GREAT LAKES FISHERY COMMISSION

1983 Project Completion Report[1]

Application of Quota Management to Yellow Perch in Lake Erie

by:

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[1]Project completion reports of Commission-sponsored research are made available to the Commission's Cooperators in the interest of rapid dissemination of information that may be useful in Great Lakes fishery management, research, or administration. The reader should be aware that project completion reports have not been through a peer review process and that sponsorship of the project by the Commission does not necessarily imply that the findings or conclusions are endorsed by the Commission.

INTRODUCTION

This report is the fourth in a series of studies of alternative procedures for setting quotas for Lake Erie fisheries. In previous reports (Shuter _et al._, 1979; Koonce and Shuter, 1979, 1981), we have analyzed historical data from the walleye fishery in Western Lake Erie to determine the existence of a stock-recruitment relationship and sources of environmental variability. With these analyses, we used both simulation and stochastic dynamic programming techniques to develop biologically optimal strategies of harvesting the walleye population. The results of these studies suggested that alternative quota derivation procedures were feasible and that a range of policy options could be explored. Furthermore, these analyses could in principal be extended to other species, and the possibility of interactions between yellow perch and walleye led us to prefer extension to yellow perch and possible joint management of yellow perch and walleye. Our original proposal stated three objectives:

1. To analyze historical data of yellow perch harvest in the western and central basins of Lake Erie to obtain patterns of mortality and recruitment for the species;
2. To explore optimal strategies for establishing quotas for perch based on the data analyses in 1 and our stochastic dynamic programming algorithm; and
3. To study through simulation and limited dynamic programming the consequences of both independent and joint management of walleye and yellow perch through quota estimation procedures developed earlier.

Two initiatives of the Lake Erie Committee, however, resulted in an altered set of objectives during the project period. These two initiatives were the formation of a Yellow Perch Task Group under the chairmanship of Gary Isbell of Ohio Division of Wildlife and a call for an Adaptive Management Workshop on fish community management in Lake Erie. Because these two initiatives blended well with our original objectives, we modified our objectives to take advantage of joint work with various federal, state, and provincial agencies in the context of the Yellow Perch Task Group and the Lake Erie Fish Community Workshop. Given the priorities in these initiatives, therefore, our work on yellow perch quotas focused only on central basin populations, and joint management consequences were explored through simulation only. Although reports have already been made for the Yellow Perch Task Group (Isbell, 1981) and the Lake Erie Fish Community Workshop (Koonce et al., 1982), some additional technical details and alternative formulations of models are reported here.

ANALYTICAL PROCEDURES

In many ways, the extension of our procedures to yellow perch was not difficult. The existence of good catch records for the central basin allowed the Yellow Perch Task Group to estimate historical population dynamics by directly estimating virtual population from the harvest data. Both mortality patterns and stock-recruitment relationships could be obtained from these data. Because these analyses were to be used in policy decisions by the agencies, however, uncertainty about the accuracy of the analyses became quite important. To a similar degree, the Walleye Task Group faced a related problem when considering some of the alternative management strategies suggested in our earlier work. Uncertainty about the current state of the walleye stock and about natural mortality levels did not allow a comfortable committment to drastically higher quota levels. Much of the technical analysis performed in this project, therefore, dealt directly with sources of uncertainty and their effects on policy options. We took two approaches to this problem: a direct examination of error in estimation of stock-recruitment relationships and a retrospective analysis of error propagation from catch data collection to quota derivation.

Two different sources of uncertainty complicate the development of stock-recruitment relationships for quota derivation. The first is the difficulty of selecting a basic model appropriate for the analysis of data, and the second is parameter estimation for any single model of stock-recruitment. In our earlier work on walleye, we compared two models, a power function and a Ricker type function, in terms of the quota recommendations that could be derived from each model. For walleye, these two models had quite different policy recommendations (Koonce and Shuter, 1981), but for biological reasons we chose to rely on the Ricker model. Nevertheless, in the work reported here, we were sensitive to the implications of model selection. Before discussing tentative results from further consideration of this problem, however, we must move to a more general consideration of uncertainty in parameter estimation for any model.

Both walleye and yellow perch stock recruitment relationships have large process error or combination of process and measurement error. These problems are common to many stock-recruitment cases (Walters and Ludwig, 1981), and parameter estimation becomes a serious problem (Waltes and Ludwig, 1981, Ludwig and Walters, 1981). In the context of using these estimated parameters to derive management recommendations, uncertainty about the effects of estimation errors on quotas or fishing mortality limits confidence one may place in recommendations. As Walters and Ludwig (1981) point out, observation errors can lead to biased parameter estimates, and these biased parameters may lead to overexploitation policies. Where a Ricker stock-recruitment relationship is assumed, however, effects of uncertainty must be determined on a case by case basis.

To interpret effects of uncertainty on Lake Erie fishery management requires an explicit statement of the relationship between parameter estimation and policy variables. Recent management initiatives by member agencies in the Lake Erie Committee indicate a preference for quota management. Following the example of the Walleye Task Group, quota recommendations depend upon 1) identification of the abundance and age structure of the population; 2) estimation of the abundance of the fishable stock; and 3) selection of a fishing mortality level that can be used to calculate a quota.

Although never pursued as an actual goal of management policy, the concept of maximum sustainable yield has been a convenient reference point for quota recommendation (cf. Isbell, 1981). Our procedure, therefore, is to relate various sources of uncertainty to the fishing effort required to produce a maximum sustainable yield for a defined catchability schedule (i.e. age specific catchability, Ricker 1975). As we have shown in earlier work (Koonce and Shuter, 1981), this effort is a useful reference in both deterministic and stochastic policy formulations. In our work with formulation of control laws based on stochastic dynamic programming, these control laws when analyzed during simulation recommend a mean fishing effort equivalent to that derived from a deterministic model. Our previous work, however, relied upon simulated catch vs. effort curves for estimation of optimal effort, and we developed an analytical procedure to calculate optimal efforts.

Garrod and Jones (1974) outlined a method for computing optimal harvest given parameters for a stock-recruitment relationship in an age structured population with overlapping generations in the fishery. Their approach requires a reformulation of the stock-recruitment relationship to put recruitment and stock in the same units. To provide a similar assessment, we assumed steady state population dynamics and provided for alternative stock-recruitment models.

Following Walters (MS), we formulate the population dynamics as a simple balance model.

$$N_t = N_{t-1}\, s + G\,(faN_{t-1}, \underline{B}), \qquad (1)$$

where N_t is the total abundance of individuals age k and older.

$$N_t = \sum_{i=k}^{\infty} N_{k,t},$$

s is the average survival, a is the fraction of the population that is reproductively mature, f is the average fecundity, and $\underline{B}$ is a vector of parameters for a given stock recruitment function, G. Using ordinary life table notation, mean survival may be formulated as

$$s = \frac{(\sum_{i=k}^{c-1} l_i s_i) + l_c/(1-s)}{(\sum_{i=k}^{c-1} l_i) + l_c/(1-s)}$$

l_i is the surviorship of age group i, where $s_i = \exp\,(-q_i\, E - m_i)$ with q_i

being age specific catchability (normalized to maximum catchability), E being fishing effort, (in units of 1/yr) and m_i being natural mortality. Definition of other coefficients include: c is the age of full recruitment to fishery (i.e. $q_i = 1.0$) and s is the survival fraction of these fish. Notice that this formulation does not allow for a dome shaped catchability schedule. Similarly, a may be formulated as:

$$a = \frac{(\sum_{i=k}^{m=1} r_i l_i) + l_m/(1-s)}{(\sum_{i=k}^{c-1} l_i) + l_c/(1-s)} ,$$

where r_i is the fraction of an age group that is reproductively mature, m is the age of full reproductive maturity, and the other terms are as described above.

For a Ricker stock-recruitment relationship, the steady-state condition is

$$N^* = N^* s + faN^* e^{(B_o - B_1 afN^*)} ,$$

which simplifies to

$$N^* = [B_o - B_1 \log (\frac{1-s}{af})] / (B_1 af). \qquad (2)$$

Harvest at steady-state is

$$H^* = N^* \frac{[\sum_{i=k}^{c-1} l_i\ q_i E(1-s_i)/z_i] + l_c/(1-s)}{[(\sum_{i=k}^{c-1} l_i) + l_c/(1-s)]}, \qquad (3)$$

where $z_i = q_i\ E + m_i$. In this formulation, optimal fishing effort, for a given parameter vector <u>B</u> and a catchability vector <u>Q</u>, maximizes H^*. This optimum can be estimated numerically by recursively evaluating equation 3 to find the effort at which dH^*/dE is zero.

Equation 3 may also be used for a power function stock-recruitment model, but the steady-state population density is

$$N^* = [B_o{}^{1/(1-B_1)}]\ [(af)^{B_i/(1-B_1)}]\ [(1-s)^{1/(1-B_1)}], \qquad (4)$$

where the power function stock-recruitment is given by

$$N_k^* = B_o\ (faN^*)^{B_1} ,$$

where N_k^* is the abundance of recruits at age k.

The fecundity coefficient, f, may be derived in various ways. If numerical harvests are of interest and if the stock-recruitment relationship is in numerical units, then f may take a value of unity. Alternatively, if effects of age specific variability in fecundity are of interest, f may be defined after Walters (MS) as

$$f = f_0 + f_1/(1-s),$$

where fecundity is assumed to increase linearly with age. In the work reported here, we only explore the first assumption. The end result of the derivation of equation 3 is that we may examine directly the effects of parameter and model uncertainty on the essential policy variable used to calculate a quota.

APPLICATION TO YELLOW PERCH QUOTAS

Using the virtual population estimates of the Yellow Perch Task Group (Isbell, 1981) and the analyses outlined above, we could examine the effects of various sources of uncertainty on this quota setting problem. Over the past few years, average catchability, in relative units, seemed to suggest that full recruitment to the fishery did not occur until age 4 and that the catchabilities for ages 1 to 3 were 0.01, 0.3, and 0.7 respectively. In our subsequent analyses, we assume this catchability schedule, but we realize that this is another source of uncertainty that may need to be explored in future work. Further assuming that 85% of 3-yr old and all older fish were reproductively mature, we could fit various stock-recruitment models to the YPTG data. The results were as follows:

Ricker Model	Power Model
$B_0 = 2.26$	$B_0 = 2.8*10^5$
$B_1 = 1.22*10^{-8}$	$B_1 = 0.294$
$F_{opt} = 0.63$	$F_{opt} = 0.60$

where the ricker model is

$$R = B_0*S*\exp(-B_1*S),$$

with R being recruits and S the adult stock, and the power model is

$$R = B_0*S^{B_1} .$$

Because optimal fishing mortality is nearly equal for the two models, the basic model as a source of uncertainty is less of a problem for yellow perch than we observed for walleye. However, the parameters of the two models are very sensitive to results at higher adult abundance, and this seeming indifference to model form may be an artifact of the particular time series we obtained.

The next source of uncertainty about which we were concerned was possible bias in parameter estimation. Walters and Ludwig (1981), propose some procedures for estimating the extent of bias in estimated parameters caused by observational errors. Using their procedures, therefore, we examined the effect of various levels of observational error. Observational error is assumed to be log-normal and the indicator of error used below is simply the standard deviation of the log-transformed error. The summary that appears below was taken directly from the parameters used in recommending quota options

(Isbell, 1982). A standard deviation of observation error of zero corresponds to a biased estimate, and the remaining error levels indicate the corrected parameters that should be used with the given level of observational error. The appropriate optimal fishing effort estimates, which were calculated using equation 3, are also included:

Error	B_0	B_1	F_{opt}
0	2.28	$1.211*10^{-8}$	0.67
0.1	2.30	$1.230*10^{-8}$	0.67
0.3	2.43	$1.386*10^{-8}$	0.71
0.5	2.75	$1.762*10^{-8}$	0.83

Taken together, these results indicate that for yellow perch any bias introduced by not considering observational error is likely to result in a conservative harvest policy.

Observational error characterized by Walters and Ludwig (1981), however, may not fully capture the kinds of data errors and sources of environmental variabity that occur in this case. To examine the way uncertainty propagates error in this case, we simulated the population and data collection for twenty year periods. In these simulations, we assumed that a yellow perch population existed with the Ricker stock-recruitment parameters estimated from the data (i.e. B_0=2.28 and B_1=$1.22*10^{-8}$). We next assumed that a random environmental process error with a standard deviation of 0.5 modified the stock-recruitment model to be

$$R = B_0*S*\exp(-B_1*S + e),$$

where e is a normally distributed random variable with mean 0 and variance of 0.25. We also assumed that only a variable fraction of the catch was actually reported:

$$C = C_t * C_1,$$

where C_t was the true catch, C_1 was a random variable with mean of 0.8 and standard deviation of 0.05. Finally, we assumed that estimation of effort incurred an additive error, which was also normally distributed with mean 0 and standard deviation of 0.05. Age composition was assumed to be estimated correctly in all cases. The hypothetical data sets thus generated contained the same information that the Yellow Perch Task Group used for yellow perch in the Central Basin. Using the same alogrithm for performing the virtual population reconstruction, we then estimated Ricker stock-recruitment parameters and optimal fishing effort indicated by them. The results were as follows for three replicate catch data sets:

Replicate	B_o	B_1	F_{opt}
1	2.60	$1.97*10^{-8}$	0.78
2	3.74	$2.21*10^{-8}$	1.17
3	1.64	$0.69*10^{-8}$	0.45

These results are inconsistent with those considering theoretical sources of observational error only. Because the true value of F_{opt} is 0.67, overexploitation is a real possibility. It is important to note, however, that this result may be the consequence of a relatively short time series and the low probability of really strong year classes. This same type of sampling variability may also be the reason why the walleye and yellow perch data sets show different sensitivity to the form of the stock-recruitment model. Clearly, this finding is an argument for the kinds of adaptive estimation procedures advocated by Ludwig and Walters (1982).

APPLICATION TO QUOTA SETTING IN MULTIPLE SPECIES QUOTA MANAGEMENT.

Uncertainty due to observational errors and model choice for a stock-recruitment function is certainly a persistent problem. In large fisheries, these estimation problems will never be completely resolved, and agencies responsible for Lake Erie management have committed themselves to long term monitoring studies to provide additional information. It seems increasingly clear, however, that single species management must be more carefully considered in a fish community context. Such a consideration should naturally include understanding of by-catch problems associated with fishing regulation (i.e. gear selectivity placement, and seasonal restrictions), but also must deal with changes that the fishery may cause in the basic stock-recruitment relationships of each of the target species.

This latter problem area has been the subject of much theoretical speculation but has seen little direct experimental work. Our approach was again to use simulation to explore the consequences of various assumed interactions among fish species to the ability to manage them as independent fisheries. The key link between community approach and single species approach remains the parameters in the stock-recruitment relationships. However, these parameters become time-varying functions of the state of the community. Although we developed a community fishery model for Lake Erie, this work served only as a guide to the more complete formulation of a Lake Erie fish community model in the workshop sponsored by the GLFC in Bowling Green, Ohio, June 1982 (Koonce et al., 1982).

The development of the Lake Erie Fish Community model revealed weaknesses in both understanding of the functioning of the community and in measurement of its state. Nevertheless, as has been observed in the Atlantic herring fishery, interactions among species may dramatically alter the apparent stock-recruitment behavior of various species (Skud 1982). In the model simulations (Koonce et al., 1982), fishery policy and species interactions could lead to extreme changes in the survival of young-of-the year. Although these findings can not yet be interpreted in a quantitative manner for Lake Erie, they do add another source of uncertainty. Namely, managers can no longer rely on increasingly long time series to formulate contemporary fishing policy.

CONCLUSIONS

At the beginning of our series of studies we felt that alternative procedures to set quotas for Lake Erie fisheries could be developed. Through application of simulation and techniques of dynamic programming, we have begun to explore the limits of various traditional fishery management approaches. Both in a statistical or sampling sense and in basic theoretical understanding, uncertainty has become the central obstacle to application of our findings. The case studies of walleye and yellow perch, however, have indicated some ways that uncertainty can be reduced. In no case, however, can uncertainty be eliminated. Rather, management actions must explicitly consider potential consequences that may follow from various sources of uncertainty and, thereby, balance various objectives of fishery management.

Although uncertainty is an obstacle to obtaining the "best" policy choice, it most certainly does not defy rational analysis. We have focused on four main sources of uncertainty: 1) Process error associated with density independent regulatory factors such as the rate of water warming in spring; 2) Observational error associated with measurement of population state; 3) Structural error associated with a model used to describe the true stock-recruitment model for a population; and 4) Errors due to historical changes in community structure - i.e. systematic or abrupt change in the parameters of the true stock-recruitment relationship. We have found that the second and fourth sources of uncertainty are particularly troublesome for the Lake Erie case. Observational errors have been shown for some fisheries (Walters and Ludwig, 1981) result policy recommendations that would cause over exploitation. This does not appear to be the case for either walleye or yellow perch in Lake Erie, but some inconsistencies in different approaches to this problem should be more carefully explored.

As Walters and Ludwig (1981) point out, measurement errors are only one source of observational error. An equally important aspect is the number of observations and their range and spacing. In the cases of walleye and yellow perch, very wide ranges of population fluctuations have been observed for at least 20 years. Our retrospective error analysis indicates that substantial variation in optimal fishery policy could be produced with such short time series. While longer time series could be obtained for Walleye, considerable care must be exercised in assuming that no major change in the density dependent regulatory factors have occurred over this time period. Thus, long time series will probably never fully resolve the observational error problem. Instead, management actions themselves must be viewed for their potential information content as well as their appropriateness to the objectives of management. In this context, we can only conclude by echoing the recommendation by Ludwig and Walters (1982) for active, adaptive approaches to fishery management. To do otherwise is to fall into a trap of increasiing uncertainty of the basis for management decisions.

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Great Lakes Fishery Commission

ESTABLISHED BY CONVENTION BETWEEN CANADA AND THE UNITED STATES TO IMPROVE AND PERPETUATE FISHERY RESOURCES

CONTRACT FOR DEVELOPMENT OF PROCEDURES TO SUPPORT THE APPLICATION OF QUOTAS TO YELLOW PERCH HARVEST IN WESTERN AND CENTRAL LAKE ERIE

This contract entered into this 26th day of March 1981 between the Great Lakes Fishery Commission (hereinafter called the Commission), and Case Western Reserve University (hereinafter called the Contractor).

1. Description of work: The Contractor will conduct research investigations to develop procedures to support the application of quotas to yellow perch harvest in western and central Lake Erie, as more particularly set forth in the Contractor's proposal, attached and made a part of this contract. It is understood that the research will be under the supervision of Dr. Joseph F. Koonce, Department of Biology.

2. Total cost: $22,842.01
   A. The total cost to the Commission for the full performance of this contract will not exceed the estimated amount specified. The Commission further advises the Contractor that any requests for additional funds must be reviewed by the Commission which could take several months. The Commission discourages the Contractor from seeking additional funds and reminds the Contractor that this agreement is a contract and not a grant. The Contractor shall notify the Executive Secretary in writing whenever it appears to the Contractor that the cost of completing the performance of this contract will exceed the total cost specified. The Commission shall not be obligated to reimburse the Contractor for, and the Contractor shall not be obligated to incur, expenditures in the performance of the work contemplated by this contract in excess of the cost limitation unless, and until, it shall have been increased by amendment of this contract.
   B. The Commission shall pay to the Contractor as full compensation for his undertakings the total cost of $22,842.01. Seventy-five percent of the total shall be payable upon receipt of the signed contract and the remaining 25% following acceptance of the final report by the Commission.

3. Time of performance: 1 June 1981 to 30 May 1982

CASE WESTERN RESERVE UNIVERSITY

Allen C. Moore, Director
Research Administration Officer

Joseph F. Koonce
Dr. Joseph F. Koonce

31 March 1981
Date

GREAT LAKES FISHERY COMMISSION

Carlos M. Fetterolf - Jr.
Carlos M. Fetterolf, Jr.
Executive Secretary

26 March 81
Date

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DEVELOPMENT OF PROCEDURES TO SUPPORT THE APPLICATION OF QUOTAS TO YELLOW PERCH HARVEST IN WESTERN AND CENTRAL LAKE ERIE

A Proposal for Research Support

Joseph F. Koonce
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Case Western Reserve University
Cleveland, Ohio

and

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Ontario Ministry of Natural Resources
Fisheries Research Section
Maple, Ontario

Submitted to the Scientific Advisory Committee
Great Lakes Fisheries Commission

Project Duration: 6/1/81 to 5/30/82
Total Cost: $22,842.01

Joseph F. Koonce
Joseph F. Koonce
Associate Professor
Department of Biology

James T. Koppenhaver
James T. Koppenhaver
Assistant Director
Research Administration
Case Western Reserve University

BUDGET

Salaries	
1. Principle Investigator (2 mos. summer, 1 mo. academic yr.)	8,500.00
2. Secretary (0.8 mos.)	750.00
3. Technician (8.4 mos)	5,600.00
Total Salaries	14,850.00
Fringe Benefit Charge on Salaries (19%)	2,821.50
Total Salaries and Fringe	17,671.50
Supplies	
Miscellaneous Supplies and Charges (Xeroxing, Drawing, Photograph, Office Supplies, etc.)	600.00
2 RL01 Diskpacks	400.00
Maintenance Charges on Computer Facility (in lieu of CPU charges)	1,000.00
Travel	
Local (Ohio and Michigan)	400.00
International (Canada)	600.00
Total Supplies and Travel	3,000.00
Total Direct Costs	$20,671.5~~1~~0
Indirect Costs (10.5% of TDC)	2,170.51
Total Cost	$22,842.01

OBJECTIVES

The objectives of this proposed project are

1. To analyze historical data of yellow perch harvest in the western and central basins of Lake Erie to obtain patterns of mortality and recruitment for the species;
2. To explore optimal strategies for establishing quotas for perch based on the data analyses in 1 and a stochastic dynamic programming algorithm, which was developed under previous contracts; and
3. To study through simulation and limited dynamic programming the consequences of both independent and joint management of walleye and yellow perch through the quota estimation procedures developed by Koonce and Shuter (1979).

JUSTIFICATION

As part of its concern for regulation of walleye catch in Western Lake Erie, the Great Lakes Fisheries Commission authorized a series of small projects to explore alternative ways of establishing quotas (Shuter and Koonce 1977; Shuter et al. 1979; and Koonce and Shuter 1979). Our approach to the quota problem deals explicitly with the effects of environmental randomness on management of walleye. In agreement with a number of other authors (Walters 1975; Walters and Hilborn 1976; and Beddington and May 1977), we found that the inclusion of random variability in stock-recruitment relationships can lead to management strategies more effective than those derived from deterministic equilibrium yield models. In fact, our work (Koonce and Shuter 1979) indicates that much higher quotas than recommended may be obtained from the Western Lake Erie walleye population if the information already available were more fully utilized.

Our current work on this problem has focused on limitations of our quota setting procedure imposed by certain assumptions and parameter conditions and on the feasibility of extending the analysis to yellow perch and possible joint management of yellow perch and walleye. Although we can not report fully on this work until September, we are encouraged by our results, and given the growing interest in yellow perch quotas in Ontario, we feel that a full scale analysis of yellow perch is justified. Furthermore, with the availability of complete analyses of yellow perch and walleye, we can formally examine the consequences of managing these populations independently and establish a framework within which to explore optimal procedures for joint management of the two fisheries.

PROPOSED WORK

Our approach to the problem of quota derivation is two-fold. First, we use a formal method known as stochastic dynamic programming to develop optimal strategies of harvesting a fish population under specified conditions. This procedure has appeared in recent literature (Anderson 1976; Walters 1975; and Walters and Hilborn 1976), and we have extended it to age-structured populations with overlapping generations (Shuter et al. 1979; Koonce and Shuter, 1979). Secondly, we evaluate the effectiveness of the strategies by simulating an exploited population over 100 year periods. This approach, however, depends upon the availability of information on stock-recruitment relationship and on sources of variability in year-class strength. Our work on the walleye in Western Lake Erie, for example, relied extensively on the data summary provided by Kutkuhn et al. (1976). Because no such data summary exists for yellow perch, we must begin this work at a different level. Our proposed work, therefore, will be in three major areas.

1. Collation and Analysis of Historical Data on Yellow Perch in Western and Central Lake Erie. Preliminary analyses of

yellow perch data collected by the Ontario Ministry of Natural Resources (Nepszy, personal communication) has indicated that a stock-recruitment relationship, which incorporates rate of water temperature increase in the spring, could account for 96% of the variability in recruitment over the period 1967-78. Because a long record of catch data, age composition of catch, and a shorter time series of index catch data are available from the Ohio Department of Natural Resources, Ontario Ministry of Natural Resources, and the U. S. Fish and Wildlife Service, we believe it is possible to reconstruct the dynamics of yellow perch over a comparable period to our previous walleye analyses. In the first phase of our work, therefore, we will collate these data for yellow perch and analyze them with appropriate environmental data to determine the possible sources of variability in recruitment. This effort will produce a stock-recruitment relationship that we will use in 2 below. In addition we can use the data sets for walleye and yellow perch to explore possible interactions between these two species.

2. Quota Studies and Simulations of Yellow Perch Management Schemes. In this part of our studies, we will repeat the analysis of strategies to set quotas that we developed for walleye in Western Lake Erie (Koonce and Shuter 1979). Our work this summer indicates that this extension is feasible, but that some new and interesting problems arise. The main difference from the walleye applications seems to be the complications that arise from fairly discrete stocks of yellow perch in the western and central basins of Lake Erie. We hope to explore this

complication more in the context of the STOCS Symposium to be held in October.

3. Studies of Joint Management of Yellow Perch and Walleye. One of the most elusive yet intriguing aspects of our studies of walleye was the possible interaction of the two fisheries and the potential existence of unintended negative consequences of managing the two species independently. This summer we are exploring possible ways of modifying our dynamic programming algorithm to analyze optimal strategies for joint management. It is too early to judge the feasibility of this approach, but we can attempt simulation studies of various independent and joint management schemes. Our approach will involve analyses of the data summaries we will prepare in 1 and information available about incidental catch of each species in gear set for the other. To the extent we can develop optimized strategies for joint management, we will also explore these in simulation studies.

COLLABORATION

Because Dr. Koonce has access to a computer facility dedicated to simulation studies and graphical analysis, most of the computation work will be performed at Case Western Reserve University, but it will be jointly designed. Dr. Shuter will be responsible for access to Ontario Ministry of Natural Resource data sets, and Dr. Koonce will contact personnel in the Ohio and Michigan Departments of Natural Resources as well as the U.S.

Fish and Wildlife Service. Dr. Koonce has already obtained an indication of interest in this problem from Scholl, Isbell, and others in the Ohio Department of Natural Resources, and we anticipate no problems in gaining access to all relevant data sets. Ontario Ministry of Natural Resources will continue to contribute Dr. Shuter's time and expenses for collaboration in this project.

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