasionally, desires for maintaining stable harvests through time might cause gradually increasing quotas not to keep pace with increasing recreational fishing quality during periods of rapidly increasing abundance. It is during these periods of rapidly increasing abundance that quota could be exceeded by a recreational fishery, as was the case in the MI waters of Lake Erie in 2016. MI biologists remained unaware that the quota had been exceeded until creel surveys and analyses were completed after the 2016 fishing season. Until 2016, Michigan had never approached their yellow perch quota. Similarly, the NY yellow perch quota has never been exceeded, contributing to a sense that NY's fisheries do not have the capacity to exceed quota (Figure 1).

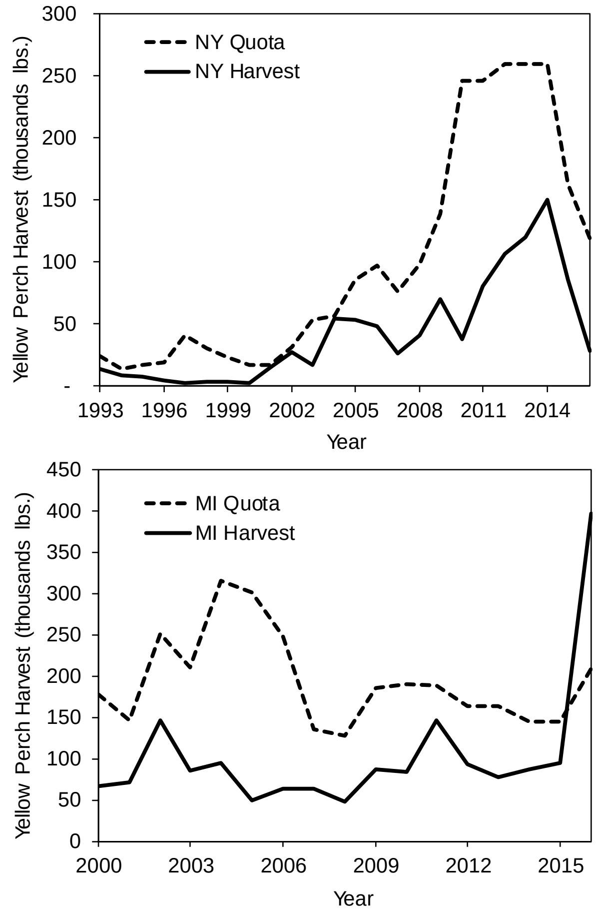

Figure 1. New York yellow perch quota (dashed line) and total harvest (solid line) in upper panel, and Michigan quota and harvest in lower panel. New York's time series begins in 1993 and Michigan's begins in 2000.

The goal of this report is to determine whether we can forecast situations under which the yellow perch quota in the NY waters of Lake Erie could be exceeded, and prescribe management actions that could be implemented to prevent that from happening. We take a model-based approach to projecting total annual yellow perch harvest and employ a simulation-based approach to evaluate the effectiveness of potential daily limit regulations. Finally, we describe scenarios under which action should be considered, and the proper steps to follow prior to action being taken. The specific objectives of this work were to:

1. Evaluate our ability to project yellow perch harvest relative to the annual quota.
2. Evaluate our ability to reduce recreational yellow perch harvest through more restrictive daily limits.
3. Lay out a plan of action for remaining under quota.

Many aspects of this work will apply broadly to percid populations in NY and elsewhere. Harvest dynamics described here are likely applicable to many other harvest-oriented fisheries.

Methods

General approach

A modeling approach was used to project total annual yellow perch harvest and a simulation approach was used to predict the effects of daily limit regulations on recreational yellow perch harvest. The modeling approach is designed to be annually updated as new information becomes available with the expectation that our annual

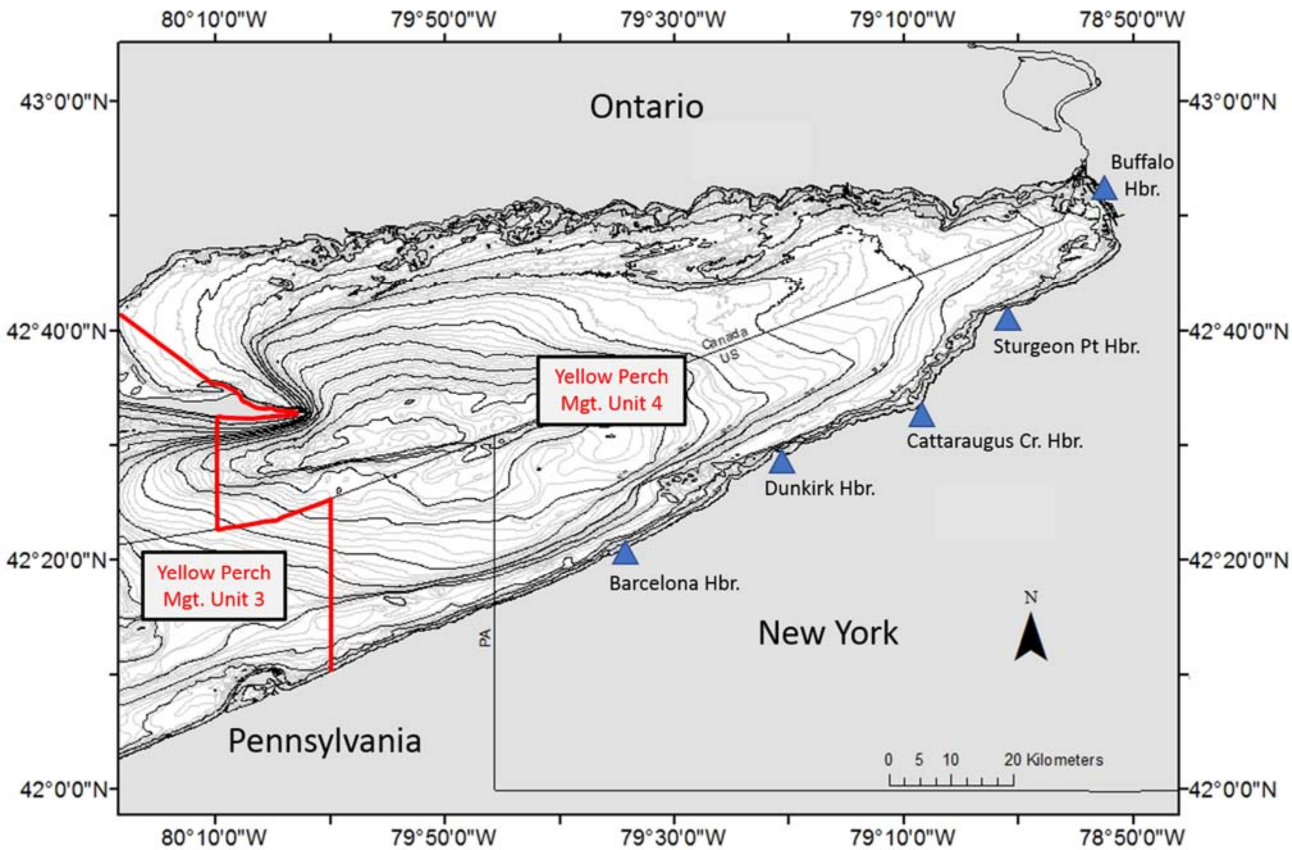

Figure 2. Lake Erie's eastern basin yellow perch Management Unit 4. Major New York harbors, state and international boundaries, depth contours and management unit boundaries are displayed.

surveys will improve our ability to adequately project harvest over time. Similarly, the simulations that inform the effects of regulations on harvest could be easily updated if the demographics, operation, or overall character of the yellow perch fishery change, which could alter the conclusions of this investigation.

Study Area

NY's portion of Lake Erie is 229 sq. km or 6 percent of the lake's total surface area and is in the southeast portion of Lake Erie's eastern basin (Wolfert 1981, Figure 2). The eastern basin is the least productive and deepest portion of the lake with an average depth of 24.4 m (Hartman 1972). Much of the nearshore substrates in NY waters are relatively steep sided slopes of sand and gravel, or rock (Bolsenga and Herdendorf 1993). New York's Lake Erie coastline is largely devoid of protected embayments, therefore angler access to the open lake is mostly limited to five major harbors of refuge shown in Figure 2. The eastern basin of Lake Erie also represents one of the lake's four yellow perch management units. Management Unit 4 includes all New York Lake Erie waters, and portions of Ontario and Pennsylvania waters. New York waters comprise 31% of the surface area of Lake Erie's eastern basin management unit. Annual consensus decisions on TAC are allocated to jurisdictions by surface area share of each management unit. As such, NY annually receives 31% of the Management Unit 4 TAC.

Fishery Description

There are currently two primary fisheries targeting yellow perch in the NY waters of Lake Erie; A small scale commercial trapnet fishery, and a large recreational boat fishery. Other subordinate and unmonitored yellow perch recreational fisheries include an ice fishery and a shore/pier fishery. A 1984 angler survey (NYSDEC 1989) found the shore/pier fishery component to be trivial, but the ice fishery component has potential to be large during years with extended ice cover. Years with extended ice cover are currently rare on eastern Lake Erie. Presently the commercial fishery has four license holders, only two of which currently report an annual harvest (NYSDEC 2017). Over the last ten years the commercial fishery has produced very consistent annual yellow perch harvest totals ranging from 10,000 to 22,000 lbs. Regulation of the commercial fishery consists of mandatory reporting, gear restrictions and geographical limitations on where fishing can occur (6 NYCRR 36.2 b). This commercial fishery is not constrained by annual quotas and currently operates only near Barcelona Harbor. The recreational fishery performance has been far less consistent with annual effort, harvest, and CPE often rapidly changing in response to angling quality, indicating relatively strong fishery self-regulation (Figure 3). Over the past decade recreational harvest of yellow perch has ranged from 16,000 to 139,000 lbs., and effort has ranged from 27,000 to 77,000 angler hours. Regulation of the recreational fishery is limited to the NY statewide regulation of 50 yellow perch per day of any size (6 NYCRR 10.1 b 15, Table 1).

Table 1. Yellow perch sport fishing regulations by jurisdiction in selected waters of the Great Lakes during 2017.

Juris.	Lake	Recreational Yellow Perch Reg.		
		Season	**MSL**	**Daily Limit**
NY	Lake Erie	none	none	50
PA	Lake Erie	Dec-1–Apr-30	7-in	30
		May-1–Nov-30	none	30 *
OH	Lake Erie	Jan-1–Apr-30	none	30
		May-1–Feb-29	none	30 *
MI	Lake Erie	none	none	50
ON	Lake Erie	none	none	S-50/C-25**
NY	L. Ontario	none	none	50
	L. Ontario (Jefferson Co.)	none	none	none
ON	L. Ontario	none	none	S-50/C-25**
ON	Lake Huron	none	none	S-50/C-25**
ON	Georgian Bay	none	none	S-25/C-12**
MI	Lake Huron (Saginaw Bay)	none	none	25
MI	L. Michigan (N of 45° Lat.)	none	none	50
MI	L. Michigan (S of 45° Lat.)	none	none	35
IN	L. Michigan	none	none	15
IL	L. Michigan	June-16–Apr-30	none	15
WI	L. Michigan	June-16–Apr-30	none	5
WI	L. Michigan (Green Bay)	May-20–Mar-17	none	15

* - adaptive daily limit announced each spring
** - S = Sport fishing license limit / C= Conservation fishing license limit

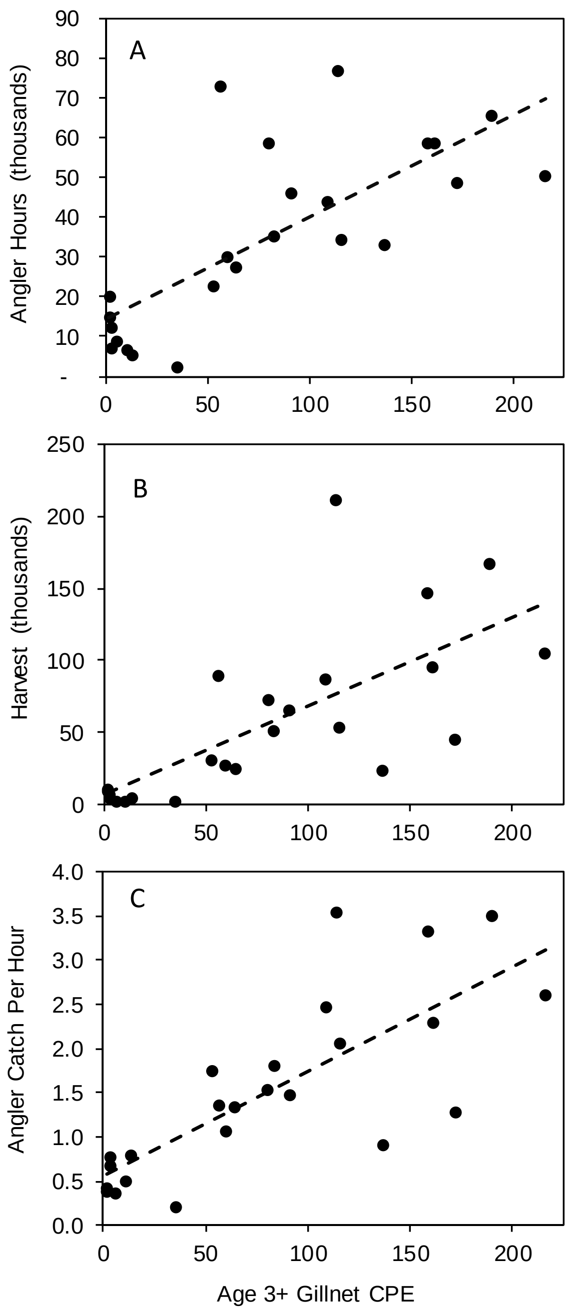

Figure 3. Trends in A) annual targeted yellow perch angler effort (angler hours), B) harvest, and C) catch per hour relative to annual age 3+ yellow perch gillnet catch-per-net. Fishery metrics are calculated using the annual LEU Lake Erie open water creel survey. Gillnet catch-per-hour is calculated using the annual LEU warmwater gillnet survey. All data are continuous from 1993–2016.

In a typical year, Cattaraugus and Sturgeon Point harbors account for the majority of recreational yellow perch harvest, and most anglers fish for yellow perch at depths ranging from 40 to 70 feet.

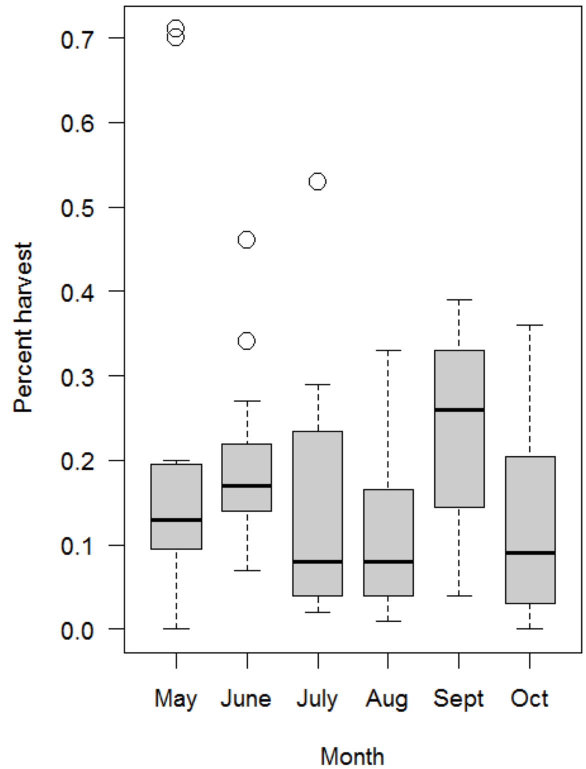

Figure 4. Box plot of percent yellow perch harvest by month. Harvest data from 2002–2016 are included. Bold black lines represent medians, boxes represent the interquartile range, and whiskers represent the data range excluding outliers. Outliers are represented by open circles.

Timing of yellow perch harvest varies greatly from year to year (Figure 4). In many years, yellow perch effort and harvest are relatively high in May and June, fall off in July and August, and then peak in September. About 25 to 45% of yellow perch harvest has usually occurred by the end of June but this has varied from 20 to 80%. A full accounting of these fisheries and their long-term performance can be found in the Lake Erie Research Unit Annual Report (NYSDEC 2017).

Data Sources

Several data sources were used to inform harvest in the modeling portion of this work. The Lake Erie Fisheries Research Unit (LEU) open lake creel survey provided effort, harvest, and angler CPE associated with the recreational yellow perch fishery in NY. The LEU warm

Table 2. List of variables available for inclusion in models 1 through 6. X denotes the inclusion of each variable in each model. Harvest refers to the yellow perch kept by New York sport anglers. Angler Effort and CPE are targeted rates. Gillnet and trawl refer to standard index gears and methods used by NYSDEC on Lake Erie (NYSDEC 2017). Model refers to the model-based estimates of total yellow perch abundance in Management Unit 4 produced by the Yellow Perch Task Group (YPTG 2017).

Variable	Units	Model Year	Model 1-2	Model 3-4	Model 5-6
Harvest (response)	Number	y	X	X	X
Harvest (May & June)	Number	y			X
Harvest	Number	y-1	X	X	
Angler Effort	Angler hours	y-1	X	X	
Angler CPE	Catch-per-hour	y-1	X	X	
Gillnet age-2 CPE	Catch-per-net	y-1	X		
Gillnet age-3 CPE	Catch-per-net	y-1	X		
Gillnet age-4 CPE	Catch-per-net	y-1	X		
Gillnet age-5 CPE	Catch-per-net	y-1	X		
Gillnet age-6 CPE	Catch-per-net	y-1	X		
Gillnet age-7 CPE	Catch-per-net	y-1	X		
Gillnet age-2+ CPE	Catch-per-net	y-1	X	X	
Gillnet age-3+ CPE	Catch-per-net	y-1	X		
Gillnet age-4+ CPE	Catch-per-net	y-1	X		
Trawl age-2+ CPE	Catch-per-hectare	y-1	X	X	
Model age-2+ N	Total abundance	y-1	X	X	
Model age-3+ N	Total abundance	y-1	X		
Model age-4+ N	Total abundance	y-1	X		

water gillnet survey provided gillnet CPE at age for yellow perch in NY waters. The LEU trawl survey provided a density for adult (age-2 and older) yellow perch in NY waters. Detailed methods and citations for the LEU creel, warm water gillnet, and trawl surveys can be found in the LEU annual report (NYSDEC 2017). Yellow perch population estimates were based on results of the annual statistical catch at age modeling of the Lake Erie Yellow Perch Task Group (YPTG 2017). Full data sets for all the above data sources existed from 1993-2016.

Selecting a method for projecting yellow perch harvest

Two groups of models were developed to project yellow perch harvest. Models 1–4 used fishery dependent and independent data from 1993–2016 to project harvest in the following angling year. Models 5 and 6 used only combined May and June harvest data from 1997–2016 to project total harvest in the current angling year (Table 2). No interaction terms were included. Models 1–4 were fit as generalized linear models with a normal error structure to aid in the automation of model selection and averaging which was performed using the glmulti function in program R (Calcagno 2015; R Core Team 2013). In models 1–2 all available variables were used to fit all possible combinations of parameters (Table 2). Model 1 used untransformed variables and in model 2 all variables were $\log_e$ transformed. All variables were included in the model selection procedure for models 1 and 2 even though some of the variables were necessarily correlated and/or nested (e.g., CPE of age 2 and CPE of age 2 and older). The full model and all nested models (models with fewer parameters) were evaluated using the small-sample-size corrected version of Akaike information criterion (AICc; Akaike 1973; Burnham and Anderson 2002). Models within 2 AIC were considered very similar in terms of goodness of fit and were included in model-averaging procedures. The relative importance of each parameter was determined by the number of top models that included the parameter.

Parameters included in more top models were presumed to be more important to model fit. Models 3 and 4 employed the same fitting and averaging approach as models 1 and 2. However, in models 3 and 4 parameters that were likely to be correlated or parameters that were known to be nested in other parameters were excluded (Table 2). Model 3 used untransformed variables and in model 4 all variables were $\log_e$ transformed. Models 5–6 used a single variable – combined May and June harvest – to project harvest in the current year and were fit using a simple linear model. Model 5 used untransformed variables and in Model 6 all variables were $\log_e$ transformed.

Model performance was evaluated based on how closely projected total harvest matched measured harvest. Projection performance was evaluated for the most recent five years of data (2012-2016). Each model was fit to the available data and then used to project harvest to simulate a real management scenario. For example, a model would be fit using all the data up to 2011, and then the parameter estimates were used to project the 2012 harvest. Models were fit independently as successive years of data were added, therefore parameter estimates and top models ($\Delta AIC_c<2$) had the potential to change as new data became available. We developed a performance metric using the total projection error (TPE) for each model. TPE was calculated by summing the squared deviations between projected and observed yellow perch harvest (on a $\log_e$ scale) for 2012 to 2016 (Brenden and Liu 2010):

$$\mathrm{TPE} = \sum_{i=2012}^{2016} \left(\mathrm{h}_i - \hat{\mathrm{h}}_i\right)^2$$

where h_i is the actual measured harvest in year *i* (on a $\log_e$ scale) and $\hat{\mathrm{h}}_i$ is the model projected yellow perch recreational harvest (on a $\log_e$ scale) in year *i*. The lowest TPE was used to identify the best projection method. TPE is similar to the PRESS statistic, which is often used to evaluate regression model performance (Myers 1990). Prediction intervals were produced for estimates of projected recreational harvest. Prediction intervals estimate the range in which you would expect a forecasted observation to occur, whereas a 95% confidence interval estimates the range in which you would experience a 95% probability of encountering the true mean observation from re-sampled data (Ott and Longnecker 2001). For this reason, the prediction interval is a logical choice for this application because we are interested in projecting an event (*i.e.*, a data point) that has not yet occurred. Projected harvest based on the best performing model must be converted from numbers to pounds because the harvest quotas for each jurisdiction are assigned by weight. To accomplish this, the projected recreational harvest in number of yellow perch was multiplied by the average weight of an individual harvested yellow perch in the previous year. The average commercial harvest (15,000 lbs.) was then added to the projected recreational harvest to obtain a projected total harvest.

Simulating changes in daily limits

Changes in daily limits were the only regulatory mechanism to reduce harvest considered in the simulation. Because of the deep-water nature of NY's recreational perch fishery in Lake Erie, barotrauma often precludes releasing fish that will survive. Therefore, length limits are likely not effective in reducing yellow perch harvest in eastern Lake Erie.

Existing angler survey data from 2002-2016 were used to simulate potential changes in daily creel limits for yellow perch. This period represents a wide range of stock conditions and levels of angler success (NYSDEC 2017). A detailed description of NY's "access survey approach" methodology (Pollock et al. 1994) and analysis can be found in NYSDEC technical

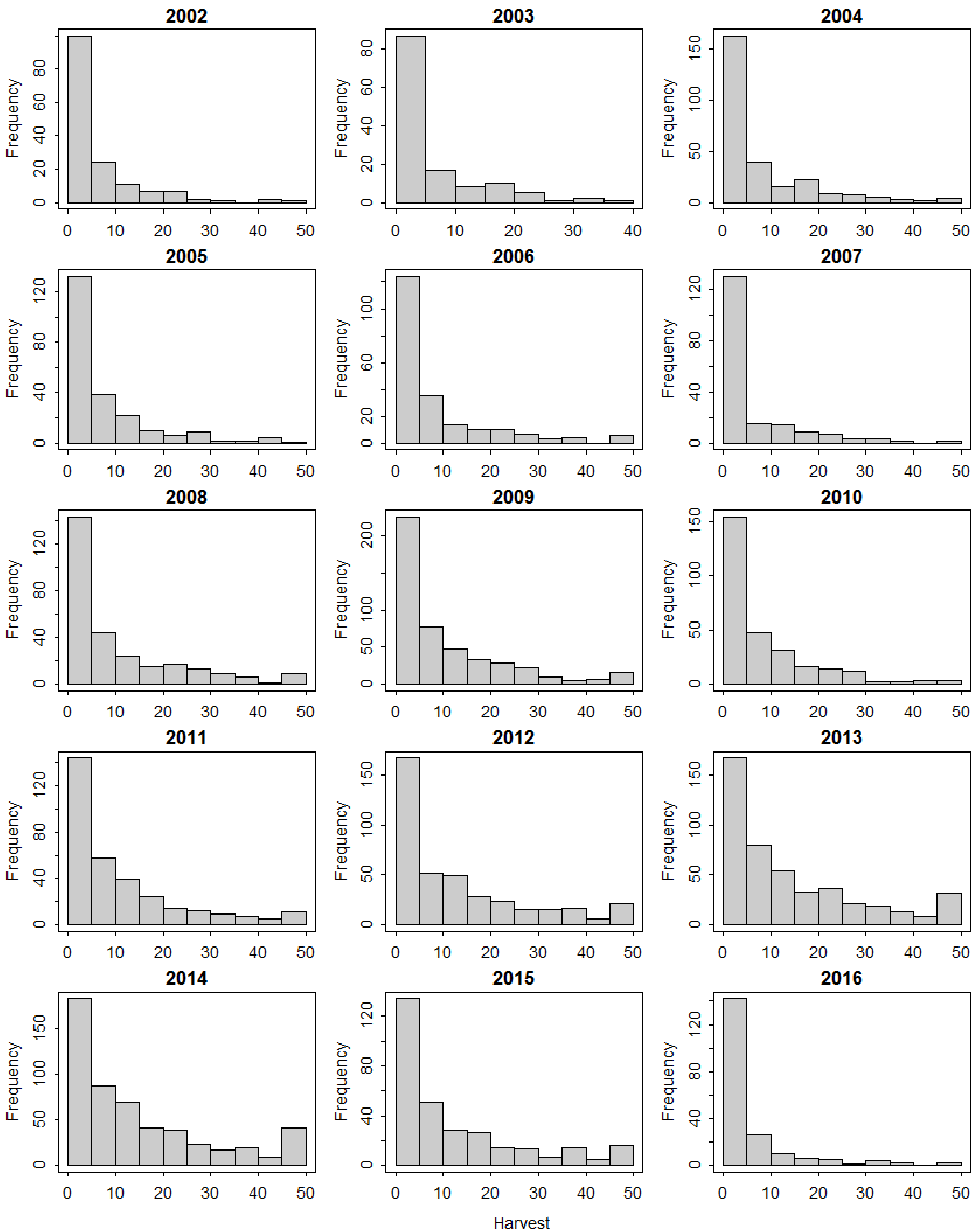

Figure 5. Frequency distribution of yellow perch harvested per angler trip in the New York waters of Lake Erie from 2002 to 2016. Data are binned in 5 fish increments.

reports (NYSDEC 2017, Einhouse 2005). Daily limits from 0 to 50 were simulated in five fish increments. Although daily limits are regulated for individual anglers, there is no regulatory language for "boat limits" per se. Simulated changes in daily limits were applied by constraining the maximum harvest of each fishing boat to the number of anglers multiplied by the proposed daily limit. For example: if an angling party of two individuals harvested 70 fish and the simulated daily angler limit was 50, the collective boat limit would be 100, so the harvest would not change within the simulation. However, to simulate a daily limit of 30, that same party's harvest would be reduced from 70 to 60 prior to performing the analysis that would estimate total harvest. This approach assumes that if an angler achieved a full limit, that angler would have also achieved a lower creel limit during the same trip. This approach ignores the potential for human behavior to alter fishing effort and harvest. As daily limits are reduced some anglers may leave the fishery in response to diminished harvest opportunities, or perhaps from a perception that lower daily limits imply poor angling quality.

We also simulated the potential for lower daily limits to incentivize harvest by making it easier for an angler to achieve a full limit. This "incentivized harvest" hypothesis assumes that an angler closer to their limit would be more likely to expend some additional effort in an attempt to "limit out". There is evidence for this behavior in our harvest data (Figure 5). During years with exceptional fishing quality we observe a higher number of limit catches relative to catches just below the limit, indicating that some anglers potentially extend their effort to achieve the limit. This "incentivized harvest" was simulated by increasing an angler's harvest to the limit if they were within five fish of the new limit. For example: if the limit was lowered to 30 and an angler harvested 26 fish, that angler would keep fishing until they attained their limit. This assumes that achieving a limit is the goal and that if an angler is very close to a limit they are likely to keep fishing.

Results

Model performance

Model 5, which used the current year's untransformed May and June harvest data to project total harvest, had the best performance based on the TPE performance statistic. This indicates that the projections from model 5 were closer to the actual measured harvest than the projections based on the other models (Table 3). Models 5 and 6 (TPE: 1.02, 1.25 respectively), which used the current year's May and June harvest data, outperformed models 1-4 (TPE: 2.86, 2.82, 3.21, 4.14 respectively), which used the previous year's metrics to predict harvest. Models that used the current year's May and June harvest data (models 5 & 6) correctly projected the direction of the harvest (Table 3). That is, they successfully predicted if harvest increased or decreased in any given year (Figure 6). Conversely, models 1 – 4 were not able to consistently predict the direction of the harvest trend. Figure 6 presents the projections of total harvest (commercial included) based on the best performing within-year model (model 5) and the best performing model that uses the previous year's information (model 2). There was a substantial amount of error associated with all model projections, including those based on model 5. Prediction intervals (95%) for models 2 and 5 indicated that NY quota would not be exceeded over the period examined (2012-2016, Figure 7, Table 3). Upper 95% prediction intervals for all other models exceeded quota in at least one year.

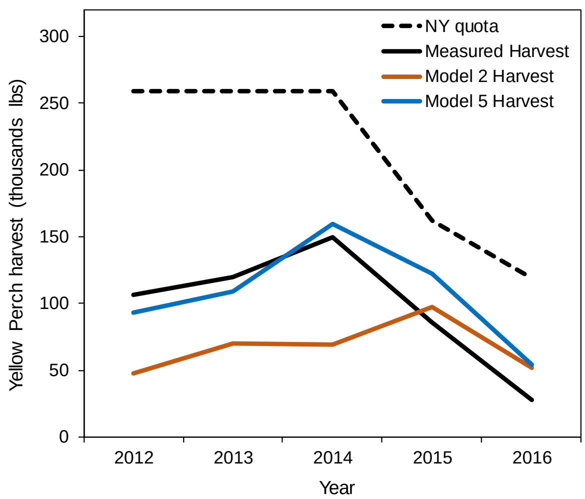

Figure 6. Projection of total harvest based on models 2 and 5 relative to actual measured harvest in lbs. of yellow perch. The dashed line represents the New York yellow perch quota from 2012 to 2016. The solid black line represents the combined reported commercial and estimated recreational yellow perch harvest in New York waters. The orange and blue lines represent the projected harvest based on models 2 and 5, respectively. Projections for models 2 and 5 include the addition of 15,000 lbs. to represent the projected commercial harvest

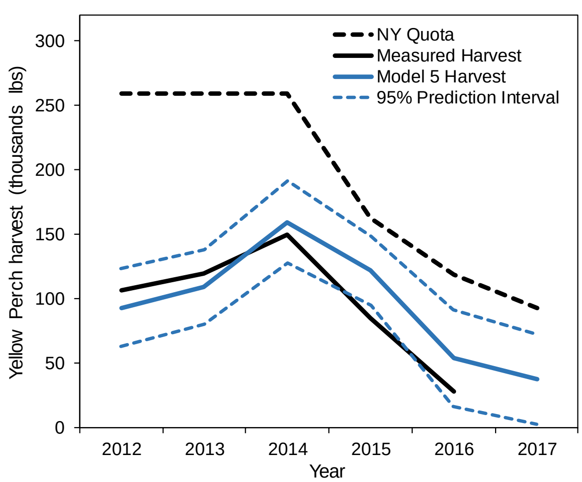

Figure 7. Projection of total harvest based on model 5 relative to end-of-year harvest estimates in lbs. of yellow perch. The black dashed line represents the New York yellow perch quota from 2012 to 2016. The solid black line represents the combined measured commercial and estimated recreational yellow perch harvest in New York waters. The solid blue line represents the projected harvest based on model 5. Dashed blue lines represent the 95% prediction intervals associated with model 5 projections.

Table 3. Total prediction error (TPE) score, percent correct directionality, and percent quota prediction for each model. Percent directionality is the percent of the time the model correctly predicted if the harvest would increase or decrease. Percent quota is the percent of the time that the upper 95% prediction interval correctly predicted if the harvest would exceed the annual quota.

Model	TPE	% Directionality	% Quota
Model 1	2.86	50	80
Model 2	2.82	75	100
Model 3	3.21	75	80
Model 4	4.14	50	60
Model 5	1.02	100	100
Model 6	1.25	100	80

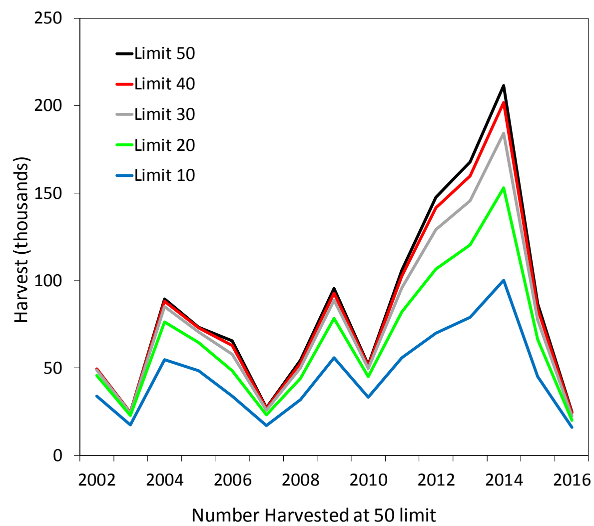

Figure 8. Number of yellow perch harvested in the recreational fishery through time (2002-2016) based on simulated daily limits of 50 (current limit), 40, 30, 20, and 10 fish.

Simulating changes in daily limit.

Simulation results indicate that reductions in harvest based on changing daily limits were highly dependent on stock conditions (i.e. the total harvest or angler success), the daily limit selected in the simulation, and the interaction of total harvest and daily limit. Decreasing limits resulted in reductions in overall harvest regardless of the stock conditions at the time of the limit change (Figures 8 and 9). However, decreasing daily limits had a greater impact on overall harvest as stock conditions improved

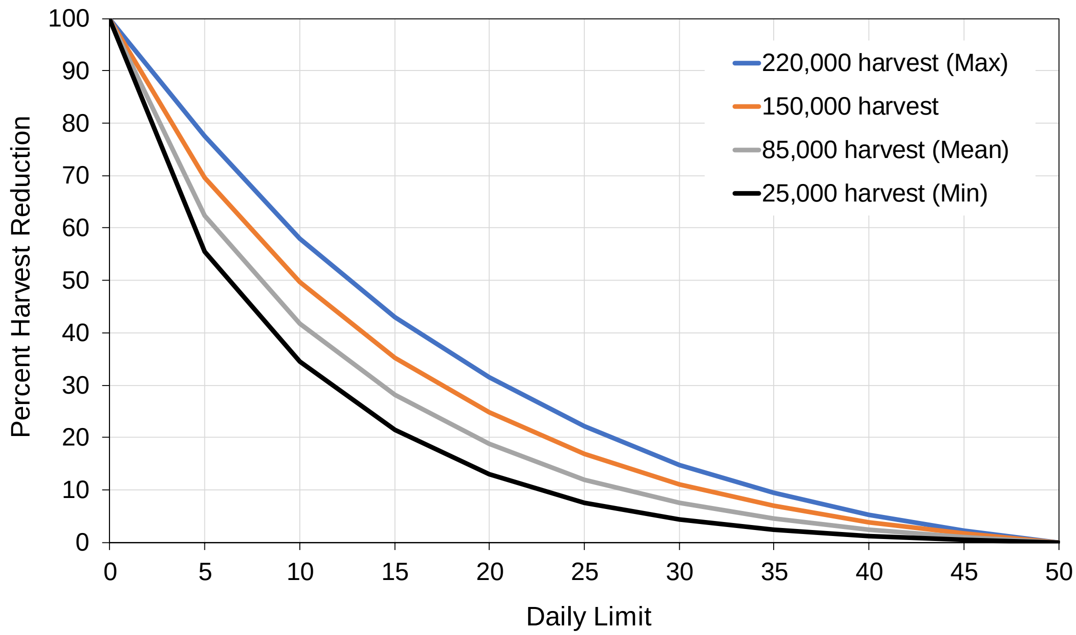

Figure 9. Expected percent harvest reduction across a range of potential daily limits and four levels of total harvest. Each line represents a simulation based on different total harvest conditions ranging from the minimum observed (black) to the maximum observed (blue).

(i.e., overall harvest increased, Figures 9, 10, and 11). For example: if the limit was decreased from 50 to 20 fish, the percent reduction in harvest at the lowest stock condition observed would be 13%, compared to a 30% reduction at the highest stock condition observed (Figure 11). Stock condition had a much greater impact on the effect of daily limit regulations as daily limit became more conservative (Figures 10 and 11). For example: adopting a very conservative limit of 10, results in a decrease in harvest of between 34% and 53% depending on stock status. In contrast, a daily limit of 40 would result in a percent reduction between 1% and 5%, relative to the existing 50 fish limit.

Simulation results indicate that the potential effect of incentivized harvest through lowering daily limits was minimal for the NY recreational yellow perch fishery (Figure 12). The effect of incentivized harvest increased as the limit decreased. Decreasing the daily limit from 50 to 20 resulted in a harvest increase of only 1% to 5% due to simulated incentivized harvest. A daily limit of ten resulted in incentivized increases in harvest from 8% to 15%.

Research Conclusions

1. Using known May and June harvest estimates to predict the remaining total annual harvest in the current fishing year was relatively successful, but a high level of uncertainty was associated with the estimates.

2. Our ability to accurately predict yellow perch harvest prior to the start of fishing season based on previous years' data is very limited although model 2 successfully predicted that quota would not be exceeded.

3. The prospect of enacting meaningful reductions in yellow perch harvest through daily limit reductions occurs only during periods of high population abundance and would require a substantial limit reduction to be effective under current fishery conditions.

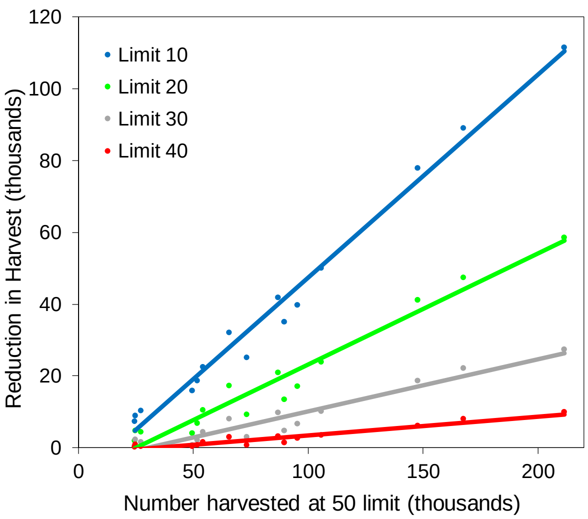

Figure 10. Simulated reduction in number of recreationally harvested yellow perch at four potential daily limits. Reductions are relative to the number harvested at the current limit of 50 perch. Values on the x axis represent harvest that occurred at the current 50 limit under many stock conditions.

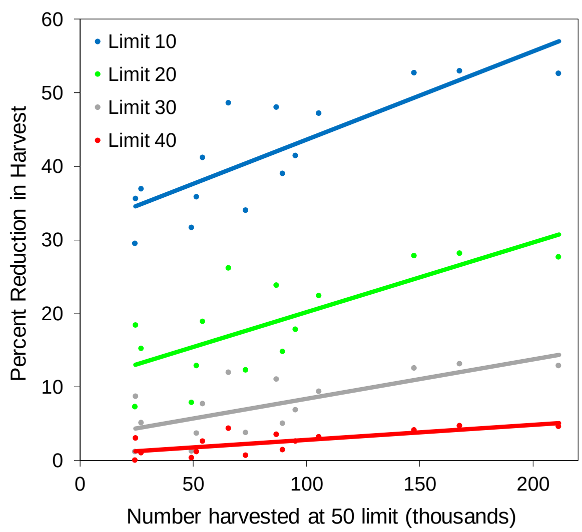

Figure 11. Simulated percent reduction in number of recreationally harvested yellow perch at four potential daily limits. Reductions are relative to the number harvested at the current limit of 50 perch. Values on the x axis represent harvest that occurred at the current 50 limit under many stock conditions.

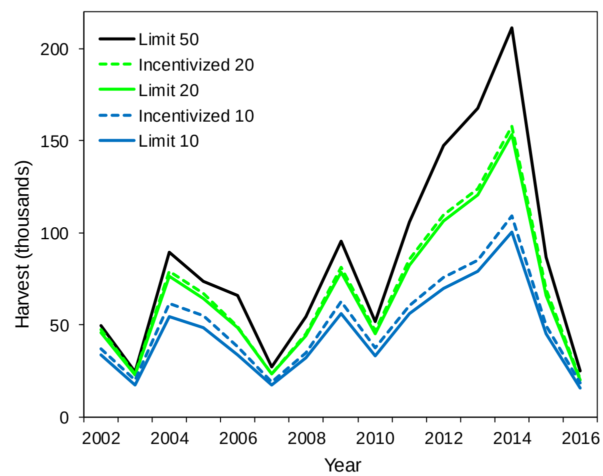

Figure 12. Number of yellow perch harvested in the recreational fishery through time (2002-2016) based on simulated daily limits of 50 (current limit), 20, and 10 fish. Dashed lines of the same color represent simulated incentivized harvest.

Discussion

Understanding how stock status, angler behavior, and regulations interact to influence overall harvest is essential for making science based management decisions. However, recreational fisheries managers often suffer from a paucity of data on which to base these decisions. In the absence of data, managers are forced to implement regulatory changes based on intuition, public pressure, or through a sense of exercising necessary caution without knowing if regulatory changes are likely to have the intended effect. The Lake Erie fisheries management environment is the beneficiary of a long history of high quality, long-term data describing yellow perch fishery and population dynamics which can be brought to bear when making science based management decisions. Yellow perch are one of the most recreationally and commercially important species in the NY waters of Lake Erie. Here we take a model- and simulation-based approach to understand how we can project harvest to ensure quota compliance and moderate harvest through regulation, if necessary. We tested several model-based methods for projecting yellow perch harvest based on previous and current years' fishery independent and fishery dependent data. We also simulated the effect of changing harvest regulations and angler behavior on total yellow perch harvest across a range fishery conditions.

Models that predicted harvest prior to the start of the fishing season (models 1–4) performed poorly as predictors of future harvest, and in many cases failed to predict the directionality of changing annual harvest (*e.g.* reductions of harvest in 2015). Models that used the current year's May and June harvest to predict total harvest in the rest of the year (models 5-6) had better performance and could successfully predict the direction of harvest as well as whether the harvest would remain under quota. Therefore, the model results indicated that some known harvest data from the current year are more useful when trying to project the current year's total yellow perch harvest than a large amount of data from previous years. This is somewhat intuitive because using May and June harvest data to predict the current year's total harvest dictates that some portion of the harvest has already occurred. Even so, the large amount of uncertainty surrounding model-based harvest projections is likely to limit the utility of these models as a tool to drive regulatory changes. Moreover, using models that require data from the current year is limiting because it greatly reduces the amount of time in which to consider options, and potential actions become more onerous to implement. Even though models that predicted harvest prior to the start of the fishing season performed poorly relative to those that used May and June data from the current year, they have some potential utility in that they give more advanced warning about the chances of exceeding quota. It seems logical that an iterative approach should be taken when applying the results of this work to management in a real-world setting.

The results of this modeling exercise indicate that NY's recreational yellow perch harvest in Lake Erie is not tied exclusively to stock size. If it was, measures of abundance from our various surveys and lakewide stock assessments would be excellent predictors of future harvest. Many other factors beyond the scope of these models likely impact angler success, including weather, fishing quality for other prominent species, forage base, fish movement patterns, and the overall capacity of our recreational fleet to exploit yellow perch.

Simulation results illustrating the effectiveness of harvest regulations should be very useful in informing regulatory decisions surrounding recreational catch limits for yellow perch in the NY waters of Lake Erie and potentially elsewhere. The ability to moderate harvest using daily limits was strongly positively related to the overall level of harvest (*i.e.*, stock size and angler success). As stock size and angler success increases, reductions in harvest limits are more effective at reducing harvest because proportionally more anglers can achieve a limit. However, the ability to make meaningful harvest reductions with regulation changes is limited because most anglers achieve only modest harvest levels even in years with exceptionally high stock size and angler CPE. For example, during 2014 when the highest angler CPE was documented, only 16% of anglers harvested more than 30 yellow perch and the median harvest per angler was only 10 fish. Under these conditions, the daily limit would need to be reduced from 50 to 25 to achieve a 20% reduction in total harvest, saving approximately 40,000 yellow perch. At low stock sizes and levels of angler success, even more restrictive harvest regulations would be necessary to achieve meaningful reductions in harvest. Other investigators also found that changes in daily limits had little effect on total harvest or individual angler harvest for walleye (*Sander vitreus*) and white crappies (*Pomoxis annularis*), (Munger and Kraai, 1997; Webb and Ott, 1991).

Our simulation results may be most useful in illustrating the limits of our ability to regulate recreational harvest. When angler success and accompanying harvest is low due to insufficient abundance of desirable size classes of yellow perch, anglers often advocate for restrictive daily limits to reduce harvest and preserve spawning stock biomass. As an example, in 2016 – a year with relatively low stock size and angling success – some Lake Erie yellow perch anglers advocated that the daily limit be lowered to 30 as a conservation measure. Our simulation shows that this regulation change would have resulted in only a 9% reduction in harvest which would have saved approximately 2,000 yellow perch. The potential effectiveness of such a regulation change would be further reduced if implemented as an emergency measure later in the fishing season. This simulation will allow us to respond to future angler inquiries about regulation changes from a scientific, data-driven position. These results should generally apply to smaller scale, harvest oriented fisheries that do not have the associated long-term data required to implement the analyses presented here. The results of this work will help managers make informed decisions regarding reduced limit regulations and their potential impact on conserving fish stocks.

It is likely that changing angling regulations would result in changes in angler behavior that would affect harvest (Beard et al. 2003). We attempted to address one of these changes in behavior by simulating potential for harvest to be incentivized by lowering the limit. The rationale for this simulated behavior is that when anglers near their daily limit, they are likely to expend some additional effort to try to achieve their limit. There is evidence for this behavior in Lake Erie angler survey data and through our own experiences as anglers. Our simulation indicated that there is potential for a small amount of increased harvest due to this behavior. However, the amount of added harvest associated with this behavior is inconsequential compared to the overall reduction in harvest resulting from the decreased limit.

It is important to consider how other regulation induced changes in angler behavior could influence our simulation results. As the limit is lowered, it is likely that some anglers would stop, or reduce their fishing effort. This response is probably not linear, nor is it likely to be fully rational. Even in the best fishing years most anglers do not harvest 20 yellow perch per trip. However, lowering the limit to 20 would probably result in anglers exiting the fishery due to a perception that their harvest would be reduced. This effect is likely to be short lived at reasonable harvest levels, because anglers will likely adapt to the new norm over time. When the walleye limit in the NY waters of Lake Erie was lowered from 5 to 4 (in 2002), there was initial angler dissatisfaction which quickly dissipated once anglers became accustomed to the new regulation. Other investigators have found evidence for reduced effort in response to daily limit reductions (Beard et al. 2003). This effort response is not necessarily linked to fishing quality but rather to the perceived implications of the lowered limit. Our estimates of the impact of reduced harvest limits on overall harvest are best viewed as minimum because we cannot account for behavioral changes, especially at more restrictive limits. It is also important to consider the potential for regulations to influence angler norms for harvest expectations. Establishment of an upper bound on daily harvest is consistent with the concept that unbounded exploitation of natural resources can be risky. The current limit on yellow perch harvest (*i.e.* 50 per angler) was established with this foundation and the accompanying concern that commercialization of angler caught yellow perch could expand without catch limits.

As part of this work we developed a decision tree (Figure 13) to illustrate the timing of potential decision-making steps, and expose challenges and uncertainties that could arise. Each March the LEC adopts a TAC recommendation for the upcoming fishing year, and very shortly

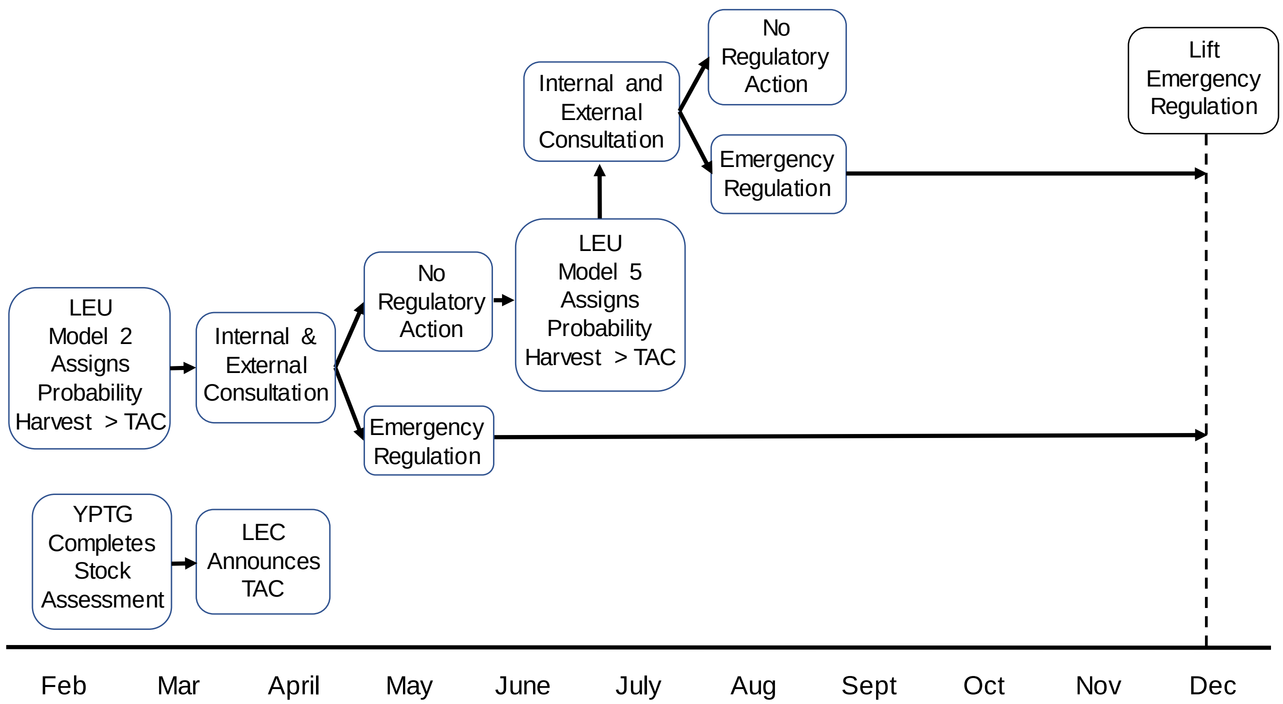

Figure 13. Decision tree detailing how managers of the New York yellow perch fishery would decide if there was a chance of exceeding quota and if so what steps should be taken, if any, to prevent it.

thereafter most LEC jurisdictions also implement regulations (if needed) to remain compliant with this TAC decision. Based on the work presented here, beginning each March, NY will run our best performing model using the previous year's information (currently Model 2) to project total yellow perch harvest. Model results will assign a probability that NY's harvest will exceed quota. These results will be communicated to the NYSDEC Great Lakes Section Head and the Chief of Fisheries. If the probability of exceeding quota is sufficiently low, then no further action would be taken in the spring. Conversely, if the projected harvest is likely to exceed NY's quota, regulatory actions would be considered based on strength of model projections and accompanying knowledge that projected harvest estimates remain very uncertain at this stage of the annual management cycle. A suite of regulatory options and their potential impact would be evaluated and the best course of action selected following consultation with senior NYSDEC staff and members of the LEC.

A second opportunity to predict the probability of NY exceeding quota occurs in early July, using the best performing "within year" model (currently Model 5) to project total annual sport harvest from estimated May-June harvest. Again, the results of this model will be communicated to the NYSDEC Great Lakes Section Head and the Chief of Fisheries. If the probability of exceeding quota remains low, no action will be considered for the remainder of the fishing year. However, if the total harvest estimated in July appears likely to exceed NY's quota, potential regulatory actions would be evaluated following consultation with senior NYSDEC staff and members of the LEC. If a regulatory action is recommended, an emergency regulation would need to be implemented. This regulation would extend only to the conclusion of the current quota year. Regulations would revert to the status quo in the following quota year unless there was a compelling reason to believe that quota would be exceeded in the following year. It is critical that uncertainty, risk, and opportunity cost be considered at every node in the decision tree.

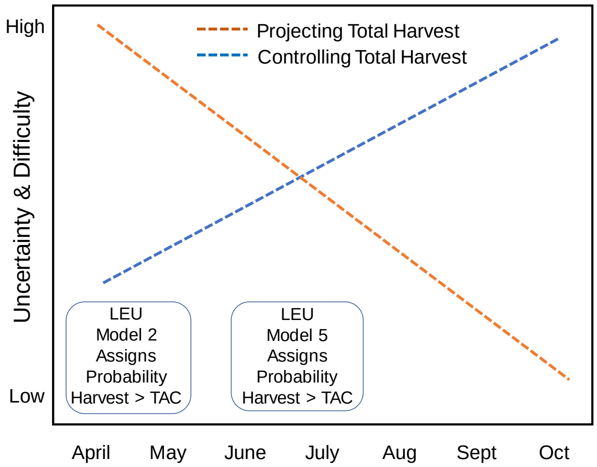

Figure 14. Conceptual diagram of the relative uncertainty associated with model projected harvest and the difficultly associated with implementing effective emergency regulations as the fishing year progresses.

In Figure 14 we conceptualize trade-offs between uncertainty in projecting NY harvest through the current fishing season and difficulty in implementing short-term emergency measures to remain below quota. Each March, NY will be faced with high uncertainty in assessing whether NY's harvest might exceed quota for the upcoming fishing year. By July the ability to estimate total harvest has improved while the effectiveness of reduced daily limits to control harvest is compromised with every passing day. Fortunately, under NY's current fishery conditions, it seems that emergency regulatory actions would very seldom be needed to maintain quota compliance. Nevertheless, we advocate that annually performing the prescribed modeling exercise and steps of the accompanying decision tree will be useful in keeping NYSDEC managers and LEC partners informed of NY's yellow perch harvest expectations, and in deliberating accompanying ramifications, if necessary. The model, simulation, and general process laid out here should be flexible enough to accommodate changing conditions.

Management Implications

Many challenges and uncertainties are associated with implementing a within-year emergency regulation to limit yellow perch harvest. These include public reaction, the short timescale in which to act, and uncertainty surrounding the projected effectiveness of the proposed regulation. The decision tree should be thought of as a tool for considering these challenges and uncertainties before they occur rather than a strict blueprint driving management actions. Thinking through the decision-making process as part of this work helped identify many of the challenges associated with actively managing for quota compliance in a largely recreational fishery. In most situations, the opportunity cost of acting and being wrong likely outweighs the benefit of taking actions to stay under quota, especially since our simulation indicates that management actions necessary to limit harvest over a short timescale would need to be very restrictive, and likely unpopular, to be effective. Moreover, implementing an emergency regulation half way through the fishing season further reduces the effectiveness of any regulation. The strength of this approach is much more in advanced notification and increased understanding rather than regulatory action. Notifying our partner agencies of the potential for NY to exceed quota before it happens is acting in the spirt of GLFC consensus management agreements. Understanding the limits of our ability to predict and manage harvest for our recreational yellow perch fishery allows us to be realistic when considering management actions.

New York is on the liberal end of the regulatory spectrum regarding yellow perch daily harvest limits on Lake Erie and in the Great Lakes in general (Table 1). Michigan, Ontario, and NY have 50 fish limits, while Ohio and Pennsylvania currently have 30 fish limits. Pennsylvania and Ohio can adaptively change their yellow perch limit depending on the stock size and the quota each year. Our analyses indicate that any change in daily limit regulations that would be in the range of those considered by other Lake Erie agencies would not have a substantial impact on yellow perch harvest in NY waters. We routinely receive angler requests to lower the daily limit for perch under the assumption that a decreased limit will reduce harvest. We must be able to speak to the effectiveness of these requests based on rigorous analysis, and thereby avoid succumbing to pressure to implement regulations that may appear conservative, but are otherwise ineffective. This work indicates that to have a meaningful impact on harvest, the limit would have to be lowered to a minimum of 20. A relatively restrictive limit of 10 to 20 yellow perch would likely not be palatable to NY anglers but is not unreasonable relative to yellow perch daily limit regulations in many other Great Lakes states (Table 1). Moreover, daily limit reductions only become effective at reducing harvest at relatively high stock sizes, when anglers are not especially focused on over-harvest problems.

In the absence of significant co-occurring commercial yellow perch fisheries (most notably in Ontario waters) on Lake Erie, it is unlikely that a quota based approach would be used for management of recreational fisheries. The NY recreational perch fishery responds to changes in abundance by increasing or decreasing effort in kind, indicating some level of self-regulation, and the NY commercial yellow perch fishery is not of significant scale to derail self-regulation in the fishery. However, managing broadly shared, interjurisdictional Lake Erie fisheries resources necessitates lake-wide cooperation in the quota based management structure to maintain sustainable fish stocks. New York and the entire Lake Erie fisheries management community agree to pursue good faith efforts to stay within quota recommendations. In recent years, there has been an increasing recognition of the difficulties associated with managing Lake Erie recreational fisheries via the quota management format. This analysis indicates that NY's ability to predict when we will exceed quota and then prevent quota from being exceeded using preemptive regulatory changes is limited. Selecting a daily limit that is likely to produce consistent quota compliance over a broad range of conditions is the most efficient way to proceed provided the performance of the commercial fishery remains consistent. New York's current yellow perch sport fishing regulation (50 fish daily limit) has thus far proven effective for remaining quota compliant, albeit with a few close calls over the last 23 years. Still, the ability to inform senior NYSDEC managers and our Lake Erie partners in years that there is potential for NY to exceed quota and to illustrate the potential management actions necessary to perhaps achieve quota compliance is the only responsible way to proceed within the current management structure.

This analysis was conducted based on the recent past and current performance of commercial and recreational yellow perch fisheries in the NY waters of Lake Erie. While this work indicates that New York has limited ability to project and control yellow perch harvest, this may not always be the case. Changes in the scale of NY's commercial trapnet fishery, ecosystem shifts, species introductions, changes in angler attitudes or demographics, shifting stock productivity, or changing catchability could all alter yellow perch fishery dynamics such that harvest predictors may improve along with our ability to effectively regulate harvest. This analysis may also inform future regulatory decisions that are not driven by yellow perch quota compliance. Caution should be used when considering curtailing recreational harvest in the name of yellow perch quota compliance or conservation when there is little evidence that any regulatory action will have an impact beyond public perception. The chief benefit of this research is that it provides us with a scientific basis that underlies our current regulatory framework and upon which future decisions can be based.

Management Conclusions

1. Understanding how fisheries and regulatory tools perform over a range of population conditions allows us to pursue more informed regulatory decision-making and effectively communicate those decisions based on available science
2. The high uncertainty associated with projecting harvest and the drastic cuts in daily limit that would be necessary to avoid exceeding quota likely means that projecting harvest is an exercise in advanced notice rather than emergency actions.
3. Adopting an “emergency” regulatory action of reducing daily limits with the objective of remaining compliant with quota decisions appears to be effective only when fishing is exceptional and stocks are at high levels, which will likely be counter-intuitive to the angling community.

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