J. Great Lakes Res. 24(2):351–360
Internat. Assoc. Great Lakes Res., 1998

Benefits and Costs of the Ruffe Control Program for the Great Lakes Fishery

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ABSTRACT. *Although data on Great Lake fish stocks and values are uncertain estimates, reasonable approximations can be made concerning economic losses for the United States from various types of management practices. Based on biometric changes that are projected to occur, it appears that early control of a non-indigenous fish species, specifically ruffe* (Gymnocephalus cernuus), *can result in significant investment returns. By instituting a ruffe control program, benefits to the public will exceed costs by 44 to 1 over the next five decades. Under a moderate case projection of benefits this will yield an estimated net public savings of $513 million for the United States. Since sportfishing values are much greater than commercial fishing values, anglers will benefit the most from this program.*

INDEX WORDS: *Ruffe, discount rate, costs, control.*

INTRODUCTION

Non-indigenous species (NIS), animals and plants that are not native to the United States, are creating a growing economic, environmental, and health burden. Most non-indigenous species are innocuous, some may be beneficial, generally under ten percent become successfully established (Williamson and Brown 1986). However, this small yet significant portion of NIS imposes hardships on regional economies and can have a dramatic effect on the local ecology. A 1993 report to Congress titled "Harmful Non-Indigenous Species in the United States" stated the United States annually spends $7.4 billion for pesticide applications, with a significant portion devoted to NIS control (U.S. Office of Technology Assessment, OTA, 1993).

OTA estimated that since the turn of the century, of the known NIS, comprising 14% of the total, economic losses to the United States were $97 billion (1991 dollars). If the unknown losses are proportional to what is known, then total economic losses for this same period would approach $700 billion or about $8.2 billion annually, a figure consistent with current estimated annual economic losses. Although year by year losses have not been recorded in any systematic way to demonstrate historical trends, the evidence suggests that the pace of invasions by NIS are rising precipitously both nationally and globally (Drake and Mooney 1989).

Although the economic impacts from NIS are significant they often do not take into account non-market values. For example, NIS can lead to significant ecosystem alterations, including general reductions in biodiversity (Norse 1993). This can lead to accelerated extinction rates of native species with effects and consequences sometimes taking decades to emerge (Wilson 1992). Other adverse effects may be noted within the biogeochemical and hydrological cycles, and geomorphological processes. Due to constraints in time, methodology, and databases, this paper does not take into account these non-market impacts.

GREAT LAKES AND NON-INDIGENOUS SPECIES

Of the wide range of industries affected by the expansion of NIS, the U.S. fishing industry has been substantially impacted (Wilson 1988). Some native fish have been virtually eliminated with sig-

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nificant costs to the regional economies of the United States, particularly the Great Lakes. For example, in Lake Michigan the yellow perch population collapsed in 1965, principally from overfishing, pollution, and competitive interactions with a NIS, alewife (*Alosa pseudoharengus*) (Kraft 1982). By 1982, the alewife population began to recede, but fishing pressure on yellow perch in one of Lake Michigan's prime fishing areas, Green Bay, remained high. Annual commercial harvest declined 58%. It averaged about 550,000 kg before 1965 but was 230,000 kg from 1978 to 1982 (Johnson *et al.*1992). Sport harvest also experienced a dramatic decline and was estimated at 15% of total harvest from 1978 to 1982.

The sea lamprey (*Petromyzon marinus*) is another example of a NIS that severely impacted the Great Lakes region (Lawrie 1980). This species is believed to have arrived several decades ago and migrated throughout the Great Lakes. Its presence initially caused multi-million dollar losses to the commercial and recreational fisheries. However, a control program was instituted that payed rich dividends. Annual benefits exceeded costs by half a billion dollars (Talhelm and Bishop 1980).

If there are parallels, then a ruffe control program may be a worthwhile investment for protecting fish populations. However, it is important to recognize that attempting to predict the extent and degree NIS will displace, disrupt, and persist in a native environment is highly problematic and often beyond our current scientific capability. This problem is exacerbated by the fact that population biologists and community ecologists often find it challenging to predict population changes of native species in relatively undisturbed systems, let alone those that are subject to NIS (Hastings and Higgins 1994). Therefore, attempts to project population shifts of native species, and thus angler day changes, from the influences of NIS over long time horizons is highly speculative. For example, current sport fishing angler days for Lake Erie are about one third of their 1980s levels, making assumptions about fish population stability and usage highly problematic and variable.

THE INTRODUCTION OF RUFFE

In the early 1980s a fish from the perch family, ruffe (*Gymnocephalus cernuus*) native to Eurasia from the Arctic Circle to the Black Sea, was introduced to North America. It was conjectured that the most likely means of transport was through the ballast water of seagoing vessels (Great Lakes Fishery Commission 1992). Ballast water, used for ship stability, is one of the principal means of introductions of NIS into U.S. Waters (Wilson 1988). It is estimated that millions of gallons of ballast water with thousands of accompanying stowaway species of marine plants and animals is discharged every day (NOAA 1996).

Over the past 15 years, ruffe have become the dominant fish in the southwestern regions of Lake Superior where over five dozen species of fish reside. Based on bottom trawl samples, ruffe make up an estimated 80 percent of the fish abundances. It is believed that ruffe are likely to be highly successful in both cool and warm water habitats that extend from the Great Plains to the northeastern seaboard of the United States and Canada (Hokanson 1977). Ruffe have few predators, no commercial or recreational value, and are believed to be displacing or interfering with the populations of native fish, such as yellow perch and walleye.

Yellow perch and walleye are highly valued recreational fish and comprise 32 percent and 37 percent of the total Great Lakes sport fishery, respectively (U.S. Department of the Interior 1991). Consequently, under the authority of Non-indigenous Aquatic Nuisance Prevention and Control Act of 1990, Public Law 101-646, the Great Lakes Fishery Commission in 1991 organized an Aquatic Nuisance Species Task Force to examine the problem. The Task Force reviewed European literature and also assessed potential impacts on endemic fish communities. In 1992, they declared that ruffe is a nuisance species which warrants a control program (Great Lakes Fishery Commission 1992).

PURPOSE AND PROBLEMS OF ANALYSIS

This paper evaluates the cost-effectiveness of alternate control strategies as well as the cost and benefits of taking action versus no action to control ruffe. The mission is to reveal the economic value of enacting the ruffe control program using a cost benefit analysis. This involves the establishment of a baseline. Once this is achieved, the effects of NIS on an environment are projected over time. In principle, the values of future prospects are *ex ante* (values that assume and project future use). This is generally done by *ex poste* use (values obtained from observations of historical use of natural resources).

A cost benefit analysis of this nature is often uncertain as it requires information about key relationships in complex ecosystems that often pose problems for biologists and economists alike. Often the analysis will reflect this scientific uncertainty and highlight our ignorance. Therefore, a sound cost benefit analysis for environments adversely affected by NIS presents major challenges for resource economists. Often such analyses generate quantitative output that looks more authoritative than it really is. However, if the analysis can produce a reasonably accurate accounting framework to help decide whether expected consequences of a proposed action are beneficial in the net, the analysis has then achieved its task. It is important to also highlight that a cost benefit analysis is not a regional analysis on how ruffe will impact the Great Lakes economy. Economic impact analysis estimates how businesses in an area will be impacted if there is no action to control ruffe. Such assessments mainly attempt to gauge the inter and intra changes in the flow of goods or resources within specific regions or industries.

In general, fishery management practices are felt at the local level, but are often offset by opposite impacts on other communities, businesses, and individuals. For example, if sport fishing is unavailable, recreational activity may shift to other areas such as water skiing. Therefore, net economic impacts from the ruffe control program may be small at the regional and national levels, but significant to the sport and commercial fishermen, as well as other interest groups whose livelihoods depend on the robustness of a natural resource.

CONTROL MEASURES

A ballast water voluntary control program was the first and most immediate attempt to reduce or eliminate the possibility of further transport of ruffe, by boat, to other lake regions. With the exception of this program, non-chemical measures to either suppress or control ruffe populations were determined by the Ruffe Task Force as ineffective. For example, predatory control was attempted by stocking walleye, northern pike, and muskie from 1989 through 1993 but was unsuccessful as ruffe populations continued to grow.

Although the ballast water control program will significantly reduce the likelihood of transporting ruffe to other lake regions it will not retard natural migration. Therefore, a different method of control is needed to dramatically slow the pace of migration, such as pesticides, some of which have been used before on other lake nuisance species. For example, over the past 30 years, the pesticide 3-trifluoromethyl-4-nitrophenol (TFM) has been effectively used to control Great Lakes sea lamprey (Great Lakes Fishery Commission 1985). TFM met all safety requirements by the EPA and Environment Canada including no long-term effects on the environment, human and other animal life, does not leave persistent residues, and does not join with other new chemicals with hazardous effects (Great Lakes Fishery Commission 1985).

What is particularly unique about TFM is its selective capability to reduce ruffe populations without affecting other species of fish or imposing undue harm to the lake ecology (Kindt and Busiahn 1994). Therefore, being a viable control candidate, TFM was selected to estimate potential costs to control ruffe. If used, TFM treatments would be applied at the mouth of rivers at specific times of the year where and when ruffe have a tendency to concentrate. This would allow selective removal of ruffe from river estuaries with only limited mortality among non-target species (Boogaard and Bills 1996). For example, in 1992 sea lamprey TFM treatments in the Brule River, Wisconsin, killed 97% of the ruffe, with negligible mortality among other non-target fishes (Bills *et al.* 1992).

COSTS TO CONTROL RUFFE

The total estimated cost to implement the ruffe control program over an 11 year period will be about $12 million. Costs for the first 5 years will be $ 6.8 million and $ 4.8 million over an additional 6 years. The Ruffe Task Force does not believe further treatments will be required past an 11 year program of control. However, as the major cost of control centers on the amount of chemical pesticides used, and this can vary depending on the unpredictable nature of river flow rates, these estimates could fluctuate between 10% to 20% in either direction.

A $12 million control program is not an inexpensive public enterprise, but to evaluate its worth requires that the benefits to the public outweigh the cost for the program. As a result, this economic analysis is premised on the net cost and benefits operating with and without the control program in order to produce value added information for policy decision making. Since there is no realistic way to separate the ruffe control program from other rehabilitative and management influences, it is assumed in this analysis that projected fish reductions of native fish are solely correlated to the proliferation of ruffe. It is also assumed that treatments will be fully effective at controlling ruffe proliferation and migration.

RUFFE MIGRATION

In order to undertake a cost and benefit analysis it was necessary to project the rate of ruffe migration over estimated time horizons along with expected percent displacements of native fish in all lake localities. Due to limited and sketchy scientific information, biologists are greatly challenged by the complexity of how fish populations respond to NIS. Therefore, the extent that ruffe will displace native fish in the Great Lake region is highly speculative. Nevertheless, the federal government mandate, under the Non-Indigenous Aquatic Nuisance Prevention and Control Act, requires that before a control program is considered it must be demonstrated that the benefits exceed costs.

Based on observations of present ruffe migration rates along with native fish population displacements in Lake Superior, as well as past experience of ruffe in European waters, it appears that ruffe will be in direct competition with yellow perch and that the same type of competitive interaction will occur, though not as intensely, with whitefish populations. The highly productive whitefish grounds of Lake Michigan and Lake Huron will likely be particularly impacted. Walleye will be indirectly affected by alterations in the food chain. Species of less sport or commercial value are also likely to be affected, such as the white sucker which is expected to decline as ruffe proliferate. However, for simplification, walleye, yellow perch, and whitefish are the main focus of this analysis.

The Ruffe Control Task Force speculates that if a chemical control program is not implemented complete colonizations are likely to occur over the following time horizons 2010, 2033, 2035, 2038, and 2043 for Lakes Superior, Huron, Michigan, Erie, and Ontario respectively. When this occurs, it is speculated that yellow perch populations will decrease by 10% to 60%, and whitefish and walleye by 1% to 25%. If these reductions are accurate, then the ruffe control program must be implemented promptly; otherwise ruffe migration will be uncontrolled. The pace of migration is likely to accelerate when the ruffe reach warmer waters. Once this occurs it is unlikely that attempts to control ruffe will be cost effective, and local and regional control may be prohibitively expensive.

ECONOMIC VALUES

To determine economic consequences, economic values have to be established. The economic values of the Great Lakes fishing industry is measured by what consumers are willing to pay for this freshwater resource. Values of fish, like any other values, are predicated on several primary variables such as taste, preference, the ability to pay, and the prices of other possible substitutes. The value of the Great Lakes commercial and recreational fisheries rests on the willingness of society to pay for these resources.

Economic values for recreational fishing are deduced from a wide range of variables but since recreational fishing is considered a free public resource, a traditional market analysis is generally not possible. Therefore, the principal framework for deducing recreational fishing values are through indirect approaches. For example, one approach may entail a direct random survey of anglers by personal interview or mail. This approach, referred to as contingent valuation, entails asking anglers how much they value their angling experience.

Other approaches for determining angler values may include examining how fishermen respond to many types of expenses, such as fishing equipment, travel costs, gas prices, food, and lodging. The extent to which costs affect participation rates is directly observable. Not surprisingly and quite consistently, if costs rise, participation decreases. Based on cost variations on any of these variables, economists can reasonably predict recreational fishing participation rates and determine angler day values.

For this analysis, angler day values have already been determined. The value of an angler day for Great Lakes sport fish, excluding salmonids, was estimated by the Great Lakes Fishery Commission in 1985 to be between $10 and $20 (Talhelm 1985). The average angler day values for yellow perch and walleye was approximately $12. Using this value, a 1995 angler day value was determined by referencing the consumer price index that averaged about 3 percent per year. This resulted in angler day values for yellow perch and walleye to be $16.56.

A $16.56 angler day value is a conservative estimate. A 1986 contingent valuation survey by the Sea Grant College Program at the University of Wisconsin determined that the value of a yellow perch angler day for Green Bay, Lake Michigan, was approximately $26 (Bishop *et al.* 1990). However, since angler quality and thus values can vary significantly from site to site, and Green Bay is a prime location for sport fishing, such values are not representative for the Great Lakes as a whole.

SPORT FISHING BENEFITS

To estimate sport fishing benefits from the ruffe control program it was necessary to determine how angler days will be reduced by lessening angler day quality if the program was not instituted. Through a census, the number of angler days is directly observable and have an observable price, in that anglers must pay trip expenditures. The catch rate is treated as a quality variable where angler days will likely decrease if catch rates are reduced from decreases in fish populations. In the area of resource economics, and therefore in this analysis, it is assumed that angler days will proportionally decrease when fish populations decrease.

Decreases in quality, including decreases in catch rates may, all things being equal, lead to a decrease in the demand for trips and hence a decrease in the welfare of the consumer (consumer surplus). Consumer surplus is the excess of an individual's willingness to pay for a good over what is actually paid. Thus, when a fishery project prevents a decline in fishing trip quality it avoids any decline in the consumer surplus and the welfare of the public is preserved.

Such a benefit to the consumer can be divided into two parts. It avoids a decrease in the average consumer surplus per trip as well as a decrease in the number of trips taken. Angler benefits for any given year are then calculated as the number of trips that would have been lost if the ruffe control program were not implemented, multiplied by the value of each angler day. In the case of walleye and yellow perch, as stated, this is a value of $16.56.

POPULATION REDUCTION SCENARIOS

The uncertainty surrounding the degree native fish populations will be reduced by the presence of ruffe requires that this analysis consider three possible scenarios. These scenarios are characterized as minimum, moderate, and maximum for their possible reductions in fish populations or net consumer benefits for the Great Lakes fishery. For example, the three scenarios for reductions of yellow perch populations are 10, 35, and 60 percent respectively; for walleye the projected reductions are 1, 12.5, and 25 percent respectively.

As previously stated, it is assumed that yellow perch comprise 32 percent and walleye 37 percent of total Great Lakes angler days (Table 1). From these percentages estimated angler day losses were derived using the most extensive data base generated by the Great Lakes Fishery Commission (Talhelm 1988). Angler day losses with accompanying dollar losses, as mentioned in this paper and in subsequent tables, should be viewed as forgone benefits if the ruffe control program is *not* enacted. Inversely, if the program is initiated then the losses are avoided and should be viewed as benefits.

The estimate that yellow perch and walleye comprise 69% of the Great Lake sport fishery is both reasonable and conservative. The Ohio Department of Natural Resources fish management and research data records over the past 14 years reveal that Lake Erie's walleye and yellow perch sport fishing comprise, on average, about 91% of total sport fishing (Ohio Department of Natural Resources Division of Wildlife 1994). Since Lake Erie is expected to experience the greatest displacements of walleye and yellow perch, our total portions of walleye and yellow perch of 69% for all of the Great Lakes may likely be an underestimate.

For yellow perch and walleye each lost angler day was multiplied by the established average angler day value of $16.56 (Tables 2 and 3). This determined total Great Lake consumer surplus losses. Therefore, for a "moderate" scenario of a 35% reduction of yellow perch and a 12.5% reduction in walleye, the angler day losses would result in a

TABLE 1. The Great Lakes angler days for yellow perch, walleye, all other, and total angler days for the Great Lakes.

Location	Yellow Perch	Walleye	All Other	Total U.S.
Superior	340,000	394,000	331,000	1,065,000
Huron	2,352,000	2,720,000	2,278,000	7,350,000
Michigan	4,601,000	5,320,000	4,458,000	14,379,000
Erie	5,051,000	5,842,000	4,897,000	15,790,000
Ontario	1,857,000	2,147,000	1,800,000	5,804,000
Total	14,201,000	16,423,000	13,764,000	44,388,000

TABLE 2. Reductions in benefits from reduced populations of yellow perch in the Great Lakes U.S. sport fishery.

	10% Reduction		35% Reduction		60% Reduction	
	Angler Day Loss	Annual $ Loss	Angler Day Loss	Annual $ Loss	Angler Day Loss	Annual $ Loss
Lake Superior	34,000	563,000	119,000	1,971,000	204,000	3,378,000
Lake Huron	235,000	3,892,000	823,000	13,629,000	1,410,000	23,350,000
Lake Michigan	460,000	7,618,000	1,610,000	26,662,000	2,760,000	45,706,000
Lake Erie	505,000	8,363,000	1,769,000	29,295,000	3,030,000	50,177,000
Lake Ontario	186,000	3,080,000	650,000	10,764,000	1,116,000	18,481,000
Total	1,420,000	23,516,000	4,971,000	82,321,000	8,520,000	141,092,000

TABLE 3. Reductions in benefits from reduced populations of walleye in the Great Lakes U.S. sport fishery.

	1% Reduction	12.5% Reduction		25% Reduction	
	Angler Day Loss	Angler Day Loss	Annual $ Loss	Angler Day Loss	Annual $ Loss
Lake Superior	0	49,000	811,000	98,000	1,623,000
Lake Huron	0	340,000	5,630,000	680,000	11,261,000
Lake Michigan	0	665,000	11,012,000	1,330,000	22,025,000
Lake Erie	0	730,000	12,089,000	1,460,000	24,178,000
Lake Ontario	0	268,000	4,438,000	537,000	8,893,000
Total	0	2,052,000	33,980,000	4,105,000	67,979,000

17% reduction in the Great Lakes sport fishery. The annual reductions in benefits, for the United States only, will be $82,321,000 for yellow perch and $33,980,000 for walleye if colonization were to occur immediately (Tables 2 and 3) for a moderate case scenario. This is a total annual consumer surplus loss of $116,301,000.

COMMERCIAL AND TOTAL REDUCTION IN BENEFITS

To determine commercial reduction in benefits from reduced populations of walleye and yellow perch the same scenarios were used for the sport fishing industry. For reductions in the whitefish populations the percent reductions are estimated to be identical with the walleye populations. Therefore, the whitefish population scenarios are 1%, 12.5%, and a 25% reductions under a minimum, moderate, and maximum scenario for a reduction in consumer and producer surplus benefits of $481,000, $2,762,000, and $5,042,000 respectively for the entire Great Lakes.

Table 4 captures the total annual reductions in benefits for both the U.S. sport and commercial fishing industries if colonization were to occur suddenly. Therefore, Table 4 is simply the summing up the totals found in Tables 2 and 3 along with the commercial reductions cited above. Under a minimum, moderate, and maximum case scenario, the added annual reduced benefits for the Great Lakes would be $23,997,000, $119,063,000, and $214,097,000 respectively. Therefore, an estimated $12 million one time commitment over an 11 year period to control ruffe would avert one of these an-

TABLE 4. Annual reductions in benefits from reduced populations of whitefish, walleye, and yellow perch in the U.S. sport and commercial fishery (in dollars).

	Minimum	Moderate	Maximum
Lake Superior	563,000	2,893,000	5,223,000
Lake Huron	3,911,000	19,615,000	35,303,000
Lake Michigan	8,013,000	39,713,000	71,413,000
Lake Erie	8,426,000	41,626,000	74,777,000
Lake Ontario	3,084,000	15,216,000	27,381,000
Totals	23,997,000	119,063,000	214,097,000

nual losses if ruffe were to suddenly colonize the Great Lakes region.

Based on the present rate of migration in Lake Superior, as well as other observed patterns of population expansions in European waters, it is conjectured that the most likely time for ruffe to fully colonize the Great Lakes will take approximately five decades. As previously stated, a time path on a lake by lake basis was constructed up to the year 2050, the time when ruffe populations are projected to stabilize in the Great Lakes. Table 5, column two, reveals the length of time ruffe colonization will occur on a lake by lake basis up to 2050. Impacts from ruffe will likely continue beyond this time; however, it was the decision of the Ruffe Task Force not to exceed a 50 year projection.

DISCOUNTING ECONOMIC VALUES

Once the variable of time is factored into a cost benefit analysis an adjustment is necessary because future gains are worth less than current gains; current gains can earn interest by being placed in, for example, a bank account. Money today, even in an inflation free economy, is always worth more than money obtained some time in the future because of earning potential as well as the psychic gratification of having money today rather than tomorrow.

The rate with which we attempt to make future dollars equal current dollars is called the present discount rate. A high discount rate lowers the present value of future economic gains or, in this case, benefits. This is what happens in many fishery rehabilitation plans with the plan becoming less attractive economically as time passes. Discount rates are usually in "real terms," that is they have been adjusted to eliminate general inflation.

Two basic schools of thought exist on how the discount rate should be set for public projects. One school believes the discount rate should be set to equal interest rates found in private capital markets. The other school of thought emphasizes that the discount rate should reflect "social time preferences" for current versus future income. From this point of view the discount rate should be whatever

TABLE 5. Accumulative discounted reductions in benefits from reduced populations of whitefish, walleye, and yellow perch in the U.S. sport and commercial fishery.

	*Years	Minimum	Moderate	Maximum
Lake Superior	41	10,766,000	53,830,000	89,718,000
Lake Huron	18	21,363,000	106,819,000	189,605,000
Lake Michigan	16	36,783,000	183,917,000	328,751,000
Lake Erie	13	30,281,000	149,626,000	267,189,000
Lake Ontario	8	6,085,000	30,426,000	55,781,000
Totals	N/A	105,278,000	524,618,000	931,044,000

* Total number of years reflects colonization up to the year 2050

value society collectively places on future resources for the next generation.

In this analysis the latter view, of social time preference, was adopted. This rate is considered to be about 3% by many environmental economists. It is also the rate that is used by the National Oceanic and Atmospheric Administration's Damage Assessment Division when attempting to calculate damages from industrial accidents.

ACCUMULATIVE REDUCTIONS IN BENEFITS

To determine accumulative reductions in benefits, each year's annual values were discounted by a 3% rate. This provided a loss, progressively, on a year by year basis to the year 2050, the time when ruffe are projected to have reached population stability in the Great Lakes. The results indicate that the discounted reductions in benefits are significantly different and are much less than the undiscounted ones. For example, the total discounted reductions in benefits up to the year 2050 for all lakes is $105,278,000, 524,618,000, and 931,044,000 for the minimum, moderate, and maximum scenarios respectively (Table 5). If discounting was not applied, the losses would be $355,900,000, $1,770,000,000, and $3,189,000,000 respectively for the same scenario categories. The latter numbers are derived by simply multiplying all the numbers in Table 4 by the total number of years

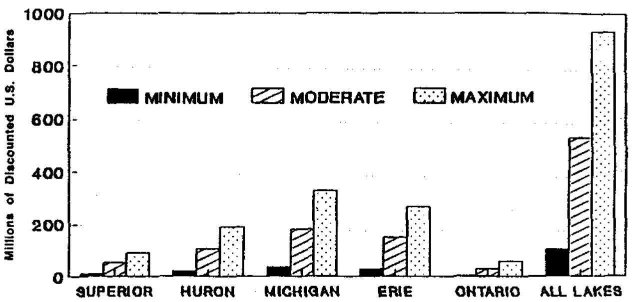

FIG. 1. The cumulative discounted benefits from instituting the ruffe control program for all three scenarios on a lake by lake basis to the year 2050. Irrespective of what scenario unfolds, Lakes Michigan and Erie will benefit the greatest from the ruffe control program. Even under a minimum scenario, benefits will be evident, although marginally, in all five lakes.

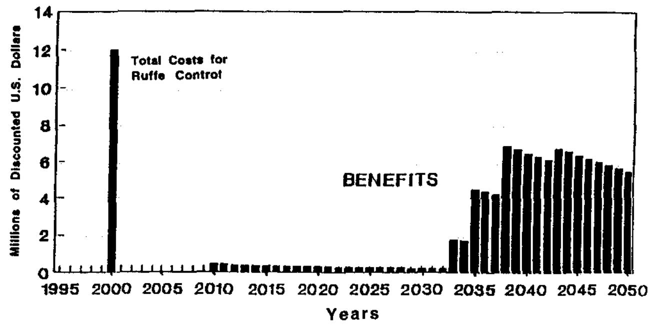

FIG. 2. The minimum discounted benefits are represented over a 50 year time horizon. The figure reflects the least amount of benefits that could be expected from instituting the ruffe control program.

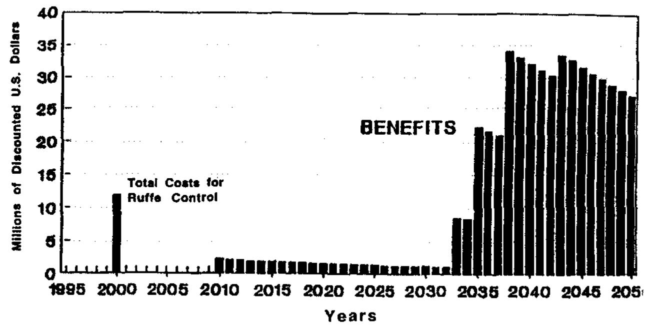

FIG. 3. The moderate discounted benefits are represented from instituting the ruffe control program over a 50 year time horizon. If the ruffe control program is undertaken, returns on investment will be evident by 2010, when Lake Superior would otherwise reach complete ruffe colonization. By 2033, Lake Huron is projected to reach complete colonization and returns on investment are higher from avoiding losses from Lakes Superior and Huron combined. This process proceeds in succession until all five lakes are inundated if there is no control program.

colonization will occur on a lake by lake basis up to 2050, as specified in Table 5, column two. This illustrates the degree that discounting can significantly reduce benefits.

To gain a visual perspective, Figure 1 illustrates the cumulative discounted benefits for instituting the ruffe control program for all three scenarios on a lake by lake basis to the year 2050. Irrespective of what scenario unfolds, that Lakes Michigan and

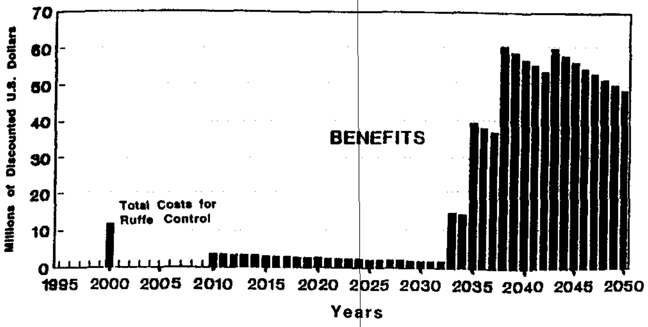

FIG. 4. The maximum discounted benefits are represented over a 50 year time horizon. The figure reflects the most amount of benefits that could be expected from instituting the ruffe control program.

Erie will benefit the greatest from the ruffe control program. Even under a minimum case scenario, reduced benefits will be evident, although marginally, in all five lakes.

In Figures 2, 3 and 4 the discounted benefits for a minimum, moderate, and maximum scenario are represented over a 50 year time horizon. Therefore, if the ruffe control program is undertaken, returns on investment will be fully evident by 2010, when Lake Superior would otherwise be completely colonized. By 2033, Lake Huron is projected to reach complete ruffe colonization and returns on investment are higher from avoiding losses from Lakes Superior and Huron combined. This process proceeds in further succession until all five lakes are otherwise ruffe inundated if there is no control program. It is important to note that these calculations are underestimates because losses to each lake would likely be incurred gradually as each lake is progressively fully colonized. However, due to the difficulty in estimating these progressive impacts, losses were not calculated prior to complete colonization.

The tapering of the benefit values represented in these figures are attributed to the discounting formula. Potential benefits extended out progressively into the future results in greater and greater reductions in these values. For simplification, the year 2000 was selected as our start year as it reflects the mid-point year between the initiation of the control program and when it is projected to end. The total estimated cost for the program over this 11 year period, as stated, will be about $12 million.

In conclusion, if ruffe migration proceeds as anticipated, by 2050 accumulative discounted losses will range from $105 million to $931 million. However, if expansion of ruffe populations were to occur more rapidly, then expected losses may reach a range of $24 to $214 million per year and, within a few years, quickly exceed projected accumulative discounted losses. Therefore, the degree of losses will rest on the pace of migration and the extent that ruffe displace or interfere with native fish populations. It will also rest on the assumption that the fishery will continue to be robust to the year 2050. Under a moderate case scenario, where ruffe migration are projected to occur over the next 50 years, estimated accumulative discounted losses are expected to be $525 million.

SUMMARY

In economic terms, the ruffe control program is an investment in a fish stock that can be interpreted as a means by which the "biological capital" of the Great Lakes is preserved. In a time where sustainability of natural capital and intergenerational equity is receiving greater attention, the ruffe control program is an investment that is made today to sustain the long-term bio-economic production of the Great Lakes fishery for the next generation.

In accounting for public expenditures on the Great Lakes fishery the important question is not the value of the resource, nor the value of the angling or commercial fishing; the important question is the value produced by the public expenditure, that is, the public's return on investment if the ruffe control program were to be initiated. It appears, based on existing information, that a ruffe control program would be a worthwhile expenditure where costs and benefits may be comparable to the sea lamprey program. To quote from a paper that was a part of the proceedings of the Sea Lamprey International Symposium, August 1979, "Sea lamprey control and salmonid stocking programs in the Great Lakes are emerging as one of the great success stories in modern applied ecology. For an investment of roughly $25 million per year, the public is enjoying a fishery worth perhaps 20 times that much. Lamprey are down to 5–10% from their peak abundance (Walters *et al.* 1980)."

In March 1993 the Office of Technology Assessment published a report titled "Harmful Non-Indigenous Species." This report identified and summarized the economic losses the United States incurred from harmful non-indigenous species in the past 85 years from 1906 to 1991. For those losses where economic values were available (14 percent of total) the U.S. lost nearly $100 billion (1991 dollars) from the intrusion of non-indigenous plants and animals. Based on a moderate case scenario outlined in this paper, it appears that if the ruffe control program were not implemented the economic losses would be substantial and clearly add to this figure.

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Submitted: 30 April 1997
Accepted: 7 January 1998
Editorial handling: Michael R. Klepinger