WALLEYE-REHABILITATION GUIDELINES FOR THE GREAT LAKES AREA

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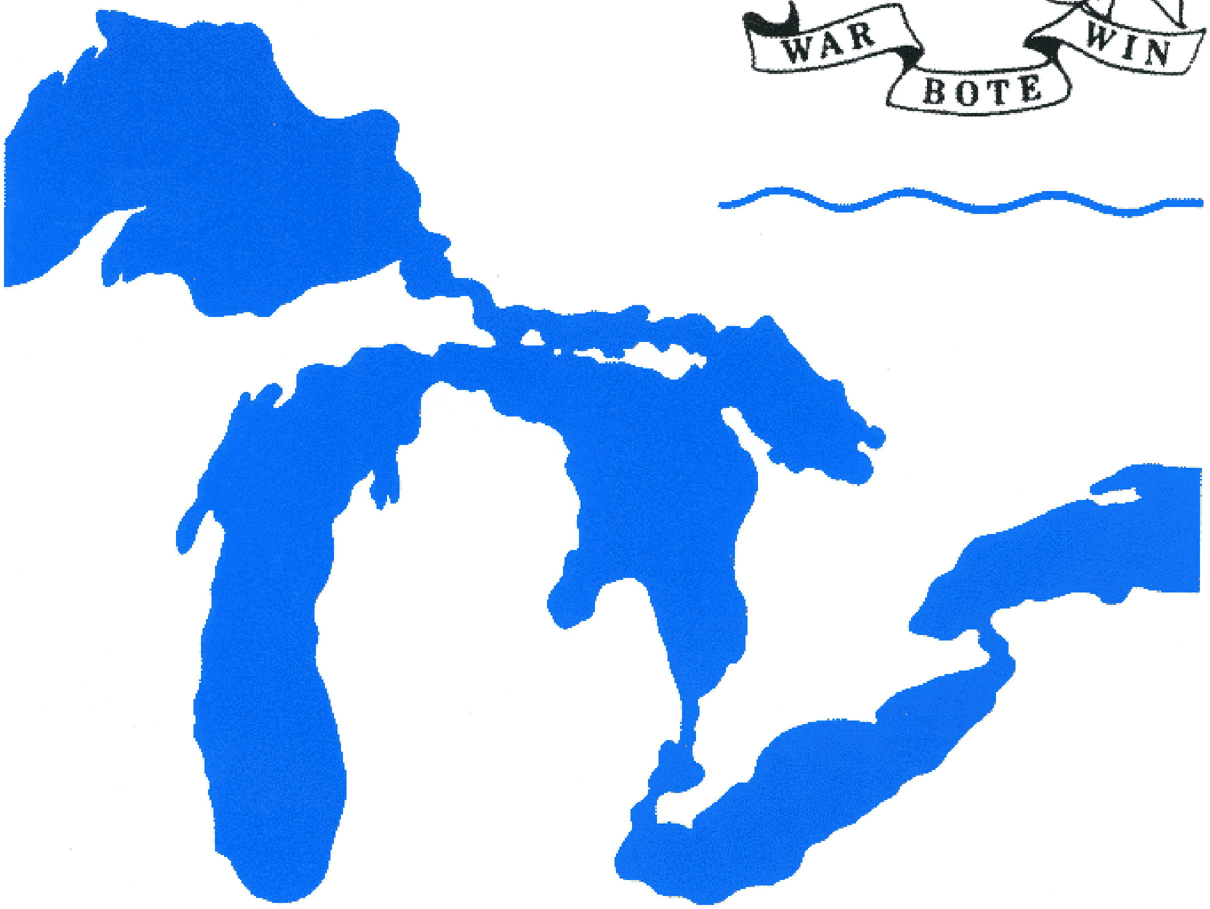

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September 1994

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WALLEYE-REHABILITATION GUIDELINES FOR THE GREAT LAKES AREA

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ABSTRACT. Rehabilitation of Great Lakes walleye *(Stizostedion vitreum vitreum)* stocks has been highly successful in some cases and has failed to be initiated in others. A review of case histories has provided for the development of a general model of rehabilitation for managers and a decision-making framework for use anywhere along the rehabilitation continuum of that model.

We recommend three steps in evaluating the potential of a water body to produce a healthy, self-sustaining population of walleye:

1) Determine the potential to produce walleye based on historical as well as current edaphic, morphometric, and biological conditions.

2) Build a framework for deriving maximum public benefit by assessing public demands and expectations. Expectations of the public must be reasonably matched with the potential for extraction from the walleye resource.

3) Develop a plan of action incorporating a historical review, a status report of current conditions listing status indicators, and a management plan. The management plan should describe remediation measures, walleye population-enhancement initiatives, and a public-awareness campaign.

The evaluation process should determine the projected entry point for management on the rehabilitation continuum. If the stock has been depleted, action begins in the initiation phase where the majority of management resources are directed at restoration of the walleye population-especially remediation ofenvironmental stresses. As the condition of the stock progresses toward rehabilitation (approaches biological carrying capacity), a larger share of management's resources should be directed toward monitoring stock status and managing exploitation.

Techniques for initiating walleye rehabilitation are described, and indicators are presented, to facilitate tracking of the process. Also, the issue of managing user expectations and affected publics in an environment of uncertainty is discussed, and approaches to management of that issue are presented.

This report and the stock-status report published earlier (Colby et al. 1991) represent the final products of the walleye-rehabilitation workshop. Together they comprise a useful reference on Great Lakes walleye stocks and a practical guide for managers of rehabilitation efforts on the Great Lakes and elsewhere.

INTRODUCTION

The decline of the percid stocks in the Great Lakes in recent decades because of anthropogenic disturbances was summarized at the Percid International Symposium (PERCIS) (Colby and Rigmore 1977) by Schneider and Leach (1977). Since PERCIS, many of these disturbances have been reduced. Various percid stocks, therefore, have been allowed to recover to the extent that a substantial amount of the total angling effort (31%) on the Great Lakes is currently directed towards percid fishes-as opposed to 22% for salmonids and approximately 19% for centrarchids (Talhelm 1988). Similarly, a survey of angling in Michigan waters of the Great Lakes during a 1-yr period estimated that 80% of the 10.6-million fish harvested were percids (Rakoczy and Rogers 1988).

Much of the credit for the recovery of percid fishes is because of the success of various Great Lakes fisheries and environmental agencies in rehabilitating habitat, controlling exploitation, and introducing predatory fishes to reestablish a more-balanced fish community. These initiatives have contributed to a more-favorable predator-prey balance.

The rapid rehabilitation of walleye *(Stizostedion vitreum vitreum)* in certain areas is creating new and unique problems for fisheries agencies-problems of how to live with success by maintaining higher stock densities where possible and satisfying elevated angler expectations.

The magnitude of the walleye-rehabilitation effort, the multitude of stresses on the various walleye stocks, and rehabilitation successes to date prompted the Board of Technical Experts to request funding for a workshop on the subject. The objectives of the workshop were:

1) Bring the Great Lakes Fishery Commission (GLFC), as well as the Great Lakes community in general, up to date on the present status of walleye stocks in the Great Lakes.

2) Explore the ecological, economic, and social issues arising from walleye-rehabilitation initiatives.

3) Develop a practical guide to rehabilitation for managers. The guide is to include issues, techniques for management, and policy implications.

Approach

The objectives were accomplished in three steps:

Step One

Step one consisted of five working groups preparing reports on the status of various walleye stocks for each of the five Great Lakes.

Step Two

Step two involved five separate groups exploring the following issues:

biological trade-offs associated with rehabilitation,

initiation of rehabilitation,

finding the end point of rehabilitation,

evolution of management objectives as rehabilitation progresses, and

socioeconomic issues associated with rehabilitation.

The first two steps were completed prior to the workshop. Reports of the stock-status working groups have been published (Colby et al. 1991).

Step Three

Step three comprised a 4-day workshop (June 5-9, 1989) at Stone Biological Laboratory, Put-in-Bay, Ohio. There were 50 participants from various Great Lakes resources agencies and academic institutions having access to data and an understanding of the various rehabilitation efforts in progress throughout the Great Lakes area (Appendix A). The workshop involved:

a review of advanced working-group reports,

panel discussions of policy implications, and

discussions by workshop working groups of biological and socioeconomic issues relating to stock status.

The workshop focused on the rehabilitation of walleye stocks rather than rehabilitation or development of fisheries. Therefore, technology or guidelines for developing new stocks (where none existed before), or for maintaining fisheries above the level that can be sustained by natural reproduction, were beyond the scope of this workshop.

In this report, we present a framework for the discussion of walleye rehabilitation, indicators of stress and of stock status relative to the rehabilitation goal, and techniques for management of both stocks and the socioeconomic context throughout the rehabilitation process. It is our hope that this report will serve as a reference and practical guide to walleye managers in the Great Lakes and elsewhere.

REHABILITATION

We define rehabilitation as the process of realizing or achieving historical potential-as far as technologically possible. Our definition requires that rehabilitated stocks be naturally self-sustaining. This report is not concerned with the stocking of walleye as a means of supporting a put-grow-take fishery or as an introduction into a new area. Our definition also implies that the objective of rehabilitation is not constrained by what is economically feasible-although such factors may be considered in the decision to proceed with the initiation of rehabilitation. Therefore, rehabilitation (by our definition) can only be achieved where the population was previously depressed to low abundance as a result of man-made disturbances (overexploitation, habitat degradation, andspecies introductions).

The Three-Phase Model: A Framework For Discussion

Rehabilitation of walleye stocks in the Great Lakes is an ecological and social phenomenon, and all stocks can be described as falling on a continuum between extinct and fully rehabilitated. However, for the purposes of discussion at the workshop and in this paper, we have divided the continuum into three phases: the initiation phase, the rehabilitating phase, and the rehabilitated phase (Fig. 1A). General descriptions of the three phases are:

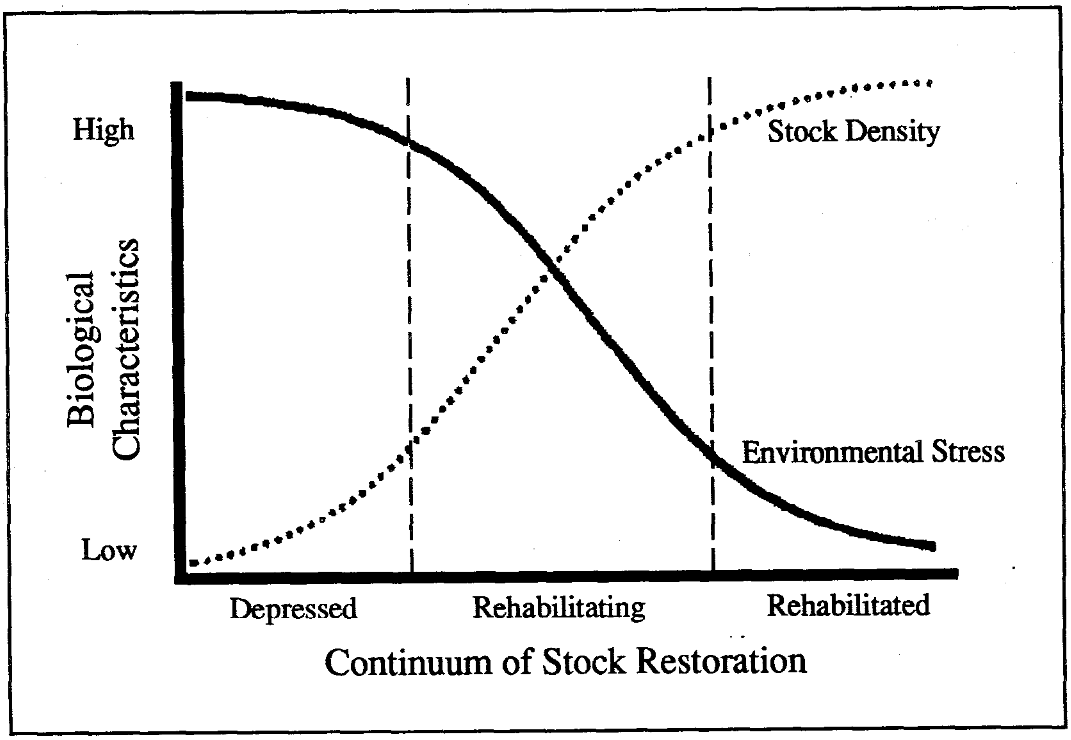


Fig. 1A. Generalized relationships for biological and management issues throughout the three phases of walleye rehabilitation, showing the increase in walleye-stock density as constraining factors are reduced or eliminated.

The Initiation Phase

The initiation phase is characterized by stocks that are depressed (greatly reduced below their historical abundance). This phase involves developing objectives for rehabilitation and implementing tactics to meet those objectives by identifying and overcoming (through remediation) the stresses that keep a stock depressed. These triggering tactics set rehabilitation in motion and move the stock into the rehabilitating phase.

The Rehabilitating Phase

The rehabilitating phase is characterized by stocks that have begun to recover, but have not yet reached their full potential as defined by the stock objectives. Improved recruitment is the primary sign of this phase.

The Rehabilitated Phase

The rehabilitated phase is characterized by 'stocks that are self-sustaining, having recovered from a depressed state to either a former or an acceptable level of abundance.

The three-phase model provides a framework for discussion of ecological and socioeconomic issues associated with walleye rehabilitation. We propose that these issues change in relative importance as rehabilitation progresses (Fig. 1B). In the initiation phase, ecological remediation issues are of primary importance. As stocks begin to recover, remediation issues decline in importance, while socioeconomic issues increase. After full rehabilitation has been achieved, management of socioeconomic issues gains priority in managing the fishery, while the importance of ecological remediation efforts plays a much-reduced role. Maintenance of environmental quality and stock abundance contributes significantly to the social and economic issues during this phase.

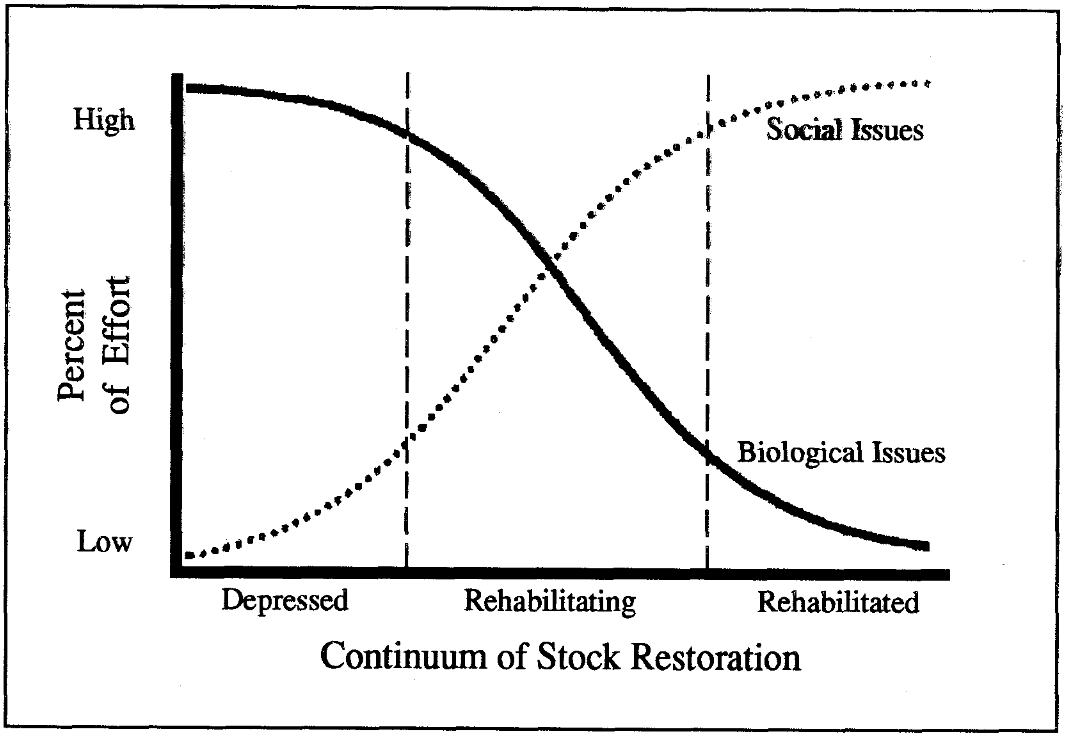


Fig. 1B. Generalized relationships for biological and management issues throughout the three phases of walleye rehabilitation illustrating the shift in management effort and priorities during the rehabilitation process. As biological issues are resolved, social issues regarding stock allocation and maintenance become more prevalent.

Precise descriptions of the rehabilitation trajectory are elusive, and we, like Christie et al. (1987a), recognize that it will be defined in part by "human evaluation of the biotic products." Our rehabilitation model recognizes this caveat and blends both socioeconomic and ecological concepts in describing the phases of walleye-stock recovery. The case histories developed for this workshop (Colby et al. 1991) provide a strong rationale for a general model of this nature. First, few of the Great Lakes walleye stocks identified in the case histories as requiring rehabilitation now or in the past were well studied before degradation occurred. This scarcity of historical data makes application of a general model attractive. Second, Great Lakes fish communities and edaphic conditions have undergone extensive changes since the late 1940s (Schneider and Leach 1977). In spite of strong desires to reestablish walleye stocks to what they were before perturbations occurred, there are good arguments to suggest that rehabilitated stocks may not mirror historical dynamics. Therefore, a general model may be useful for defining targets even in those instances where good historical data are available.

We draw on the case histories for Great Lakes walleye stocks (Colby et al. 1991) to develop practical indicators of the rehabilitation process. These will assist managers to determine where a given stock falls on the rehabilitation continuum, and permit managers to examine the ecological and socioeconomic issues and management implications associated with each phase of rehabilitation.

INDICATORS OF REHABILITATION

The rehabilitation model (Figs. lA, 1B) recognizes the need for an ongoing feedback system to determine the status of the stocks as they respond to the elimination of past stressors. Therefore, the status of a given stock or population along the rehabilitation continuum can be judged relative to the stock objectives. For example, target stock density would probably be higher (walleye production would be lower) under a prevailing sport fishery because good angling success requires higher walleye density than traditional yield and production models dictate.

To monitor the rehabilitation process, three types of indicators are useful:

1) Habitat indicators describe the potential of a water body to produce walleye.

2) Stock-status indicators reflect walleye-population dynamics and are used for tracking rate of recovery throughout the rehabilitation process. These indicators are the more-traditional measures that have been used by fishery scientists to monitor changes in fish populations and their relative health (Ontario Ministry of Natural Resources 1983; Colby 1984).

3) Socioeconomic indicators allow tracking of progress toward socioeconomic objectives for the stock (including type of fishery provided) and social and economic benefits.

These indicators identify physicochemical, biological, and cultural attributes of walleye stocks and their environments. The three types of indicators can be used together to help set rehabilitation objectives and to determine whether an end point in the rehabilitation process has been reached.

Habitat Indicators

Walleye are generally most abundant in moderate-to-large (> 100-ha) lakes or river systems characterized by cool temperatures, shallow-to-moderate depths, extensive littoral areas, moderate (Secchi-disk depth <2 m) turbidities (Table 1), extensive areas of clean rocky substrate and mesotrophic conditions. However, smaller lakes may contain natural populations, especially if they form part of a large contiguous system. Walleye are also found in oligotrophic, clear-water lakes (usually dominated by salmonids) if they are sufficiently large and deep and have extensive littoral areas. Similarly, walleye are found in some eutrophic lakes, usually dominated by centrarchids. Kitchell et al. (1977) suggested that the littoral and sublittoral habitats occupied by walleye in lakes are the equivalent of extensions of suitable riverine habitat into the lake environment.

Walleye are tolerant of a wide range of environmental conditions (Colby et al. 1979):

temperatures (0°-30°C),

dissolved oxygen (DO) concentrations (<2 mg/L in laboratory experiments),

pH (6.0-9.0), and

total dissolved solids (< 1,500 mg/L).

They will also accept a wide range of turbidity, but they avoid high levels of illumination. Ryder (1977) reviewed much of the literature on abiotic factors controlling temporal and spatial dimensions of walleye feeding and reproduction. He concluded that light is principal among these. Kerr and Ryder (1977) also suggest that a critical limiting factor for walleye populations is light intensity.

Table 1. Selected indicators of either optimum walleye or mesotrophic habitat. For additional indicators of mesotrophic habitat or community status, see McMahon et al. (1984) and Edwards and Ryder (1990).

Variables and indicators	Attribute	References
Lake bathymetry	Shallow to moderately deep	Kitchell et al. 1977
Lake morphometry	Extensive littoral and shoreline area	Kitchell et al. 1977
Substrate	Sand to large gravel Submerged vegetation	Kitchell et al. 1977
Lake size	>100 ha	Kitchell et al. 1977
Light penetration	Secchi-disk depth <2 m	Kitchell et al. 1977
Optimum growth temperature: Juveniles Adults	 <27°-31°C <22°-26°C	Kitchell et al. 1977
Gonadal maturation requires < 10°C	> 134 cooling degree days < 10°C	Colby and Nepszy 1981
Mean weekly water temperature above thermocline, summer	18°-25°C	McMahon et al. 1984
Mean weekly water temperature in shallow shoreline areas, late spring/early summer (fry)	18°-23°C	McMahon et al. 1984
Mean weekly water temperature during spawning, spring (embryo)	11°-18°C	McMahon et al. 1984
Minimum DO above thermocline, summer	>4.5 mg/L	McMahon et al. 1984

Continued on next page

Table *1, continued*

Variables and indicators	Attribute	References
Minimum DO along shallow shoreline areas, summer/fall (fry)	>5.0 mg/L	McMahon et al. 1984
Minimum DO in spawning areas, spring (embryo)	>6.0 mg/L	McMahon et al. 1984
Minimum 0_2 at spawning substrate (kg/ha/yr)	>2-4 mg/L	Kitchell et al. 1977
Chlorophyll a-walleye yield (mesotrophy-mg/m^3)	7.5-12.5 3.0-7.0 4.3-8.8	Oglesby et al. 1987 Forsberg and Ryding 1980 Dobson et al. 1974
Total nitrogen (mesotrophy-mg/m^3)	300-650 400-600	Vollenweider 1968 Forsberg and Ryding 1980
Total phosphorus (mesotrophy-mg/m^3)	1O-20 15-25	Chapra and Robertson 1977 Forsberg and Ryding 1980
Organic matter in sediments (mesotrophy-% dry weight (dw)	17-30	Entz 1977
Relative abundance of small forage fishes, spring and summer	High abundance of forage fish	McMahon et al. 1984
Amount of water body with cover (%)	Sparse cover assumed to be less suitable Excess cover assumed to be less suitable by reducing foraging ability (Swenson 1977)	McMahon et al. 1984
Water level during spawning and embryo development	Rising Normal and stable	McMahon et al. 1984

McMahon et al. (1984) present a habitat-suitability model that can be used to predict the habitat suitability of a given water body for walleye. Table 1 incorporates some of their indices as well as those of others to describe optimum walleye habitat. The probability and rate of recovery of Great Lakes walleye stocks will probably depend in part on the degree to which the various walleye habitats in the Great Lakes match up to the indices presented in these tables. The problem we find is that the walleye habitats in the Great Lakes are not adequately described to predict the success of various rehabilitation efforts. In order to accelerate our predictive capability, we have proposed an initial habitat classification system for the Great Lakes. Area managers comparing both the optimum-habitat indices (Tables 1,2) and our recommended walleye-habitat classification for the Great Lakes should get a feel for the probable success of their rehabilitation initiatives.

Stock-Status Indicators

A number of indicators of stock status may be used to track progress of rehabilitation. Below we examine eight stock-status indicators:

1. mean age,
2. age at maturity,
3. growth,
4. total mortality,
5. recruitment,
6. stock-recruitment relationship,
7. catch per effort (CPE), and
8. equilibrium and sustainable yields.

We draw on observations of these indicators in the dynamics of Great Lakes stocks to evaluate their utility as rehabilitation indicators.

Table 2. General habitat and population characteristics of north-temperate walleye lakes with low and high yields (P. Colby; Ontario Ministry of Natural Resources (OMNR), 435 James Street South, Suite 335, Thunder Bay, Ontario, Canada, P7E 6E3, unpubl. data).

Low yields	High yields
Shorter growing season, lower energy[1]	Longer growing season, higher energy
Lower nutrient-loading and exchange rates	Higher nutrient-loading and exchange rates
Deeper and clearer lakes with abundant vegetation favoring northern pike *(Esox lucius),* smallmouth bass *(Micropterus dolomieu),* and other centrarchids	Shallower, turbid lakes with good wind fetch and a favorable food base
Limited spawning habitat	Spawning habitat is not limited
Lower production/biomass (P/B) ratio[1,2]	Higher P/B ratio
Later maturation[1]	Earlier maturation
Slower growth, except for trophy fish where larger adults are feeding on an abundant forage base-coregonids or rainbow smelt *(Osmerus mordax)*	Good growth
Poor survival of younger age groups	High survival of younger age groups
Lower population density	Higher population density
Lower population fecundity	Higher population fecundity
Lower exploitation rate (<50% quartile)[3]	Higher exploitation rate (>50% quartile)

[1]Fig. 2.
[2]Table 10.
[3]Table 11.

Mean Age

The age structure of walleye populations describes their stability, longevity, survival, reproductive potential, and permissible level of exploitation (Table 3). The progression of weak and strong year-classes through the population also provides a basis for stock-management strategy.

The relationship between mean age at harvest and mean age at maturity (or age at first spawning) may be a useful indicator (Abrosov 1969). A stable or rehabilitated walleye stock may exist when the mean age of the catch exceeds the mean age of maturity by at least 1.5 yr. However, age and size biases (for example, in the Bay of Quinte) may result because of different harvest methods or migration of older fish (J. Bowlby, OMNR, R.R. #2, Aurora, Ontario, Canada, LAG 3G8, pers. commun.). These biases may limit the utility of Abrosov's method (Colby 1984) and may lead to erroneous conclusions. The rehabilitated stocks of western Lakes Erie and St. Clair and the sustaining walleye population of eastern Lake Erie have Abrosov values >1.5. The rehabilitated Bay of Quinte stock sustains a value of approximately 1.0. Values <1.0 imply the population's reproductive potential is limited to the youngest females. Such stocks are at risk from weak year-classes, and there may not be a sufficient number of established age groups present in the population to consider the population rehabilitated.

Age At Maturity

Age at maturity often responds to density changes (Table 3). Lowered densities and faster growth generally shorten time to maturity for walleye within the limits of their ability to compensate for changes in their environment. First maturity commonly occurs over a range of ages, but no single statistic adequately describes the maturation schedule (Ontario Ministry of Natural Resources 1983). Currently, mean age at first maturity (Abrosov 1969; Lysack 1980) seems to be the most-promising method for reflecting changes in population density. Colby and Nepszy (1981) relate age at maturity and longevity to growing degree days (GDD) >5°C (Fig. 2). Northern stocks mature later and over a greater number of years than southern stocks. Note the position of the crisis curve for walleye in relation to the various ages to maturity (first, 50% and 100% maturity). On average, the curve falls approximately one-half year below the age at which 50% maturity usually occurs over the growing degree range. If the mean age of the catch (all groups equally vulnerable to the gear) falls below the crisis, the stocks are susceptible to over-harvest and possible collapse.

Table 3. Stock-status indicators.

	Time in the rehabilitation process			
	Early		Late	
Indicator	Level	Trend	Level	Trend
Age structure	LOW	Increasing	High	Flat
Mean age because of:				
Overfishing	LOW	Increasing	High	Flat
Recruitment failure	High	Decreasing	Lower	Flat
Age at maturity	LOW	Stable	Medium	Increasing
Growth rate	High	Stable	Medium	Decreasing
Survival'	High	Stable	Medium	Stable
Total annual mortality rate	LOW (40%)	Stable/ increasing	Medium (40%)	Variable
Abundance	LOW	Flat	High	Increasing/ stable
Stock-recruitment ratio	LOW	Increasing	Medium/ high	Variable
CPE	High	Decreasing	Lower	Stable
Equilibrium and sustainable yields	LOW	Increasing	Higher	Relatively stable

'Survival rates may depend upon the exploitation strategy selected.

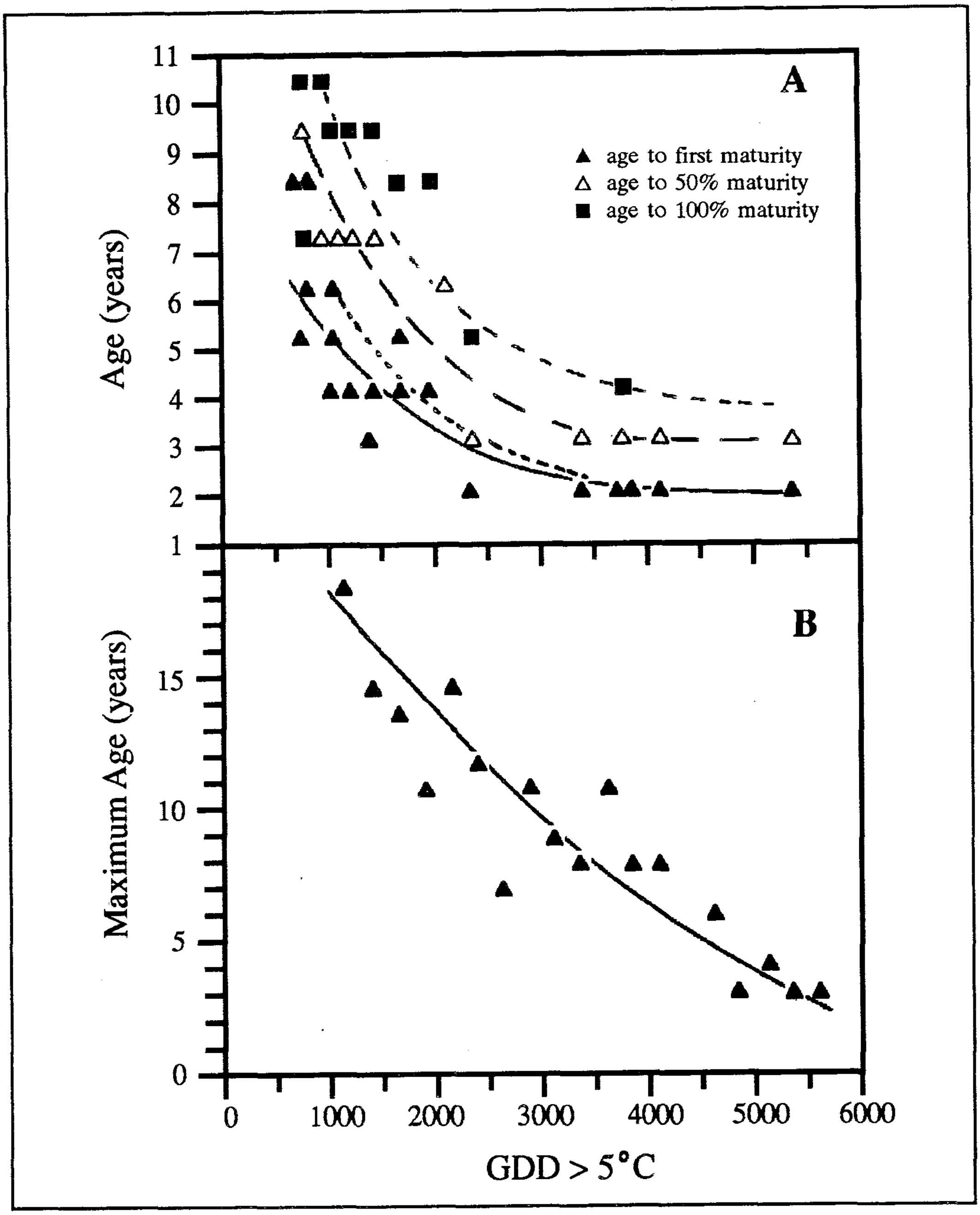


Fig. 2. Relationship between degree days >5°C and various ages to maturity (Fig. 2A) and longevity (Fig. 2B). The crisis curve is the first dotted line (Fig. 2A) above the age to first maturity curve (solid line). The crisis curve is a suggested relationship between the minimum scale age (weighted mean) the walleye catch can be reduced (assuming equal vulnerability of mature fish to the gear) and available energy (expressed as accumulated GDD>5°C) to permit adequate recruitment to perpetuate the stock (Colby and Nepszy 1981).

Growth

This parameter can be accurately quantified and reasonably monitored throughout changes in stock density, and growth response in walleye populations is generally immediate. In the western basin of Lake Erie, decreases in growth among fishable age groups have been associated with the steady increase in their density. Von Bertalanffy growth coefficients (CV)-actually the product of K and *L* infinity-of walleye year-classes during the initial years of western-Lake Erie stock resurgence (mid-1970s) showed a declining trend with increases in year-class abundance. Among younger walleye-even young-of-the-year (YOY)-condition factors declined through this same period and persisted as these cohorts grew older. Increased competition for prey may have occurred as soon as a large year-class appeared and may have persisted until walleye became large enough to consume larger prey. There was some initial concern that a progression of strong year-classes might overwhelm the forage base. However, these fears have not materialized to date-possibly because of high exploitation and expansion of the western-basin population into central Lake Erie. Natural populations and fish communities will probably be self-regulating. However, artificial ones supported by continuous stocking might constitute a potential problem, because there would be no self-regulating feedback mechanism involved.

In the Bay of Quinte, growth rates and maturity schedules have not changed appreciably since the stabilization of the walleye population in the mid-1970s. However, a density-dependent relationship has been found linking growth of a particular year-class with densities of the same year-class and the two previous year-classes of walleye. The immediately preceding year-class has the greatest depressing effect on growth of a year-class (Bowlby et al. 1991). Because rates of maturity and walleye forage preferences have remained unchanged, there seems little to observe in growth response. Reduced eutrophication, reduction in commercial-fishing pressure, and low annual mortality rates (40%) have interacted to maintain a relatively stable walleye stock and growth response.

Upper-Great Lakes managers have used growth to some degree in determinmg the success of walleye restoration. In Green Bay, two stocks under rehabilitation through stocking young fish have shown no density-growth relationship, suggesting further expansion of the population is possible. Along the southeastern shore of Lake Michigan, the Muskegon River stock has historically demonstrated an inverse relationship between growth and population density, especially among older walleye. However, younger walleye from recent rehabilitation efforts have shown surprisingly slow growth despite low density, a fact probably related to their general preference to remain in the river system, where they are without access to the large forage base of Lake Michigan. Unless there is strong and consistent evidence to distinguish walleye stocks on the basis of movement and distribution, growth will probably not be much of an indicator of the rehabilitation of these Lake Michigan stocks.

Most of the Georgian Bay stocks may be too early into the rehabilitation or initiation phases for growth changes to be apparent. Saginaw Bay walleye-restoration efforts have been under way since 1972 and, based on environment, the walleye population should be able to expand considerably. Saginaw Bay walleye growth is faster than any other Midwest population. Increasing walleye density may now be influencing their growth (decreasing growth rate). It is in the highly productive systems (such as Saginaw Bay) where growth responses can be expected.

Total Mortality

Total mortality is the preferred mortality indicator reflecting changes in stock dynamics because it accounts for all sources of mortality and is easier to measure (Ontario Ministry of Natural Resources 1983). Total mortality rates >50% may cause concern for the well-being of the stock (Ontario Ministry of Natural Resources 1983). If significant proportions of older fish continually appear in catches it is unlikely that total mortality is high or that fishing threatens the stock. Declining abundance, associated with continuing presence of older fish, is usually symptomatic of a recruitment problem linked to environmental conditions or size-selective fisheries for younger age groups.

Walleye populations will have different sensitivities to total mortality depending on energy and nutrient regimes, habitat quality, and community structure. If habitat is known to be marginal or degraded, lower total mortality rates is preferred (Ontario Ministry of Natural Resources 1983).

Recruitment

An early recognition point along the path of walleye rehabilitation is the stock's capacity to produce year-classes that can be recognized either early as YOY or at some subsequent life stage-for example, the age of entry into an angling or commercial fishery. Estimates of larval recruits are most useful where walleye-stock size is severely governed by environmental factors (for example, river flow and temperature during spawning and incubation of embryos) or where a walleye population relies on only a few spawning or nursery areas. Progress towards rehabilitation may also be measured by following changes in the ratio of stocked to unstacked recruits. Detection of recruits of hatchery origin may be possible using stocking checks on otoliths or genetic and biochemical analysis.

In Saginaw Bay, reestablishment of native spawning runs has apparently started the process towards rehabilitation. However, adult-walleye stocks are not yet sufficiently abundant to produce substantial numbers of offspring, and environmental factors (flow reversals, poor water quality) or biological factors (predation, starvation) may be preventing successful recruitment to the sport fishery (Jude 1992).

In Georgian Bay, a few walleye stocks have shown signs of success in initiating restoration despite irregular and low runoff (river-spawning stocks affected), acid runoff, excessive states of eutrophication, and changes in fish-community composition. In certain areas where natural reproduction has been weak (for example, the Moon River stock), modest fish-culture efforts have had a significant impact. For these reemerging populations, estimates of natural and planted larvae indicate that for groups age 0+ to age 2+, approximately 40% of the population is of hatchery origin. Therefore, rehabilitation efforts are continuing.

Stock-Recruitment Relationship

Variability about the stock-recruitment curve often obscures its specific utility in assessing stock recovery. The density-dependent relationship in stock-recruitment functions is often disturbed by climatological and meteorological conditions and other less-understood influences (exploitation, exotic species, cannibalism). Of all the walleye stocks in the Great Lakes (where sufficient data is available), only the Bay of Quinte and western-basin Lake Erie stocks provide evidence of functional stock-recruitment relationships. In fact, functional stock-recruitment relationships occur only during early stages of rehabilitation when stock abundance was low and rapidly increasing. Also confounding the method is the less-than-satisfactory delineation of many individual stocks that reproduce in western-basin rivers and lake shoals.

Catch Per Effort

Angler CPE may be used as an indicator of rehabilitation. However, this measurement is influenced by variables other than density. These variables might include weather, age structure of the population (strong year-class entering the fishery), and forage abundance. In the sport fisheries, the number of legal walleye harvested is usually expressed as harvest per unit effort (HUE). However, some surveys report total walleye caught (CPE) and include those released. Lake St. Clair, the Bay of Quinte, and Lake Erie (western, central, and eastern sections) all support angler catch rates >0.3. Saginaw Bay walleye stocks support catch rates between 0.02 and 0.20. The northern-Lake Michigan sport fishery provides catch rates averaging 0.05-0.06. Under optimum conditions (by season and site), catch rates are close to 0.2 in the Green Bay fishery. Although catch data may be highly variable, the data may often be useful for identifying stocks with further rehabilitation potential.

Equilibrium and Sustainable Yields

If the conditions implied by describing fish populations at a state of equilibrium are acceptable, then several single-species models are available to portray the dynamics of walleye stocks in the Great Lakes. These models may have their greatest utility at the very start of restoration. The models can be applied throughout the progressive phases towards rehabilitation. It is possible to make midcourse corrections to the model input parameters during the annual evaluations. The ability to make these corrections is one of the assets of dynamic-pool yield models. Over time, this strategy may even permit a fishery manager to presume the stock is approaching a steady-state condition or an end point of rehabilitation. Because walleye year-class recruitment is often highly variable, it might be wise initially to circumvent the constant recruitment assumption. Instead, attention should be directed to the estimation of stock maximum sustained yield (MSY) using yield per recruit as a function of fishing mortality or effort. The conventional F (0.1), will promote stock expansion while using the steady-state model. If estimates of recruitment are required for issuing catch quotas, survey forecasts may be used. A time series of indices can be developed to reflect the relative abundance of recruits entering the fishery at some future point in time.

Summary

Three distinct population characteristics that respond to stress were identified by Shuter (1990):

1) habitat occupation,

2) the well-being of a typical population member, and

3) the balance of birth and death rates.

Therefore, use of habitat and stock-status indicators (Tables 1,2,3) helps to identify the potential of a given habitat to produce walleye and to evaluate changes in the walleye stock throughout rehabilitation. It is important that managers have both habitat and population descriptors in order to monitor success and to determine effective and realistic rehabilitation objectives. Although each stock-status indicator has its own limitations, using several indicators should provide a manager with fairly reliable sense of rehabilitation progress.

Catch Equality: A Socioeconomic Indicator

A potential method for evaluating the status of a walleye fishery and its rate of rehabilitation may be by measuring the inequality of the catch (Smith 1990). Catch distributions become even more skewed with increasing resource scarcity. This creates a situation where few fishermen are highly successful with most other fishermen taking increasingly smaller shares of the resource. Smith (1990) provides a simple method to measure inequality in resource-catch distributions using a Gini CV (a numerical representation of equality) calculated from Lorenz curves. The ratio of the area between the actual distribution and the 45" line divided by the total area under the 45" line gives the Gini CV. The more the catch curve departs from perfect equality the greater the Gini CV (Smith 1990). Perfect equality with a Gini CV of 0.00 is represented by the 45" line from the origin to 100%. We used this approach to describe a number of inland walleye fisheries (Fig. 3). As a recreational walleye fishery is rehabilitated, a larger proportion of people should catch fish and increase the equity of the catch-resulting in lower Gini CVs as the Lorenz curves approach perfect equality. For example, the following text table (K. Paxton, Ohio Department of Natural Resources (ODNR), Fountain Square C-4, Columbus, OH, 43224, pers. commun.) illustrates the relationship between HUE and Gini CVs from the Ohio waters of Lake Erie, 1975-86 (private boat anglers only). Note the decline in the Gini CVs and simultaneous rise in the HUE over time. This relationship would have been more apparent had effort not extended into the central basin as the fishery recovered. The inverse relationship between HUE or CPE and Gini CV is more dramatically drawn by Baccante (OMNR, 435 James St. S., Suite 335, Thunder Bay, Ontario, Canada, P73 6E3, pers. commun.) who has made comparisons between numerous walleye fisheries.

Year	Gini	HUE	Year	Gini	HUE
1975	.65	.115	1981	.48	.300
1976	.58	.310	1982	.44	.440
1977	.50	.586	1983	.59	.260
1978	.51	.439	1984	.45	.550
1979	.44	.639	1985	.51	.470
1980	.48	.380	1986	.45	.510

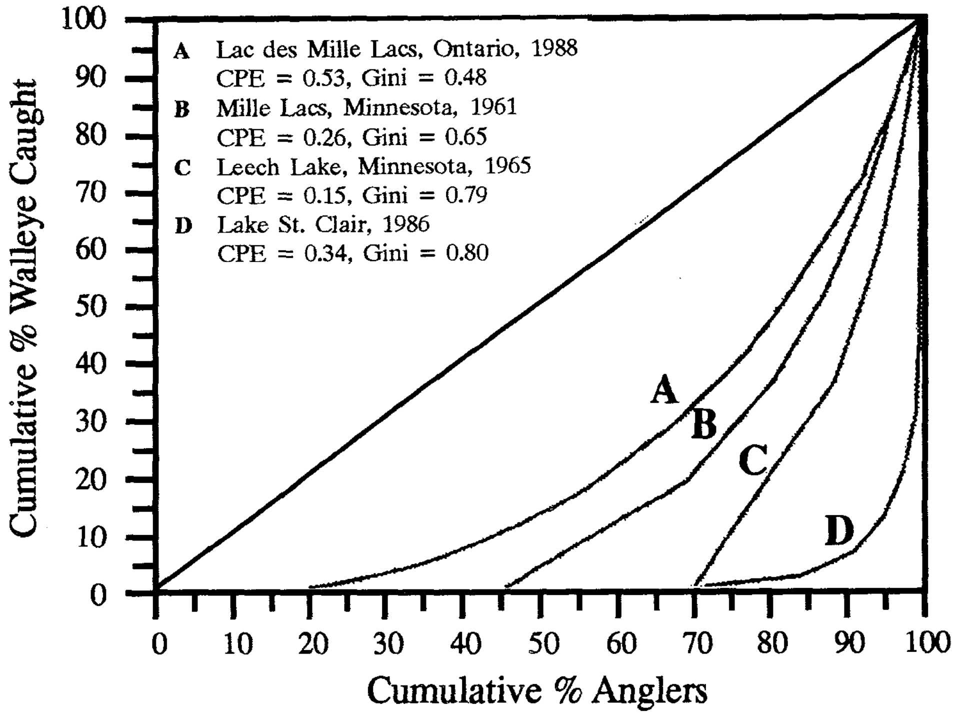


Fig. 3. Lorenz curves reflecting the distribution (equality) of the catch among fishermen for four walleye fisheries. Respective CPEs and Gini CVs are shown for the fisheries (perfect equality line (straight line through the origin), Gini = 0). (A: M. Fruetel, Quetico Mille Lacs, 435 James St. S., Suite 221, Thunder Bay, Ontario, Canada, T73 6E3; B, C: D. Schupp, P. 0. Box 278, Pequot Lakes, MN, 56472; D: D. MacLennan, OMNR, R.R. #2, Tilbury, Ontario, Canada, NOP 2L0; unpubl. data). ,

This technique could be useful in identifying various recovery phases of rehabilitation and the effect of subsequent regulations imposed on the fishery following rehabilitation. If Smith's (1990) approach turns out to be less than satisfactory as a rehabilitation indicator, it should be useful in describing the fishery. Note in Fig. 3 that CPEs and Gini CVs may differ. Lake St. Clair has a higher CPE than the Minnesota lakes but a lower Gini CV. This indicates that a smaller proportion of fishermen in Lake St. Clair are catching a disproportionally higher number of fish. Therefore, the Gini CV tells more about the fishing experience than using CPE alone, and this may help the manager to improve equality and overall fishing experience.

End-Point Indicators

No precise threshold identifies the level at which a walleye population can be considered rehabilitated. Identifying end-point thresholds is conceptually difficult because fish communities, in successional terms, oscillate around some limits associated with juvenescence and maturity (Christie et al. 1987b). Therefore, population demographics are subject to inherent variability and respond to pressure from exogenous sources (weather, fish-community interactions, exploitation, marginal habitat, and habitat alterations). Recently, however, the energies of fisheries scientists and managers have proven quite successful in the Great Lakes basin in directing the recovery of valued walleye stocks (Colby et al. 1991). In spite of problems with inherent variation, a number of end-point indices were useful in enabling managers to estimate, with several years data, when a population had been rehabilitated (reached carrying capacity and equilibrium yield under existing conditions).

Various combinations of all three types of indicators (habitat, stock status, and socioeconomic) can be used to monitor progress towards rehabilitation. Once the end-point indicators suggest that original objectives have been met, maintenance costs and rehabilitation efforts can be reduced. Criteria for determining end points and their values will vary according to the type of fishery anticipated and the nature of the habitat (Tables 1,2).

Recreational fisheries concerned with societal overfishing (Table 4) may set objectives to obtain a certain level of quality fishing experience, depending on behavioral motivations (Table 5). Maintenance of fish densities or sizes that exceed or at least differ from a commercial or native subsistence fishery may be required. Different methods of harvest will require the use of different end-point criteria-the value of which will vary with habitat. Recreational fisheries may decide that when certain expectations (CPE, HUE, proportional stock densities (PSDs), quality fishing indices, or kept-released ratios) are reached, rehabilitation has occurred (Baccante and Colby 1991). Therefore, these indices may be used to reflect both stock status and socioeconomic value of a given fishery.

Table 4. Definitions of two types of overfishing (Ontario Ministry of Natural Resources 1983).

Biological overfishing	Nonbiological overfishing
Recruitment overfishing reduces the spawning stock through overfishing to a point where recruitment (reproduction) limits yield in some (if not all) years	Economic overfishing results in loss of economic rent to commercial fisheries, tourist outfitters, and society in general
Growth overfishing involves heavy exploitation (usually at early ages) to prevent realization of growth potential (in biomass) of a stock or cohort with a resultant loss in yield	Societal overfishing causes an intensity of recreational use that reduces an individual's experience below a level of satisfaction
Community overfishing causes changes in community composition not easily reversed by reducing or eliminating fishing pressure	

Early in the rehabilitation phase, an abundance of small fish are common, giving high CPE and low PSDs. Expectations of catching large fish are low and anglers will release fewer fish. As the stock rebuilds, PSDs get larger and anglers may begin to release smaller fish. Finally, when a certain level of experience or expectation has been reached, the fishery can be considered rehabilitated. If the above fishery is also to accommodate a commercial or subsistence fishery whose objectives are obtaining a certain yield, then additional end points are required and the angling expectations may be lower.

Commercial and subsistence fisheries will have yield objectives and end-point indicators that will require age data, and size and abundance indices to: determine the status of the stock, prevent biological overfishing, and determine when an equilibrium or sustainable end point has been obtained. Multiple-use fisheries will require quotas and allocation of resources. End-point criteria for multiple-use fisheries will require greater negotiations and will be more complex in order to define when the stock has been rehabilitated sufficiently to support the various expectations.

Table 5. Categorization of three behavioral motivations for fishing as summarized by the Northwestern Region Technical Subcommittee on Recreational Fishing Quality (Ontario Ministry of Natural Resources 1990).

Motivation	Psychological	Environmental	Resource based
Escape daily routine	✓		
Physical rest	✓		
Escape physical pressure	✓		
Tranquility-privacy	✓		
Be with others	✓		
Slow down mentally	✓		
Exercise	✓		
Escape role overloads	✓		
Family togetherness	✓		
Security	✓		
Self-reliance	✓		
Independence	✓		
Teaching and sharing skills	✓		
Introspection	✓		
Achievement	✓		
Seek stimulation	✓		
Seek creativity	✓		
Spirituality	✓		
Social recognition	✓		
Risk taking	✓		
Adventure	✓		
Exploration	✓		
Tradition	✓		
Cooperative endeavors	✓		
Water quality		✓	
Natural beauty		✓	
Weather		✓	
Access		✓	
Facilities		✓	
Healthful environment		✓	
Size of fish caught			✓
Number of fish caught			✓
Variety of fish caught			✓
Eating fresh fish			✓

The types of indicators necessary to reflect the ability of the fish population to meet various social needs and the values of these indicators will vary among habitats. Walleye grow faster, mature earlier, and have shorter life expectancies in warmer or more-productive waters (Colby and Nepszy 1981). The difference between northern Lake Superior and western Lake Erie (GDD$\geq$5°C) is large-they vary from 1,400 in the north to 2,500 in the south. In addition, nutrient loading and subsequent fish food production varies greatly among the previously described Great Lake habitats. Consequently, the size, age structure, growth rate, density, exploitation rate (stock maintenance-harvest ratios), and rate of rehabilitation will vary accordingly.

Desired end-point values, therefore, should reflect realistic cultural expectations from various walleye habitats. Therefore, the more-northern or less-productive (marginal) habitats will:

have lower yields and exploitation rates;

support less effort for maintaining a desirable angling experience; and

require a longer time, and probably more effort, to rehabilitate a walleye fishery.

Because a stock's capacity to compensate for exploitation is less in low-productivity systems, age to maturity values will be greater. Mean age of the catch should also be greater if an Abrosov approach is used either to protect a stock from Overharvest or define an equilibrium harvest end point.

Where walleye grow faster, mature earlier, and have shorter longevity, the mean ages of catches and maturity can be lowered-similar to the minimum mean age in the crisis curve (Colby and Nepszy 1981). Even where walleye grow fast and mature early, the Abrosov value should >1.0 if the harvest is intensive and all age groups are vulnerable.

Exploitation rates should be lower for northern stocks. Conversely, for many southern stocks or stocks in productive environments (such as Saginaw Bay) where growth is excellent and longevity is reduced, exploitation rates could be higher at least until the stock reaches carrying capacity. Also, the environment is continually changing, especially in the Great Lakes, as is the carrying capacity for walleye. Note the increasing transparency in Lake St. Clair, decreasing chlorophyll a in western Lake Erie, and the potential negative effect on walleye production. This dynamic quality of walleye environments calls for regular monitoring to ensure stock status is in line with objectives.

PLANNING FOR REHABILITATION

Planning for rehabilitation is primarily concerned with determining the feasibility of bringing about ecological change consistent with our general model. However, development of a proposal for rehabilitation that provides a rationale and approach for initiation is a desirable first step. The proposal should consider physicochemical, biological, and socioeconomic issues. A plan of action for client involvement should also be included.

Development of a proposal before initiation efforts begin is preferred. A well-researched proposal will not only be helpful in securing resources and political support for such efforts, but it will also lay the foundation for managing client demands in succeeding phases-assuming the initiation phase is successful. In most instances, it should be relatively straightforward to obtain protective measures on a depressed stock, because clients will not perceive that they are relinquishing opportunity and many will be supportive of efforts to restore the resource. Conversely, it can be difficult to restrain a new fishery once under way, and this difficulty may preclude a full recovery in the future. The logic here is that it is preferred to liberalize, rather than restrict, fishing opportunities as rehabilitation proceeds. The prospects for this position are improved if precautions are established at the outset.

How thorough or rigorous a proposal for initiating rehabilitation should be depends upon the effort perceived necessary to effect desirable ecological change. We see considerable latitude allowed with documentation proportional to effort. For example, a more-rigorous proposal may be needed to secure protective measures if bycatch has the potential to become a serious problem. In particular, if live release of walleye from commercial-fishing gear is unlikely, the proposal should be comprehensive and make a strong case for rehabilitation with benefits and costs clearly defined. Likewise, if major environmental remediation is prescribed as necessary for initiating rehabilitation, a well-researched proposal will be needed to gain the support of environmental-management agencies. However, the 1978 Great Lakes Water Quality Agreement between Canada and the United States is not predicated on a benefits philosophy (for example, new fishing opportunities needed to offset the costs of pollution abatement). This philosophy implies that degradation is tolerable if it is cost effective. Instead, the goal is to restore the physical, chemical, and biological integrity of the waters. Therefore, proposals seeking environmental remediation should focus on biological integrity rather than cost-benefit ratios.

Situations where there appears to be key impediments to initiating rehabilitation call for comprehensive proposals with well-defined goals. More-modest proposals may be adequate where the former stocks were small or where the initiating action does not have major socioeconomic components. Because of the uncertainties in former abundance and changed edaphic conditions, the objective for preparing a modest proposal may be simply to push the stock into the next phase (the rehabilitating phase). At the minimum, a proposal for initiation should:

identify broad objectives for rehabilitation,

assess potential causes of the depression,

analyze feasibility of options for remediation,

determine the need for regulatory measures,

suggest measures of accomplishment, and

recommend a course of action.

In order to initiate rehabilitation and increase the probability of success, information is required in four key areas. This information assists in the setting of realistic objectives and the evaluation of options for achieving those objectives.

1) It is necessary to determine the status of the stock in question.'

2) If the stock is depressed, a quantifiable objective for its rehabilitation should be defined.

3) The reasons for the depressed condition (stresses) need to be identified, and the range of available options explored for mitigating those stresses and initiating rehabilitation.

4) An assessment of the feasibility of each option should be conducted, and one or more options should be selected.

Attempts to rehabilitate depressed walleye stocks in both the Great Lakes and inland lakes have had mixed success. Evaluation of case histories across the Great Lakes and inland waters have allowed us to develop a framework for initiating the recovery of depressed stocks. Use of this framework, and the techniques it describes, should maximize the probability of success in initiating a walleye-rehabilitation program.

Stock Evaluation

First, it must be determined whether the stock in question is, in fact, depressed. This evaluation will assist in the setting of clear and realistic rehabilitation objectives. As a first step, managers should compile all available information on stock history. These data may be derived from commercial records, state or provincial records of fisheries statistical districts, and agency population and creel surveys. In some cases, only anecdotal local-history descriptions are available. The longer the historical record, the more likely it is that a realistic assessment of current stock status relative to long-term potential can be made.

The record of stock dynamics must then be examined. We hypothesize two extreme patterns of stock dynamics.

1) Trend-through-time data may indicate that a relatively high level of production has been followed by a rapid or a gradual decline.

2) The stock may generally be at a low level of abundance, but it may have exhibited occasional peaks based on infrequent strong year-classes.

Such dynamics constitute one key to the long-term average abundance that might be expected from the stock. This information will strongly influence the setting of a realistic biological objective-for example, acceptable biological catch (Quinn et al. 1990).

In the absence of a good historical record, other factors may guide the evaluation of stock status and the setting of a realistic objective. Low stock abundance does not necessarily imply a depressed stock, but may simply be a function of low system productivity. If the stock is at the distributional range limit of the species-or is in an area where habitat is naturally marginal in quality or extent-the stock may be habitat limited, rather than depressed relative to historical levels (Reckahn and Thurston 1991; Schram et al. 1991). Rapid means of assessment of the potential productivity of the fish community and the walleye population are available by means of a morphoedaphic index (Ryder 1965) and a morphoedaphic model (Rempel and Colby 1991; Adams and Olver 1977; Ontario Ministry of Natural Resources 1982; Oglesby et al. 1987).

Community Evaluation

It is increasingly apparent that stock objectives cannot stand alone, but they must be developed within a broader context of fish-community objectives. In the end the community must be the management focus to account for effects such as partitioning forage stocks utilized both by man and by species harvested by man. Development of objectives for walleye stocks without reference to fish-community *goals* can constrain the achievement of those goals. For example, Hernandez (1989) suggests that walleye stocks at very high levels of abundance can impoverish the fish community. Similarly, the addition of other top predators can limit management options for walleye by suppressing their ability to recover from overfishing (Hernandez 1989). The desired end point of rehabilitation must therefore take into account the full range of fish-community goals and objectives.

Present Limitations

Goals and objectives for rehabilitation must be based not only on the historical record but also on an understanding of how conditions may have changed since that record began. It is important to determine whether system productivity has changed; whether habitat for spawning (Auer and Auer 1990) or other life stages has been lost or degraded through physical, chemical or biological effects; or whether the fish community itself has changed (Christie et al. 1987b; Colby et al. 1987; Evans et al. 1987).

Changes in system productivity may be from eutrophication or acidification and can alter the balance of pelagic and littoral primary production. Climatic changes may alter the input of nutrients from the watershed (Reckahn and Thurston 1991). Invasions of new species such as the zebra mussel *(Dreissena polymorpha)* may alter energy flow and the production of preferred forage species. Physical and chemical characteristics of the environment determine if plankton or benthos and macrophytes dominate the aquatic community and if the resultant community favors walleye. For example, lake morphometry is a major determinant of the edible phytoplankton and herbivorous zooplankton ratio (food for walleye fry) (Gates et al. 1983). Marshall and Ryan (1987) found mean depth had a pronounced affect on all fish species under investigation. For 75 lakes (primarily in northwestern Ontario), a mean depth of 6.3 m approximated a key point (a boundary between two adjacent depth classes) along the mean depth gradient that separated:

relative abundance of lake trout *(Salvelinus namaycush),* burbot *(Lota lota),* and lake whitefish *(Coregonus clupeaformis),* and

relative abundance of walleye, northern pike, white sucker *(Catostomus commersoni),* and yellow perch *(Perca flavescens).*

The 6.3 m mean depth appears to represent most closely the point on a mean depth gradient at which a lake thermally stratifies. We feel that morphometry also has a significant effect on current patterns; nutrient cycles; and ultimately, fish production. Obviously, constraints such as latitude, meteorological conditions, geology, and morphometry cannot be readily manipulated. However, Great Lakes water levels can significantly alter certain habitats.

The major factors contributing to degradation or loss of physical spawning habitat have been:

sedimentation of inorganic materials on spawning areas, and

the alteration of spawning habitat or spawning patterns.

Examples include dams, dredging, bulkheading, filling of inshore areas, and aggregate mining (Johnson 1961; Priegel 1970; Regier and Hartman 1973; Schneider and Leach 1977). Sedimentation is usually associated with runoff from agricultural land and is therefore more pronounced in the lower Great Lakes. In practice, measurements of sediment deposition rates are usually rare. However, historical accounts of alterations may be available.

Nutrient additions can lead to excessive production of organic matter in the lower Great Lakes and some embayments in the upper Great Lakes (Minns et al. 1986; Leach et al. 1977). A deleterious effect of enrichment and addition of pulp-mill wastes is the degradation of spawning habitat through sedimentation of organic matter with subsequent oxygen depletion effects. For example, walleye stocks have been affected in this way in some parts of the Bay of Quinte, western Lake Erie, Saginaw Bay, and southern Green Bay (Leach et al. 1977; Schneider and Leach 1977). Pulp- and paper-mill wastes have caused habitat problems for walleye stocks in the St. Louis River and Nipigon Bay in Lake Superior (Schram et al. 1991). Other habitats may be affected during stratification if the hypolimnion is shallow (central Lake Erie and Bay of Quinte). If temporary stratification occurs in shallow enriched areas, the resulting anoxia can lead to shifts in walleye feeding patterns (Leach et al. 1977). Western-basin Lake Erie walleye were affected by the loss of mayflies *(Hexagenia)* in the 1950s (Britt 1955; Regier et al. 1969). Trend or long-term data on oxygen depletion may be necessary to determine if habitat has been, or is being, severely impacted in this way.

Concentrations of toxic substances in sediments may be sufficient to affect egg and larval stages, for example in the Fox River, Wisconsin (Hokanson and Lien 1985; Auer and Auer 1990). Toxic-substance concentrations should be considered, especially if there are no obvious reasons why rehabilitation is not proceeding. Toxics may have been a factor in the decline of walleye in Nipigon Bay (Ryder 1968) and the Spanish River (Spangler et al. 1977; Reckahn and Thurston 1991). Tainting from phenols affected both of these stocks and also the St. Louis River stock. Acid deposition from SO_2 fallout may be affecting some stocks found in Georgian Bay-Shawanaga, Magnetawan, Chikanishing, and McGregor Bay (Spangler et al. 1977; Johnson 1985; Reckahn and Thurston 1991).

Changes in the fish community can be important modifiers of the historical potential of walleye stocks (Hernandez 1989). These changes may include a new top predator, expansion of an existing species, and the introduction or invasion of a new species. Changes in one *or* more species in a community can lead to instability in walleye stocks:

> High abundance of alewife *(Alosa pseudoharengus),* and possibly white perch *(Roccus americanus),* have been suggested as having a negative influence on walleye abundance in the Bay of Quinte (Hurley and Christie 1977; Bowlby et al. 1991).
>
> Alewife were implicated in the decline of walleye in northern Green Bay, eastern Lake Michigan, and Saginaw Bay (Schneider and Leach 1977).
>
> Rainbow smelt may have affected walleye populations in northern and southern Green Bay and western Lake Erie (Schneberger 1936; Regier et al. 1969; Nepszy 1977; Schneider and Leach 1977).

Using a Lake Erie-based model, Hernandez (1989) found that the ability of depressed walleye stocks to recover to a position of community dominance was in part dependent upon changes in the fish community. Also, the addition of other top predators with similar niche requirements could be potentially damaging. Assessment of the present community is necessary to understand population shifts and their implications for rehabilitation of walleye.

Commonly, exploitation plays a critical role in the status of walleye stocks, and it can severely constrain the initiation of rehabilitation-especially when the stocks are not habitat limited (J. Koonce, Case Western Reserve University, 2080 Adelbert Rd., Cleveland, OH, 44106-7080, pers. commun.). This may be a particularly important factor in oligotrophic waters. Exploitation was the primary reason for stock declines in Lake Superior (Schram et al. 1991) and was the cause of the western-Lake Erie decline in the 1960s (Schneider and Leach 1977). In Black Bay and Nipigon Bay (Lake Superior) stocks were completely eliminated. The western-Lake Erie stock and smaller stocks in Lake Superior were reduced in abundance. It is our opinion that walleye stocks can recover more quickly in warmer or more-eutrophic waters because they grow faster, mature earlier, and have greater fecundity (Colby and Nepszy 1981; Baccante and Reid 1988). However, a community imbalance can develop if a vacant niche is filled by other species.

Cause-and-effect relationships may be revealed after an appraisal of historical trends in the stock-in relation to trends in habitat quality and quantity, community changes, and exploitation rates. However, in many cases, more than one factor has contributed to the decline, particularly in the lower Great Lakes and enriched embayments in the upper Great Lakes. If sufficient information is available, it may be possible to prioritize stress effects and use this information to implement rehabilitating actions (Marshall et al. 1987; Cohen et al. 1991).

In some cases, ecosystem conditions have permanently altered the potential for walleye production through reduction of walleye habitat or other effects. If this occurs, the estimate of potential production will have to be reduced from historic levels.

Potential Initiating Actions

Rehabilitation may be initiated with the removal or minimization of key stresses. For example, the western-Lake Erie and Lac Seul stocks recovered when all forms of exploitation were eliminated (Hatch et al. 1987; Ontario Ministry of Natural Resources 1987). There are four potential types of action to initiate the rehabilitation process:

1) fishery regulations,

2) habitat restoration,

3) fish-community manipulations, and

4) stocking.

When attempting to increase natural recruitment and standing stock, the sequencing of actions will have to be coordinated according to the analysis of primary stress effects.

Fishery Regulations

The goal of rehabilitating fish stocks should be the development of self-sustaining populations in the shortest time possible and with minimal cost. Stringent regulation of the harvest is mandatory to achieve this goal (J. Koonce, Case Western Reserve University, 2080 Adelbert Rd,, Cleveland, OH, 44106-7080, pers. commun.). Harvest of both commercial and sport fisheries must be controlled if the stock is to be allowed to expand-for example, in Lake Erie and Lac Seul following closure of the fisheries from Hg contamination.

The recovery of walleye in western Lake Erie and Lac Seul are dramatic cases where exploitation was implicated as the main cause of population reduction. The history of the western-Lake Erie walleye fishery has been extensively documented (Regier et al. 1969; Nepszy 1977; Hatch et al. 1987; Nepszy et al. 1991). The commercial fishery was closed in both United States and Canadian waters in 1970, and retention of walleye by anglers was banned in Ontario and Michigan waters (Hatch et al. 1987). The fishery was reopened in 1972, and the estimated fishable stock of walleye had increased dramatically by 1976.

Ten years after closure of the Lac Seul commercial fishery because of concern for high Hg levels, walleye abundance increased (Fig. 4). Following protection, angler harvests and quality fishing indices have increased (Ontario Ministry of Natural Resources 1988; McGovern 1983; D. Gibson, OMNR, unpubl. data). The Lac Seul walleye-angling harvest increased from 88,690 kg (1979) to 130,092 kg (1985) and to 160,031 kg (1986), exceeding previous commercial harvests (Fig. 4). Similarly, in Lake St. Clair, after the mercury-contamination problem of 1970, angling effort and harvest were reduced but then gradually increased in Ontario waters from 37 t (1973) to 62 t (1988).

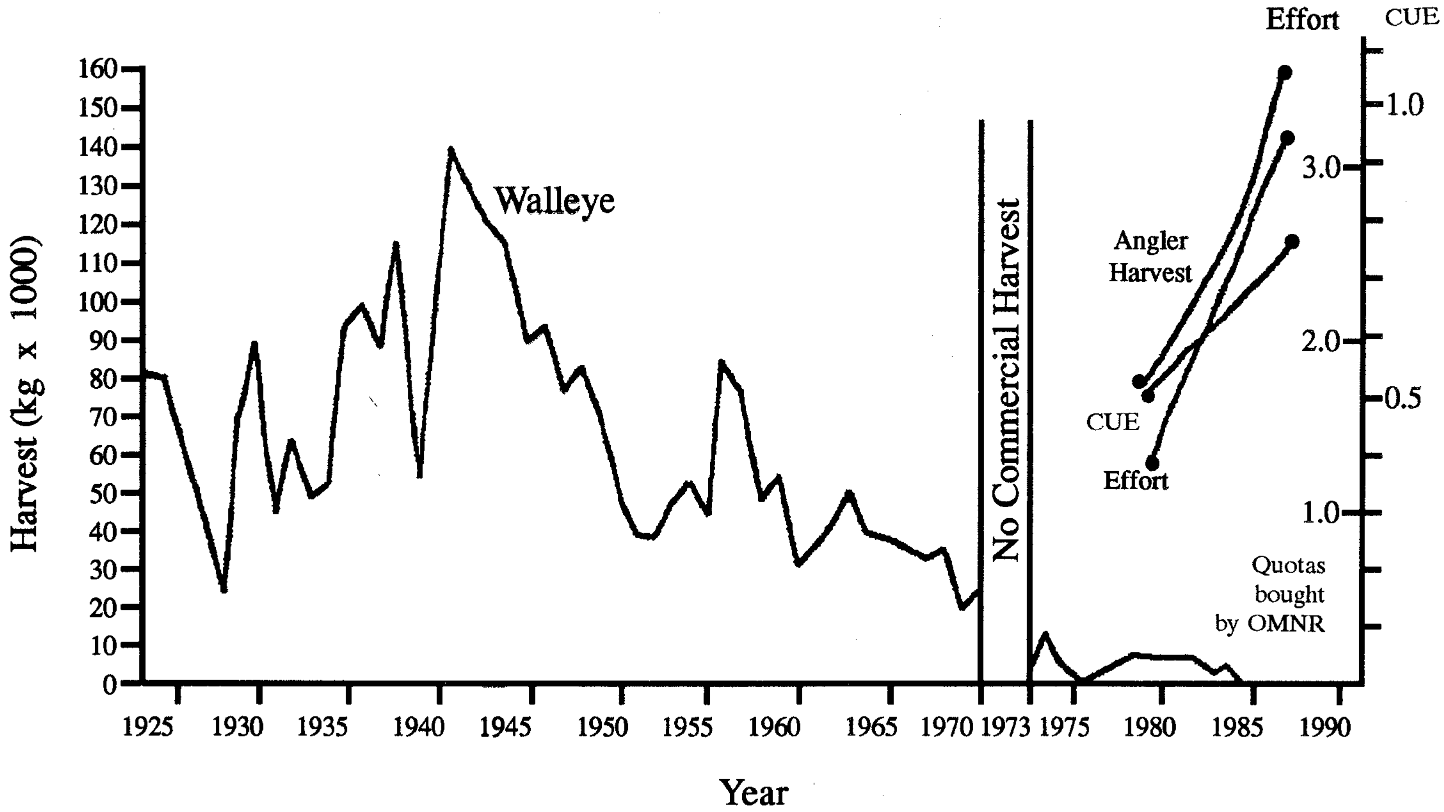


Fig. 4. Commercial-fish harvest from Lac Seul (1924-84) and recent angler activity (Ontario Ministry of Natural Resources 1988; McGovern 1983; D. Gibson, OMNR, unpubl. data). Effect is in man-hr/ha and CPE is in walleye/man-hr.

The closure of the Lake Erie, Lac Seul, and Shoal Lake walleye fisheries were drastic measures. There was a rapid recovery in Lake Erie and a more-gradual recovery in Lac Seul. It is presumptuous to assume, however, that the remarkable recovery of these fisheries will be repeated in every case where exploitation is dramatically reduced. Recovery of the central-basin Lake Erie walleye was not simultaneous with the recovery in the western basin (Nepszy et al. 1991). If closures are initiated too late, the stocks may not recover at all. To date, the walleye stocks in Shoal Lake, Black Bay, and Nipigon Bay (Lake Superior) have not recovered after 15-23 yr (Table 6). In Shoal Lake (situated on the northwestern corner of Lake of the Woods, Ontario), the walleye population collapsed in 1979 (V. Macins, OMNR, Kenora, Ontario, Canada, pers. commun.). The population has not recovered to date despite a 1983 closure of the fishery. In 1987, the estimated walleye-spawning population was at a low ebb (0.6 fish/ha), and 67% of this consisted of the 1979 year-class. Recent monitoring indicates that the walleye population is slowly rebuilding in Shoal Lake after a 10-yr closure (Minnesota Department of Natural Resources et al. 1992).

Table 6. Stock-recovery compilations for Lake Superior (Nipigon and Black Bays) and large, northern, inland-lake walleye fisheries following their collapse or severe reduction.

Stock	Period covered	Duration (yr)	Status	Comments	References
Shoal Lake	1979-present	15	0[1]-1[2]	Complete closure Recovery delayed and slow	Matins 1979 Minnesota Department of Natural Resources et al. 1992 Lockhart 1988
Lac Seul	1970-85	≤15	2[3]	Commercial closure Full recovery	McGovern 1983 D. Gibson, OMNR, unpubl. data Ontario Ministry of Natural Resources 1987
Rainy, North	1971-present	≥22	0[1]	Continued exploitation No recovery	Ontario Ministry of Natural Resources 1984b Minnesota Department of Natural Resources et al. 1992
Redgut	1970-84	≥23	1[2]	Shift from commercial to angling Population remains low Recovery delayed	Ontario Ministry of Natural Resources 1984b Minnesota Department of Natural Resources et al. 1992
South	1960-93	≥33[1]	1[2]	Sport fishing reduced Commercial closure Recovery not complete	Ontario Ministry of Natural Resources 1984b Minnesota Department of Natural Resources et al. 1992
Lake of the woods (Minnesota waters)	1970-85	≤15	2[3]	Reduced commercial activity	Payer et al. 1987
Nipigon and Black Bays (Lake Superior)	1970-present	≥23	0[1]	No recovery Remedial Action Plan (RAP) attempting initiation of rehabilitation in Nipigon Bay	MacCallum and Selgeby 1987

[1]No recovery.
[2]Recovering.
[3]Complete recovery.

Similarly, the walleye population in Black Bay (Lake Superior) collapsed in 1969 after a peak in commercial catch in 1966. Overexploitation was cited as the most-probable cause of the collapse (Colby and Nepszy 1981). Despite attempts in 1972 and subsequent years to achieve rehabilitation through adult transfers and reductions in exploitation, the stock has not yet shown signs of recovery (Schram et al. 1991).

Shoal Lake, Black Bay, and Nipigon Bay lie at more-northern latitudes and are less productive than Lake Erie. It might be anticipated that recovery of these walleye stocks would take longer. In addition, the following reasons may have contributed to the stock failure to show evidence of recovery:

> emigration by adults transferred into Black Bay from other areas of Lake Superior (Schram et al. 1991),
>
> the exposure of those transferred to exploitation, and
>
> the one-time-only transfer of relatively small numbers of fish .

Closed seasons are a common component of walleye-management strategies, although they are considered by some to be an ineffective conservation measure (Noble 1980; Everhart and Youngs 1981). Closed seasons serve principally to allocate the resource rather than to protect it. However, under certain circumstances a closed season may provide some benefit by reducing exploitation on large adults-especially in northern nutrient-poor systems such as Lake Superior. For example, walleye may be most vulnerable prior to spawning when concentrated in restricted areas - specially streams accessible to anglers. Providing sanctuary areas (Reckahn and Thurston 1991), or delaying the opening of angling until post-spawning dispersal has occurred, may reduce exploitation in such circumstances. At Lake Winnibigoshish (Minnesota), tag-return rates for both sexes were higher when spawning occurred later, rather than in years when spawning was completed several weeks before the angling season opened (Osborn and Schupp 1985). Where lake closures are not socially acceptable, area closures or sanctuaries may be effective in reducing exploitation of fish where they are concentrated and vulnerable.

Size limits are probably one of the most-effective regulatory controls for protecting adults or age groups about to recruit to the spawning stock. For sport fisheries, a minimum size limit (MSL) is the most-common approach and is most-easily understood by anglers. MSLs may be the best approach where rehabilitation is initiated through stocking. Limits can be set to provide nearly complete protection until fish reach maturity. However, a MSL that is high enough to protect mature females may substantially reduce harvest of both sexes-particularly males.

P. Festa (New York Department of Environmental Conservation (NYDEC), 50 Wolf Rd., Albany, NY, 12233, pers. commun.) indicated that a 46-cm MSL was to be applied for this purpose to all waters in New York state stocked with fingerlings. MSLs have been in force for walleye in the Michigan portions of the Great Lakes (Mrozinski et al. 1991; Schneider et al. 1991; Schram et al. 1991). These size limits were applied as statewide limits in Michigan and not specifically as protection measures for Great Lakes stocks.

Another potentially useful regulation for protecting fast-growing walleye that are being overharvested or rehabilitated is to impose a MSL and reduced catch for spring fishing. The South Dakota Department of Game, Fish, and Parks reduced daily possession limits 6/12 to 4/8. A MSL of 35.5 cm was imposed during April, May, and June. This regulation was designed to correct an Overharvest situation on Lake Francis Case and to reverse the decline of walleye populations in Lakes Sharpe and Oahe. Size-limit regulations for only three months annually were used to protect younger and smaller fish during periods of high fishing pressure and harvest. MSLs also maximized survival of released fish during this cooler-water period when fish were in shallower water. Later in the season, anglers may keep smaller fish caught in warmer and deeper water when hooking and angling practices cause higher mortalities. This regulation should also allow harvest of smaller fish when large, naturally produced year-classes occur-encouraging good growth and condition. Results from imposing these regulations are very encouraging to date (1989-90) with an increase in abundance and mean age of the walleye catch.

If a very strong natural year-class appears during the course of rehabilitation, the buildup of adult biomass may be accelerated by judicious application of a slot size limit. Although slot size limits for walleye are presently being tested, they can be designed to provide nearly complete protection for females of a cohort throughout most of their life span. The slot can be established at the onset of recruitment of the cohort to the sport fishery. Then the slot can be adjusted upward annually, based on the growth of female walleyes. During the first 2 yr of the slot limit, almost complete protection can be afforded both sexes. Once a sexually dimorphic size difference is established, males can be available for harvest while protection of females continues (D. Schupp, P. 0. Box 278, Pequot Lakes, MN, 56472, pers. commun.). However, even with this protection, simulation modelling suggests that the number of trophy-sized walleye would only be increased by 9% in Mille Lacs, MN (D. Schupp, P. 0. Box 278, Pequot Lakes, MN, 56472, pers. commun.).

In a preliminary report (M. G. Sullivan, Alberta Forestry, Lands, and Wildlife, 14515 122nd Ave., Edmonton, Alberta, Canada, TL5 2W4, pers. commun.), an Alberta walleye task force proposed harvest regulations to compensate for weak year-classes, slow growth, late age of maturity, and limited spawning habitat that limits the provincial supply of walleye. The proposed regulations control both the daily catch limits and size of fish that can be harvested depending on the status of the stock. These stringent regulations may apply to certain northern-Great Lakes stocks where habitat is more oligotrophic. As these stocks advance through various stages of recovery or decline, the regulations are adjusted among the following three stages:

1) recovery and development,

2) maintenance, and

3) exceptional walleye fisheries.

Because these innovative and conceptually appealing proposals have not been reduced to practice, their application should be considered experimental. This combination of protected slot and limited catch prevents overharvesting.

Daily creel limits represent another measure of regulatory control; however, most daily creel limits (5 or more fish, depending on jurisdiction) are ineffective in limiting harvest except when catch rates are high. Where high angler harvest may hamper restoration efforts, minimum length limits are probably more effective than reductions in creel limits. On the Bay of Quinte, when the fishery began to recover and catch and harvest rates were high, the daily creel limit was reduced from 6 to 4 walleye/day. Recent data from that fishery indicate that a reduction in the daily limit from 4 to 3 walleye/day would reduce the total open-water harvest by 9.4% (Mathers 1989). In the Fox River (southern Green Bay), a trophy fishery has been established through the combination of a high MSL and a l-fish daily creel limit (Schneider et al. 1991).

Regulation of incidental catch is a common regulatory control of commercial harvests. Where commercial fisheries for species other than walleye are operating, control of incidental catch of walleye is required. Mortality of incidentally caught walleye is gear dependent, with mortality in gillnets higher than in dropnets or trapnets (Schneider et al. 1991). Limited harvest quotas on walleye may be necessary to prevent the waste of incidental catch.

Alternatively, commercial fisheries may be restricted by time or location to minimize walleye catches. These restrictions, however, imply a knowledge of walleye distribution and behavior that may not always be available. Sport and commercial fisheries may also be separated by boundary lines (Reckahn and Thurston 1991), but regulations of this nature address social rather than biological problems. Gear restrictions are common in nearly all commercial fisheries. These are usually restrictions on mesh size, net length, or net size.

Although further restrictions on commercial fisheries may be desirable when rehabilitating stocks, the efficiency of the fishery for target species other than walleye may also be reduced.

Habitat Restoration

Water-quality improvement continues to be the most-proven method of habitat restoration. The Green Bay case history provides an excellent example of the success of restoring walleye habitat by improving water quality. Prior to the industrialization of the Fox River Valley in the 1800s, the Fox River supported an abundant walleye fishery that also contributed to the fishery in southern Green Bay (T. Lychwick, Wisconsin Department of Natural Resources (WDNR), 200 N. Jefferson, Suite 511, Green Bay, WI, 54301, pers. commun.). The combined effects of construction of navigation dams, water pollution, and Overharvest caused the fishery to decline to only a remnant population by the late 1960s. The recovery of the river fishery began with the passage of the Clean Water Act of 1972 that funded or subsidized the construction of municipal and industrial sewerage-treatment facilities. By 1978, the river (that in the past had been anoxic during the summer months). had improved enough to attempt the first restocking with walleye fingerlings. Between 1978 and 1984, 5- to 10-million walleye fry were stocked annually. In 1985, the first natural fry production was documented and stocking was discontinued. In 1986, naturally produced yearling walleye were captured. Since 1985, natural recruitment has occurred annually and the walleye population has increased dramatically. However, Auer and Auer (1990) conclude that successful natural reproduction by walleye in portions of the lower Fox River is still limited by the availability of suitable substrate.

More research is needed on effects of toxicants on walleye reproduction (egg and fry stages) in order to further the positive effects of water-quality improvements on walleye stocks. In addition, reduction of sedimentation in spawning streams should be stressed in management plans.

Removal of obstructions and construction of fishways are potential means of restoring walleye habitat. Dams on tributary streams have been reported by many authors as a cause for decline in walleye fisheries in Great Lakes waters. Even low-head dams have been reported to effectively block migration of walleye to upstream spawning areas (Priegel 1970; Gibson and Hughes 1977). Removal of obsolete dams has the potential to increase stock abundance by providing access to stream- or river-spawning sites. However, the benefits of such action must be weighed against the cost of increased sea lamprey *(Petromyzon marinus)* treatment that may result from providing lamprey access to spawning and rearing habitat.

In many situations, removal of dams is not a viable alternative to allow passage of walleye. However, it may be possible to pass walleye over low-head dams with certain fishway designs. In Manitoba, a successful walleye fishway was constructed on the Fairford River (Derksen 1988). In 1988, the WDNR constructed a fishway at the Eureka Dam on the upper Fox River to allow passage of walleye to upstream-spawning marshes (M. Endris, WDNR, pers. commun.). A 12-m-wide by 26-m-long structure was built at one end of the low-head dam on the river to create a channel with the appearance of shallow rapids. The channel bottom is covered with rock. At normal, spring water levels there should be no waterfall to prevent walleye movement. At this writing, it is not known if walleye will use the channel.

Biette and Ode11 (1976) conducted an evaluation of a fishway manufactured by Aeroceanics Fishway Corporation that was installed in a lamprey barrier in the Saugeen River (Ontario) to allow the passage of salmonids past the barrier. The authors felt the fishway might work for walleye because no jumping is required to travel up the incline.

Regulation of flow is another method of habitat restoration. Because year-classes are often correlated with spring runoff volumes (Winterton 1975; Reckahn and Thurston 1991), regulation of flow below dams during the spawning period may increase reproduction. Discharge flow rates from control dams may significantly influence walleye spawning in downriver areas through fluctuations in water level (MacCrimmon and Skobe 1970; Bidgood 1971; Nelson and Walburg 1977; Cohen et al. 1991). There may be opportunities to develop water-flow agreements with water-regulating authorities to maximize year-class production (Reckahn and Thurston *1991).*

Cohen et al. (1991), in an international boundary-water study on Rainy Lake, found that in addition to mean water levels, periodic fluctuations in the range of water levels are important in regulating fish populations. The dominating period of these fluctuations is approximately 5 yr. These authors suggested that allowing higher-than-normal water levels in both Rainy Lake and the Namakan Reservoir, followed by lower-than-normal water levels within a single year, and repeated at approximately 5-yr intervals would benefit the fishery and the ecosystem. The diversity of aquatic vegetation would be enhanced, and shoals and other spawning grounds would be cleaned. It is the variability of water levels that should be managed (not the mean). The authors admit such a policy would probably cause periodic damage from flooding and low water levels. They suggest additional work on damage assessment using geographical information systems. Their work also illustrates the value of time-series and spectral analyses as potential approaches to better understand and explain long-term fluctuations and trends among Great Lakes fish stocks.

Spawning-substrate enhancement or creation may also be a useful restoration practice. Spawning populations of walleye in streams may be reestablished or enhanced by construction of spawning beds. Armstrong and Dyke (1967) built artificial spawning beds with cobble below a dam in the Otonabee River, Ontario. They found more eggs deposited and more live eggs on the cobble than on the natural rock. Egg deposition and survival were highest in areas with stronger water currents.

Gibson and Hughes (1977) obtained similar results on a study conducted on Hamilton Creek-a tributary stream to Falcon Lake, Manitoba. Spawning walleye selected artificially placed gravel and cobble substrate over natural rock or sand stream bottom. Higher egg counts and higher egg survival were found on gravel and cobble compared to sand and rock. The authors recommended placing gravel on shallow areas near pools 1.0-1.3 m in depth with overhanging cover for protection from predators.

In cases where walleye spawn over vegetation, improvements in spawning success can also be obtained through water-level management. Priegel (1970) reported that several marshes in the Lake Winnebago region, Wisconsin, were improved for walleye spawning by removing or lowering dikes or roads to allow water to flow freely through the marshes.

In addition to spawning-habitat improvements in streams and marshes, there are a number of case histories of walleye-spawning reef construction on inland waters. These efforts have met with varying degrees of success. Discussion here will be limited to those projects located on large, inland waters that might have more application to the Great Lakes.

In 1982, limestone, field stone, and crushed limestone were placed on a natural reef l-2 m deep in 1,052-ha Fox Lake (Dodge County, Wisconsin) to augment the sparse, naturally occurring limestone rubble. The artificial reef was built on an area that had a history of walleye usage. Natural year-classes have been produced sporadically in the lake. However, Larson (1986) found that walleye-egg deposition on the natural shoreline was >5 times higher than on the reef. There was no significant difference in survival between the natural shoreline and artificial reef. The rock on the reef had heavy filamentous algae growth. However, there was no algae growth on the shallow natural rock. Larson (1986) concluded that it would be less costly, in strictly economic terms, to stock hatchery-produced walleye fry than to build artificial spawning substrate that would produce an equal number of fry. He estimated the payback time to be 18.7-45.5 yr.

Newburg (1975) evaluated walleye usage of an improved shoal in 2,538-ha Lake Osakis, Minnesota. Two areas on a narrow point with a history of walleye spawning were improved by placing rock of two sizes in water 0.3-1.0 m deep. The reef with the larger rock received greater use by walleye and had higher egg-survival rates. The author felt that the larger rock provided greater protection to the eggs, while the smaller rock became covered with sand and silt within 2 yr. After several years, the entire reef became covered with sand and silt and useless for spawning. However, if good hydrological data had been available, the rocks may have been placed elsewhere (over an area of less deposition), resulting in greater success (D. Schupp, P. 0. Box 278, Pequot Lakes, MN, 56472, pers. commun.). Total cost of the reef was $6,400. Payback for the reef construction was 64.6 yr based on cost of hatchery fry and the productivity of the reef before it became inundated with sand. This case may have implications for Great Lakes waters where sand movement is extensive.

Michaletz (1984) found that riprapped shoreline in 37,000-ha Lake Francis Case, South Dakota, provided important walleye spawning areas in this Missouri River reservoir. The cobble- to boulder-sized rock was used to stabilize roadfills across the reservoir. Few walleye spawned on non-riprapped areas. Greatest density of eggs was found in water O-l m deep.

The largest reef built (610 m long) was constructed in Brevoort Lake, Michigan (1,713 ha) at a cost of $350,000. Brevoort Lake had no natural reproduction of walleye prior to the reef construction (Bassett 1987, 1988). Walleye spawned on the reef the first spring after construction in 1984. Egg deposition increased each year from 1985 to 1988, with greatest egg deposition in water <0.75 m in depth. There was little difference in egg survival between deep- and shallow-water spawning sites. The abundance of YOY walleye increased after construction of the reef.

Spawning-reef construction in the Great Lakes is unproven and may not be economically justifiable in many cases. Spawning-substrate augmentation in tributary streams may be less expensive and less risky. The unavailability of spawning substrate is often considered to be the limiting factor for walleye reproduction. However, failure to successfully produce year-classes may be from other causes. Possible reasons for failure are:

plankton species composition;

timing of plankton pulse;

predation on eggs, fry, or fingerlings;

climatic factors; and

forage size or species.

Thorough investigation of all factors should be done before investing in costly habitat construction Cohen et al. (1991) reported that generally non-linear links between YOY fish and adult populations in the boundary waters suggest that improvements of spawning habitats (such as the practice of constructing shoals) is probably not effective in improving the fishery.

Fish-Community Manipulations

In many cases of changes in dominance of fish communities, collapsed populations have remained at low levels even after the stress causing the collapse or decline was removed. This lack of recovery suggests the existence of more than one stable-community state (Holling 1973). In such cases, manipulation of the fish community-for example through control of the abundance of smelt, alewife, and other species that may prey on or compete with walleye early life stages-may be an option. There are several inland-lake examples of fish-community manipulations benefiting walleye, including the removal of white suckers (Johnson 1977) and northern pike (Colby et al. 1987). Johnson (1977) found that the standing stock of walleye increased 33% when >85% of the sucker biomass was removed. He suggested such removals might benefit walleye populations in lakes with limited species diversity. In more-productive waters with more-diversified species composition, released productivity may be assimilated by species other than percids.

In the Great Lakes, there is little conclusive evidence for secondary species constraining the recovery of walleye stocks (Schram et al. 1991). Both smelt and alewife have been suggested as factors constraining walleye recruitment either directly through predation or indirectly through overgrazing zooplankton (Mrozinski et al. 1991; Nepszy et al. 1991; Schneider et al. 1991). On the Bay of Quinte, a winterkill of alewife in 1977 and of white perch in 1978 may have caused or contributed to the resurgence of walleye (Bowlby et al. 1991). A link between walleye abundance and black crappie *(Pomoxis nigromaculatus)* has also been suggested on Georgian Bay (Reckahn and Thurston 1991). However, Hernandez (1989) found no evidence in modelling trials to suggest secondary predators or planktivores would hinder the recovery of walleye (assuming there were no habitat constraints). There are also few instances where the presence of other top predators is viewed as affecting walleye-stock restoration. Exceptions might include the introduction or invasion of predators with niche characteristics similar to walleye and competition for shared forage resources (Hernandez 1989). In addition, other management programs may have spin-off effects such as the impact of salmonid stocking on alewife abundance in Lake Ontario (Bowlby et al. 1991). For the most part, effective fish-community manipulations on the Great Lakes will probably be difficult given the large scale of the systems involved.

Stocking

Construction of hatcheries in the late 1800s and the release of billions of O-3 day-old walleye fry into the Great Lakes through the early 1900s failed to produce the dramatic increase in walleye stocks predicted by early fish culturalists (Regier et al. 1969). Confidence in the efficacy of stocking was further shaken by the inability to link fluctuations in walleye abundance to numbers of fry stocked (Hile 1937), and most hatcheries were quietly closed. More recently, Cohen et al. (1991) found that the yearly maximum range in water levels affects survival between age 0 and the age of recruitment. Also, short of stocking adult fish, stocking will probably not produce noticeable improvements in the fisheries they studied on the Ontario-Minnesota boundary waters.

Success of supplemental fry stocking is generally judged by the presence or absence of a correlation between numbers stocked and relative abundance of corresponding year-classes in subsequent years. Fluctuations in abundance and survival of native fry easily mask the contribution of stocked fish to the year-class unless stocked fry substantially outnumber native fry. Strong correlations between numbers stocked and year-class strength were observed in lakes stocked at a rate of 2,000-20,000/ha (Rose 1955; Carlander and Payne 1977; Momot et al. 1977). Strong correlations are unusual in waters where low stocking densities (40-300/ha) were employed (Hile 1937, Carlander 1945; Smith and Krefting 1954). Densities of native fry in these waters were not measured at the time stocking was evaluated. However, in Spirit Lake (Iowa), later studies (Rose 1955) indicated hatchery fry outnumbered native fry at least 5 to 1 when 8,300 fry/ha were stocked (McWilliams 1976).

It is generally held that walleye fry should be stocked when there is abundant zooplankton to provide food after absorption of the yolk sac. In practice, this is usually only accomplished by chance. It is difficult to coordinate hatchery production with changing and unpredictable weather conditions that affect the spring plankton pulse. By regulating water temperature in the hatchery, it is possible to control hatching time to some extent. Stocking of southern-Wisconsin waters can be delayed to allow warming and development of the zooplankton population by using fry produced in northern-Wisconsin hatcheries where walleye eggs are taken l-2 weeks later. It has not been documented if there is any benefit to this practice. T. Lychwick (WDNR, 200 N. Jefferson, Suite 511, Green Bay, WI, 54301, pers. commun.) reported that fry stocking has been successful in southern Green Bay and the Fox River. However, less success was achieved in northern Green Bay that warms more slowly. It is his conjecture that plankton abundance in northern Green Bay is not in synchrony with the production of hatchery fry available for stocking.

In Minnesota, guidelines for stocking consider the influence of water warming rates on fry survival. The general guidelines suggest that where water bodies warm rapidly (water is shallow, turbid, or fed by a large stream), fry stocking may be effective. Otherwise, fingerling stocking is recommended (D. Schupp, P.O. Box 278, Pequot Lakes, MN, 56472, pers. commun.).

Fingerling stocking has been effective in rebuilding spawning populations in some embayments-notably Green Bay, Saginaw Bay, and parts of Georgian Bay (Mrozinski et al. 1991; Reckahn and Thurston 1991; Schneider et al. 1991). However, natural recruitment has been limited. The success of fingerling stocking suggests the recruitment bottleneck occurs before young attain a length of 3-6 cm, but it is unclear whether recruitment is impeded primarily by losses during embryonic development or mortality during the post-hatching limnetic stage. Close synchronization of walleye and yellow perch year-classes might be expected if mortality during the limnetic stage governed recruitment because temporal and spatial distributions of walleye and yellow perch broadly overlap. Failure of walleye recruitment to match the resurgence in yellow perch abundance in the early 1980s may indicate recovery of walleye is limited by low densities of larvae.

The walleye fishery in Saginaw Bay (Lake Huron) collapsed by the late 1940s, primarily because of the intensive commercial fishery and environmental degradation (Mrozinski et al. 1991). Early fry plants were unsuccessful. However, fingerling stocking initiated in 1978 began to show signs of success as early as 1980 when commercial fishermen were reporting incidental catches of yearling walleye in their perch nets. By 1981, spawning runs were beginning to develop in tributary streams. Natural reproduction has been documented in some streams, but the contribution to the fishery is not known. Good spawning substrate is lacking in most tributaries. There is a need to determine the contribution of natural recruitment to the fishery, to determine the amount of quality spawning area available in tributaries and on offshore reefs, and to improve and protect these areas.

The northern-Green Bay stock was bolstered by a total of 3.0-million fingerlings and 24-million fry up to 1988. Stocking in southern Green Bay was discontinued in 1984-after 3.5-million fingerlings and 86-million fry had been stocked. Although stocking combined with water-quality improvements has increased spawning stocks, yields are still below historic peaks (Schneider et al. 1991). Good reproduction may still be constrained by:

suboptimal thermal regimes in some years-for example, in Sturgeon Bay,

poor water quality-for example, in the Rapid River, and

scarcity of spawning substrate or contaminant loading-for example, in the Fox River.

These cases point out the need to ensure the actions chosen to initiate rehabilitation address all constraints and serve to rehabilitate self-sustaining stocks.

Few studies have compared the effectiveness of adult transfers and fry and fingerling plantings. In Lake Superior, fingerling-stocking programs in Chequamegon Bay (Wisconsin) and Huron Bay (Michigan) have been successful in terms of survival and growth. However, adult transfer programs in Black Bay and egg, fry, fingerling, and adult stockings into Nipigon Bay (Ontario) have failed to rehabilitate those stocks to date (Schram et al. 1991). In Sturgeon Bay (Lake Michigan), survival of stocked fry was negligible; survival of fingerlings to age 4 was estimated to be 4.4% at most (Schneider et al. 1991). Relative survival of fry and fingerlings to the adult stock in West Blue Lake (Manitoba) indicated a narrow 1:4 survival advantage for 21-cm fingerlings over fry (Schweigert et al. 1977). Whether survival of fry was exceptionally high or survival of fingerlings exceptionally low was unclear. Relative survival to fall in two Illinois reservoirs stocked with fry and fin-clipped fingerlings ranged from 4 (in a year when 4.3-cm fingerlings were stocked) to 286 (when larger 11.3-cm fingerlings were released) (Heidinger et al. 1985). Evidence that 4-300 fry are approximately equivalent to 1 fingerling does not provide much guidance in assessing economic trade-offs.

Intensity of predation may determine success or failure of fry stocking. The recovery of yellow perch stocks in the upper Great Lakes as numbers of alewives declined is strong circumstantial evidence that planktivores can suppress recruitment of percids. Walleye, like yellow perch, are pelagic for 4-6 weeks after hatching. During surveys of five New York lakes stocked with 15,000 fry/ha, no fry were recovered in two lakes where white perch and clupeids were the most abundant planktivores (Forney 1987). Svardson and Molin (1973) argued that predation by adult zander *(Stizostedion lucioperca)* enhanced survival of young zander by suppressing competitors. Extending the argument to walleye, rehabilitation through stocking may be best initiated by a program of stocking fingerlings first. After predator biomass is built up, predation may create an environment in which fry stocking will succeed if needed.

The evidence indicates that stocking can assist in reaching rehabilitation objectives if there is no remnant stock and may speed rehabilitation even in the presence of a remnant stock. It is essential that spawning habitat be sufficient to support natural reproduction if stocking is to be only an interim measure in the rehabilitation process.

The preferred source of eggs for restoration of a depleted population is the remnant population or nearby stocks with which the stock being rehabilitated may have exchanged genes in the past (Krueger et al. 1981). Walleye spawning on shoals 2.8 km apart in Clear Lake (Iowa) intermingled extensively (Whitney 1958). There is evidence that some walleye tagged in the Moon River (Ontario) in 1968-70 switched to spawning grounds in the Blackstone River in 1971 (Winterton 1975). These examples suggest considerable latitude in selection of donor stocks with similar genotypes. Choice of native or nearby stocks for stocking will minimize the risk of swamping the native gene pool and losing locally adapted genetic traits. However, the southern Green Bay stock, which has exhibited the best recruitment of all Lake Michigan stocks, was built up by walleye from inland Wisconsin lakes rather than from remnant native stocks (Schneider et al. 1991).

There is some evidence that stocked walleye are less migratory than native stocks (Mrozinski et al. 1991; Schneider et al. 1991).

The most-direct method of evaluating stocking is positive identification of stocked fish in surveys following stocking. However, evaluation of walleye stocking has been hampered by the lack of suitable methods of marking large numbers of small fish. Inability to accurately assess the contribution of stocked fry to the fishery has hampered the development of guidelines for the use of stocking in walleye rehabilitation and management.

Walleye fingerlings appear to be very sensitive to stress from handling. Methods suitable for other species, such as fin clipping, may lead to excessive mortality of walleye.

In the absence of a technique for identifying stocked fish, many jurisdictions have attempted to evaluate inland stocking programs through tests for correlation between numbers stocked and strength of year-classes in the fishery. In Chequamegon Bay (Lake Superior), such a technique has been used to assess alternate-year plantings of walleye fingerlings (S. Schram, WDNR, P. 0. Box 589, Bayfield, WI, 54814, pers. commun.). However, evaluation of the correlation between year-class abundance and numbers stocked is time consuming, costly, and probably impractical in the Great Lakes with its numerous stocks of walleye and poorly defined spatial boundaries of populations.

In recent years, several new techniques have been developed to assist in the evaluation of stocking programs. In certain situations, analysis of scale pattern may allow discrimination between hatchery and native stock (Reckahn and Thurston 1991), although this technique requires careful validation (J. Casselman, OMNR, R.R. #4, Picton, Ontario, Canada, K0K 2T0, pers. commun.). Use of genetically tagged fish (Schweigert et al. 1977; Ward and Clayton 1975; Murphy et al. 1983; Ward et al. 1989), which can be identified through recruitment to the fishery, is an effective means for assessing stocking. This technique is obviously inconsistent with maintaining the integrity of native gene pools, but the benefits may outweigh the risks where previous introductions have produced mixing of stocks. Dye marking (Priegel 1970) and marking of fry with trace elements (Muncy and D'Silva 1981) are genetically less intrusive. However, marks are generally transitory-lasting a few days to several weeks. However, Casselman (OMNR, R.R. #4, Picton, Ontario, Canada, K0K 2T0, pers. commun.) has developed two methods for identifying hatchery walleye:

1) examining otolith microstructure for stocking checks (J. Casselman, OMNR, R.R. #4, Picton, Ontario, Canada, K0K 2T0, pers. commun.), and

2) causing a permanent mark to be placed in the otolith by immersing fry in a solution of strontium prior to stocking.

Coded wire tags have been used to mark several species (Wydoski and Emery 1983). Large numbers of small fish can be tagged with relative ease. An evaluation of walleye-fingerling stocking using coded wire tags inserted in the musculature of the gill cover is currently under way in Minnesota (D. Schupp, P. 0. Box 278, Pequot Lakes, MN, 56472, pers. commun.).

THE REHABILITATING PHASE

Ecological Dimensions

The preceding section on planning for rehabilitation deals with identification and remediation of stresses that impede walleye rehabilitation. These remediation strategies need to be continued in the early rehabilitating phase to stimulate recruitment.

If the remediation strategies are successful, the stock will be rebuilding during this phase. Because stock recovery may not mirror historical conditions of stock abundance, or historical conditions may not be known, it can be difficult to determine the position of the stock on the recovery trajectory in the rehabilitating phase. This uncertainty, the end-point problem, makes it difficult to assess when rehabilitation has been achieved. The problem can be addressed indirectly by monitoring various indicators. But strictly speaking, there are no statistics at either the population level or the community level to define precise thresholds at which walleye populations can be considered rehabilitated. This is because fish communities can be expected to oscillate around some limits associated with juvenescence and maturity, The end-point question for managers is therefore related to defining the limits or boundary conditions for natural variations (Christie et al. 1987b; W. Christie; R.R. #4, Picton, Ontario, Canada, K0K 2T0, pers. commun.). For example, water-level changes in the lower Great Lakes may dictate community structure.

We believe that a definition and description of this stage is important because client expectations and fishery policies will probably be greatly influenced by perceptions of the degree to which a depressed stock has recovered. Moreover, it will be important for managers to clearly link fishery policies with ecological states to avoid, as much as possible, having management resources devoted to dampening client expectations and demands for fishing opportunities. The rehabilitating phase in our general rehabilitation model for Great Lakes walleye is bounded at the start by stocks in a depressed condition and at the end by increased abundance that is naturally reproduced. By definition, the rehabilitating stage of walleye recovery is very dynamic in that improvements in stock productivity are anticipated and encouraged.

Early rehabilitation is characterized by increases in the magnitude and frequency of natural recruitment. In combination with a high annual survival rate, the age structure will expand to include a larger number of age groups. In western Lake Erie, for example, a period of 15 yr (1955-70) of poor recruitment was ended with improved recruitment of year-classes in 1970, 1972, 1974, 1977, and 1982 (Nepszy et al. 1991). The age structure increased from 5 age groups (ages O-4) to 8 age groups (ages O-7). Similarly, walleye populations in the Bay of Quinte produced signs of larger year-classes in 1977 and 1978 (Bowlby et al. 1991).

The transition to the late rehabilitating phase occurs with the onset of density-dependent responses, such as decreased growth rate and increased age at sexual maturity. In systems that are open to emigration, changes in growth and maturity may be preceded or accompanied by expansion of the stock into a larger range.

As stocks build during the rehabilitating phase, issues of catch allocation-including allocation to stock maintenance (Loftus et al. 1987) - will become increasingly important. Fishing policies should be conservative, especially in the early rehabilitating phase, as fishing can inhibit the achievement of increased recruitment. For example, in the western basin of Lake Erie, an interagency quota-management program beginning in 1986 maintained a conservative harvest policy that apparently provided the conditions necessary for successful rehabilitation (Nepszy et al. 1991). Similarly, reduction in commercial exploitation on the Bay of Quinte (Bowlby et al. 1991) and Lac Seul may have accelerated the rehabilitation process in those populations. Transition from the late rehabilitating phase to the rehabilitated state will be managed through control of survival rate. Selection of a fishing policy will affect the rate and ultimate level of stock recovery. However, choice of policy will probably be determined less on the basis of biological-status indicators or objectives than on sociological objectives. An initial policy of MSY may allow large immediate harvests, and stock size will decline below the recovery zone. A policy to allow no immediate harvest, or to delay significant harvest, may allow stock size to build and possibly overshoot the desired end point. Finally, an intermediate policy to allocate a fixed proportion of the surplus production to both harvest and stock enhancement will allow a more-gradual increase of stock size within the recovery zone (Fig. 1).

In addition to careful selection of fishing policy, the adoption of a no-net-loss policy for habitat and the curtailment of stocking as soon as recruitment is dominated by naturally produced fish will enhance the rehabilitation process during this phase.

Use of indicators to assess progress in rehabilitation can be exemplified by examining seven of the best-documented case histories (Tables 7, 8). A brief description of each stock is shown in Table 7 and some appropriate stock-status indicators are shown in Tables 7 and 8. The 1989 position on the rehabilitation continuum and its potential are also indicated in Table 7.

If degradation of spawning habitat has been a primary stress leading to stock collapse, then a YOY index should indicate the presence of stocked and natural fish. Technology may be required to distinguish stocked fish from naturally reproduced stocks. It may be expected that year-class strength will be most variable during this stage because it is set by stochastic physical events and not restrained by density-dependent, intraspecific mechanisms. Limitations because of degraded spawning habitat may be confounded with other reproductive constraints-for example, loss of egg viability because of contaminant loading as inferred in the Fox River study (Hokanson and Lien 1985). This may necessitate surveys of spawning substrate for viable embryos (sperm- and egg-viability studies). During the late phase of rehabilitation, the YOY index should indicate the consistent development of natural year-classes. Year-to-year variations may be of smaller magnitude than during early rehabilitation because intraspecific, density-dependent controls should dampen the magnitude of variation caused by stochastic physical events. The YOY index should be sensitive to environmental degradation and reflect the quality of spawning and nursery habitat. Further degradation of spawning and nursery habitat would lead to a loss in natural reproduction-for example, in the Fox River (Auer and Auer 1990).

Although only limited field evidence exists (Munkittrick and Dixon 1989), laboratory research has shown that contaminant chemicals can disrupt fish reproduction and other essential behaviors (Cairns et al. 1984; Walker et al. 1991). During the early stage of rehabilitation, body burdens should be monitored for potential deleterious effects on gameto and embryogenesis. Growth, fecundity, and fry viability may be affected. If contaminant problems are suspected, spawn should be taken from the wild, reared, and then compared with uncontaminated controls. During late stages of rehabilitation, contaminant-body burden should also be monitored with emphasis on concern for public safety.

Table 7. Characteristics of rehabilitated and rehabilitating stocks identified in the Great Lakes in 1989.

Stock	Time depressed (yr)	Time rehabilitation (yr)	Spawning habitat	Recruitment type (% natural)
Fox River	50	15	One river	100
Muskegon River	15	15	One river	Stocked and natural
Saginaw Bay	31	10	One river (?) reefs	50
Moon River	5	16	Two rivers	12-100
Central Lake Erie	1 0	10	(?) rivers (?) reefs	Predominantly immigration
Western Lake Erie	12	14	Two rivers Eight reefs	100
Bay of Quinte	15	8	Three rivers Two reefs	100

Continued on next page

During early stages of rehabilitation, fisheries should be tightly constrained and closely monitored. Excessive extraction will be manifested as a premature increase in total mortality, no increase in average age, and a suppression in the rate of increase of stock biomass. During later stages, excessive exploitation will again result in total mortality above target values. This will slow continued increases in stock biomass. Other indicators may include increased variation in recruitment (Ontario Ministry of Natural Resources 1983), increased growth rate, increased maturity rate, and decreased J,,. J_{max} is a tool to define (quantifiably) the point in longevity where 95% of ultimate walleye length has been achieved.

Table 7, *continued*

Historical yield	Historical stock size	Potential for rehabilitation	Rehabilitation phase
28,000-38,000 fish	Unknown	Fair	Early stage
9,000 fish during the 1950s	139.000 fish during the 1950s	Questionable temperature limits reproduction	Early stage
454 t	Unknown	Good Poor spawning	Early stage
4.000-11,000 fish	20,000 fish	Questionable improved habitat and fish community	Late stage
250 t	500,000 fish	Good Poor spawning	Late stage
1,000-7,000 t	Unknown	N/A	Completed
141 t	1 million fish	N/A	Completed

Socioeconomic Dimensions

Socioeconomic issues arise as rehabilitation progresses (Fig. 1). The rights to fish for walleye and other species are distributed among native, commercial, and sport interests. The fisheries themselves must exist in the context of other uses that are being made of the Great Lakes. Other uses of the Great Lakes waters might be as water supplies for urban centers and industries, disposal sites for waste products, and transportation arteries. When these uses are complementary and enhance an alternative use, resource management decisions are simplified. When these uses are competitive and one use displaces another in whole or in part, tough choices about which alternative is to prevail face resource managers.

Table 8. Stock-status indicators identified in the Great Lakes in 1989.

Stock	Recruitment	Growth	Age at maturity	Mean age (trend or range)	Instantaneous and total (A) mortality rates
Western Lake Erie	High Variable	Declining	Older	Increasing	0.420
Bay of Quinte	High Variable	Declining	Increasing with time	Increasing	A=40%
Moon River	Spotty due to flows	Fast Steady	Increasing with time	Unknown	0.429
Fox River	LOW	Very high	Males: age 3 Females: age 4	Males: ages 34 Females: ages 4-7	1.609 A=80%
Muskegon River	Significant Improving	Fast	Males: age 5 Females: age 7	Males: ages 5-7 Females: ages 7-9	1.040 A=65%
Saginaw River	Slight Increasing	Fast Slight decline	Females: age 4	Ages 4-5	0.480
Central Lake Erie	Limited within the basin	Fast Slight decline	Males: age 3 Females: age 4	Increasing	0.510 A=40%,

The combination of complementary socioeconomic issues requires a holistic approach. A framework for analysis and management that encompasses all of these issues is required if use of the resource is to be optimized.

Socioeconomic analysis can contribute to resource-management decisions with an emphasis on fisheries management and, more specifically, on the management of walleye-rehabilitation efforts. Neither biological nor socioeconomic implications exist in vacuums independent of considerations of the other disciplines. Joint consideration of the contributions from each discipline will lead to better management decisions. Therefore, it is desirable that management agencies bring social scientists into the decision process at an early stage.

Although socioeconomic issues were considered in past rehabilitation efforts, information regarding this subject has either been limited or unorganized for efficient utilization. Therefore, we suggest that:

1) Early in the rehabilitation process, managers incorporate socioeconomic data and concepts into a decision-making framework-even if the concepts are initially hypothetical.

2) Socioeconomic issues facing walleye-rehabilitation efforts should be synthesized.

3) Priorities for the analysis of socioeconomic issues be addressed to increase the effectiveness of walleye-rehabilitation efforts.

Discussion

Fish-community constraints during early rehabilitation may include competition and predation from exotic species, and prey partitioning with secondary predators. This will certainly manifest itself as suppression of the rate of stock increase and may also include a decrease in growth rate and low indices of YOY abundance. During late rehabilitation, community constraints (primarily competition) may compound density-dependent effects. This will increase total mortality even in the presence of fishing restrictions. It may be anticipated that stable oscillations may occur around carrying capacity because of community dynamics. These oscillations may be driven by the stochasticity in the physical environment that is expected to continue causing variable recruitment in both walleye and their prey species (Table 2).

Increased natural reproduction is the primary measure of the recovery process. Supplemental walleye stocking is considered to be an acceptable rehabilitation procedure as long as there is evidence that natural reproduction increasingly contributes to expansion of stock abundance. There should also be evidence that continuous existence of a given stock is not dependent on stocking. Stocking walleye in locations that may be suitable for survival, but where this species did not occur naturally, may well be a valid management option to meet user demands for new recreational opportunities. However, such action does not constitute stock rehabilitation. Initiation of this latter put-grow-take management option should be decided on the basis of biological and socioeconomic considerations that are not necessarily. identical to those for achieving recovery of depressed stocks.

The western-Lake Erie and Bay of Quinte stocks were both designated as rehabilitated by workshop participants. Both were severely depressed from approximately 1960 to the mid-1970s when recovery began to demonstrate positive responses to recent initiatives to restore water quality and reduce fishing. There was an increasing trend in natural reproduction and recruitment although large variation in year-class success is still evident. Growth rates were initially high. They have declined as rehabilitation progressed and stock density increased. Sexual maturation has been delayed for both sexes, although it is more evident for females in both stocks.

As the fishable stock increased (Table 9), the allocation and subsequent harvest increased as reflected in the harvest-stock ratio. The .222 harvest-stock ratio closely approximated the mean exploitation rate (22.3%). This rate is a reasonable harvest value considering the P/B ratios and exploitation rates reported for walleye in the literature (Tables 10, 11). The literature, therefore, supports the contention of Oglesby et al. (1987) that, given the current biomass estimates and a P/B ratio of 20%, the western-basin walleye population could sustain harvests of up to 15 kg/ha. The published P/B ratios (Table 10) and exploitation rates (Table 11) also support the Lake Erie Standing Technical Committee recommendation that a 20%-25% exploitation rate is appropriate for the western basin (Nepszy et al. 1991).

Table 9. Estimates of fishable stock (millions of fish), allocation, actual harvest, harvest-stock ratio, and exploitation rate (Nepszy et al. 1991) for western-Lake Erie walleye (S. Nepszy, OMNR, R.R. #2, Wheatley, Ontario, Canada, NOP 2P0, pers. commun.).

Yr	Fishable stock	Allocation	Harvest	Harvest-stock ratio	Exploitation rate (%)
1976	13.79	.99	.49	.04	6.5
1977	12.97	.99	.92	.07	20.3
1978	11.26	-83	2.14	.19	19.0
1979	24.94	2.35	4.19	.17	16.7
1980	18.37	2.97	3.48	.19	18.9
1981	17.91	4.18	4.29	.24	23.9
1982	25.18	5.73	4.82	.19	19.1
1983	21.31	6.50	3.50	.16	17.0
1984	32.85	7.69	5.57	.17	17.0
1985	40.51	4.89	6.04	.15	14.9
1986	33.83	7.50	7.09	.21	20.9

In the western basin of Lake Erie, abundance of selected prey fish has probably decreased while walleye-diet diversity has tended to increase. Walleye abundance has increased dramatically and distribution has expanded geographically. Age structure of both Lake Erie and Bay of Quinte walleye stocks has increased from only a few age groups to eight or more. Total mortality has tended to increase as walleye rehabilitation progressed in Lake Erie. However, changes here, as with a slowdown in growth, have apparently been much lower than anticipated. As changes in status indicators become more density dependent, we approach the end point of rehabilitation that is predetermined according to management objectives.

The Lake Erie and Bay of Quinte scenarios stand apart; in every other instance of depleted Great Lakes walleye populations, residual stocks were apparently insufficient to spark recoveries. For these other populations (including those of Saginaw Bay, Fox River, Muskegon River, and Moon River), further management action in the form of stocking was undertaken. In most cases, stocking of fry has been extremely ineffective and only the planting of fingerlings has had positive effects (Colby et al. 1991). The Fox River is an exception where highly productive receiving waters allowed good growth and survival of stocked fry that contributed significantly to the rehabilitation effort (Schneider et al. 1991).

The Fox River, Muskegon River, and Saginaw Bay were considered to be in an early rehabilitation stage. Central Lake Erie was considered to be in a late rehabilitation stage (Table 7). These four stocks can be combined into two groups:

1) the Fox and Muskegon River stocks representing single genetic units utilizing the river as their spawning ground, and

2) the Saginaw Bay and central-Lake Erie stocks representing a complex of discrete or semidiscrete genetic units that mix during the nonspawning (exploitation) seasons.

Some walleye migrate between these widely separated areas and may be vulnerable to sport or commercial exploitation in both.

Table 10. Walleye turnover ratios P/B and P/B, (P/B available beginning of the season) for various age groups of walleye from Clear Lake, Iowa (Carlander and Payne 1977); Escanaba Lake, Wisconsin (Kempinger and Carline 1977); Dexter Lake (Moenig 1975); Savanne Lake (Sandhu 1979); Henderson Lake (Reid and Momot 1985; Wisenden 1988); and Ice Lake (Wilson 1989) in northwestern Ontario.

	Age Groups						
	1	2	3	4	5	6	7
Latitude 44							
Clear Lake							
1948-73	2.24	1.00	.43	.24	.16	.11(6+)[1]	-
Latitude 46”							
Escanaba Lake							
1966	-	.58	.28	.22	.18	.06	-
1967	-	.46	.35	.24	.06	.06	-
1968	-	.49	.65	.53	.05	.04	-
Latitude 48”							
Dexter Lake							
1967	-	-	.54	.36	.29	.15	.04
1968	-	-	-	.50	.36	.23	.19
1969	-	-	-	-	.50	.24	.19
Latitude 48”							
Savanne Lake							
1973	-	-	-	-	-	-	*.10*
1974	-	-	-	-	-	-	.24
1975	-	-	-	-	-	-	-
Latitude 48”							
Henderson Lake’							
1979	-	-	-	.35	.35	.12	.19
1980	-	-	-	.67	.55	.44	.44
1981	-	-	-	.14	-	-	-
1982	-	-	-	.17	.11	.03	.10
1983	-	-	-	.44	.37	.23	.26
1984	-	-	-	.30	.32	.17	.17
198.5	-	-	-	-	.05	.24	.20
Latitude 48”							
Ice Lake							
1987	-	-	.60	.45	-	.14	.28

[1] + = fish of specified age and all older fish in the population.

[2] **Walleye** production fell in 1984 and 1985 as a consequence of the increase in mean age of the population and absence of recruitment during a period of heavy exploitation when the stock was experimentally collapsed (Reid and Momet 1985).

Continued on next page

Table 10, continued

Age Groups								Total population
8	9	10	11	12	13	14	15	P/B
-	-	-	-	-	-	-	-	-
			-	-	-	-	-	.26
			-					.27
			-	-	-	-	-	.45
.04	.02	.03	.25	-	-	-	-	.25
.19	.26	.02	.03	.48	-	-	-	.30
.12	.04	.07	.13	.01	.73	-	-	.23
.23	.25	.31	.21	.22	-	-	.53	.15
.22	.17	.14	.14	.12	.45	-	-	.22
.22	.20	.16	.13	.13	.11	.37	-	.20
.30	.27	.18	.29	.14	.20	-	-	.25
.30	.34	.29	.21	.15	.42	-	-	.45
.32	-	-	-	-	-	-	-	-
-	-	-	-			-	-	.08
.24	.28	.08	-			-	-	.32
.12	.04	.26	-	-	-	-	-	.18
.15	.15	.14	-			-	-	.18
.25	.61	-	-	-	-	-	-	.33

Table 11. General characteristics of north-temperate walleye populations showing quartiles (25%, 50% (median), and 75%), range, and number of observations (D. Baccante, OMNR, 435 James St., S., Suite 335, Thunder Bay, Ontario, Canada, pers. commun.).

	Quartiles				
	25%	SO% (median)	75%	Range	Number of observations
Harvest weight (kg)	0.48	0.58	0.67	0.26-1.18	113
Adult density (no./ha)	7.80	14.80	23.90	0.10-168.00	85
Annual yield (kg/ha)	0.50	1.24	2.95	0.01-49.60	168
Exploitation rate (%)	14.00	21.00	25.00	3.00-55.60	46

Significant numbers of walleye also migrate from what are termed rehabilitated stocks-for example, western Lake Erie and Lake St. Clair. These stocks migrate into what we call rehabilitating zones where they mix with local walleye-contributing to the harvest. This is particularly evident for two stocks:

western-basin walleye migrating into the central basin of Lake Erie, and

Lake St. Clair walleye migrating north to Saginaw Bay.

When these stocks congregate, excellent yields have been reported-the average annual harvest of walleye from Michigan waters of the Detroit and St. Clair Rivers in recent years was estimated to be 15.3 and 26.7 kg/ha (Nepszy et al. 1991). In comparison, the 1987 annual harvest for the western basin of Lake Erie was estimated to be 17.7 kg/ha/yr. However, the estimate for the whole lake was 3.08 kg/ha/yr (J. Leach, OMNR, R.R. #2, Wheatley, Ontario, Canada, NOP 2P0, pers. commun.) which makes Lake Erie one of the good, inland walleye lakes.

The transition into the late stage of rehabilitation occurs with the onset of density-dependent responses. The most-apparent responses to further increases in stock size would probably be decreased growth rate and increased age at sexual maturity. In systems open to emigration, changes in growth and maturity may be preceded or accompanied by expansion of the stock into a larger range.

During the late stage of rehabilitation, the remediation of walleye habitat and population damage has been mostly or completely accomplished. Flexible management will be necessary to balance the rapidly accelerating socioeconomic demands with maintenance of the rehabilitated stock and its habitat. For example, natural reproduction has recovered to substantially support recruitment needs. Exploitation has been controlled only to the extent that stock size and demographics have approached the pre-depressed condition allowing for fishery development. In addition, stock dynamics have been monitored so that status indicators are known to have approached their end-point condition. These indexing programs should be continued indefinitely to check for negative impacts of management decisions (overshoot) that might drive the rehabilitated stock back into the rehabilitating mode.

One, and possibly two, of the rehabilitating stocks (central basin of Lake Erie, and Moon River, Georgian Bay, respectively) are considered to be in the late stage (Table 7)-even though natural reproduction in the central basin was estimated to provide <5% of the recruits. This is justified by the consideration that central-basin walleye were probably recruited from the western basin prior to stock degradation. Lake Erie walleye have demonstrated a marked propensity to migrate relatively large distances that permits a management approach encouraging high density and natural reproduction in the western basin. It should also result in higher rates of movement to the central basin and north to Lake St. Clair (Nepszy et al. 1991; Reckahn and Thurston 1991).

The general shape of an abundance curve through the recovery process is sigmoid (Fig. 1). The concave early section has its origin at a place on the ordinate of a graph depicting abundance through time, which is defined by how low density became during the depressed period. In stocks reduced to zero, or close to it, the line of the graph typically starts at the origin, rises to a starting level through artificial propagation (as in Saginaw Bay), and then assumes a normal trajectory as natural reproduction takes over. This early period is characterized by fast growth and relatively large year-classes. Density-dependent mechanisms are minimum at the outset. The point where the curve changes from concave to convex marks the point where these mechanisms have reached their maximum impact, and where the stock is at approximately one-half its final equilibrium biomass. The walleye case histories suggest that early compensation relates more to density effects on reproductive success in the early phase and governed more by growth changes in the later phase. Conflicting evidence has been found relating to compensatory mortality effects in this species, but the best evidence for stock-size recruitment relationships occurs when stocks are depressed (Shuter and Koonce 1977; Bowlby et al. 1991). Serns (1987) found a significant ($P<0.05$) negative relationship ($r = -0.60$, $df = 14$) between the size of a year-class at the end of its first summer and the percent of harvest over the life of the cohort. Serns provides one of the best pieces of evidence to suggest that density-dependent (compensatory) mortality occurs among walleye populations. Although the larger year-classes produced higher yields, the yields were not in proportion to the size of the fingerling hatch produced.

As we move into the maintenance of rehabilitated stocks, management actions in at least three areas are important.

1) A no-net-loss policy for walleye habitat that involves sustainable development planning is critical.

2) Managers should plan for curtailment of stocking as soon as recruitment is dominated by naturally produced fish, and certainly before the late phase begins.

3) Judicious expansion of harvests can be considered. This requires working to ensure that the public understands and accepts the limitations, trade-offs, and objectives of the harvest policy.

It is agreed that the biological constraints to achieving rehabilitation become progressively less onerous as the process continues. Social and economic obstacles are quantitatively difficult at all stages but their character changes. In the early stages, defending against development that may cause degradation ofwalleye habitat poses the greatest management difficulty. During later stages, allocation issues and problems associated with unrealistic expectations among members of the public assume greater importance. For example, walleye abundance fluctuates naturally and fishing experiences will vary accordingly.

A decision-making and policy framework incorporating social and economic concepts, in conjunction with effective information transfer and public education programs, holds the key to solutions of the social problems mentioned above. Also, as noted earlier, public involvement is essential. It can be best undertaken in the context of environmentally sustainable development-with fish promoted in terms of their environmental as well as their conventionally recognized value. It will be necessary to involve the whole public rather than just the traditional client groups.

REHABILITATED STOCKS

Ecological Dimensions

As soon as rehabilitation is achieved, ecological issues relate primarily to the maintenance of a healthy stock through maintenance of community homeostasis. In this phase, socioeconomic issues are significant and relate to management of expectations in the face of natural variations within the rehabilitated stock.

Watt (1973) explains that all types of structural complexity in the environment constitute a regulatory mechanism that reduces oscillations in species populations within communities-preventing wide-amplitude oscillations in interspecies systems. Therefore, the community is an open biological system-a cybernetic system that fluctuates within homeostatic boundaries as defined by Sutton and Harman (1973). Watt (1973) further explains there are two sets of forces that can deal severe blows to this order:

1) a very old set of forces-geophysical and the weather, and

2) a very new set-the increasing influence of man.

Maintenance of a relatively stable and sustainable walleye population and fishery implies that the magnitude of population fluctuations within the community is somewhat manageable, Community homeostasis (stability) is affected by several factors that can be measured and, to some degree, altered by fishery managers. These include fish-community dynamics, walleye-stock dynamics, and habitat.

Fish-Community Dynamics

Components of a rehabilitated walleye-dominated fish community include walleye as top predator (which serves to structure the community), secondary predators, and a number of prey-fish species. The western basin of Lake Erie and the Bay of Quinte provide examples of such rehabilitated community structures (Table 7).

This type of predator-controlled community is in contrast to many Great Lakes fish communities following the demise of the percid predators (Schneider and Leach 1977). Reductions in predator biomass enabled expansion of prey-fish species. This resulted in effects on the composition and dynamics of lower trophic levels and alteration of energy and nutrient pathways. Examples of changes brought about by loss and recovery of top predators in the Great Lakes have been described by Scavia et al. (1986) and Christie and Spangler (1987).

In eutrophic systems, top predators exert a major influence on community structure (Shapiro and Wright 1984; McQueen et al. 1986; Carpenter et al. 1985). This idea is referred to as the top-down or cascade effect. As initially conceived, the principle is that top predators control, or at least strongly influence, the abundance of planktivorous fishes-which, in turn, control or influence zooplankton density and size. Therefore, high densities of top predators maintain relatively low abundance of planktivorous fishes, resulting in larger zooplankton and higher zooplankton densities.

The western basin of Lake Erie and the Bay of Quinte have a more-complex community structure than typically addressed in top-down studies. In both systems, this complexity results from a number of secondary predators and a group of planktivores. However, through trophic interactions, top-down control can be a factor. Walleye prey on both secondary predators and planktivores. In addition, secondary predators prey on the planktivores. Imbalances in the fish community, such as abundant secondary predators, may be corrected by promoting exploitation of adults of these species at a level sufficient to overcome their ability to compensate for exploitation.

A diverse fish community provides walleye with a large forage base. This provides several alternatives when fluctuations in year-class strength of one or more secondary predators or planktivores occur. Walleye prefer soft-ray fishes over spiny-ray fishes (Knight et al. 1984). Therefore, the presence of these species is particularly important as evidenced in Green Bay (Lake Michigan), Saginaw Bay (Lake Huron), and the western basin of Lake Erie (Schneider et al. 1991; Mrozinski et al. 1991). Initially, walleye abundance may overshoot the production of one or more of the forage species. However, walleye density will probably compensate and decline somewhat-for example, in the Bay of Quinte (Bowlby et al. 1991). Or, as in Lake Erie (Nepszy et al. 1991), walleye may move to other areas. In addition, in high-energy systems such as western Lake Erie, multiple and protracted spawning events within a year by preferred prey such as gizzard shad *(Dorosoma cepedianum)* may sustain predatory demands despite relatively low abundances of other soft-ray species. However, the stability of this less-diverse forage base is unknown.

A diverse fish community also offers anglers alternative fishing opportunities during periods of lower-than-expected walleye abundance and temporary declines **in catch rate.**

The issues of how much stability is inherent in rehabilitated walleye communities and how stability in rehabilitated systems compares with lightly perturbed walleye communities were not addressed during this study. Although an understanding of these issues would be helpful for the formulation of management policies, we believe walleye rehabilitation on the Great Lakes is too recent to offer any insights as to how widely rehabilitated stocks will fluctuate in abundance or yield in the future. Much of the inherent variation in species composition in the Great Lakes is because of habitat changes and species interactions that we are only beginning to understand. White sucker, freshwater drum *(Aplodinotus grunniens),* and yellow perch are known to eat fish eggs. Imbalances in predator-prey ratios that favor these species may therefore inhibit walleye-egg survival and subsequent recruitment to the adult stage. Additions to the community of non-native egg predators-for example, ruffe *(Gymnocephalus cernuus),* white perch, and carp *(Cyprinus* carpio) - can intensify these effects. Currently, the zebra mussel (endemic to Europe) has established itself in Lakes St. Clair, Erie (Hebert et al. 1989), and now Ontario. It will probably become a dominant member of the shallow-water benthos throughout the lower Great Lakes. However, there is no evidence, either current or historical, of adverse impact of zebra mussel invasions on fish populations. Data from Lake Balaton (Hungary)-although incomplete during World War II-indicate no impacts on the harvest of zander attributable to zebra mussels (Schloesser et al. 1990).

No adverse impacts of zebra mussel colonization on walleye reproduction was apparent in the western basin of Lake Erie in 1990 and 1991 (J. Fitzsimmons, Department of Fisheries and Oceans Canada, 867 Lakeshore Dr., Burlington, Ontario, Canada, L7R 4A6, pers. commun.; Ontario Ministry of Natural Resources 1992). Bottom trawling for YOY walleye in the western basin during August 1990 and August 1991 indicated an average index of abundance-much larger than results recorded for the previous 3 yr (Ontario Ministry of Natural Resources 1992). Studies to date indicate that DO conditions and spawning substrate in western Lake Erie remain favorable for walleye reproduction. Spawning conditions may in fact have been enhanced by creating additional and protected crevices to hold developing eggs in a sufficiently aerated environment. A second species of nuisance mussel is the quagga mussel *(Dreissena* sp.), that was discovered very recently in Lakes Erie and Ontario.

Also of biological concern is the recent establishment of the zooplankter *Bythotrephes cederstroemi* (BC). Fall sampling of young yellow perch revealed spines of this species clogged the intestines of a few individuals (Schneider et al. 1991). This, and the influence of BC on endemic zooplankton, is of concern and requires further monitoring to determine the ecological impact on the Great Lakes fish community. For example, Lehman (1991) concludes that BC, rather than fish, changed the plankton community of Lake Michigan. He noted the *Daphnia* community changed in a way consistent with the removal of the smallest individuals present (an attribute of invertebrate planktivory) and not with the known predation patterns *of Alosa* or *Coregonus.* Moreover, this author suggests that planktivory by fish was relaxed during 1987 and 1988 because of the increase of very large specimens of *D. pulicaria* (>2.5 mm body length). In total, approximately 136 non-endemic species of aquatic organisms have been introduced into the Great Lakes-more than one-third within the last 30 yr. This surge coincided with the opening of the St. Lawrence Seaway in 1959 (Mills et al. 1991).

However, in spite of all the interactions within walleye fish communities, relatively consistent walleye yields have been maintained in larger inland lakes in northern Ontario for more than 70 yr (Adams and Olver 1977). This indicates some degree of stability is possible in those systems and, hopefully, stability of the Great Lakes ecosystems can be improved with proper predator-prey control.

Walleye-Stock Maintenance

Stability of the fish community and of walleye fisheries is affected by the dynamics of the walleye stock(s) involved. Because walleye are top predators and structure communities via predation, changes in the stability, population homeostasis (Sutton and Harmon 1973), of the walleye stock(s) will indirectly affect community structure.

Abundance of walleye will be determined largely by variation in recruitment and exploitation. Recruitment variability for walleye has been attributed to water levels (Chevalier 1977; Kallemeyn and Cole 1990; Cohen et al. 1991) and warming rates and temperature variation during the spring (Busch et al. 1975; Serns 1982). The impact of these relationships seems less significant for rehabilitated stocks, because an abundant population with a healthy age structure (numerous year-classes) is more likely to withstand occasional recruitment failure. Stock-recruitment relationships *seem* to be most apparent when population densities are low and recovering (Shuter and Koonce 1977; Colby 1984; Bowlby et al. 1991). They appear to be less noticeable after rehabilitation. However, adverse weather conditions may account for at least a portion of year-class failures at high walleye densities. This may be particularly true in northern areas of the Great Lakes where general climatic conditions may be less favorable for strong year-classes than in southern areas. Cursory evidence for a stock-recruitment relationship is available for the Bay of Quinte walleye stock and suggests that recruitment declines at high spawning-adult densities (Bowlby et al. 1991).

Variability in recruitment also is influenced by the number of discrete spawning stocks. Several river-spawning and shoal-spawning stocks of walleye have been identified in western Lake Erie (Wolfert 1963) and the Bay of Quinte (Bowlby et al. 1991). Therefore, there is an increased probability that the species will encounter favorable spawning habitat in a given year. In addition, spawning will probably be protracted because:

> spawning behavior is triggered by water temperature (the rate of warming differs between river and lake habitats), and
>
> movement of stocks onto spawning grounds can be gradual.

Therefore, the probability is increased that some progeny will encounter favorable survival conditions such as plankton pulses at the time of hatching.

Maintenance of the diversity of discrete stocks is important to sustain high walleye densities. Rehabilitated populations will probably have one or more stocks that spawn in rivers, on reefs, and on shoals. Ensuring the health of discrete stocks maximizes genetic diversity and protects populations from possible recruitment failure (P. Ihssen, OMNR, P. 0. Box 5000, Maple, Ontario, Canada, L6A 1S9, pers. commun.).

Annual variations in walleye abundance also are related to the amounts and types of exploitation. Because fishing efficiency varies with gear type (for example, gillnets are more efficient than angling), apportioning of effort among gear types can be an effective tool to regulate and distribute fishing mortality rates. The presence of multiple stocks within a management area complicates this allocation process. It also introduces flexibility into the management program. If stocks can be identified they can be exploited under different strategies. Policies that restrict or abolish certain fishing gears may restrict the options of the manager.

Upon achievement of rehabilitation, harvest-control strategies should be shifted from stock building to stock maintenance. Harvest of a rehabilitated stock should be maintained at a level that is restricted to utilization of surplus production. Surplus production can be expected to fluctuate within a system over time-reflecting natural variations in year-class strength and recruitment to support the stock. Fluctuations may also be a response to overexploitation of the stock (Christie et al. 1987b). Harvest levels should be managed to remain within a specified range of oscillations from natural variability instead of exploitation Currently, maintaining a conservative approach to exploitation of the western-basin population is preferred. This approach should encourage high standing stocks and eventual movement into the central and eastern basins as well as Lakes St. Clair and

Huron. However, high densities of walleye in the western basin might risk negative density-dependent impacts on their growth and recruitment and depletion of some prey stocks. Some yet-to-be-determined optimum density is desirable.

The establishment of reasonable harvest levels for rehabilitated stocks is difficult, because they can be expected to differ from reported historic levels. Methods by which historic levels were determined and changes that may have taken place in the system while the stock was depressed, contribute to this potential difference. Historic harvest levels may be used to determine a CV of variation that reflects past stock fluctuations, and they can be used as a guide for the rehabilitated stock.

In the absence of good, historic harvest data, harvest levels may be developed by consensus using end-point indicators (Table 3). The use of end-point indicators is especially attractive if they are also used to define a rehabilitation objective. These levels should be adjusted as monitoring improves the data base.

At the completion of the late phase, the stock moves into the range of densities within which it will oscillate as a rehabilitated stock. This theoretical continuum offers several options to be considered as end points depending on management strategies. The consensus is that attempting to hold stock abundance at any place along the early, concave part of the population growth curve is not a viable option because of uncertainty and probably instability.

A range of fishing effort (or resource-use opportunities) may be set as an alternative to managing harvests. Like harvest level, an acceptable range of fishing effort can be based on historic levels, adjusted for improved technology, and used to determine a CV of variation. Another approach, using rates of exploitation, was adopted in 1984 by the Lake Erie Standing Technical Committee for the rehabilitated western-basin walleye stock (Hatch et al. 1987).

Managing for high density (equilibrium) will usually require taking rather low yields. This would be slightly offset by:

higher stability in the fisheries,

better return on capital investment in the commercial and guideboat industries, and

higher catch rates and better satisfaction in the sport fisheries.

This is the only appropriate level within the context of managing for system maturity (Christie et al. 1987b). The best scenario seems to be that a fully restructured ecosystem will probably not be achieved much in advance of the completion of a walleye generation. Determination of walleye equilibrium densities can be based on ecosystem structure and dynamics.

Reaching the 50% point (MSY) was considered essential for years, but fell into disrepute because economic returns were often maximized at yield levels substantially below it. In addition, MSY often is too close to the point of overfishing that may cause collapse of the stock or, "surfing the crest of catastrophe" (Walters 1986) This is especially dangerous with high reproductive variability. Yields are highly variable from year to year and the size of the fish is often unattractively small for sport fisheries.

Taking yields at <25% of the stock provides a buffer against the effects listed above. It still provides less-than-complete certainty of sustainability, however, because of instability in fish-community structure and the possibility of sustained periods of poor reproductive conditions.

For this strategy, standard fishing-theory monitoring and modelling are used. They are, however, more intensive and expensive during rehabilitation because of rapidly changing stock circumstances. Monitoring and modelling are much more expensive for predicting and (sustaining) equilibrium density levels. High cost is because the whole system is involved, and because the lack of guiding theory at present requires a large research component.

When acceptable harvest levels are established, a commitment must be made to monitor both harvest and stock-status indicators in order to manage the stock at a sustained level.

Habitat Maintenance

Stability within the fish community can be adversely affected by changes in abiotic-habitat characteristics. Examples of these changes cover a wide spectrum:

alterations to localized habitats (for example, shoals and tributaries used for spawning),

wide-ranging environmental changes in water quality (for example, eutrophication or pollution, localized perturbations that occur naturally (for example, weather and water-level fluctuations. and

localized perturbations that occur artificially (for example, damming, dredging, and point-source pollution (Schneider and Leach 1977).

The effects are often highly transient. For example, poor recruitment in the lower Fox River (Wisconsin) may be partly attributed to a contaminant problem (Auer and Auer 1990; Schneider et al. 1991). Hokanson and Lien (1985) found a negative relationship between larval survival and size of adult female walleye-suggesting the eggs of larger females are contaminated by some kind of harmful toxin. Effects from a wide range of water-quality changes are generally more severe and are manifested in lagged recovery of stocks. Auer and Auer (1990) provide a good example of differences in substrate suitability for walleye-egg development in the lower Fox River, Wisconsin (Table 12). Table 12 also illustrates the water-quality changes that will be necessary to improve the capability of a system to support walleye reproduction.

Habitat degradation or alteration might also be attributed to biotic factors, as previously discussed in "Rehabilitated Stocks, Fish-Community Dynamics." The potential for habitat degradation to affect fish-community stability (and, therefore, the walleye fishery) dictates an urgency for fishery managers to monitor appropriate indicators of habitat. These include quantitative measures of abiotic parameters such as water temperature, DO, and Secchi transparencies (Table 1). Managers must be aware of all sources of relevant data to stay current with local perturbations and a wide variety of changes. In addition, managers should be ready to initiate remedial actions, as necessary.

Drastic physical changes (such as dredging) may be irreversible. Therefore, prevention is the most-appropriate course of action. This requires some degree of forecasting ability. The effects of less-severe perturbations may be reversed using habitat-improvement techniques, as previously discussed in "Planning For Rehabilitation, Habitat Restoration." Water-quality deterioration requires a wide range of concerned supporters. Agreement among a variety of agencies is often necessary to enact regulations that will reduce point-source pollution, agricultural runoff, and any other changes that might interfere with successful habitat rehabilitation.

Table 12. Chemical suitability for walleye-egg development and frequency of stations where sediments were considered primarily chemically suitable or unsuitable in the lower Fox River (Auer and Auer 1990).

Chemical suitability		
Item	Suitable level	Authority
DO’	>5 mg O_2/L	Oseid and Smith 1971
H_2S[1]	<12 µg H_2S/L	Smith and Oseid 1974
Free NH_3-N[1]	<29 µg N/L	U.S. Environmental Protection Agency 1985
Chemical oxygen demand	<40 mg O_2/g dw	Auer and Auer 1990

Sediment suitability		
Substrate type	Suitable	Unsuitable
Hard, clean sand	2	0
Firm sand	1	1
Soft sand	2	0
Clean sand and rubble	1	0
Sandy muck	1	1
Soft, black muck	0	8
Muck; peat detritus	0	1

‘To be judged suitable for egg development, sediment chemistry must simultaneously meet 0,, H_2S, and NH,-N criteria.

Habitat Changes

Habitat maintenance may not always be feasible or controlled. Presently there are major habitat changes occurring in the Great Lakes that could have a profound effect on walleye production. There is a noticeable increase in water clarity in Saginaw Bay, Lake St. Clair, and the western basin of Lake Erie-believed to result from the recent proliferation of zebra mussels (Leach 1992; D. MacLennan, OMNR, R.R. #2, Tilbury, Ontario, Canada, N0P 2L0, pers. commun.). There is concern about the long-term effects of shifting so much organic matter from pelagic to benthic zones by these organisms (Neary and Leach 1992). Leach (1992) reports that the mean chlorophyll a for the May-November period declined 54% in the western basin of Lake Erie between 1988 and 1990. More recently, the chlorophyll a level has dropped by 66% (J. Leach, OMNR, R.R. #2, Wheatley, Ontario, Canada, N0P 2P0, pers. commun.). Concentrations of chlorophyll a are now in the 1-2 **µg/L** range-the oligotrophic end of the trophic scale (Leach 1992). If the Oglesby et al. (1987) model (Fig. 2) relating walleye yield to chlorophyll a is causal and correct, then we can also expect a concurrent drop in walleye production and subsequent yield in the western basin of Lake Erie (Table 1).

Environmental influences in Lake St. Clair may be having a negative impact on walleye recruitment. MacLennan (OMNR, R.R. #2, Tilbury, Ontario, Canada, NOP 2L0, pers. commun.) finds evidence that the suitable-habitat volume for walleye in Lake St. Clair has been reduced because of increased water transparency. This reduction might be a result of zebra mussels and low water levels (more than a threefold increase in transparency over the last 3 yr). Significant changes in the aquatic community have followed. The macrophyte beds are expanding with an associated increase in catches of muskellunge *(Esox* masquinongy), smallmouth bass, black crappie, and white bass (Morone *chrysops).* There has been an explosive colonization of white perch-with its peak in abundance occurring in 1987. These changes in Lake St. Clair have been associated with 5 yr (1987-91) of very-low walleye recruitment (D. MacLennan, OMNR, R.R. #2, Tilbury, Ontario, Canada, NOP 2L0, pers. commun.).

At times, the effects of habitat changes on walleye density may be subtle or confounding. For example, lowering water levels in the Great Lakes may have an opposite effect on walleye density in different water bodies-making modelling of water-level effects difficult. However, lowering water levels combined with the presence of zebra mussels increased water transparency in Lake St. Clair-the reverse was true in the Bay of Quinte. Lower water levels in the shallow Bay of Quinte probably enhance the resuspension of sediments (nutrients) (Nicholls and Hurley 1989). This contributes to decreased water clarity-both directly through turbulent energy and indirectly through enhancement of plankton blooms-and the subsequent decline in macrophyte growth. Bowlby et al. (1991) suggest that decreased water clarity and decreased macrophyte growth in the Bay of Quinte (Lake Ontario) favored walleye over northern pike and may be preventing a recovery of northern pike to former levels.

We need to increase our predictive capabilities by conducting more-detailed studies on the relationship between climatic trends and water-level changes and fish-community structure in the Great Lakes and adjust harvest accordingly.

Managing Rehabilitated Stocks

Planning Remedial Actions

Maintaining a self-sustaining stock requires early detection of problems coupled with effective management response mechanisms in order to permit rebounds. The ability for managers to react will probably require that potential changes in density of stocks are anticipated. An approach is to imagine various scenarios that may occur and, for the adverse scenarios, establish criteria for concern and possible remedial actions that might be contemplated. This procedure will reduce anxiety and simultaneously ensure that the resource manager proactively develops management options. Remedial actions could include predetermined harvest strategies or regulations to be imposed-depending on how a given stressor is impacting the dynamics of the fishery. Table 13 provides a list of concerns relating to harvest and possible solutions.

Table 13. List of concerns and possible remedial actions for managing rehabilitated walleye stocks.

Current situation	Criteria for concern	Remedial management action
	Overharvest	
Harvest; size of fish; mean age: CPE dropping, fluctuating, or falling below a threshold	Inadequate harvest-control mechanisms Abnormal succession of poor year-classes Degradation of habitat Altered predator-prey ratios, community structure. and exotics	Bag limits for the sport fishery and lower creel limits Size limits for the sport fishery and increase minimum size limits Seasons: shorten seasons for the sport and commercial fisheries Quotas for the commercial and sport fisheries: reduce harvest
	Underharvest	
High CPE; annual yield relatively stable; slower growth; lower fecundity; condition and population comprised of many year-classes	Developing or expanding fishery Abnormal succession of strong year-classes Enhanced environmental conditions (better than anticipated) Altered community structure	Plan future expansion carefully (promote risk analysis) to avoid overcapitalization Avoid promoting short-term utilization (reserve as recruitment banking)

Institutional constraints may emerge that could cause problems-including prevention of equilibrium harvests or targeted-catch experiences. Some of these institutional constraints may have been imposed during rehabilitation. For example, closed commercial fisheries may represent a lost option for monitoring fish stocks or manipulating the fish community. Such institutional constraints should be anticipated in advance and, where possible, overcome by policy that can allow development of legislation to provide the manager with real-time (rapid) flexibility.

Public Awareness and User Involvement

Fisheries-management strategies for maintaining a rehabilitated stock depend heavily on the cooperation and support of the resource users. Managers need to recognize that users are:

directly involved-for example, commercial fishermen, native groups, anglers, and charter guides, or

indirectly involved-for example, bait dealers and motel owners.

Managers and users influence the success of plans for sustaining rehabilitated stocks. Managers who effectively and continuously promote user awareness and involve users in the management process are more likely to lessen the conflict that is inevitable in times of crisis. This strategy may enhance the prospects of maintaining fishery objectives.

Users must have a broad, fundamental understanding of general principles of fishery biology. Without this understanding, more-detailed discussions of management actions are likely to be unproductive. We need means to convey concepts of community dynamics as they relate to fisheries-management practices. Generally, we need to raise user awareness of the complexity of the problems and types of control we can exert on a fishery-and the limitations on those controls.

Specifically, we need to communicate the fact that change and variability are always aspects of the fisheries we manage and that users are certain to be affected by population changes within the fish community and our management responses to those changes, If we do not emphasize these factors, we may not be able to set up contingency plans in advance, and users may even hinder the management response in times of crisis. Also, by informing users about specific features, changes, and trends of the rehabilitated stock, we enhance our credibility as managers who anticipate problems before they actually occur. By exposing users to the realities of population change and the related scope of management actions, there is a high probability that their involvement will be positive and their expectations rational.

Managers must assess user expectations in order to formulate workable policies for times of change. Failure to do so may jeopardize the rehabilitated stock. We need to understand, in advance of the crisis, who the major user groups are, how they will respond, and what their relative stakes are in the outcome of the management action.

Part of the process of user involvement relates to the idea of power sharing. Clear mechanisms should be defined for users to express opinions about management options. Managers can direct users to meaningful roles in developing goals, assessing trade-offs, communicating management rationales, and facilitating implementation of policies. Avenues of communication between managers and users are of utmost importance. Mechanisms such as angler diaries, formal public hearings, and informal meetings allow users to transmit information back to managers about demands and expectations. Managers can use this feedback to assess the positions of the various user groups as they relate to established goals for the rehabilitated stock.

Successful management of rehabilitated stocks requires a continual, productive dialogue between responsive managers and educated users. Anticipation of change and communication of contingency plans can diffuse problems with users in times of crisis. Enhanced user awareness of biological principles can eliminate unrealistic or irrelevant expectations. The best product of such a relationship with users is the development of mutually acceptable goals, which can be modified to meet changing biological, political, and social circumstances. Good user-manager relations have a cost to the manager in terms of repetitive education programs, risks of exposing contingency plans, and time-consuming communications. Perhaps the most-important outcome of good relations is the recognition of inevitable choices to be made and their consequences to the well-being of the rehabilitated stock.

EVOLUTION OF MANAGEMENT OBJECTIVES

Case histories have shown that management objectives change over the course of rehabilitation. The common elements from single jurisdiction to multi-agency initiatives provide insights about events that might be anticipated when walleye rehabilitation is initiated and as it progresses. In this section, we review the means by which the public provided input and the role of planning processes in setting and modifying management objectives.

Objectives stated at the initiation of rehabilitation efforts varied in the degree to which they were specific. However, the objectives generally made reference to:

reestablishment of self-sustaining populations-for example, in southern and northern Green Bay, or

improved benefits from the fishery-for example, in Saginaw Bay and western Lake Erie.

Although the objectives associated with rehabilitation efforts in Saginaw Bay were to diversify the fishery, it is believed that reestablishment of a naturally reproducing population was a consideration (L. Mrozinski, Michigan Department of Natural Resources (MDNR), 8015 S. Mackinaw Trail, Cadillac, MI, 49601, pers. commun.), articulated later as rehabilitation progressed (Keller et al. 1987) In Lake Erie, the situation was somewhat different in that a degree of rehabilitation based on natural reproduction had been achieved with the closure of the fisheries because of mercury contamination (Nepszy et al. 1991) prior to the establishment of rehabilitation objectives. Rather than being expressed as agency objectives, the objectives for walleye rehabilitation in Lake Erie were presented within minutes and reports of GLFC-sponsored initiatives as broad statements referring to yield: "...yield maximal harvest to the combined fisheries, achieve socially optimal returns from the resource."

In Ontario, a general approach to fisheries management based on rehabilitation in the south that included Lake Erie was adopted. Lake Erie objectives identified in fisheries-management planning processes recognized restoration of the percid community and walleye as a part of that community. By virtue of a number of regulatory changes introduced for all Great Lakes waters of Michigan in 1969 and 1970, conservation and presumably rehabilitation of walleye was considered.

The role of the public in formulating initial rehabilitation objectives for walleye appeared limited in the case histories reviewed. That is not to imply that the public did not influence management agencies through routine association of interest groups and the management agencies, but formal arrangements for public input were limited. Ontario's fisheries-management planning exercise, which included public participation, was an exception.

Maintenance of fishery resources is not a new concept for fisheries managers nor is the goal of rehabilitation. Efforts resulting in biologically sustainable improvements to fish stocks, at least to the point where improvements are considered adequate, are rare. As success attracts users of the resource, the challenge that faces fishery managers is how to deal with success itself.

For example, increased walleye abundance and a broader distribution of the western-Lake Erie stocks have attracted and continue to attract new participants in the sport fisheries. In Ohio and Michigan, this continued escalation in demand has resulted in harvests in excess of the recommended allowable share of the resource. In Ontario, the major part of the harvest is taken commercially; however, continued escalation of the sport fishery will presumably stimulate a review of current allocation policies.

Fisheries-management agencies generally have two categories of actions at their immediate disposal:

1) regulation of the number of fish extracted from fish populations, or

2) propagation of fish to supplement natural populations.

In instances where reproduction has been limited by degradation of spawning areas, artificial means have been employed to supplement existing stocks-for example, in Saginaw Bay and Green Bay. The development of culture techniques is believed central to the adoption of rehabilitation strategies where degradation of spawning areas was identified as contributory to the decline in walleye. The ultimate test of achieving self-sustaining populations through supplementing the population is in termination of planting-as in southern Green Bay. The involvement of the public in artificial production may become so strong that even if natural reproduction is unable to sustain a walleye population, stocking would continue to replace natural reproduction. This may be the situation in Saginaw Bay. Unfortunately, this does not address the limiting factor-environmental degradation-it just circumvents it.

Generally, regulations to reduce exploitation have been introduced near the time when rehabilitation objectives were embraced. Regulations that reduced exploitation were not always introduced to achieve walleye rehabilitation and regulation changes have not been limited to waters targeted for walleye rehabilitation. While fry planting was initiated in Saginaw Bay in 1972 and fry and fingerling planting in northern Green Bay in 1971, Michigan introduced regulations to reduce the harvest of walleye in the sport and commercial fisheries in 1969 and 1970, respectively, for all Great Lakes waters. In Lake Erie, commercial fisheries for walleye were closed in Ohio and Ontario waters in 1970 because of mercury levels. Retention of walleye by anglers was prohibited in Ontario and Michigan waters (Hatch et al. 1987). Regulation changes have been introduced in direct response to rehabilitation objectives as demonstrated by the imposition of a quota-management system for walleye in the Ontario waters of Lake Erie.

As rehabilitation has progressed, agencies have imposed regulations to control harvest, for example:

in Lake Erie, Ohio reduced the daily catch limit from 10 to 6 in 1979 and from 6 to 5 in 1990;

in southern Green Bay, Wisconsin closed the walleye commercial harvest in 1978 and reduced the daily catch limit from 5 to 3 in 1983.

In addition, increased harvests have been allowed in response to progress in rehabilitation. For example:

Ontario gradually increased harvest by increasing commercial quotas from 1976 to 1988, and

Michigan increased daily catch limits from 5 to 6 in 1983 and from 6 to 10 in 1985.

Regulation changes have been imposed on both commercial and sport fisheries to achieve a reduction in harvest in support of rehabilitation. However, it appears that once commercial fishing is terminated, the prospects for its reintroduction are poor if significant sport fisheries exist in the same territorial waters. Commercial fishing for walleye was reintroduced in Ontario waters of Lake Erie, but only a limited sport fishery existed at that time.

Waters subjected to walleye rehabilitation ranged from being managed by a single jurisdiction (for example, in Saginaw Bay) to multiple jurisdictions (for example, in Lake Erie). Green Bay, although shared by two jurisdictions, was managed as two separate areas: northern and southern. Planning processes leading to the formation of fisheries-management objectives varied among waters. For Saginaw Bay and northern Green Bay that fall within Michigan, initial regulatory actions taken were in accord with broad strategies applied statewide. However, walleye-planting strategies were conducted in response to objectives specific to each water area. Future management of northern Green Bay will be influenced by fisheries-management planning processes that are in progress. For southern Green Bay, objectives were established unilaterally by Wisconsin. While public involvement is presumed to have increased through routine interactions between management agencies and user groups as rehabilitation progressed, formal public participation in the planning process appeared limited for both Saginaw Bay and Green Bay.

The degree to which the public has influenced the revision to agency objectives is difficult to determine, but generally as fisheries for walleye emerge and flourish and as public participation in stocking programs increases, the influence of these groups escalates.

In Lake Erie where a number of jurisdictions share the walleye resource, planning exercises occurred prior to the implementation of rehabilitation and as rehabilitation progressed. These have been conducted under the auspices of the GLFC involving representation by participating agencies, and also unilaterally by agencies (for example, Ohio and Ontario within their own jurisdictions). Although traditional representation from user groups has continued as rehabilitation progressed, established user groups have strengthened with increased participation. For example, angler organizations and new groups such as charter boat organizations have emerged. Also, planning processes that solicit public input have increased-for example, in Ontario and Ohio. The seeking of public involvement in fisheries-management planning is presumed to reflect the attitudes of the management agencies rather than being a response to rehabilitation.

In response to the Strategic Great Lakes Fisheries Management Plan (Great Lakes Fishery Commission 1980) the development of fish-community objectives for each Great Lake will provide input to agencies in development of local (within jurisdiction) fisheries-management plans. Local planning exercises that draw upon fisheries managers, scientists, and the public will in turn provide feedback on broader fish-community objectives for the lake including the place of walleye in the fish communities. This report should be a useful reference in those discussions.

SOCIOECONOMIC ISSUES

Fish-stock rehabilitation is associated with a variety of social and economic changes. These may include direct and indirect changes.

> Direct changes include changes in user behavior, changes in management-agency structure, and the economic impacts of angler spending.
>
> Indirect changes include stimulating tourism-based economic growth, changes in political and social behavior, and changes in public values and beliefs.

Economic and Social Impacts

The local development process depends on four factors.

1) The size of the existing walleye stock, in particular at the beginning of the rehabilitation process, will determine the level of economic activity in the recreational area.

2) The anticipated change in the size of the stock will determine the expectations of anglers and of local businesses, and their resulting participation and levels of investment in new activities.

3) The location of the stock (whether in a highly populated area or in a sparsely populated area) will affect the number, duration, frequency of angler trips, and the development of complementary recreational activities.

4) The concentration of the fishery (whether a highly concentrated fishery such as the western basin of Lake Erie or a dispersed fishery such as the salmonid fisheries of the Great Lakes) will affect the types of fishery-related businesses and the types of complementary activities that develop.

We describe the changes associated with an expanding fishery because it is relevant for walleye in the Great Lakes at this time. A depressed or rehabilitated fishery is a more-stable situation and would imply little economic or social change over time. A declining fishery may imply the opposite kinds of changes to those of interest here, with one general exception. An expanding fishery may catalyze the growth of a larger, nonfishery tourism industry, but a declining fishery would not necessarily cause a nonfishery tourism industry to decline. Furthermore, we have used the western-Lake Erie experience as a model for the change associated with rehabilitation. The scale of change may be larger in that instance than elsewhere, but the same principles generally apply.

Pattern of Use

The pattern of use depends on the size and rate of growth of the rehabilitating walleye stock. Early in the rehabilitation process, use will probably be dominated by anglers who have utilized the fishery throughout its depressed period. They will be supported by existing businesses - for example, marinas, bait and tackle shops, and restaurants. As the size of the stock grows, existing anglers will probably increase their activity and new anglers will be attracted; some will transfer their angling from other fishing sites. For example, since 1975, with the return of large populations of walleye to Lake Erie, a major recreational industry has grown around sport fishing for walleye between May and August (Hushak et al. 1988). Hushak et al. (1988) report that a creel census conducted by the ODNR showed that angler-hours for sport fishing increased from 7.5 x 10^6 in 1975 to more than 13.6 x 10^6 in 1982. Western-basin effort increased from 500,000 hrs in 1975 to 5,900,000 hrs in 1982 (C. Baker, ODNR, 305 Shoreline Dr., Sandusky, OH, 44870-2816, pers. commun.). Supporting businesses will experience increases in sales-generating increased income within the region. At some point, economic activity may become sufficient to generate new businesses in the form of new marinas, bait and tackle stores, hotels and motels, and restaurants.

If a walleye stock grows sufficiently large, as is the case with the western basin of Lake Erie, new anglers attracted to the fishery will probably increase economic revenues for the region. Lake Erie anglers spend nearly $100/day of fishing activity (C. Baker, ODNR, 305 Shoreline Drive, Sandusky, OH, 44870-2816, pers. commun.). Because many of these new entrants will probably not have local experience, they will demand services such as boat rentals, charter guides, better restaurants, and nicer hotels. A satisfactory recreation experience to them requires a set of complementary activities.

Ohio’s charter industry expanded from 25 licensed captains in 1975 to 525 in 1983 (C. Baker, ODNR, 305 Shoreline Dr. Sandusky, OH, 44870-2816, pers. commun.). In 1990, there were 1,211 captains 1990 (Lichtkopper and Hushak 1993). Nepszy et al. (1991) reported that the estimated sport catch in Ohio waters alone rose from 110,000 walleye in 1975 to 2.16 million in 1977. Hatch et al. (1987) reported the combined harvest of all jurisdictions:

>2,500 t in 1977,

>4,000 t in 1982, and

>7,000 t in 1986.

In an urban setting such as western Lake Erie, anglers may be encouraged to bring their families, many of whom have little or no interest in angling. These visitors present opportunities to develop complementary activities. In the case of Lake Erie, examples include Cedar Point, the Bass and Kelleys Islands, and Geauga Lake. At the present time (1989) non-angling interests exert substantial control over development policy in the western-basin area of Lake Erie.

As business activity grows, demand for location and space within the nearshore area of the fishery region will grow. New marinas need waterfront property. New hotels, condominiums, and restaurants view lakefront locations as desirable. The fisheries-management agency and local policy makers face the difficult, but critically important, task of maintaining sufficient nearshore space in wetlands and productive littoral zones in a natural state to ensure that the environment for the fishery is maintained. Development of waterfront and nearshore areas is often under the jurisdiction of local governments as well as state-management agencies. Therefore, these groups need to work together by only permitting development in an ecologically sound manner. It is particularly important that the fisheries-management agency anticipate and plan for policies that maintain and enhance the environment. Educational programs about the role of wetlands, streams, embayments, and other critical areas to the total productivity and attractiveness of the recreational environment will probably provide high-payoff activities in the future.

Social Impacts

As external venture capital and business interests gain control of the region, local residents and businesses will be affected. Local residents may lose the quiet rural environment to which they have been accustomed. At the same time, they can prosper economically by taking advantage of the opportunities of increased support services in a growing fishery. Local businesses could be hurt by the modern, outside-owned, new businesses unless they also gain access to new investment capital and develop modern facilities. Evidence from the western basin of Lake Erie suggests that relatively few local businesses participate in these opportunities for expansion. A recent survey of Ohio's Lake Erie marinas showed that the only change in distribution of marinas by size between 1979 and 1986 was in the expansion of 7% of the large marinas into very large marinas (Lichtkoppler and Hushak 1989):

Finally, and perhaps most importantly, local residents may lose political control of economic-development policy in their region. The fishery might become dominated by non-resident anglers, and business interests might become dominated by non-resident owners and investors. As a result, residents may lose some of their say in fisheries-management and local economic and development policy. The statewide or provincewide distribution of political power could shift as well.

Managing Development

Several considerations appear important when setting the stage for determining who manages, when, and how. Early in the rehabilitation process, it has been the fisheries-management agency that initiates action. Early action may be in the form of a special program to initiate walleye rehabilitation through fish stocking, habitat improvement, or water-quality improvements. Managers can help other public and private organizations anticipate and plan for change by alerting them to the potential for change resulting from rehabilitation. However, raising expectations may not initially be the preferred strategy. If reasonable expectations are desired, it is important to emphasize the difficulty in making accurate predictions in a field characterized by variability and uncertainty.

As walleye stocks grow, it is important that the fisheries-management agency open lines of communication with other groups important to further development of the fishery. New access roads, new launch ramps, increased water and sewer capacity, and expansion of other public services may be required from local government. Such services may take years to plan and develop. Local businesses need to be apprised of new or expanded business opportunities soon enough to take advantage of expanded activity as it develops. The involvement of the fisheries-management agency will probably expand from a local rehabilitation program to a broader management strategy that will protect the stock of walleye as well as reconcile the interests of the expanding number of groups affecting, and affected by, the fishery.

Finally, the fisheries-management agency needs to be aware of the growing interests of other activity groups and be prepared to involve them in regional economic development and fisheries-management policy in a cooperative instead of an adversarial way. These cooperative efforts will probably be more effective if carried out locally with regional, state, and provincial technical and policy support. It is critical that groups be alerted to the potential roles of the rehabilitating fishery in the total recreational picture of the region.

Identification of Impacted Publics

During the course of the walleye-rehabilitation process, each interest group experiences certain kinds of impacts. Commercial fishermen and angler groups seem to be affected in a straightforward manner. In fact, the impact on them may depend upon other factors. For example, commercial fishers are more likely to benefit from a rehabilitated walleye fishery if the cause of the decline of the fishery was poor recruitment. However, they may be less likely to benefit if the cause was overexploitation. Similarly, the effects of rehabilitation on anglers utilizing other fisheries may be positive or negative. For example, as the rehabilitation of the fishery proceeds, more and more anglers come to see the catching of walleye as a central part of their personal identities. These are walleye enthusiasts. They will probably be disappointed during sequential occurrence of poor year-classes-an unavoidable event in the natural fluctuations of walleye fisheries (as recently observed in western Lake Erie).

Long-term residents in the local community experience a series of impacts during the course of the rehabilitation process. The amount of economic and social activity in the community is increased, which may be perceived as good or bad. Local real-estate values will almost certainly increase, which creates potential benefits but also immediate costs. Local taxes increase as a result of increased property values and increased levels of demand for social services (water, sewer, roads, and policy). Many long-term residents will probably perceive a decline in the quality of life in their community and an increase in the level of social disorganization (litter and rowdiness).

Power Sharing

Public consultation is the process by which a fishery manager can assure that impacted publics are informed about the rehabilitation process and how it might affect them. However, even when consultation is systematic and thorough, a manager may fail to gain informed consent unless sufficient power sharing is undertaken. The fishery manager's ability to make and effect certain decisions within the policies of his government is legitimate and need not be given away. However, when consultation is under way, knowledge is power and the manager usually has more knowledge and more ability to gain knowledge than the other participants in the consultation.

Depending on the circumstances, power sharing may be as simple as fully informing participants of all relevant information. Under slightly more-difficult circumstances it may be necessary to allocate time and program resources to obtaining information that, though required, is not readily available. When the public is potentially an adversary with much less ability to explore an issue than the manager, it may even be appropriate to allocate funds to the control of the public representative for the purpose of hiring expert advice. Rarely, but under unusual circumstances, funding expert representatives may be in order. These courses of action will seem extreme to many managers and are outside the experience of many agencies. However, they have been used successfully to empower those who will be affected by management decisions. For example, Ontario instituted a port-observer program in western Lake Erie for self-policing the commercial fishery. The program benefits both government and industry through confirmation of catch figures and providing more-accurate information for management (S. Nepszy, OMNR, R.R. #2, Wheatley, Ontario, Canada, NOP 2P0, pers. commun.). For another example, Michigan has assisted small communities around Saginaw Bay by obtaining a grant to pay a township official from the area with professional planning skills to act as liaison between the communities and the Department of Natural Resources in joint planning to mitigate the impacts of walleye rehabilitation in Saginaw Bay (R. Haas, MDNR, 33135 S. River Rd., Mount Clemens, MI, 48045, pers. commun.).

Managing Expectations

In the course of planning and consulting with publics, expectations can easily vary among participants and can lead to substantial misunderstandings. Therefore, a manager who is engaging in participatory decisions or planning should explicitly manage public expectations.

There are three pitfalls to be avoided:

1) The manager must not oversell his proposal.

2) Those who will benefit from rehabilitation of a stock will probably acquire inflated expectations of stock abundance, fishing activity, economic impacts of increased fishing, or other benefits.

3) Those who will be adversely affected may be persuaded to expect too little effect or to expect too much mitigation.

One of the most-critical consequences of unreasonable expectations is the investment which will occur based on those expectations. As stock abundance increases and fishing activity follows, the flow of funds created by the fishery will increase. This flow of funds induces investment that will be based on expectations about future growth of the fishery. Such investments may overshoot beyond those that can be financed by the ultimate level of fishing activity. This overcapitalization can make it hard for fishery managers to control harvest because these controls will be viewed as having adverse economic consequences.

Interim management decisions can also be misleading. A useful example is the effect on expectations of inappropriately liberal fishing regulations during stock rehabilitation. It may happen that as the walleye stock increases, fishing activity will increase with a significant lag so that harvest is below the level that would be tolerable to the fishery manager. This may lead the manager to liberalize regulations to use what is considered surplus production in the interim - even though the stock may not be sustainable at optimum levels under these regulations. Anglers, commercial fishermen, and business investors are likely to base expectations on these liberal regulations and become opponents of the manager when tighter regulations become necessary.

The most-effective way to manage expectations is to be explicit and honest in projecting the benefits and effects of a plan. When the results are uncertain, the uncertainty and risks should be equally explicit. For example, the walleye and yellow perch task groups in Lake Erie tried to do this through their modelling approach, that includes not only stock size and yield modules but also a risk module (Henderson et al. 1990). One focus of public consultation should be to reach consent to these projections. This information should be systematically communicated through public information processes as described above.

As management proceeds, the manager needs to actively track the evolution of expectations and intervene when they appear to be unrealistic.

Decision Making: A Framework For Rehabilitation

Decision making involves the selection of goals, objectives, and approaches to rehabilitation. We advocate the combined use of two distinct methodologies in the decision-making process-the rationalized method and the bargaining method.

1) The rationalized method involves the identification and evaluation of logical options, and then making a decision based on costs and benefits. For example, this may be an economic analysis of fish allocation, or rehabilitation. end point, defined by a MSY model.

2) The bargaining method involves negotiation among the various publics to identify and evaluate options. Bargaining takes place to mitigate impacts on these publics to find an option that has a consensus of agreement and thereby obtain public acceptance through informed decision making.

The development of goals and objectives is an integral part of the rehabilitation process, and goals or objectives must be in place before specific decisions can be made. Objectives are considered more-general statements-for example, "...to provide a summer walleye angling fishery at a location." Goals are more specific to provide a benchmark for achievement within a time frame-for example, "...to provide density of catchable walleye of 10-ha." Goals might be modified or refined after the initiation of rehabilitation as a result of monitoring and reviewing the rehabilitation process. Other goals should be stated in socioeconomic terms. Each rehabilitation project will probably have its own specific goals and objectives-these will reflect the expectations of the managers and the various publics.

We have identified four generalized decisions to be made in all rehabilitation projects. Each of these decisions is associated with a particular phase of rehabilitation.

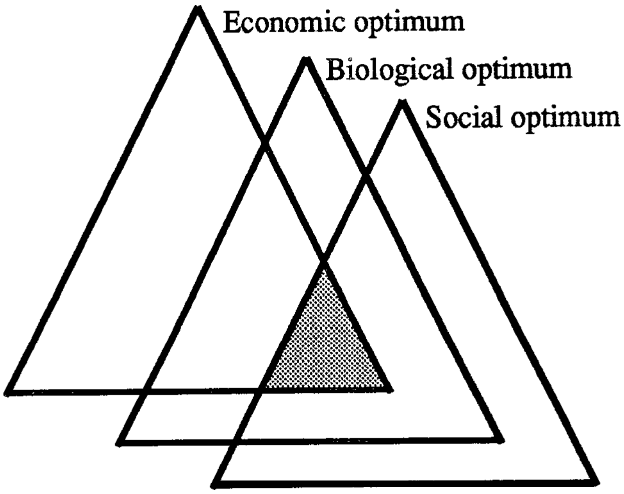
For depressed stocks, we first make the decision of whether or not to rehabilitate. This decision must take into consideration local, social, and economic impacts and the biological impacts and constraints on the fish community. If the decision is to rehabilitate, objectives should be defined. Next, decide on the approach to rehabilitation while considering economic, technical, and biological constraints. The rehabilitation goals should be stated with this decision.

In the rehabilitating phase, the major decision is the end point of rehabilitation. This is accomplished primarily by judging the adequacy of the previously stated goals-for example, some optimum sustainable yield. New data become available as rehabilitation proceeds and might allow redefinition of goals and the end point of rehabilitation. We have seen this in Lake Erie when the western-basin stock was declared rehabilitated in 1984 because specific goals were achieved. However, expansion of this stock into the central basin resulted in redefining the goals and the stock was reclassified as a rehabilitating stock. If it becomes apparent during the rehabilitating phase that the goals cannot be achieved without stocking, then the aggregate benefits of the system would be less. The benefits of ecosystem integrity would be missing, and we would be settling for less.

For rehabilitated stocks, the major decision(s) involves maintaining the stocks at some sustainable level. Changes in fish-community dynamics, water quality, fishing effort, and other stresses may require trade-offs in development and exploitation to maintain sustained yields. At this phase, social and economic mechanisms are generally most important. This phase may not differ greatly from the rehabilitating phase, except that expectations should be reflected in the harvests.

Decision-Making Criteria

Rehabilitation decisions affect numerous interests and values-some will be competing, some complementary, and some incommensurable. Public agencies must articulate choices made in the public interest integrating everyone's expectations and in an acceptable manner. Intuitively, the task becomes one of finding solutions that are acceptable in economic, biological, and social terms.



Each triangle represents viable outcomes within a given perspective. The shaded area represents the minimum acceptable compromise or the constrained maximum (weighted integrate).

In practice, the acceptable solution rarely, if ever, occurs on the basis of a single, mathematically defined optimum. In addition, the manager will probably not be in a position to employ the rational model of planning-leading from problem identification to arraying the alternatives, evaluating the alternatives, and choosing the best one. What might be feasible is some kind of a broad-based bargaining model that would include some of the following components:

identification of the biological, social, and economic effects of a change (of natural or human origin);

assessment of the aggregate losses and gains and the distribution of these losses and gains among the various stakeholders;

adoption of course(s) of action after deliberate consideration of the trade-offs implicit in the decision;

the conduct of such a choice-making process in an open and accessible environment, with full opportunity for the publics to contribute to the process; and

mitigation of adverse impacts, consensus building, negotiation, or other means to arrive at solutions that will enhance the public acceptance of the initiatives.

Rational models, derived from specific individual disciplines, may be included in this overall decision-making framework. These could be considered as necessary inputs into the social contracting process. Consider the following:

Biological Feasibility. What is the likelihood of a sustainable population?

Economic Efficiency. This is the predominant, but not exclusive, form of economic rationality. It seeks to increase the overall size of the societal "pie." Terms of walleye rehabilitation would:

1) dictate whether the decision to rehabilitate is economically rational or not based on whether aggregate benefits exceed aggregate costs (both broadly defined and over appropriate time horizons).

2) be involved in choosing among alternate approaches to rehabilitation as well as in designing the scale of the rehabilitation effort. For the latter, knowledge of the benefits and costs (gains and losses) as density-dependent functions is necessary. It should be noted that the benefits and costs would include both within and outside the market system. Divergences between private and public costs will need to be recognized.

Equity Considerations. The distribution of losses and gains and an accounting of these on the basis of appropriate public segments. This is often necessary to understand social ramifications and attain consensus.

Social Acceptability. The manager will need to apply some judgement as to whether adequate social acceptance of the initiatives exists. Because specific mechanisms and rationale have been dealt with in earlier sections, suffice it to say that fisheries agencies can not expect unanimity on the part of various competing interests. Criteria for sufficient social acceptability and public consultation could include:

procedural fairness in consultation,

open and accessible consultation, and

the decision to rehabilitate is an informed decision, with a reasonably sound understanding of the nature and magnitude of the various social impacts.

In addition, the degree to which the rehabilitation process incorporates or considers each of the criteria (and the balance between the criteria) will probably be determined by the degree of scrutiny expected by the various publics.

Data and Methods

The data and methods in decision making will cover a wide variety-for example, casual field observations, proxy indicators, and structured questionnaire instruments. Some of these, especially public consultation, have been described in sections on identification of publics and public involvement. Data and methods should help in understanding at least the following:

Primary Economic Benefits. These benefits include recreational fishing activity,, commercially caught fish, expanding economic activity, increased tourism, and reduction in management costs-anything that adds to overall societal welfare in both quantitative (monetary) and qualitative terms. In addition, certain intrinsic values-for example, those involving no financial exchange-may be important. These values might be what we call existence values, option values, and bequest values. These are values associated with clean, healthy ecosystems, and regarding societal contracts to sustain resources for future generations.

Economic Impacts or Secondary Benefits. The benefits relate to the income and employment benefits resulting from enhanced activity in given areas. Included are what we call multiplier effects.

Other Social Benefits. These benefits include changes in income distribution, improved access or opportunities for specific groups, quality-of-life considerations, subsistence dependencies, and other distributional questions identified at the public-consultation stage.

Costs. Parallel to the benefits, social and economic costs need to be identified that relate to primary and secondary levels-paying attention to both monetary and non-monetary kinds. Non-monetary costs might inciude loss in enjoyment of displaced recreational and cultural activities, water quality, and deterioration.

Trade-Offs

In the rehabilitating or rehabilitated phase, many decisions involve trade-offs of one resource for another. For example, walleye populations on the Great Lakes may have been traded off to some degree for control of sea lamprey by the use of electric barriers. Other trade-offs include allocation between commercial and angler fisheries. **The combined value of two fisheries on a lake may be higher than if** either fishery existed alone.

A trade-off involving species interaction may also be possible. For example, a decision regarding a trade-off of the rehabilitated walleye population in the Bay of Quinte for northern pike and increased water clarity is currently being evaluated by the Bay of Quinte RAP (Bowlby et al. 1991; J. Bowlby, OMNR, R.R. #2, Aurora, Ontario, Canada, LAG 3G8, pers. commun.).

RECOMMENDATIONS

Habitat Classification

The case histories prepared for this workshop (Colby et al. 1991) indicated the response of walleye to rehabilitation efforts varied greatly throughout the Great Lakes and seemed to be related to differences in habitat. Warmer and more-productive environments recovered faster and with less effort from fishery managers (for example, the Bay of Quinte and western Lake Erie). Because there seems to be a relationship between rate of recovery and habitat, a walleye-habitat-classification scheme for the Great Lakes seems necessary. Acknowledging the difficulty in classifying habitat and realizing that much more-detailed information is desirable, we recommend the following general classification to aid managers in predicting rehabilitation success and interpreting or relating to the various indicators of habitat and stock status as they vary throughout the Great Lakes:

Small Northern Rivers

Walleye production in rivers is generally more dependent on detritus than walleye production in lakes. These smaller oligotrophic systems depend on snowmelt to push organics into the associated bays to stimulate zooplankton production for recently hatched fry. These snowmelt stocks are characterized by very irregular recruitment and are depressed in many areas of the upper Great Lakes. Low flows may account in part for the depressed walleye stocks in Georgian Bay-the Moon River is a good example (Reckahn and Thurston 1991). Also, walleye in smaller rivers may be more available and, therefore, vulnerable to exploitation. Northern-Lake Superior streams provide marginal walleye habitat. These fragile stocks seem to be vulnerable to exploitation and, once collapsed, appear to be difficult to rehabilitate (Schram et al. 1991).

Large (Often-Impounded) Northern Rivers

Many of these rivers-such as, the St. Louis, Spanish, French, and St. Marys-have retained productive stocks of walleye. The Nipigon River stock should be in this group, but pollution or overfishing or both (Schram et al. 1991) has led to its collapse. The St. Louis stock was not overexploited because the walleye had tainted flesh and were not desirable for eating. Flows in these larger systems:

are more chemically buffered,

have higher turbidities or areas sheltered from light,

have more-stable flows and temperatures, and

have more-abundant zooplankton during the critical fry stage.

These large northern rivers probably influence estuarine conditions more than the smaller snowmelt streams.

Northern Embayments

These habitats are often deep and exposed to Great Lakes storms. These environments, without intrusions of warmer river water or protected embayments, are more inhospitable to walleye early life-history stages. The Black Bay stock (Lake Superior) could be included in this category. Although it was (until depletion by overfishing) primarily a reef-spawning stock, the large Black Sturgeon River was probably important in its maintenance. The Black Sturgeon River provided favorable estuarine conditions-such as, darker-colored water favored by walleye-in Black Bay. Therefore, embayments with more river influence (either in size or number) are probably more favorable for walleye recruitment.

Large Southern Embayments

Large productive embayments-such as, Southern Green Bay, the western-Lake Erie complex, and the Bay of Quinte-have higher turbidities, chlorophyll a values, and are well known for their production of walleye. Northern Green Bay and the eastern shore of the Door County Peninsula, Wisconsin (Sturgeon Bay), probably fit somewhere between the northern and southern embayment classification because of temperature instability as a result of frequent upwellings and cold currents. In the southern embayments, spawning usually occurs in one or more rivers and on reefs. Recruitment in these systems is a function of temperature mediation of spawning, growth, and predation processes. Many of these systems have been impaired by pollution and species introductions, especially in the upper reaches where extensive settlement was attractive. However, these larger embayments are less vulnerable to overexploitation because of their size and productivity. They are able to recover more rapidly because of compensation (faster growth and earlier maturity) and with less stocking effort.

Large Southern Rivers

These habitats support, or have supported in the past, large walleye populations that behave and respond similarly to warmer embayments. Often these walleye intermingle with other stocks, therefore contributing to population complexes that segregate during the spawning season. Rivers (for example, the St. Clair and Detroit Rivers) serve as conduits of many intermixing stocks moving between various water bodies.

Water Levels

It is apparent that we need to improve our ability to predict community changes. A study to evaluate the long-term trends in Great Lakes water levels, their influence on water clarity, and subsequent changes in the aquatic community are needed. Special statistical techniques now are available-for example, time series and spectral analysis (Cohen et al. 1991)-which should aid in separating out the effects of water levels and zebra mussel filtering rates on water transparency.

Therefore, we recommend that studies be initiated immediately to review the long-term trends in Great Lakes water levels with respect to their influence on water transparency and subsequent effects on fish-community structure (especially walleye populations).

Climatic Changes

There is increasing evidence that climatic trends occur that influence fish populations. Reckahn and Thurston (1991) mention the potential negative influence of low snowfall and subsequent low spring flushing rates on walleye abundance. Cohen et al. (1991) found a clear link between changes in the yearly maximum range of water levels and changes in fish populations, including walleye. The periodic injection of nutrients into water bodies from flooding changes the quality and quantity of spawning habitat for walleye and northern pike. Svardson and Molin (1973) found warm summers favored zander. Colby and Lehtonen (in press) believe a combination of cooling climate in the 1940s and 1950s, along with the introduction of nylon gillnets, contributed to the demise of zander in north-central Finland. Therefore, we recommend that more studies relating climate change to fish-community dynamics be conducted to increase our predictive capabilities. We should advance fishery forecasts beyond those of Bogdanov et al. (1968) to predict the effects of weather and climate on various fish stocks so that fishing pressure can be adjusted accordingly.

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APPENDIX A

Participants in workshop working groups at the Walleye Rehabilitation Workshop, Stone Biological Laboratory, Put-in-Bay, Ohio (June 5-9, 1989).

Group 1-Depressed Stocks

Chairman:	Cheryl Lewis, Ontario Ministry of Natural Resources
Facilitator:	Kenneth Minns, Department of Fisheries and Oceans Canada
Members:	
Dennis Schupp	Minnesota Department of Natural Resources
Dell Siler	Michigan Department of Natural Resources
Milt Austin	Ohio Department of Natural Resources
Steve Schram	Wisconsin Department of Natural Resources
Jim Reckahn	Ontario Ministry of Natural Resources
Joe Leach	Ontario Ministry of Natural Resources

Group 2-Rehabilitating Stocks

Chairman:	Robert Haas, Michigan Department of Natural Resources
Facilitator:	Joe Koonce, Case Western Reserve University
Members:	
Jerry Paine	Ontario Ministry of Natural Resources
Don Pereira	University of Michigan
Jack Christie	Ontario Ministry of Natural Resources
Mike Rawson	Ohio Department of Natural Resources
Phil Schneberger	Michigan Department of Natural Resources
Ken Muth	U.S. Fish and Wildlife Service
David Davies	Ohio Department of Natural Resources

Group 3-Rehabilitated Stocks

Chairman:	Peter Colby, Ontario Ministry of Natural Resources
Facilitator:	Terry Lychwick, Wisconsin Department of Natural Resources
Members:	
Bruce Vondracek	Ohio State University
Steve Nepszy	Ontario Ministry of Natural Resources
Roger Kenyon	Pennsylvania Fish Commission
Leo Mrozinski	Michigan Department of Natural Resources
Gary Isbell	Ohio Department of Natural Resources
Don MacLennan	Ontario Ministry of Natural Resources
Roger Knight	Ohio Department of Natural Resources

Group 4-Overview/Socioecouomic

Chairman:	Doug Jester, Michigan Department of Natural Resources
Facilitator:	Carl Baker, Ohio Department of Natural Resources
Members:	
Leroy Hushak	Ohio State University
Jim Bowlby	Ontario Ministry of Natural Resources
Craig Harris	Michigan State University
Dan Talhelm	Michigan State University
Jim Schneider	Michigan Department of Natural Resources
Don Einhouse	New York Department of Environmental Conservation
Jim Atkinson	Ontario Ministry of Natural Resources
Nilam Bedi	Ontario Ministry of Natural Resources

Group 5-Rotating Group and Support Staff

Carlos Fetterolf	Sponsor
Ken Fritz	Chief, Fish Section (Host)
Lee Kernen	Policy Panel
Jim MacLean	Policy Panel
Ken Paxton	Policy Panel
‘Randy L. Eshenroder	Commission Coordinator
Marie Rinnie	Clerk-Typist
Pat Bronkowski	Clerk-Typist
Bonnie Benovske	Clerk-Typist