North American Journal of Fisheries Management 23:1329–1342, 2003

Initial Attempts to Actively Manage Recreational Fishery Harvest in Minnesota

PAUL RADOMSKI*

Minnesota Department of Natural Resources,
1601 Minnesota Drive, Brainerd, Minnesota 56401, USA

Abstract.—The theories and management style of commercial fisheries management have recently been applied to recreational fisheries. Several Minnesota recreational fisheries are now managed with target harvest levels based on sustainable yield predictors or quotas based on constant fishing mortality rate strategies. Creel limits and length-based regulations are being used to meet established targets or quotas. Three case histories are described. Both benefits and shortcomings have resulted from applying commercial fisheries management programs directly to recreational fisheries. However, recreational fisheries managers may not be controlling total fish harvest. To effectively manage recreational fisheries for ''safe satisfaction returns,'' fisheries managers may need to adopt conservative, robust harvest regulations, kill quotas, or aggressive regulations on how people fish. The distribution and mix of those options can be determined by good social science, but the efficacy of managing for safe satisfaction returns will depend on good fisheries data (biological and sociological) and great social skill. The lessons learned from the three case histories reviewed could be used to improve recreational fisheries management.

Minnesota's recreational fishing regulations have historically consisted of creel limits and seasons. Recreational angling was assumed to be self-regulating, in that fish populations would not be driven to collapse because anglers would stop fishing depressed populations or shift their effort to populations with higher catch rates. Creel limits were imposed to limit greed and distribute the harvest, while gear and season limits were implemented to codify contrived recreational angling restrictions (Radomski et al. 2001). Recreational fishing regulations did not restrict total harvest. However, the long-term decline in the number of large fish of some species in many Minnesota waters (e.g., northern pike *Esox lucius*; Olson and Cunningham 1989) and the restoration needs of several Minnesota fisheries from recruitment overfishing (e.g., Rainy Lake; Cohen et al. 1993) forced fisheries managers in Minnesota to begin regulating the length of fish harvested or total harvest. Commercial fisheries management themes were adopted, substantially altering recreational fisheries management in the state, which was essentially laissez-faire with regards to total fish harvest.

Commercial fisheries management has been based on four major themes. In order of historical prominence, they are maximum sustained yield (MSY), optimum sustainable yield (OSY), the precautionary approach (PA), and community-based management (CBM). These themes reflect the evolution of fisheries management science, but all are still in use today, many commercial fisheries being reliant on several of them. Their tools reflect the importance of quantitative management styles in commercial fisheries.

The maximum sustained yield theme was an outcome of mathematical constructs of fish population dynamics and an illusive notion of harvest engineering by its practitioners. The tools that allowed MSY to flourish and that are still crucial today include stock–recruitment analysis, yield-per-recruit analysis (Baranov 1918; Thompson and Bell 1934; Beverton and Holt 1957), and yield-per-recruit derivatives like virtual population analysis (Jones 1963; Gulland 1965; Murphy 1965; Pope 1972). The use of these tools led to theoretical harvest strategies, such as computation of the best minimum size to obtain the maximum yield from recruits (Ricker 1975). Minimum size limits reign in many commercial fisheries, where mesh size and other gear restrictions that protect small fish are common.

The optimum sustainable yield theme was developed and employed to address the weaknesses of MSY. Roedel (1975) defined it as

> a deliberate melding of biological, economic, social, and political values designated to produce the maximum benefit to society from stocks that are sought for human use, taking into account the effect of harvesting on dependent or associated species.

Larkin (1977) had difficulties with the theme and thought that optimum was a subjective notion that differed from person to person. Many of the

* Corresponding author: paul.radomski@dnr.state.mn.us

Received April 26, 2001; accepted January 30, 2003

fisheries management tools used under this theme were refinements of those of the MSY approach, especially major advances in fish population analyses (Quinn and Deriso 1999).

The precautionary approach theme emerged from a need for greater accountability of uncertainties and management failures. The theme was put into widespread practice in the United States with the issuance of the 1998 Guidelines for National Standard 1 (Optimum Yield) of the Magnuson–Stevens act (Fishery Conservation and Management Act of 1976), which stated that ''in general, Councils [regional institutions created by the act] should adopt a precautionary approach to specification of [optimum yield].'' Restrepo et al. (1998) developed the details of implementing a precautionary approach using such tools as limit and target reference points and control rules. The PA theme has a large scope, wherein precaution in fisheries development, management, research, technology, law, capture, processing, regulation implementation, habitat alteration, and so forth is advised so that optimal yield can be obtained on a continuing basis (Mace and Gabriel 1999; Restrepo et al. 1999).

The community-based management theme draws on a mix of insights from the biological and sociological sciences and works in conjunction with the other themes to address fundamental issues related to human culture, environmental variability, and fish community interactions (Berkes et al. 1998). The tools of this theme include multispecies models (multispecies virtual population analyses [Daan and Sissenwine 1991], bioenergetics [Hanson et al. 1997], Ecosim [Walters et al. 1997], multivariate statistics [Link et al. 2002], and cognitive maps [Hobbs et al. 2002]), adaptive management (Holling 1978; Walters 1986), fisheries comanagement, and property rights (see Radomski 1999). The use of these tools substantially alters the management objectives, how a fishery is viewed, why fish harvests affect other fish in the community, and who benefits.

My first objective is to explore Minnesota case histories of target or quota recreational harvest management and the difficulties in regulating recreational harvest. My second objective is to discuss the consequences of the adoption of commercial fisheries management themes for recreational fisheries and express my opinions on how recreational fisheries management could proceed in Minnesota.

Applying Commercial Themes to Recreational Fisheries

While marine commercial fisheries management has benefited from freshwater recreational fisheries studies on species interactions and ecosystem responses to fish harvest, recreational fisheries management has been reliant on strategies and tools created for commercial fisheries management. The benefits of using commercial fisheries themes are many. First, recreational fisheries management could be improved by heeding the lessons learned in commercial fisheries management. For example, recreational fisheries managers should recognize the need to quantify socioeconomic issues and integrate these and other variables into models for determining optimal yields. This could be accomplished by quantifying recreational angler preferences, values, and behaviors and incorporating these data into population and ecosystem models to simulate various management policies (Radomski et al. 2001). Along these lines, for instance, Jacobson (1996) used value-per-recruit analysis to explore recreational angling regulation options for a Minnesota walleye *Sander vitreus* (formerly *Stizostedion vitreum*) fishery and to optimize angler satisfaction. Second, recreational fisheries management could benefit from the strong analytical resources developed to manage commercial fisheries. From statistical kill-at-age models to biological reference points and risk analysis, commercial fisheries management has led to major advances in analyzing fish population and harvest data, often by applying new statistical science in clever ways. However, these analytical resources have not seen extensive use in the setting of general recreational angling regulations, at least in Minnesota (Cook et al. 2001), and quantitative data on the status of many recreational fisheries are often sparse (Post et al. 2002). Lastly, the difficulties and failures of commercial fisheries management (e.g., fish population collapses across the world) have led to the creation of themes and strategies for harvest management that are robust to future conditions (e.g., biological reference points, the precautionary approach, and individual transferable quotas), and recreational fisheries management could benefit from them.

The shortcomings of applying commercial fisheries management themes to recreational fisheries management are also numerous. First, commercial fisheries management dogmas come with their own themes, which could be harmful. For example, many recreational angling fisheries are regulated by means of minimum length limits (Radomski et al. 2001), which may be an artifact of their extensive use in commercial fisheries. However, the appropriateness of the widespread use of minimum length limits for walleyes and northern pike has not been fully studied, and for largemouth bass *Micropterus salmoides* the strategy has not been fully assimilated by agencies (Wilde 1997). Maximizing pounds harvested per recruit is often the objective, but applying this philosophy to recreational angling may not be prudent for some species because maximizing angler satisfaction is desired. In addition, small fish dominate many fish populations in Minnesota, and protection of large fish might prove more beneficial to angler satisfaction than additional experimentation with minimum length limits. Minimum-size regulations in commercial fisheries have also evolved to include a spawn-at-least-once policy (Myers and Mertz 1998), but such a policy discounts the reproductive importance of larger mature fish and may be high risk (Tripple 1998; Murawski et al. 1999). There are other dogmas besides the apparent lack of concern for large mature fish (e.g., emphasis on effort and harvest and concerns about the efficiency of harvest). Second, commercial themes leave out recreational management objectives such as enhancing recreational value, minimizing the frequency of regulation change, and accounting for other social factors. Lastly, quota management (a key strategy for commercial fisheries management) is difficult to implement extensively in recreational fisheries management in places like Minnesota that have many fisheries and lack harvest monitoring.

Case Histories of Recreational Harvest Management

Fisheries managers have begun to set target harvest levels for Minnesota's 10 largest lakes, starting with the Ontario–Minnesota border waters in 1984 (OMNR and MDNR 1984). The approach uses the morphoedaphic index (MEI) to estimate potential fish yields (Ryder 1965). Yield estimates are then apportioned into target harvests for each species using the guidelines developed by the OMNR (1982). Additional fish yield models were also examined for these lakes (MDNR 1997). These lakes are now managed with target harvest levels based on sustainable yield predictors or quotas assuming constant fishing mortality rates. Length-based regulations are being used to meet some of these established targets or quotas. I present three case histories involving the fisheries for sauger *Sander canadensis* (formerly *Stizostedion canadense*), yellow perch *Perca flavescens*, and walleyes in Minnesota. With these cases, I briefly describe some of the issues and difficulties Minnesota is facing in its recreational fisheries management. These difficulties are not new or unique, but they document recreational fisheries management lessons that may offer insights for others.

Lake of the Woods Sauger Fishery

This case history demonstrates the problems with setting target harvest levels (based on MSY) that are scientifically defendable for recreational fisheries. Lake of the Woods is situated on the border between northwestern Ontario, southeastern Manitoba, and northwestern Minnesota and has a total surface area of 385,000 ha (Schupp and Macins 1977). Minnesota's portion of the lake includes all or portions of Big and Little Traverse bays and Muskeg Bay and covers 128,300 ha. An important winter recreational fishery exists for sauger, angler effort averaging about 6 angler-hours/ha/yr and total sauger harvest averaging about 0.5 kg/ha/yr (70,000 kg in all). Sauger recruitment is quite variable (MDNR 1997), and fisheries managers have been concerned about the possibility of overharvest.

Target harvests for sauger were established, but they were changed after periods of low or high recreational harvest. The initial work to set a target harvest level occurred while a commercial gill-net fishery still existed in Minnesota waters. A target harvest of 61,000 kg was established in 1984 using apportioned estimates of MSY determined by the MEI (OMNR 1982; OMNR and MDNR 1984). The last commercial harvest occurred in 1985. The initial MEI-based target harvest was then altered owing to fisheries managers' concerns about its viability. The target harvest level was reviewed and increased to 136,000 kg in 1992 (OMNR and MDNR 1992) and then reduced to 49,000 kg in 1997 (OMNR and MDNR 1998). There were no substantial changes to sauger recreational angling regulations during the 17 years that the three different harvest targets were in effect. Harvest exceeded the targets by a factor of two (on average) during both the 1984–1992 and 1997–1999 periods, while it was approximately one-half of the 136,000-kg target during 1992–1996 (Figure 1). This suggests that harvest levels depended on sauger recruitment and availability and that target levels had little impact on harvest because they were not accompanied by regulation changes. Analysis of vital population statistics, such as mortality

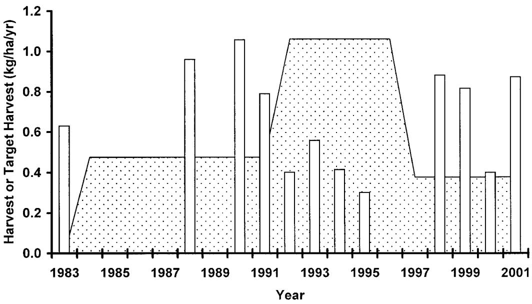

FIGURE 1.—Recreational angling harvest of saugers in Minnesota waters of Lake of the Woods, 1983–2001, as estimated by creel surveys. Targets for harvest (indicated by the shaded area) were set in 1984, 1992, and 1997.

rates, was used to aid in determining whether past harvests were excessive (Radomski 2000). The estimated average exploitation rate throughout the period was 17%, and no trends were apparent in total mortality. Target fishing mortality strategies wherein the fishing mortality rate equals the natural mortality rate or 60% of that rate suggest exploitation rates of 25% and 18%, respectively. Given that and other data, the MDNR determined that Lake of the Woods sauger harvests were probably not excessive.

The target harvest concept, for which the intermediate goal was to keep the average harvest at target levels, was ineffective in controlling the harvest of a sauger population that experienced large natural fluctuations. The sauger population was surveyed on an annual basis and sauger recreational harvest on a less frequent basis, but the lack of confidence as to a safe harvest level only resulted in changing targets. The failure to implement regulations to restrict harvest and an inability to predict harvests resulted in a loss of agency credibility. The application of such a constant-harvest strategy when recreational harvests were only periodically monitored may have also led to management indecision. Gaps in harvest information raised concerns about the exploitation rates that the fishery had experienced and led to management disagreements as to whether recreational angling was responsible for the population's variability. Until fishery managers commit to monitoring both population and harvests on a continual basis, the application of the commercial fisheries management theme that includes a constant-harvest strategy will not be complete.

Quantification of sauger population dynamics using complete harvest statistics is but one management alternative. Others include the use of various elements of adaptive management or the precautionary approach and the involvement of stakeholders in management. For example, fisheries managers could alter recreational angling regulations (e.g., bag or length limits) or become more active in regulating how people fish (e.g., specifying terminal tackle, fishing accessory equipment, fishing locations, fishing times, etc.) and evaluate any regulatory change by continuing to monitor the sauger population and harvest. If the population increased or became more stable or if angling catch rates increased sometime after a regulation change, fisheries managers could begin a continual, adaptive search for a balance in resource protection and sauger harvest. Greater public involvement in setting the objectives of the fishery and in developing the target harvest level may also result in the development of ''regulation change rules'' that provide a mechanism for action when the average harvest began to exceed the target level. Restrepo et al. (1998) stated that ''public participation is important because the public and fishing industry are more inclined to support management measures on which they have been consulted and which they understand clearly.'' The predetermined nature of regulation change rules might ensure that management actions are implemented without delay. In addition, managers can respond to changing fish population conditions that merit disrupting the local angling community because the conditions for prompt action are understood and recognized as important in maintaining the quality of the fishery.

Lake Winnibigoshish Yellow Perch Fishery

This case history demonstrates the difficulties in regulating recreational anglers to achieve optimum sustainable yields when no predetermined rules have been developed with the public prior to a crisis. This is a common problem for both commercial and recreational fisheries, and the result in recreational fisheries is often mediocre angling. Lake Winnibigoshish is a large (24,000-ha), shallow (mean depth, 4.6 m) reservoir with a population of large yellow perch. The annual yellow perch harvest in Lake Winnibigoshish was estimated to be about 1,100 kg in 1930 and 9,100 kg in the late 1950s. A substantial winter yellow perch recreational fishery developed on the lake in the 1970s, composed mostly of Wisconsin anglers using area resorts for multiple-day fishing trips (Osborn and Schupp 1985). In 1979, a daily and possession limit of 100 fish was established because

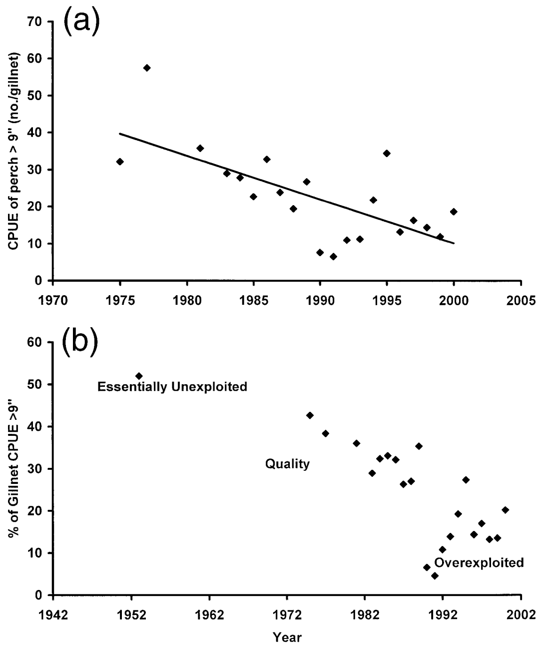

FIGURE 2.—Trends in the abundance of large yellow perch in Lake Winnibigoshish, Minnesota, expressed as catch per experimental gill net for fish longer than 229 mm (9 in), 1975–2000 (upper panel) and the percentage of fish caught that were longer than 229 mm, 1953–2000 (lower panel).

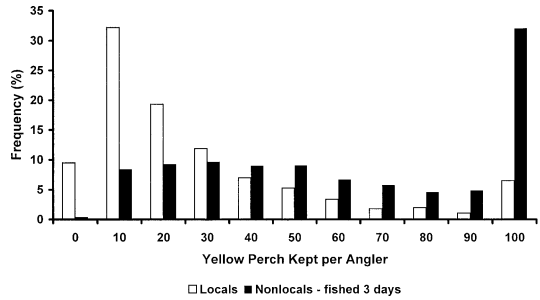

FIGURE 3.—Frequency distribution of the number of yellow perch kept by local and nonlocal anglers from Lake Winnibigoshish creel surveys, 1994–1996. Local anglers fished for 1 d, nonlocal anglers for 3 d.

of concerns that non-resident anglers were taking large numbers of yellow perch home for commercial sale. In the winter fishing season of 1994–1995 recreational anglers harvested 1 million yellow perch weighing a total of 252,000 kg (10.6 kg/ha), and for the fishing year as a whole they harvested a total of 290,000 kg (12.2 kg/ha).

The MDNR became seriously concerned about the status of the Lake Winnibigoshish yellow perch population and the level of harvest in 1997 (MDNR 2000). The abundance of yellow perch more than 229 mm (9 in) in total length had declined since 1977 (Figure 2). In 1953, when the yellow perch population was almost unexploited, 52% of the yellow perch sampled in survey gill nets were longer than 229 mm. This percentage had decreased to an average of 15% during 1996–2000 (Figure 2). The exploitation rate of yellow perch longer than 229 mm (≥age 7) was 62%, considerably higher than the sustainable rate. Other indicators of overharvest were also seen, such as an increase in recruitment and decreased condition (both density-dependent responses) of 203-mm perch. Managers were concerned that the failure to address the overharvest of large yellow perch would result in an abundant population with low recreational value. Colby et al. (1987) noted that yellow perch tend to exist in one of two states that are characterized by the abundance of large individuals. When large yellow perch are in low abundance and small yellow perch in high abundance, growth is slow because the dense population of small fish competes for a limited food supply. When large yellow perch are abundant, growth rates are high because cannibalism keeps the density of small yellow perch low. The change from a low to a high abundance of large yellow perch can only occur with substantial changes in the number of small yellow perch, and this may be difficult to achieve with angling regulations if the abundance of large yellow perch continues to decrease. An increase in the number of small yellow perch in Lake Winnibigoshish had already been noted, signaling a possible shift in the dynamics of the fishery.

The MDNR used three different models to predict the effects of various daily and possession limit reductions on the yellow perch recreational harvest (MDNR 2000). An important component of all the models was the assumption that nonlocal anglers fished for three consecutive days (Figure 3). The models differed in their complexity and assumptions but all attempted to predict the consequences of reduced possession limits.

The simplest model used Lake Winnibigoshish creel survey data from three recent winters and relied mainly on the distribution of the harvest by fishing parties. Reductions in harvest were predicted with declines in yellow perch bag limits by assuming that nonlocal anglers (nonresidents plus nonlocal residents) fished for 3 d and local anglers for 1 d. The model predicted that a possession limit between 20 and 30 fish would probably meet the objective of a 40% reduction in the yellow perch harvest.

The second model utilized the same creel data as the first but employed a Monte Carlo simulation approach with individual-angler interview data to predict the probability of achieving a 40% harvest reduction with reduced possession limits. Monte Carlo methods can be used to calculate confidence limits for predicted values. The principle behind the Monte Carlo simulations is quite straightforward; here, a 3-year ''virtual fishery'' was created using actual interview data from fishing parties seeking yellow perch during the last three winter creel surveys (data included harvest rates, trip length, number in the party, and nonlocal versus local status). The virtual fishery consisted of hundreds of angler parties. Each angler party fished and harvested fish with randomly selected harvest rates from a pool of observed harvest rates. The trip lengths for each party were derived from uncertainty distributions computed from completed-trip interview data. Harvest rates and the number of anglers per party were randomized by day for a given fishing party. Fishing parties were randomly treated as nonlocal or local based on the probability derived from the creel surveys. Nonlocal anglers were assumed to fish up to 3 d. One thousand simulated input data sets were generated and then run through the virtual fishery. The model suggested that possession limits of 20 or fewer fish would meet the objective of a 40% reduction in harvest whereas a possession limit of 50 would entail 0% confidence of success. The model results also suggested that adding a daily bag limit to the possession limit would increase the confidence of success. For example, a daily limit of 20 yellow perch together with a possession limit of 50 such fish was predicted to reduce harvest by as much as a 40-perch possession limit.

Because the first two models assumed that the yellow perch population remained at the level that was present during the creel survey years (including years with high populations of large fish), the predicted bag limit reductions might be higher than those with a fluctuating population with fewer large fish.

A third model was used to address the consequences of angler behavior using the vital statistics of the yellow perch fishery to determine which creel limits would probably produce sustainable catches. This model's basic structure was similar to that of MANSIM (Korver 1992) but incorporated Monte Carlo techniques (M. Drake, MDNR, personal communication). Fish growth and mortality (fishing and natural) were applied monthly, while catchability varied between ice and open-water seasons. The model was age and sex specific, each age-group being represented by 10 length-groups with sex-specific growth rates and length–weight relationships. The natural mortality rates of immature and mature yellow perch varied annually, and the probability of harvest was length based. Hooking mortality differed between ice and open-water seasons. The three predominant angler types (local resident, nonlocal resident, and nonresident) were represented by negative binomial functions fitted to creel data to describe the probability of an angler's catching and keeping fish during a fishing trip. For the winter fishery, effort was divided between local and nonlocal anglers assuming that local anglers fished for a single day and nonlocal anglers for 3 d. For the summer fishery, a single negative binomial function was used to describe both local and nonlocal anglers. In addition, a stock–recruitment function developed from Lake Winnibigoshish yellow perch data was used to predict recruitment from adult yellow perch abundance. For each potential regulation, 750 Monte Carlo loops were run. For each Monte Carlo loop, a new set of stock–recruitment parameters was randomly drawn from a bootstrap-generated data set for use in the 50-year simulation. Within each loop, the population was simulated for 50 years with the stock–recruitment parameters held constant and the values for the last 40 years were averaged and stored. The 40-year averages from the 750 Monte Carlo loops were used to estimate the 95% confidence intervals for the model output parameters. The results from this model suggested that a possession limit of 20–30 yellow perch had the best chance of significantly increasing the number of perch exceeding 229 mm in length and significantly reducing the exploitation rate of large perch (≥age 7). The reduced bag limit was predicted to stabilize the perch population by increasing the number of large adults and shifting recruitment to the right side of the stock–recruitment relationship, where the number of recruits per spawner is lower. Also, as the number of large fish in the population increased, the number of such fish that were harvested would increase and thereby minimize the reductions in yield.

The results of all three models indicated that a possession limit of 30 fish or less would probably accomplish the fisheries management objectives for yellow perch fisheries, whereas a possession limit of 50 was determined to have a poor chance of reducing the yellow perch harvest by 40%. The models gave insight into the possible effects of creel limit reductions but may have overestimated harvest reductions because they failed to consider the relative increase in stock abundance that may occur with lower creel limits (see Porch and Fox 1991) or changes in angler behavior (Radomski and Goeman 1996; Beard et al. 2003, this issue).

The MDNR spent 3 years meeting with anglers and resort owners and working with legislators to allow time to adjust to new limits, along with getting extensive public input to develop and implement a daily and possession limits of 20 and 30 fish, respectively. However, resort owners, concerned that such a rule would have severe negative effects on their businesses, persuaded their legislators to enact a law that established statewide yellow perch limits of 20 and 50 fish, effective December 2000. Harvest reductions with the new 50-perch possession regulation were predicted to be inadequate to accomplish the necessary overall harvest reduction. In the formal Minnesota rule-making process that followed, an administrative law judge concluded that the MDNR adequately demonstrated need and reasonableness in proposing the implementation of the 20- and 30-fish limits. However, in 2002 the MDNR implemented limits of 20 daily and 40 in possession due to the strong opposition to the 20- and 30-fish limits by the resort community.

Regulation of recreational harvest is difficult even when many acknowledge that overharvest is occurring. Attempts to define optimum sustainable yields for Lake Winnibigoshish yellow perch were viewed with suspicion by business owners. Many resort owners supported lowering the yellow perch limits from 100 but were concerned about short-term economic risk to the resort owners and related businesses that may have accompanied more restrictive regulations. The politics of regulating recreational anglers is intensive and extensive, and many agencies face hardships in managing for anything but mediocrity for many common fish. In Minnesota, species besides yellow perch have also declined. The fisheries for bluegill *Lepomis macrochirus* and black crappie *Pomoxis nigromaculatus* have experienced dramatic reductions in quality (Olson and Cunningham 1989), and these declines have yet to generate substantial angler calls for additional statewide regulation to reduce exploitation (Currie and Fulton 2001). Several phenomena may explain the recreational angling community's attitudes and responses. First, resort owners denied that the yellow perch fishery was seriously degraded, even though they witnessed large removals of yellow perch. Perhaps this denial existed because they were concerned about keeping or increasing the number of clients at their resorts. Second, anglers generally perceived that the Lake Winnibigoshish fishery (and many other fisheries) had not changed much (i.e., Pauly's ratchet; Pitcher 2001) or they lacked the ability to recognize the cumulative effect of continual removals of the largest fish.

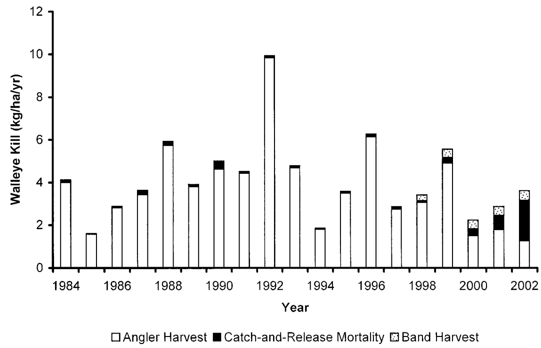

FIGURE 4.—Annual harvest of walleyes at Lake Mille Lacs, Minnesota, 1984–2002, as estimated by creel surveys (angler harvest and assumed hooking mortality rates [to estimate catch-and-release mortality]) and censuses (Indian band harvest).

Lake Mille Lacs Walleye Fishery

This case history demonstrates the need for an application of the precautionary approach in a mixed subsistence and recreational fishery. Lake Mille Lacs is a 54,000-ha glacial lake in central Minnesota and the most productive large lake for walleyes in the state (3.6 kg/ha/yr; Figure 4). Since 1997, annual quotas have been set to facilitate sustainable sharing of the total harvest by state-licensed recreational anglers and Ojibwe Indian subsistence netters and spearers. The lake's walleye fishery management is based on a constant-exploitation-rate strategy designed to set annual safe harvest levels at 24% of the vulnerable stock, which is then adopted as the total allowable harvest. The total allowable harvest is allocated to recreational anglers and Ojibwe subsistence fishers by means of quotas. The intergovernmental protocols established for this fishery have generally interpreted the quotas, which are determined at the start of the fishing season, as limits that may not be exceeded without penalty.

Virtual population analysis and statistical kill-at-age models were used to estimate the annual abundance of walleyes in Lake Mille Lacs (Bruesewitz et al. 2002). The recreational angling fish-

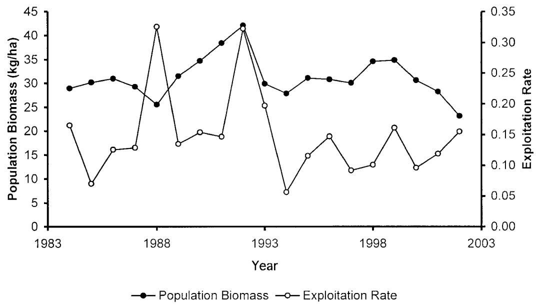

FIGURE 5.—Annual walleye biomass and exploitation rates in Lake Mille Lacs, 1984–2002, as estimated by virtual population analysis.

ery was monitored by annual creel surveys, and fish populations were monitored with annual gill-net, electrofishing, seine, and trawl assessment surveys. Although the Mille Lacs walleye population has been more stable than any other large-lake walleye population in Minnesota, the exploitation rate fluctuated greatly (range, 7–32%; Figure 5) prior to the adoption of the annual quota management system.

For the 6 years with harvest quotas, the MDNR used traditional recreational angling regulations in an attempt to reduce the probability that the total mortality of the recreational fishery would exceed its annual allocation. Two methods were used to predict recreational harvest and the consequences of various length-based regulations prior to the start of each fishing season. The first method used a gill-net selectivity and catchability model and an angler selectivity curve to estimate the length distribution of harvested fish. The second method predicted the recreational walleye kills by age from gill-net catches per unit effort (similar to Isbell and Rawson 1989), with the addition of Monte Carlo techniques to address uncertainty. This model underestimated recreational angler harvest by an average of 20%, predictions ranging from 62% less than actual harvest to 70% more than actual harvest (Figure 6). In addition, there were large uncertainties in the predictions of walleye kills by age, both models giving wide confidence limits. Although the compensatory effects of length-based regulations on total harvest were not understood, the MDNR attempted to address this issue by choosing angling regulations with lower risk that allocations would be exceeded. Angler harvest (including estimates of hooking mortality) exceeded its annual allocation in 4 of those 6 years, and total harvest (including tribal subsistence harvest) exceeded the total allowable harvest in 3 years (Figure 7). The recreational harvest of walleyes was managed with bag limit and length-based regulations that have become increasingly restrictive (Table 1). In the year with the most restrictive regulations (2002), recreational anglers experienced record high catch rates, such that their quota

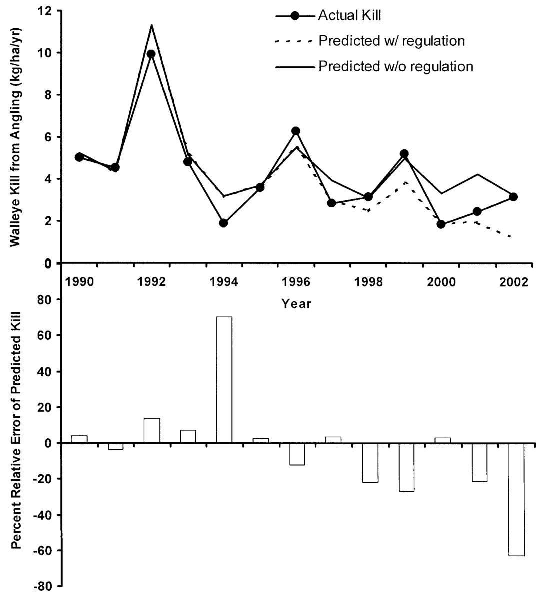

FIGURE 6.—Actual angler harvests of walleyes at Lake Mille Lacs, 1990–2002, and retrospective predictions of angler harvests with and without regulations (upper panel) and percent deviations from actual harvests (lower panel).

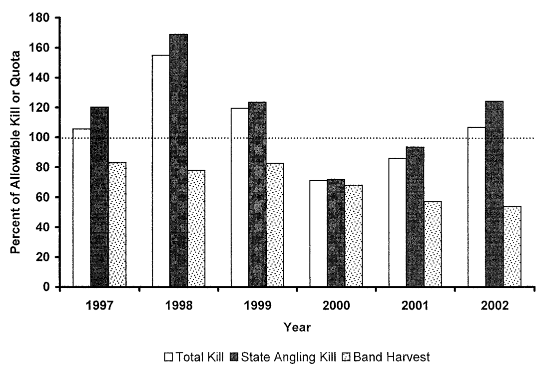

FIGURE 7.—Percentage of the total allowable walleye harvest represented by the total estimated kill (the sum of the recreational angling kill by state-licensed anglers and the Indian band subsistence harvest) and percentage of the annual quota represented by the recreational angling kill and the Indian band subsistence harvest at Lake Mille Lacs, 1997–2002. The dashed line indicates the total allowable harvest or the respective quota for the year in question.

TABLE 1.—Walleye open-water recreational angling regulations for Lake Mille Lacs, Minnesota, 1997–2002. (1 in = 2.54 cm).

Year	Daily creel limit	Length-based regulation
1997	6	15-in minimum
1998	6	15-in minimum
1999	6	14–20-in harvest slot (only one fish greater than 26 in)
2000	6	14–18-in harvest slot (only one fish greater than 28 in)
2001	6	
May 12–Jun 5		16–20-in harvest slot (only one fish greater than 28 in)
Jun 6– Jun 17		16–18-in harvest slot
Jun 18–Dec 1		16–18-in harvest slot (only one fish greater than 30 in)
2002	4	14–16-in harvest slot (only one fish greater than 28 in)

was exceeded mostly as a result of estimated catch-and-release mortality.

Minnesota considered adopting elements of the precautionary approach. This did not coincide with the imposition of quotas but rather emerged from the inability to keep the recreational harvest below a limit reference point in the case of a politically charged and contentious resource issue. The agency's management costs greatly increased and showed that regulations that are robust to the inherent variability of both fish populations and angler catchability are needed to control total fish kill from recreational angling. The angling community strongly complained about the imposition of regulations that attempted to keep harvests below quotas when tribal subsistence harvests were low and a healthy fishery appeared to exist. The established protocols only defined an annual quota setting process. The management procedure specified no feedback mechanism or evaluation plan. Thus, the system was shallow. Risks were not evaluated except for a single-year harvest. Recreational angling regulations had to be changed often with an annual ''balance-the-books'' approach, and their long-term impacts could not be evaluated because of the frequent changes. The state proposed to the intergovernmental body responsible for Lake Mille Lacs fisheries management issues that they apply a management process that formally recognized the uncertainties in population estimation, safe harvest determination, and regulation consequence predictions, while providing a robust, conservative approach with predetermined control rules. Both target reference points and predefined control rules from the precautionary approach theme may improve management. A target reference point would define the management objectives, and this point would not be exceeded more than 50% of the time. A control rule, which defines the status of the population, might use measures of population condition to scale exploitation or harvest, so that the harvest would have to be lower when the population was low. Development of the limits, targets, and control rules for the Mille Lacs walleye fishery would require extensive dialogue between Indian bands, fisheries managers, and the public.

Discussion

The three case histories demonstrate several things. First, they show how recreational fisheries management decisions are made. Recreational fisheries managers must often deal with data-poor conditions. Reliable estimates of safe harvest levels are difficult to obtain, and quantification of total harvest is often lacking. In adopting commercial management themes, however, one has to fully commit to quantifying total harvest and regulating recreational fishing mortality to stay within a quota or target. Recreational fisheries managers need to find a way to effectively deal with some of the key issues in the quantitative management style of commercial fisheries management. However this is done, managing the recreational harvest will probably require more resources or a shift in the allocation of resources. The MDNR spends much of its budget and human resources on walleye stocking and evaluation. For inland fisheries, stocking is often used to improve recreational fishing or mitigate recreational fishing declines (Radomski et al. 2001). Anglers would probably not support allocating fish stocking resources to manage recreational harvests. Second, the case histories show the limitations of regulating total harvest with bag and size limits, the traditional recreational angling regulations. They also show why recreational fisheries management sometimes fails. The lack of agency resolve to implement additional restrictions was also noted for the case histories. For some recreational fisheries, like the

Lake Winnibigoshish yellow perch fishery, continual compromise will probably have negative effects on both the sustainability of the fishery and the long-term well-being of the human community that depends on it. Finally, the recreational fishing community is as resistant to regulatory changes as the commercial fishing community. Apart from the recent implementation of size regulations, Minnesota's fishing regulations have not changed much since the first hook-and-line rules were established in the early 1900s. Some creel limits have not changed in 70 years. Tradition becomes a difficult thing to change, and it may be the biggest impediment to advancing recreational fisheries management in Minnesota.

The MDNR recently reviewed and revised statewide recreational angling creel limits, which was traumatic for many anglers. During public meetings on fish creel limits across the state, the MDNR had a hard time convincing anglers that a small proportion of anglers harvest their limit and that creel limit reductions must be substantial to save significant numbers of fish (Cook et al. 2001; Radomski et al. 2001). After a century of fish creel limits being the major angling regulation in Minnesota, most anglers assumed that such limits have been conserving and protecting quality recreational fisheries (Currie and Fulton 2001). Anglers have seen agencies change fish limits marginally, often with the subliminal message that such changes will improve fishing. The MDNR had a difficult time educating anglers as to the benefits and shortcomings of various fish limit changes. Perhaps this was due to our failure in educating anglers on the concepts of recreational fishing management or confusion created by our codification of some angler values.

During the review of Minnesota creel limits, the MDNR obtained angler opinions on bag and length limits. The MDNR received about 1,600 written comments during the creel limit rulemaking period from October 12 to December 8, 2000 (G. Grant, MDNR, personal communication). No other recreational fishing issue in Minnesota has resulted in more written public comments. About 20% of all respondents opposed any changes to creel limits. Among respondents commenting on specific creel limits for walleyes, largemouth bass, black crappies, and bluegills, 60–70% supported reducing the creel limits to a median of about two-thirds of their current value. About 40% of the respondents mentioned their support for the advancement of length limits, even though angler attitudes on that issue were not solicited, and about 25% of the respondents suggested both reduced bag and length limits. In contrast, in a statistical survey of Minnesota anglers at about the same time, Currie and Fulton (2001) found that respondents generally felt that creel limits were effective and acceptable and the median preferred creel limits were consistently close to the existing limits. Currie and Fulton also found that Minnesota recreational anglers were satisfied or very satisfied with their fishing experience in Minnesota and believed that the existing bag limits were protecting fish populations. Anglers also generally believed that length limits (minimum size and slot length limits) were effective or very effective at reducing overharvest and that voluntary catch-and-release fishing was generally ineffective or very ineffective.

We are in a period of proliferating length-based regulations (Radomski et al. 2001). Minnesota has over 130 water bodies with site-specific length-based regulations, including 8 different largemouth bass length regulations, 9 different walleye length regulations, and 11 different northern pike length regulations. The consequences of many of these regulations will be hard to determine. The ad hoc application of many of these well-intended regulations may just lead to confused and frustrated anglers (Lester et al. 2003, this issue). Anglers have concluded that fine-tuned harvest control is possible with length regulations—perhaps a false belief created by our plethora of length-based regulations. I suspect that recreational fisheries management will increasingly quantify and regulate for a safe satisfaction return based on biology (to protect or enhance fish populations in their natural habitat) and sociology (to enhance the quality of the sport) (Radomski et al. 2001). This may mean simple but broad-based, conservative recreational fishing regulations that aggressively alter an individual angler's harvest and perhaps total fish kill. Alternatively, a reduced suite of conservative regulations should be applied across the state (rather than lake-specific regulations) to reduce angler confusion and disdain for additional regulations. The Mille Lacs walleye quota management experience also demonstrates that bag and length-based regulations can be weak controls for total angling mortality, as has been suggested or noted for other fisheries (Post et al. 2002; Sullivan 2003, this issue). Lester et al. (2003) proposed watershed-scale experiments of different sets of regulations to learn what works.

Harvest and angler quotas have been discussed as possible ways of preventing overharvest from recreational fishing (Sullivan 2003). Harvest quota management for recreational fisheries in Minnesota would be difficult due to the large number of lakes. Harvest quota management for Lake Mille Lacs consumed a significant portion of agency resources; the MDNR could not afford to implement harvest quotas for more than several large recreational fisheries. Delayed mortality from catch and release was also a problem for the Mille Lacs walleye fishery because the number of anglers entering the fishery was not controlled. Harvest quota management through harvest tags was recently proposed as one option for a lake sturgeon *Acipenser fulvescens* fishery, where it was assumed that hooking and handling mortality would not be substantial. Angler quotas may also be difficult to implement. A quota system regulates how many groups can begin a trip at each entry point each day in Minnesota's Boundary Waters Canoe Area Wilderness (BWCAW), which is used to keep the number of people in the area consistent with a wilderness experience. Even given this precedent, the public has strongly opposed the implementation of angler quotas for recreational angling harvest management. This was observed for Alberta fisheries as well (Sullivan 2003). If the perfect recreational fishery were described as one that has enormous effort and no fishing mortality (Hilborn 1985), how many anglers would be allowed to fish? Would the number of anglers affect overall angler satisfaction? Perhaps some iteration of angler quotas may be workable and acceptable to the public. For example, indirect controls on anglers by management of the number or types of water access might be possible. Market-driven controls on access to fisheries, whereby access fees indirectly control or limit the number of anglers that participate in a fishery, might also be tolerated by the public, although such approaches may be inconsistent with the tradition of North American hunting and fishing privileges.

For strictly recreational fisheries in Minnesota, I am still undecided as to the extensive use of commercial fisheries management themes that include harvest quotas. I am swayed by Acheson et al. (1998), who discussed the benefits and shortcomings of ''numerical management'' (regulating how many fish are harvested) and those of ''parametric management'' (regulating how people fish). The Lake of the Woods sauger fishery, and all of the other fisheries in Minnesota, require additional quantification of vital fisheries statistics. However, approaches other than targets or quotas may achieve safe satisfaction returns. Anglers have already accepted the MDNR's authority to regulate which fish can be harvested based on size. Will anglers allow the MDNR to regulate how, where, and when they fish to a greater degree than that entailed in many of the current contrived regulations? New approaches might include fisheries managers taking an active role in regulating the tools of the sport. Minnesota has only rarely pursued limiting the gear anglers use to reduce the probability of catching fish. The use of motor-powered watercraft is not allowed in much of the BWCAW, and gas and electric motors, augers, and electronic fish-finding devices are all prohibited on one lake in Minnesota. Barbless-hook and artificial-lures-only rules exist for several water bodies in the state. There are no rules on fishing poles, fishing line, boat size, hook type, electronic devices, and other fishing gadgets for most of Minnesota. The state generally does not regulate how people fish, which is determined for the most part by the recreational angling industry and the individual anglers, who often wish to make it easier to catch fish. The question is, should fisheries management agencies make catching fish by recreational angling more difficult? Many Minnesota anglers do not harvest a single fish during an angling trip, and the total harvest is not equally distributed among anglers (Cook et al. 2001). An individual angler's share decreases with an increasing angler population, and as the fisheries resource becomes increasingly scarce the sharing of resources becomes less equitable (Smith 1990). The MDNR could consider regulating how the most effective anglers fish. This would require identification of the fishing tools, gear, and techniques (in relation to angler skill) that account for increased efficiency.

The use of fish sanctuaries, that is, the posting of no-fishing zones on lakes and streams to protect concentrated fish populations in the spring, is quite common in Minnesota. The use of permanent no-fishing zones or fish reserves, like that of marine reserves, is less common (the seasonal closures are often traditional measures that give the effect of year-to-year permanence but still allow angling in those areas at times of the year when fish are not concentrated). Marine reserves exist (and are proposed) for a variety of purposes, ranging from preserving critical habitats and biological diversity to protecting and restoring fisheries. Most models of marine reserves have been developed with mid-trophic-level fish, like rockfish *Sebastes* spp., and recognize the role of larval transport in determining the distribution and abundance of marine organisms. To be effective, a marine reserve must be large enough to protect a sufficient proportion of the population and must include relevant habitat for the protected species. Often, reserve areas and their size are chosen pragmatically with a view toward both biology and sociology. Lauck et al. (1998) suggest that marine reserves may be the simplest and best approach to implementing the precautionary principle for a fishery. Work on this tool for marine applications has progressed (National Research Council 2001). Can reserves work for fish populations in freshwater lakes that are subjected to recreational fishing? Are the movement patterns of common North American freshwater species like the walleye broader than those of coral reef fish for which reserves have shown to be an effective management tool? Will anglers accept greater use of reserves in Minnesota?

From my perspective, commercial and recreational fisheries management is converging on a balanced use of fish population dynamics and social science. This is a good thing, but it is only happening because of the demands that commercial and recreational fisheries managers face with increasing conflict. The challenge that recreational fisheries managers face is to develop management measures that incorporate the many basic approaches to dealing with risks (i.e., avoidance, reduction, retention, and sharing) that include more focus on the resource and its exploitation as well as productive interactions with angling communities to address their interests (Hilborn et al. 2001). Regulating how recreational anglers fish across the state should be considered. Development of the limits, targets, and control rules for important fisheries, like the Lake Mille Lacs walleye fishery, will require extensive dialogue between fisheries managers and the public. Predetermined rules developed with the angling public are also needed for important recreational fisheries in the state. Predetermined rules, developed before substantial problems arise, may provide greater legitimacy and political cover for the MDNR and ensure that management actions are implemented without delay. The legitimacy of the regulatory process may increase with participatory decision making or community-based management (Jentoft 1989). The other challenge for recreational fisheries management agencies will be to acquire people with the experience and skills necessary for this work and to reallocate other resources that are now being used for such activities as fish stocking.

Acknowledgments

I thank Jerry Grant, Mike Hansen, Sean Cox, Jack Wingate, and two anonymous reviewers for providing helpful comments on drafts of this manuscript. I thank Don Pereira and Mike Hansen for organizing this symposium.

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