CHARACTERIZATION OF THE CANADIAN COMMERCIAL WALLEYE FISHERY

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MASTER OF SCIENCE

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The Canadian commercial walleye fishing industry was characterized, identifying sources of commercially caught walleye, and the biological and economic factors affecting supply. The potential for increased harvests was addressed. This information will help a potential U.S. walleye aquaculture industry better understand the role and ability of the Canadian commercial fishery in meeting the U.S. demand for walleye food products and competing with a newly developed aquaculture industry. Biological and environmental factors limit the supply of wild-caught walleye. The Canadian commercial wild-caught walleye fishery is currently operating at or near maximum capacity, and substantial increases in yield are likely not possible.
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L.L.
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I. INTRODUCTION

Aquaculture is “the propagation and rearing of aquatic species, including any species of finfish, crayfish, or leaches, in controlled or selected environments” (Daily 1990, P. 1). The Egyptians were successfully farming Tilapia (*Oreochromis niloticus*) 4,000 years ago. Raising carp (*Cyprinus carpio*) has been a part of southeast Asian traditions for centuries. More recently, global aquaculture production has increased steadily, with an annual growth rate of 10 percent between 1984 and 1996 (Rana and Immink 2002), compared with 3 percent for livestock meat and 1.6 percent for capture fisheries production. At the same time, many fish populations are declining because of poor management practices and overharvest. Global production of finfish and shellfish reached 132.6 million tons in 1996, 22 percent of which came from aquaculture.

Per capita seafood consumption in the United States varied from 14.6 to 15.6 pounds between 1990 and 2000 (Harvey 2002), with aquaculture contributing 7 percent to national aquatic production in 1996 (Rana and Immink 2002). With the world’s increasing population and already stressed fish populations, it is generally expected that domestic and international demand for both high and low valued species will increase. With globally decreasing yields from many traditional marine and inland capture fisheries, the opportunities for aquaculture to provide a larger proportion of seafood products will increase.

The Food and Agriculture Organization of the United Nations estimates that the United States is the world’s largest exporter of seafood products; yet, in 2000, roughly 45
percent of U.S. seafood consumption came from imports (Harvey 2002). In addition, despite the fact that per capita consumption has not grown recently, demand is expected to increase by around 40 million pounds of edible product per year from human population growth alone. The export market for aquaculture products may also expand, and with most wild fish stocks already being harvested at or above sustainable levels, a potential exists to increase the role of aquaculture in supplying fish products (Harvey 1991).

The walleye (*Stizostedion vitreum*) is a highly valued game and food fish in the north-central, and certain parts of the northeastern, United States and central Canada. In 1988, the walleye was identified as a high-priority species for commercial aquaculture development by the North Central Regional Aquaculture Center, mainly because of its popularity as a food and game fish, and the high prices typically seen in retail markets for fillets. Walleye culture activities have been extensive, raising fry and fingerlings for stocking to supplement wild populations, but relatively little is known about the culture requirements of this species to food size or market information concerning walleye food products (Kayes 1995).

Other than a few tribal fisheries in Minnesota and Wisconsin, commercial fishing for walleye in the United States has been prohibited to protect wild populations exclusively for sport anglers and Native American tribes (Kayes 1995). Nearly all walleye food products marketed in the United States are imported from Canada, where they are harvested commercially from the wild.

While past commercial walleye aquaculture in the northcentral United States has centered around fry and fingerlings, interest in the production of food-sized walleyes has increased. Food-sized walleye producers have not been able to compete with Canadian
imports of wild-caught walleye due to higher costs of production, but recent developments in rearing techniques which have reduced mortalities have increased the possibility of economically feasible walleye production.

Accurate market information is vital to any industry, especially during the initial stages of development. Information concerning the supply and demand relationships that shape the market for walleye is not available. On the supply side, the sources and the levels of availability of commercially caught walleye, as well as prices paid for walleye, are not well documented. One factor affecting the feasibility of a domestic food-sized walleye aquaculture industry is the extent to which Canadian supply influences the U.S. market. Particularly useful is information on historic Canadian commercial walleye harvest rates and the potential for increased harvests, which could result in market prices below those compatible with profitable aquaculture production (Kayes 1995).

The purpose of this thesis is to describe the supply of Canadian walleye available for export to the U.S. market and to provide information concerning the Canadian commercial walleye fishing industry. This information will help guide investment decisions of individuals, financial lenders, and grant agencies. It will also help the U.S. aquaculture industry better understand the role and ability of the Canadian commercial fishery in meeting the demand for walleye food products.

In some lakes, walleye and sauger (Stizostedion canadense) are caught together. The taste of walleye and sauger is indistinguishable, and it is understood that some sauger are likely sold as walleye; however, documentation of these sales is incomplete. This thesis will concentrate on walleye, with the understanding that the sale of sauger as walleye will not affect the conclusions.
This thesis will summarize the biological and economic factors affecting walleye populations and supply. It will characterize the commercial walleye fishing industry in the Canadian provinces of Manitoba, Ontario, Saskatchewan, Alberta, the Northwest Territories, and Quebec. It will also draw some conclusions concerning the potential for increases in the quantity of walleye supplied by the industry.
II. WALLEYE POPULATION BIOLOGY

Several biological factors contribute to a water-body’s ability to produce harvestable walleye populations. These factors include those relative to the water-body itself, to the intra-actions of the population, to interactions with other aquatic life, and to human manipulation.

Habitat

The walleye is a member of the perch family (Percidae), which has 14 species inhabiting Canada’s inland waters. It is found in lakes and rivers of Canada from Quebec to British Columbia, and from the Great Lakes north to the mouth of the Mackenzie River in the Northwest Territories (Rodger 1991). Water temperature limits the distribution of percids by its effects on metabolic processes, with an upper limit of about 88 °F. The lower limits of the temperature range may influence reproductive success rather than the survival of the adults. The northern distributional limit of walleye to about the summer air isotherm of 55 °F probably is more a reflection of temperatures required for maturation and spawning success than limitations to metabolism (Craig 1987). The southern distributional limit of walleye extends considerably south of the Canada-United States border. The larger percids found in North America include the walleye, which is the largest; the sauger; and the yellow perch (Perca flavescens) (Eddy and Underhill 1974). Walleye-sauger hybridization is known to occur (Craig 1987), and the species probably diverged in recent time.

*Stizostedion vitreum* has been represented by two subspecies, *Stizostedion vitreum vitreum* and the blue pike (*Stizostedion vitreum glaucum*). The blue pike inhabited Lake
Erie and Lake Ontario, but is now extinct (Craig 1987). In addition to competition from stocked exotic fish and selective fishing, the gene pool of the blue pike may also have become mixed with that of *Stizostedion vitreum vitreum* by hybridization and the subspecies lost (Regier et al. 1969).

Walleye are capable of surviving in a wide range of environmental conditions; but prefer large mesotrophic lakes with maximum summer temperatures around 68 to 73 °F, low light penetration, abundant food sources, and oxygen concentrations greater than 3 ppm. Eutrophic and oligotrophic lakes are less suitable for walleye habitat (Berry 1995). Walleye compete successfully with other predators because their activities are not confined to daylight hours (Craig 1987).

The environmental requirements of walleye are similar to those of yellow perch, although the walleye extends further north than the yellow perch. Walleye and yellow perch niches are closely connected, and these species probably evolved together, with the yellow perch being the chief food of walleye in many water bodies. Predation may play a part in controlling recruitment both for the predator and prey (Craig 1987).

**Reproduction**

Walleye spawn as early as late January in the southern limits of their range and as late as late June in northern Canada. Increasing water temperature is the major spawn-inducing factor (Craig 1987). Normally, spawning occurs at water temperatures between 45 and 48 °F (Rodger 1991); however, spawning can occur from 42 to 54 °F (Berry 1995). Female walleye have been known to reabsorb their eggs when the spawning season is interrupted by cold weather (Craig 1987). Walleye appear to return to the same general
vicinity to spawn each year (Craig 1987); however, natal conditioning may be unlikely since eggs and larvae are often carried substantial distances in river currents from areas of egg deposition (Olson et al. 1978). This apparent “homing” may more likely be a result of adult learned behavior strengthened by repeated migrations. Spawning takes place at night in shallow rocky areas in the flowing waters of rivers and streams and over shallow rocky bars within lakes. The eggs hatch in 12 to 18 days (Rodger 1991).

Apart from individual exceptions, the majority of walleye populations migrate less than 10 miles between spawning and feeding areas (Craig 1987). In large water bodies, mixing among different stocks during summer feeding periods may not occur.

Optimum salinities for walleye lie in the range of 4.0 to 8.0 percent. They have been found to live in waters of much higher salinity, such as saline prairie lakes of 15.0 percent salinity where they were introduced, but they are unable to reproduce in these lakes (Craig 1987).

Walleye are also affected by pH. In the Sudbury area of Ontario, the pH of many of the lakes has decreased to 5.0-5.5 due to acid rain from a nickel smeltery. In these lakes, the walleye populations have become vulnerable to these low pH levels due, in part, to the sensitivity of eggs and embryos (Craig 1987). Runoff into streams where walleye spawn may decrease the pH considerably. Eggs from female walleye living and laying eggs in an acidic environment may produce fry more tolerant to low pH than normal, but walleye populations exposed to decreased pH levels will be more sensitive.
Population Dynamics

There are many factors and processes that regulate the size of a fish population. These factors can be categorized as density-dependent or density-independent. A factor is considered density-dependent if its influence on a population varies with the density of that population (Van Den Avyle 1993). Density-dependent factors, such as food availability, predation, cannibalism, disease, parasites, and availability of spawning sites, tend to moderate extremes in population size, regulating it in the direction of the long-term average. For example, with increasing walleye population density, food available per walleye declines, leading to slower growth and poorer condition of the surviving walleye. This occurrence, in turn, can lead to increased vulnerability to predation or delayed maturation, which would reduce survival and reproduction rates. A low population density could lead to rapid growth and maturation, and relatively high survival and reproduction rates.

Density-independent factors have effects on fish populations that do not vary with population density (Van Den Avyle 1993). Water temperature, pollution, river flow, lake level, and other environmental factors can affect a population in ways that are not influenced by fish abundance. However, some of these factors, such as temperature, can impact density-dependent factors such as disease and parasitism, so there can be some interaction between density-dependent and density-independent factors.

The relative influence of density-dependent and density-independent factors on population size can vary among ecosystem types and life stages of a species. Where the environment is relatively stable, density-dependent processes tend to produce an equilibrium level about which the population varies randomly because of density-
independent environmental factors. Ecosystems with relatively unstable physical characteristics have fish populations that are regulated to a greater extent by density-independent factors (Van Den Avyle 1993).

For walleye, the period of reproduction, including spawning and egg incubation, occurs during a relatively short period in the spring, when weather conditions, water levels, turbidity, and other factors can be unstable. Climate has a considerable influence on spawning and hatching success, which can affect year-class strength. Cold weather occurring just before or during spawning can delay, interrupt, or even prevent spawning. Especially in areas near the northern limit of the walleye’s range, spawning failures frequently result in weak year-classes (Berry 1995). Consequently, reproductive success is largely determined by density-independent factors. Survival of juveniles and adults is influenced to a greater extent by density-dependent factors. Older fish are more capable of surviving extreme environmental conditions than are eggs and larvae.

Walleye populations are characterized by considerable variation in the number of young produced annually. The extent to which this variation influences the adult population depends on the survival rate of the cohort. Year-class strength at early developmental stages may not be related to either the abundance of the spawning population that produced it or the number of fish that are eventually added to the adult population (Van Den Avyle 1993). Furthermore, the quantity of eggs laid often has no correlation with the number of adults being recruited into the population. Adult stocks of very low abundance can produce large year-classes (Craig 1987). Year-class strength is determined during some specific, relatively distinct phase of the life cycle, known as the critical period. The critical period is hypothesized to occur during early larval
development, at a time when fish become reliant on exogenous food (Li and Mathias 1982; Van Den Avyle 1993). Newly hatched walleye fry are unable to swim freely because of their large yolk sacs, which causes them to drift passively downstream or in lake currents where they are transported by bottom currents while older larvae are transported by surface currents generated by wind action (Craig 1987). Initially, the larvae use the energy contained in the yolk sac to develop functional mouthparts and become capable of swimming and foraging for food. In 4 or 5 days, the yolk reserve is completely exhausted, and the fry must begin to feed on zooplankton. At this time, energy reserves are low, and the fish are vulnerable to weather extremes, temperature variations, food shortages, and predation. If abundant populations of the right kind and size of zooplankton are not available, large amounts of fry will die from starvation. Estimates of mortality of walleye populations between spawning and the time of first feeding have been as high as 99 percent (Berry 1995).

For walleye in most Canadian lakes, a critical period may also occur at a later developmental stage. During fall and winter, prey abundance can decline to the extent that food becomes limited, especially to the smallest individuals, particularly young-of-the-year, that have the least flexibility in prey selection. Consequently, more fish are lost to starvation, predation, disease, or other stresses. Survival during this period is related to the average size and health of young-of-the-year walleye following the first summer’s growth. This growth is determined to some extent by density-dependent factors such as food availability, but primarily by density-independent factors, most importantly mean summer water temperature which can affect feeding activity and growth (Larson 1999). Forney (1966) found that growth of young-of-the-year walleye was significantly correlated with
water temperature in Oneida Lake, New York. In the spring, rising water temperatures and increasing day lengths are thought to stimulate increased activity of the pituitary gland, which stimulates growth (Craig 1987). Water temperature is the most important external influence on walleye. It affects hormone production as well as all bodily processes by its direct influence on enzymes. Essentially, water temperature controls growth, feeding, reproduction, activity, survival, and distribution of walleye (Craig 1987).

As fry grow, their diet changes from zooplankton to insect larvae and small fish. Walleye retain their fish diets as adults, becoming one of the top predators in the food chain and competing with other predators, which vary across the walleye’s range and include species such as sauger, northern pike (*Esox lucius*), smallmouth bass (*Micropterus dolomieu*), and lake trout (*Salvelinus namaycush*). Juvenile and adult walleye consume a wide range of fish species depending on what is available. In many lakes, invertebrates are eaten by all size classes, especially in late spring and early summer (Colby et al. 1979, cited by Craig 1987). In the central and northern areas of the walleye’s distribution, yellow perch are the most common prey. Abundant food fish, such as minnows, perch, and lake whitefish (*Coregonus clupeaformis*), are critical for walleye growth and survival.

**Carrying Capacity**

Every body of water has a maximum ability to support fish biomass, or carrying capacity. There are many physical, chemical, and biological factors that determine the level of fish production in a given body of water. Among these factors, food abundance and production, dissolved oxygen, temperature, pH, acidity, and availability of sites for reproduction are the most important (Hayes et al. 1993).
Factors affecting carrying capacity are closely related to the density-dependent and density-independent factors described in the previous section. Carrying capacity is the highest population level that a water-body can sustain under ideal conditions. Density-dependent and density-independent factors cause the actual population to fluctuate around the carrying capacity.

Probably the most common method used to estimate the capability of a lake to produce a crop of fish is Ryder’s morphoedaphic index, or MEI, which is the ratio of total dissolved solids to mean lake depth (Ryder 1965). These two parameters effectively integrate many of the limnological characteristics that affect lake and fish productivity. Total dissolved solids provides an indication of the amount of nutrient inflow into a lake, which drives primary production, determining zooplankton and benthic invertebrate production. Production of these food organisms, in turn, determines fish production. Mean lake depth provides an indication of lake morphometry. Deeper lakes are generally cooler and tend to have higher energy losses to deep-water sediments. Deep lakes also have more water volume than shallow lakes of the same area, causing nutrient inputs to be diluted to a greater degree (Hayes et al. 1993). Generally, shallow lakes are more productive than deep lakes, and lakes with high levels of dissolved solids are more productive than those with low levels. These parameters are naturally occurring and cannot be manipulated by man in order to increase carrying capacity.

However, when lakes are compared globally or on a continent-wide basis, production is more closely linked to latitude and radiant energy inputs (Brylinsky and Mann 1973). In North America, lakes at higher latitudes will generally be less productive than lakes at lower latitudes. For example, walleye in northern Alberta or the Northwest
Territories will have slower growth rates, higher age of maturity, more variable reproductive success, and lower abundance than those in more eastern and southern locations in Canada and the United States (Berry 1995). Maturity of females ranges from 2 years in the southern United States to 10 years in the Northwest Territories. Longevity is also related to latitude and can range from 3 to 19 years. Walleye in the northern limits of their distribution have longer life expectancies than those living further south (Craig 1987).

While nutrients and primary production play key roles in the production of fish biomass at each trophic level “from the bottom up,” biomass can also be influenced “from the top down.” Fish predation can determine the structure and abundance of prey items (Van Den Avyle 1993). By decreasing the abundance of planktivorous forage fish, zooplankton abundance and size structure are affected. Changes in the zooplankton community alter algal and nutrient dynamics. Consequently, fish predation has direct effects on prey which, in turn, affects other biological components of lake ecosystems. This relationship has been demonstrated by correlation between fish mean size and zooplankton mean size, fish biomass and zooplankton biomass, and fish biomass and phytoplankton biomass (McQueen et al. 1986). For example, introduced alewives (Alosa pseudoharengus) were shown to alter the structure of zooplankton communities, shifting species distribution from large to small species (Brooks and Dodson 1965, cited by Hayes et al. 1993).

In summary, both “top down” and “bottom up” factors are occurring simultaneously. Predation controls the fish community structure, and maximum production at each trophic level is limited by competition and availability of nutrients (Hayes et al. 1993).
Exploitation

Similar to every body of water having a maximum carrying capacity, every population of fish has a maximum level of harvest that it can sustain, termed maximum sustainable yield, or MSY. MSY theoretically occurs at a stock size equal to one-half of the maximum biomass (Figure 1) that the habitat will support (Van Den Avyle 1993). This point also represents the population size with the maximum natural growth rate (Howe 1979). Because of the risk of overharvest due to year-to-year population fluctuations from density-dependent and independent variables, target harvest levels are generally set at or below MSY.

Partitioning the potential fish production by species is often done using data from a series of lakes that have withstood moderate to heavy fishing pressure over time. The percentage of the total yield contributed by each species from these stable fisheries is used as a guideline to divide the estimated potential yield into target harvests. The allocation of
Figure 1. Maximum sustainable yield (Van Den Avyle 1993; Howe 1979).

the catch among species may vary from lake to lake, depending on the species and the type of fishery present (Minnesota Department of Natural Resources and Ontario Ministry of Natural Resources, Northern Development and Mines, and Tourism and Recreation 1992).

Unexploited stocks are characterized by a high proportion of old fish, slow individual growth rates, and low rates of total annual mortality (Goedde and Coble 1981). The presence of old fish in poor condition is often indicative of little or no exploitation. Unexploited populations recently opened to fishing are typified by a shift toward smaller and younger fish, a decline in mean age, and an increase in total mortality. For stocks
regulated by density-dependent processes, it is also typical for individual growth rates of surviving fish to increase after exploitation due to reduced intraspecific competition (Van Den Avyle 1993).

In an unexploited population, on average, the number of fish added each year equals the number dying. If the stock is subjected to a fixed level of fishing mortality annually, the population is expected to reach a new equilibrium abundance at which the number of recruits produced annually exceeds the number of adults required to produce them. This surplus production is available for exploitation. Because of density-dependent regulation, the greatest harvestable “surplus” will occur at some level of stock abundance less than the pre-exploitation level because there is no surplus production when recruitment exactly equals the stock size required for replacement. However, if harvests are further increased, the reproductive potential of the population may be reduced to an extent that the adult population declines substantially. The effects of exploitation on the abundance of mature fish in a population are determined by the extent to which replacement by reproduction is altered (Van Den Avyle 1993).

Stocking

The prairie provinces of Canada produce more than 100 million fry annually to enhance sport and commercial fisheries (Babaluk et al. 1992). While there are circumstances where the stocking of fry or fingerlings to supplement an existing population may be beneficial, political or social issues often override the biological ones resulting in an overdependence on stocking. Increasingly, resource managers will place additional emphasis on factors such as the cost and sustainability of stocking efforts, the
management needs of individual populations, and the genetic integrity of those populations.

There are several reasons why it is unlikely that stocking could increase walleye stock size beyond the carrying capacity of a water-body or to previous levels in areas where harvest rates in excess of system productivity result in low abundance. These reasons include the possibility that the genetic integrity of native walleye stocks could be compromised by introductions of non-native stocks. Billington et al. (1992) found that, out of 68 walleye populations sampled from across the walleye’s native range, 34 genetic variations were found. Mitochondrial DNA analysis showed a general pattern of regional geographic variation upon which local variation is superimposed. Three variations were most common, containing 89 percent of the fish sampled. Generally, of these three variations, one was distributed in the eastern Great Lakes region, another in the center of the range, and a third in the west and in James Bay. The remaining variations were rare and often locally distributed, representing separate and unique walleye strains in some instances. Uthe and Ryder (1970) also found three genetic patterns in walleye from lakes in central Canada. The distribution of these patterns was thought to be related to glacial isolation: one Atlantic and one Mississippi with a later mixing which may have occurred in the Great Lakes where all three forms occur.

Billington et al. (1992) further suggests that transfers of fish between drainage basins should be discouraged, especially where different genetic variations are restricted to a particular basin. These variations in mitochondrial DNA may represent local adaptations, which could be destroyed by the introduction of different strains, possibly resulting in the loss of the resident population. Although little information is available
addressing this potential problem with walleye, studies of largemouth bass (*Microperus salmoides*) have shown that the hybridization of fish from different genetic stocks results in reduced fitness (Philipp 1991). On the other hand, if stocks of fish are transferred to different parts of their range where they are not adapted to the local conditions, they may fail to become established. Although there are few documented cases involving the failure of stocking walleyes from different parts of the country, the Maryland Department of Natural Resources had more success in establishing walleye populations with fish from Pennsylvania than with fish from Minnesota (Billington et al. 1992). Walleye populations have been successfully established by stocking fish that originated in far away water bodies, but this success does not rule out the possibility of negative genetic consequences resulting from the mixing of different stocks.

Management agencies may also limit the amount of walleyes stocked because of the cost and effectiveness of stocking programs. For example, from 1990 to 1995, Minnesota stocked more walleye fry and fingerlings than any other state or province (Aubineau 1996). Now, the Minnesota Department of Natural Resources is attempting to reduce its dependence on stocking, especially supplemental stocking to maintain walleye populations, and put more emphasis on habitat protection and water quality. The Department of Natural Resources points to estimates that, of the 3.5 million walleyes caught each year in Minnesota waters, only 140,000, or about 4 percent, come from hatcheries. For every million walleye fry stocked, only about 1,000 live long enough to become adults, and 300 are caught by anglers. About 99.9 percent of stocked fry are lost to predation or disease. Stocked fry or fingerlings can also compete with wild walleyes
and other species for forage, upsetting the natural balance of predator and prey (Dickson 1993).

The success of a stocking program to enhance a Manitoba commercial fishery was evaluated in Dauphin Lake. Babaluk et al. (1992) estimated the survival of stocked walleye fry to age 3 at 0.04 percent. They also predicted that, over the 10 years they would remain vulnerable to the fishery, the stocked fish would contribute 926 pounds to an expected harvest of 286,650 pounds (and this prediction assumes no competition between stocked fish and native fish). When the value of the commercially caught stocked walleye was compared to the costs associated with producing them, a cost:benefit ratio of 2.59:1 was calculated. In other words, the cost for each dollar of benefit to the commercial fishery would be approximately $2.59. At this cost, it would be hard to justify the expansion of stocking programs in commercially fished lakes, and their continuance at current levels may also be in jeopardy.

Genetic concerns may likely have the effect of reducing or limiting the stocking of walleye due to the limited availability of particular genetic strains and the limited genetic information available for individual walleye populations. Additional information becoming available on the costs and effectiveness of many stocking programs may also have the same effect. Likely reductions in stocking levels and the general ineffectiveness of supplemental stocking for enhancement of a commercial fishery, combined with the biological factors that regulate walleye populations, suggest that stocking will have no appreciable effect on future overall harvest levels.
Disease, Parasitism, and Exotic Species

Walleye are host to a large number of parasites, but many of these parasites, as far as is known, do not cause harm to the fish. Outbreaks of diseases occur when there is an imbalance between the fish host, the pathogen or disease agent, and the environment; and are strongly affected by environmental conditions. Bacterial infections appear to be less important than viral infections in fish. There are only a few recorded cases where bacteria have been identified as being the primary cause of a disease outbreak in percids (Bauer 1962, cited by Craig 1987).

Temperature is probably the most important abiotic factor controlling the population dynamics of parasites and the outbreak of disease. Light, oxygen concentration, pH, salinity, and possibly water current and water chemistry have a lesser influence. Other living organisms in the environment have a major influence on the abundance of fish parasites. Parasite transmission is influenced by the diet and rate of food intake of the fish host. In many cases, the density of the fish host population controls the abundance of the parasite. A large host population increases the chance of success at the invasion stage of the parasite. When the fish is living at the extreme of its range and densities are low, the number of species and density of parasites is minimal compared with the host in its normal range (Bauer 1962, cited by Craig 1987). Outbreaks of disease often occur when fish populations congregate together while spawning which increases the chances of infection. Fish living near an optimum temperature will have better responses to parasite invasion and disease than those living in colder or warmer areas.
Long-term climatic and biotic changes in the environment can lead to alterations in the parasitic fauna. Parasites have been known to increase or decrease in prevalence over time.

Over time, walleye have evolved with and lived with parasites and disease. Absent a major climatic or environmental change, native parasites and disease are unlikely to have any inordinate effects on walleye populations. Additionally, any potential effects would cause reductions rather than increases in population size. While it is a risk worth noting, it is unlikely anything could be done preemptively to prevent it.

Introduced or exotic species are organisms that have moved beyond their natural geographical range of habitat. Exotic species have the potential to cause far-reaching economic and biological impacts. Establishment of introduced exotic species typically results in changes to the receiving ecosystem. In most cases, these effects are detrimental, displacing native species and altering trophic level structure (MIT 2002). Exotic species often prey on parts of an already established food web; compete with native species for food, space, or other resources; and can threaten or eliminate native species. Relatively little information exists concerning the effects of exotic species on walleye populations.

The most relevant examples of exotic aquatic species invasions and their impacts can be found in the Great Lakes. The Great Lakes have been subject to invasion by exotic species since settlement by Europeans, with the impact of some of these species being enormous. Since the early 1800s, at least 139 new organisms have been introduced into the Great Lakes (Mills et al. 1993), with the majority of these species being aquatic plants (42 percent), fish (18 percent), and algae (17 percent). Mollusks, crustaceans, flatworms, disease pathogens, and other organisms combined represent 22 percent of the exotic
species in the Great Lakes. Exotic species have entered the Great Lakes basin through a variety of means, including unintentional releases, introductions related to ships, deliberate releases, entry through or along canals, and movement along railroads and highways.

Of the exotic species in the Great Lakes Basin, Mills et al. (1993) found that about 10 percent have had demonstrably substantial impacts, with about 50 percent of exotic fish having important ecological and economic effects. Probably the best known of these exotics is the sea lamprey (*Petromyzon marinus*), which has been associated with the decline of several fish species and has caused millions of dollars in damage to the sport and commercial fisheries of the Great Lakes. Sea lampreys were discovered in all of the Great Lakes by 1946, entering the lakes through the Erie and Welland Canals. The establishment of the sea lamprey, combined with water pollution and overfishing, resulted in the decline of native walleye populations in the Great Lakes (Lawrie 1970).

The zebra mussel (*Dreissena polymorpha*) was first discovered in North America in Lake St. Clair in 1988, arriving in the ballast water of transoceanic ships originating in Europe. The mussel often occurs in very large numbers and can exert large and far-reaching impacts on freshwater ecosystems through biofouling and filter-feeding (Mills et al. 1993). These impacts, in turn, can affect survival of young-of-the-year walleye and walleye prey species.

Fitzsimons et al. (1995) found that almost total coverage of spawning beds by zebra mussels had no apparent effect on walleye egg deposition, egg viability, and interstitial dissolved oxygen; and thus no adverse impacts of zebra mussel on walleye reproduction in western Lake Erie. However, Rutherford et al. (1999) predicted zebra mussels to result in the elimination of walleye high-recruitment years and a 30 percent reduction in adult
 walleye abundance in Oneida Lake, New York, with model predictions of impacts to percids generally consistent with observed changes in the lake since the arrival of zebra mussels.

Ruffe (*Gymnocephalus cernuus*) is another example of a Great Lakes introduction which has impacted indigenous fishery resources. Ruffe arrived in Lake Superior in the mid-1980s, transported in the ballast water of ships originating from European ports. Ruffe are now well established in the upper Great Lakes, with an estimated population of six million fish (Newman 1999), and will likely spread to the lower Great Lakes and inland waters. Because the ruffe grows very fast, has a high reproductive capacity, and adapts to a wide variety of environments, it is considered a serious threat to commercial and sport fishing. Explosive growth of the ruffe population means less food and space in the ecosystem for other fish with similar diets and feeding habits. Walleye, perch, and a number of small forage fish species are seriously threatened by continued expansion of the ruffe’s range. In the St. Louis River and Duluth/Superior harbor area of Lake Superior, ruffe numbers have increased dramatically while other species such as emerald shiner (*Notropis atherinoides*), yellow perch, and troutperch (*Percopsis omiscomaycus*) have declined (McLean et al. 1992).

Hypothesized effects of ruffe on native percids include depressed growth, abundance, or shift in habitat of yellow perch; and decreased growth of walleye. Brenton et al. (1997) concluded that ruffe will result in moderate to severe declines in native percid abundance, dependent upon walleye dietary preference for ruffe.

The round goby (*Neogobius melanostomus*) was discovered in the St. Clair River, the channel connecting Lake Huron and Lake St. Clair, in 1990. The species comes from
the same area of the world as the zebra mussel and presumably arrived in the same way, transported in ballast water. Gobies are capable of rapid population growth and had established at least eight populations in the Great Lakes by 1995 (Jude 1995). Gobies can compete successfully with native benthic fish and prey on the eggs of native fish. Gobies also eat large quantities of zebra mussels, which can cause a direct transfer of contaminants from gobies to sport fish. Zebra mussels can take up high concentrations of pollutants, which are transferred to the receiving fish if eaten. Predators, including walleye, have now learned to eat gobies, increasing the possibility of transferring relatively high concentrations of pollutants to walleyes (Brush 2002).

White perch (*Morone americana*) is another well known exotic in the Great Lakes with potential impacts on walleye populations. White perch invaded the Great Lakes through the Erie and Welland Canals in the early 1950s and had spread to all of the Great Lakes by 1988 (Sea Grant Minnesota 2002). White perch prey on the eggs of walleye, white bass (*Morone chrysops*), and possibly other species. At times, depending on which fish is spawning, either walleye or white bass eggs make up 100 percent of the diet. The collapse of the Bay of Quinte walleye fishery coincided with the increase in the white perch population and may have been a result of egg predation and lack of recruitment (Schaeffer and Margraf 1987).

Many other exotic species exist in the Great Lakes area and could impact walleye populations in the Great Lakes or other drainage systems in which they become established; however, there is considerable uncertainty regarding most species introductions and their impacts on native species and ecosystems. Furthermore, the presence of an invasive species may not be detected until it is well established; it may be
difficult to remove; and its eradication may not be feasible given current technology and resources.

In summary, this chapter has shown that walleye population size and commercial harvest levels are limited. Environmental and biological factors act as a constraint, regulating population size and growth rates. Stocking and other attempts to circumvent these constraints are unsuccessful in increasing commercial harvest levels.
III. ECONOMICS OF THE COMMERCIAL WALLEYE FISHERY

In addition to the environmental and biological influences on walleye population size, economics also influence commercial harvest levels. Assuming some quantity of the total walleye population is available for harvest, additional factors including resource ownership, costs of production, available technology, regulations, and prices received determine the actual quantity of walleye supplied.

Common Property

Renewable resources are those for which the stock can be continually replenished. Some renewable resources, living populations such as fish, are also exhaustible if not managed effectively. The growth or decline of these populations depends, to some extent, on the size of the population. If, through human activities, the population is drawn down below a critical size, the species can become extinct. The size of the resource stock (population) is determined jointly by biological considerations and by the actions taken by society. The size of the population, in turn, determines the availability of the resource for the future (Tietenberg 1996).

With the existence of exclusive and well-defined property rights, markets tend to function well, allocating resources and distributing commodities in an efficient manner, without the need for external direction (Randall 1987).

Efficiency is not achieved because consumers and producers are seeking efficiency. They aren’t! In a system with well-defined property rights and competitive markets in which to sell those rights producers try to maximize their surplus and consumers try to maximize their surplus. The price system, then, induces those self-interested parties to make choices which are efficient from the point of view of
society as a whole. It channels the energy motivated by self interest into socially productive paths. (Tietenberg 1996, P. 43)

In other words, in an efficient market, the individual fisherman would treat the lake, or a portion of it, as his property and would harvest walleyes at a rate that would maximize his profits. However, the fishing industry is characterized by several market imperfections, namely common property resource issues.

The circumstances in which the outcomes of free markets are inefficient typically involve poorly defined property rights (Randall 1987). Common property resources are those which are owned in common rather than individually. When private property rights do not exist in a fishery and there is no regulation, fishermen do not take a very long-term view. They are likely to assume a very short time horizon, seeking to maximize their profits while they can (Howe 1979).

Howe (1979) identified two conditions that arise from common property resources: unlimited access to the resource and the creation of externalities among users. If free access can be denied, then the entity denying access can appropriately manage the resource. If there are no adverse interactions among users, there is no reason to deny access. Fisheries, which are a prime example of common property problems, combine the problem of excessive entry of resources seeking to capture excess profits with two types of congestion; the physical congestion in the fishing area and the stock externality. The first type is self explanatory and is analogous to highway congestion. Each vessel knows it will add to the congestion but will have to bear only a small part of the costs it creates. The stock externality results from the fact that harvesting costs increase as the stock of fish is

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reduced. The time and effort required to capture a certain poundage of fish increase as the stock becomes smaller and more dispersed.

All common property resource problems involve an overuse or excessive exploitation of the resource which brings about some type of negative externality, that is, a cost neither borne nor taken into account by the decision maker (Howe 1979). In this case, what is good or desirable for the individual may not be good for society.

Tietenberg (1996) used the history of the American bison to illustrate the problems caused by open access resources. An analogy can be drawn with the history of walleye and other fish in North America. In the early history of the United States and Canada, fish were plentiful, and unrestricted access was not a problem. Native Americans and frontiersmen could catch what they needed without much of an effect on the fishery. The aggressiveness of any one fisherman did not affect the time and effort expended by other fishermen. In the absence of scarcity, efficiency was not threatened by open access. As the years passed, however, the demand for fish increased, and scarcity became a factor. As the number of fishermen increased, eventually every unit of fishing activity increased the amount of time and effort required to produce a given yield of fish. The greater the amount of fishing effort expended, the smaller the resulting population size. Smaller populations support smaller harvests per unit of effort expended. One of the losses from further exploitation which could be avoided by exclusive owners, the opportunity cost of overexploitation, is not part of the decision-making process of open access fishermen.

Unlimited access destroys the incentive to conserve (Tietenberg 1996). A fisherman who can prevent others from fishing a particular stock has an incentive to keep that stock at an efficient level. This restraint results in lower costs in the form of less time
and effort expended to catch a given yield of fish. Conversely, a fisherman exploiting an open access resource would not have any incentive to conserve because other fishermen would, to some extent, capture the benefits derived from restraint. Consequently, unrestricted access to resources promotes an inefficient social allocation.

Unlimited access can result in overexploitation of a resource and underinvestment in the management and conservation of that resource. The solution to this problem could involve establishment and enforcement of exclusive property rights. These rights could be in the form of regulations that specify who shall have access to the resource and under what conditions. Regulations including limits on the number of fishermen and harvest quotas have been introduced in the Canadian walleye fishery, providing some limits to access.

Furthermore, the social discount rate is not equal to the private discount rate. Individuals may want all of the benefits from the use of a resource to accrue in their lifetime, while society’s goal would more likely be to utilize the resource in a more sustainable manner, spreading out the benefits to as many individuals and over as many generations as possible (Randall 1987). If resources are to be allocated efficiently, individuals must use the same rate to discount future net benefit as is appropriate for society at large. If individuals were to use a higher rate, they would extract and sell resources faster than would be efficient. On the other hand, if individuals were to use a lower than appropriate discount rate, they would be excessively conservative (Tietenberg 1996). With wild walleye populations, many of the commercial fishermen, resort owners, and anglers would have individual gain as a higher priority than long-term sustainability of
the resource. When private rates exceed social rates, production is higher than is desirable to maximize the net benefits to society (Tietenberg 1996).

**Efficient Exploitation**

In an unexploited fishery, abundance is inversely related to age because of natural mortality. As age increases, average size also increases, but for each given year-class, some age is reached at which natural mortality more than offsets the increases in individual size. The year-class achieves its maximum biomass at this point (Howe 1979).

When exploitation is introduced to a previously unexploited fishery, fishing mortality is added to the effects of natural mortality, and carrying capacity is no longer attained (Strand 1988). This increase in mortality affects the density-dependent factors that regulate stock size and results in an increase in growth rates. As the amount of fishing effort increases, a point is eventually reached where further effort reduces the sustainable harvest and revenue. As previously discussed, this point corresponds with the one stock size that will produce the maximum natural growth rate (Figure 1), which represents the greatest rate of harvest that could be sustained indefinitely, or MSY (Howe 1979).

There are two population sizes at which the unfished population reaches zero growth, that stock size at carrying capacity and that of a small dispersed population with a low reproductive capacity. Exploitation of the stock at carrying capacity would stimulate increased growth rates while exploitation of the small dispersed population would cause extinction. Up to the point of MSY, there are two stock sizes that correspond to each rate of growth, depending on the rate of exploitation.
Assuming constant efficiency in effort, there is a correspondence between the level of effort and the resulting stock size. When zero effort is applied, and thus no exploitation, stock size is determined by the carrying capacity. Extreme levels of effort will harvest more than is being grown, and a non-exploitable stock would result. High levels of effort can result in a depressed stock but still produce sustained yields. Yields are sustainable if the net growth in the stock’s biomass is equal to, or greater than, the harvest.

As effort increases from zero towards MSY, its marginal product falls because the increase in effort has lowered the stock size. The reason it is possible to obtain the same level of harvest with different stock sizes is because the increased effort has led to a smaller stock. Larger stocks of fish are more abundant and easier to harvest while smaller, less abundant stocks require more effort to obtain the same level of harvest. As effort increases beyond MSY, marginal productivity becomes negative. Although short-term production may be increased, stock size will be reduced so that the long-run sustained yield will be lower than MSY. Trying to expand production beyond MSY causes production costs to rise but yields to fall because of stock depletion (Howe 1979).

Efficiency is associated with maximizing the net benefit from the use of the resource. In order to define an efficient resource allocation, the costs of harvesting must be included as well as the benefits. The value of the fishery to society, as well as the profits gained by the fisherman, will be maximized where the difference between the total revenue received from sale of the catch and the total cost of fishing is greatest (Howe 1979). As long as there is a cost associated with increasing effort, it does not pay to increase the harvest rate to MSY (Figure 2). The efficient level of effort (E1) is less than that necessary to harvest the MSY (E2). The MSY would be efficient only if the marginal
cost of additional effort were zero. The level of effort required to produce the optimum sustainable yield leads to a larger fish population than the MSY level of effort and, if maintained perpetually, would produce the largest annual net benefit to society (Tietenberg 1996).

Figure 2. The efficient level of fishing effort (Randall 1987).
As discussed earlier, free access resources create two kinds of externalities (Tietenberg 1996), the first of which being borne by the current generation. It involves the overcommitment of resources to fishing. If entry is not controlled, more effort will be attracted to the fishery because of the existence of economic profit. Thus, inputs will continue to expand toward the point where the net benefits (and net profits) of the industry disappear (E₁). The other type of externality, being borne by future generations, occurs because overfishing reduces the stock which, in turn, lowers future profits from fishing. Therefore, if a fishery is a common property resource, that is, if there is free access, then there will be a tendency towards overfishing and excessive reduction of the stock (Howe 1979).

**Fishery Management**

In the case of goods and resources for which exclusion is infeasible, such as fish in the ocean and in lakes and streams too large for individual ownership, achieving efficiency through the establishment of exclusive property rights may not be practical. Often, however, other options are available. Rules that specify who shall have access to the good or resource, and under what conditions, may be established and enforced. These rules of access do not have all of the efficient characteristics of exclusive property rights, but they may provide a system of workable rights when exclusive property rights are infeasible (Randall 1987).

Howe (1979) identified three main classes of management techniques that have typically been used in an attempt to establish rules of access: (1) regulations relating directly to the fishery itself, such as closed seasons, closed areas, and limits on total catch;
(2) regulations relating to the kind of effort or fishing technology, such as constraints on net mesh and fishing techniques; and (3) regulations concerning the amount of fishing effort, such as limiting the licensing of fishing vessels or the imposition of taxes and fees to affect the incentives for investment in the industry. Efficient management of fisheries requires that the catch must be limited to the optimal level and that it should be harvested in the most inexpensive manner possible.

A limit on the fishing season or the areas open to fishing would likely have an undesirable effect on the problem of overinvestment in fishing inputs. Fishermen would attempt to sustain the previous catch within the shorter season and limited area by employing more efficient equipment. If the regulations are effective in reducing the catch, the net result will be to produce a lower catch at a higher cost, with more equipment now standing idle a larger part of the year. Shortening the season not only raises the direct cost per unit catch, but it also places pressure on prices and processing, storage, and distribution facilities. It also tends to put pressure on other fish stocks as the unoccupied boats seek other catches (Howe 1979).

Restricting other kinds of fishing inputs by limiting the size of fishing boats, or restricting or prohibiting the use of particularly effective devices for locating or capturing fish would be relatively ineffective in conserving the fishery (Randall 1987), as fishermen would soon substitute other, often more expensive, inputs for the restricted kinds. This process of input substitution would result in an inefficient investment of resources in fishing. The same annual catch could be taken by many fewer fishermen and boats if modern technology were permitted. Its prohibition is used as a tool to restrict the harvest by driving total costs up so that effort will be reduced and catches will fall. These cost
increases are real, again resulting in a lower catch at a higher cost, driving fishermen’s incomes toward poverty levels (Howe 1979).

The objective of licensing programs is to set the number of licenses so that those fishermen allowed to fish will harvest the optimal catch. This approach has its problems as well. If fishermen are licensed and if the restriction on the number of fishermen is successful in increasing the profitability of the fishery, then the participants will have an incentive to increase their fishing power by manipulating licensed inputs, such as size of boat, fish-finding equipment, etc. Where such substitutions are possible, limited license programs are very similar in design and effect to limitations on gear (Anderson 1977).

If the problem is overexploitation of a resource, the preferred solution will involve the direct restriction of the rate of exploitation, rather than the restriction of various inputs used in the process of exploitation. When such restrictive rules are necessary, they will be efficient only if the rights created by those rules are transferable. Even the more efficient common property rules of access will not result in the attainment of Pareto-efficiency, but when exclusion is infeasible, intelligently devised rules of access may result in workable second-best solutions that sustain productivity in the long run, discourage waste of inputs, and allow individuals in the industry to earn reasonable and secure incomes (Randall 1987).

One way of achieving the desired limit on total catch while retaining open access conditions would be to place a tax on the fish caught. By raising total costs, industry profits would be exhausted earlier, and only individuals using the most efficient techniques would be able to cover their costs. Raising costs through a tax is greatly preferred to the imposition of costly, obsolete technologies, for the tax is merely a transfer to the public
sector, not a real resource cost (Howe 1979). The problem with the tax approach is that it is very unpopular with fishermen and it can be difficult to implement because changes in prices and/or costs will necessitate a change in the tax rate in order to keep the industry at the desired level (Anderson 1977).

A policy making efficient management of the fishery possible by restricting catches but still allowing fishermen to keep the profits is a properly designed quota on the amount of fish that can be taken from the fishery. According to Tietenberg (1996, P. 287), an efficient quota system has several identifiable characteristics which include

1. The quotas entitle the holder to catch a specified weight of a specified type of fish;
2. The total amount of fish authorized by the quotas held by all fishermen should be equal to the efficient catch for the entire fishery; and
3. The quotas should be freely transferable among fishermen.

After the desired total catch is determined, it could be divided into shares, which would be assigned to individual fishermen. Since each can catch only a specified amount, it would be to the individual fisherman's advantage to take the allowable catch as cheaply as possible. With transferability, those fishermen who are more efficient could purchase the right to harvest from others. Purchase by more efficient fishermen would further decrease the real cost of harvesting the allotted catch while, at the same time, benefiting both the buyer and the seller of the quotas (Anderson 1977). Transferable quotas also encourage technological progress. Adopters of new cost-reducing technologies can make more money on their existing quotas and make it possible to purchase new quotas from others who have not adopted the technology.
Generally, the more direct the relationship is between the policy instrument and its target, the better will be the prospects for an efficient policy (Randall 1987). Net mesh size or the length of the fishing season are only somewhat related to the harvest and are rather poor policy instruments. The amount of fish sold is much more closely related to harvest and is thus a better policy instrument. The characteristics of exclusive property rights tend to promote efficiency. Thus, well-specified, exclusive, and transferable marketing quotas are policy instruments with desirable efficiency characteristics.

**Economics of Walleye Supply**

There is a basic relationship between price and the amount supplied, and this relationship is called the “law of supply.”

The law of supply states that, generally, a larger quantity will be offered for sale when price increases (other things equal). Similarly, a smaller quantity will be offered for sale when price decreases (other things equal). (Fische and Miller 1995, P. 40)

In other words, the law of supply states that there is a positive relationship between the quantity supplied and price (Figure 3). Since there is a fixed number of lakes supporting harvestable walleye populations and these populations can withstand only a limited harvest level, there is a maximum annual level of production. However, up to this point, price can influence quantity supplied. At lower prices, it does not pay for fishermen to fish small and/or remote lakes, which would have higher per unit production costs due to higher transportation costs, opportunity costs, and capital requirements.
The quantity supplied of one good may respond differently to changes in price than the quantity supplied of other goods. How responsive quantity supplied is to a change in price is the price elasticity of supply. The price elasticity of supply is the percentage change in quantity supplied divided by the percentage change in price. The price elasticity of supply is always a positive number. When price increases, quantity supplied increases (Fishe and Miller 1995).

Figure 3. Supply (Fishe and Miller 1995).
There is a distinction between quantity supplied and supply. Quantity supplied is the amount supplied at any given price. A change in the price of a product causes a movement along the supply curve and changes the quantity supplied. When supply changes, the supply curve shifts and, more or less, will be produced at a given price (Fishe and Miller 1995).

There are several factors that can cause shifts in the supply curve. Fishe and Miller (1995) identified changes in any of the following variables as the most important:

1. Prices of inputs
2. Prices of related outputs
3. Technology
4. Taxes and subsidies
5. Expectations

If prices of inputs rise, increased costs of production can affect supply, causing the curve to shift to the left. Likewise, decreased costs of production can cause the supply curve to shift to the right (Fishe and Miller 1995). Inputs required for commercial fishermen include transportation requirements, such as boats, motors, snowmobiles, float planes, gas, oil, maintenance, and refrigeration costs; other capital requirements, such as nets, anchors, floats, fish boxes, and ice makers; and labor costs.

Related outputs can be either substitutes or complements in production. If the price of a particular good has a negative effect on the quantity of another good, the goods are said to be substitutes in production. Complements in production are goods that are produced together, and changes in the price of one good have a positive impact on the production of the other good or goods (Fishe and Miller 1995). Fishermen in many instances may target walleye because of higher prices, but they rely on the income generated from all species of fish caught, not just walleye. Changes in the prices and/or
availability of other species, such as whitefish, can impact the incomes of commercial fishermen and influence their decisions on whether to fish and how much effort to apply.

Supply curves are drawn assuming a given state of technology, but over time, the technology available may change. If the change involves technology that is less costly or more efficient, the supply curve will shift to the right (Fishe and Miller 1995). In other words, if a better production technique becomes available, a larger quantity may be produced at each price. There have been numerous technological advances that have affected the commercial fishing industry over the last century. Aluminum and fiberglass boats powered by gas motors have taken the place of wooden boats powered by sail or oar; much improved refrigeration, transportation, and storage techniques have been developed; and longer lasting monofilament gill nets have taken the place of nylon and cotton nets. Most technological advances came during the first half of the century. Over the past 20 to 30 years, new technologies have not resulted in increased catches, suggesting that technology will not have a substantial impact on the supply curve.

Taxes are an additional cost of production and, therefore, shift supply to the left. A subsidy does the opposite and shifts the supply curve to the right (Fishe and Miller 1995). Licensing costs could be considered a tax, but since commercial fishing licenses are relatively easy to obtain and are of minimal cost, it is unlikely that they affect supply. There are subsidies available to many commercial fishermen. These subsidies generally exist to defray transportation costs but differ from province to province. While they generally do not cover walleye, they do cover other species that may be complements in production to walleye and may have an effect on supply.
Expectations of the future price of a product can affect producers’ willingness to supply (Fishe and Miller 1995). Relatively accurate information is available to Canadian commercial fishermen concerning fish prices. Those fishermen under the jurisdiction of the Freshwater Fish Marketing Corporation (FFMC) get a guaranteed price for all fish sold in the coming year. Other fishermen can use past prices and the FFMC’s guaranteed price as indicators of future prices.

In summary, the Canadian commercial walleye fishery is a common property, open access resource, but various regulations within the industry exist to provide rules of access and, in effect, workable property rights. In order for the industry to be operating at an efficient level, it must by harvesting the economically optimum sustainable yield rather than the biological maximum sustainable yield of fish. Additional regulations within the industry may contribute to inefficiency but are unlikely to have an effect on harvests. Various other factors can affect the supply of walleye but only on that area of the supply curve below MSY.
IV. CHARACTERIZATION OF THE FISHERY

From 1955 to 1999, a total of 581,337,225 pounds of walleye were harvested from Canadian freshwater lakes, with an average of 13,519,470 pounds (Figure 4). Harvests ranged from a high of 20,925,450 pounds in 1956 to a low of 6,304,095 in 1971 (DFO 2002).

Figure 4. Canadian walleye harvest, 1955-1999 (DFO 2002).

From 1980 through 1999, the provinces of Manitoba and Ontario accounted for 90.6 percent of the harvest, followed by Saskatchewan at 7.8 percent and Alberta, the Northwest Territories, and Quebec at a combined 1.6 percent (Figure 5).
All fish harvested commercially in western Canada and destined for export or inter-provincial trade must be sold to the FFMC. The FFMC was established in 1969 under the authority of the Freshwater Fish Marketing Act. The act requires the FFMC to purchase all legally caught fish offered for sale by licensed fishermen in the provinces of Manitoba, Saskatchewan, Alberta, the Northwest Territories, and Northwestern Ontario (Government of Canada 2002). Generally, initial prices are set for each species by estimating its market value, subtracting its projected processing and operating costs, and withholding a contingency amount. At the end of the year, the FFMC determines final payments to fishermen from the year’s pooled receipts (FFMC 2001). Great Lakes fishermen have
better access to American markets as well as a larger domestic market, and do not fall under the jurisdiction of the FFMC.

Generally, freshwater fishery regulations are set at the provincial level. However, federal law does provide for Native American (referred to as Aboriginals in Canada) rights concerning fish resources. In the Sparrow decision of 1990, the Supreme Court of Canada defined Native American peoples’ right to fish for food, social, and ceremonial purposes, with this right taking priority over all other uses of the fishery except conservation (DFO 2002). The decision also requires consultation with Native American groups when their fishing rights may be affected. Individual provinces set fish resource allocation priorities and management policies with this federal mandate in mind.

**Manitoba**

Approximately 40,000 square miles, or 16 percent, of Manitoba’s surface area is water (Statistics Canada, cited by Green and Derksen 1984). About one-third of this water area is accounted for by three major lakes: Winnipeg, Winnipegosis, and Manitoba. The remaining water area is primarily on the Precambrian Shield area in the northern and eastern parts of the province.

Manitoba’s fisheries are managed by the Manitoba Department of Natural Resources with the stated goal of long-term sustainability on an ecosystem basis. The commercial fishery goal of the province is to “foster and promote improved utilization of commercial fisheries resources, facilitate optimum fish harvests and participation levels to maximize sustained returns to commercial fishermen and commercial sport fishing operators” (Manitoba Natural Resources, Fisheries 1994, P. 5).
Commercial Production

Currently, Manitoba’s commercial fishery is the second largest in Canada, outranked only by the Great Lakes fishery in Ontario. The early growth of the commercial fishery in Manitoba was similar to that of other western provinces. Growth in the fishery was linked with settlement, and the development and growth of transportation facilities. The first successful commercial fishery began with a fishery operating from one sailboat on Lake Winnipeg in 1882 (Green and Derksen 1984). Large-scale commercial fishing started later in the 1880s after construction of the Canadian Pacific Railway and the arrival of Icelandic immigrants on the western shore of Lake Winnipeg (Gislason et al. 1982, cited by Craig 1987).

As fishing effort increased, total landings of all species rose from 127,000 pounds in 1883 to 3.9 million pounds in 1893. The construction of a railroad to Hudson Bay and growth of other modes of transportation were important in opening up commercial fisheries on Lake Manitoba in 1885, Lake Winnipegosis in 1890, and later on lakes north of the 53rd parallel. By 1925, some 20 large northern lakes were being fished. This number increased to about 40 by 1938 and eventually to the more than 300 lakes being fished in the early 1980s (Green and Derksen 1984).

As with virtually all of Canada's inland fisheries, past and present commercial fishing gear used in Manitoba has been almost exclusively gill nets, although some pound and trap nets were also used (Green and Derksen 1984). Up to 1900, the fishery operated only in the summer. With the invention of the jigger, gill nets could be fished under the ice, and winter fisheries started in many Manitoba lakes. Other important developments
included the introduction of gas-powered boats in the 1920s, mechanical net lifters in the 1940s, and nylon nets in the 1950s (Gislason et al. 1982, cited by Craig 1987).

The largest annual catch ever experienced in Manitoba’s fishing industry was 38.6 million pounds, taken in 1941. Following World War II and up to 1966, the level of commercial catches from Manitoba waters remained relatively stable, averaging around 31 million pounds. Commercial production again peaked in 1962 and 1963, when approximately 35.7 million pounds were landed each year. This peak was, in large part, related to strong year-classes and good catches of walleyes from some northern Manitoba waters, and strong demands for freshwater fish, particularly walleye and sauger, in U.S. markets (Green and Derksen 1984), which suggests that biological factors were limiting the quantity of walleye supplied. Also about this time, walleye stocks in the Great Lakes, especially Lake Erie, were in a serious state of decline. Due to overexploitation of Lakes Winnipeg and Winnipegosis, poor weather conditions, and excess (unsold) fish remaining in cold storage, commercial catches progressively declined following 1963, and dropped to record lows in 1970 and 1971 when certain areas were closed to commercial fishing due to mercury pollution. After re-opening of the fishery in 1972, commercial fish production rose to over 35 million pounds in 1980.

The commercial production of fish from Manitoba between 1950 and 1976 was closely related to the number of licensed fishermen engaged in the fishery. Prior to 1972, there were no restrictions on entries to most major commercial fisheries. After 1972, controls on the number of fishermen allowed on some lakes were introduced, and catch quotas were increased on some of the major fisheries (Green and Derksen 1984).
The characteristics of the commercial fisheries in Manitoba vary depending on the region in which the fisheries occur. Fisheries on Lake Winnipeg and lakes north and east of there are based primarily on high market value species such as whitefish, walleye, and sauger. Commercial fisheries on the southern lakes and Lake Winnipegosis exploit a greater percentage of medium and low-valued species such as northern pike and suckers (Family *Catostomidae*). The Lake Manitoba fishery produces a species mix intermediate to the above two extremes (Green and Derksen 1984).

Manitoba’s commercial fishery produces 25 percent of the total value of Canada’s freshwater commercial harvests and is a substantial source of employment and income in many communities, particularly in the north where most fishermen are Native Americans. It is the only employment opportunity available in many northern Manitoba communities. The industry employs nearly 3,500 fishermen and hired helpers annually (Manitoba Natural Resources, Fisheries 1994).

As early as the 1920s, approximately 90 percent of Manitoba’s commercial fish production was exported (Skaptason 1926, cited by Green and Derksen 1984). Most exported fish went to markets in the eastern and northcentral United States. Except for the development of some overseas markets, the present-day fish production from Manitoba waters is still largely sold in U.S. markets.

Lakes Winnipeg, Winnipegosis, and Manitoba have been the three most important fisheries in the province. About 60 percent of Manitoba's commercial fish production comes from these three lakes alone, which represent about 17 percent of the water surface area in the province. Whitefish was the most important species caught from these lakes until their abundance declined in the 1920s and 1930s. Dwindling whitefish catches were
offset by increased production of other fish species, mainly walleye from Lake Winnipegosis, and walleye and sauger from Lakes Manitoba and Winnipeg. Whitefish are still caught in substantial quantities from Lake Winnipeg and the northern lakes, but are considerably less valuable than walleye or sauger (Green and Derksen 1984). Since Lakes Winnipeg, Winnipegosis, and Manitoba have been subjected to moderate or heavy fishing effort over a substantial time period, probably the best indicator of sustainable yield potential can be derived from the long-term production records. The overexploitation of these lakes in the early 1960s suggests that they cannot support historic harvest levels over a long period of time. This past overexploitation also suggests that these lakes are currently being fished at or near MSY.

Lake Winnipeg. The south basin of Lake Winnipeg is relatively shallow and highly turbid; the north basin is deeper and less turbid; and the channel area, which separates the north and south basins, is a zone of extensive mixing. The south basin and channel area of Lake Winnipeg are more productive than the north basin, with the bulk of commercial catches coming from the central portion and the south basin of the lake. Species composition of the catches also differs depending on the area of the lake in which the catches were made. Whitefish are primarily caught throughout much of the north basin while sauger and walleye contribute the largest amount to catches from the south basin, channel area, and south end of the north basin (Green and Derksen 1984).

Commercial catches from Lake Winnipeg have ranged from a high in 1940-1941 to a low in 1972, immediately following the closure of the fishery due to mercury contamination. Total landings in 1940-1941 were 21.8 million pounds, made up of approximately 40 percent sauger; 18 percent walleye; 16 percent whitefish; 14 percent
northern pike; and 11 percent other less desirable species such as suckers, lake herring \((Coregonus artedi)\), burbot \((Lota lota)\), and yellow perch. Fish stocks apparently were unable to sustain such high levels of exploitation. During the mid 1950s through the 1960s production levels from Lake Winnipeg declined steadily, with signs of severe overharvest evident in populations such as whitefish and walleye (Green and Derksen 1984). Walleye landings dropped from 6.6 million pounds in 1951 to 1.1 million pounds per year in the late 1960s.

Between 1950 and 1980, Lake Winnipeg had an annual production of whitefish, walleye, sauger, and northern pike of approximately 8.4 million pounds. Between 1976 and 1980, the combined landings of these species averaged about 10.1 million pounds per year. However, signs of stress were beginning to appear at this time (Lysack 1980, cited by Green and Derksen 1984). Green and Derksen (1984) estimated the MSY of whitefish, walleye, sauger, and northern pike from Lake Winnipeg at around 8.8 million pounds per year. This estimate of MSY suggests that Lake Winnipeg is currently being fished at or near MSY and cannot support substantially higher harvest levels over the long term.

**Lake Manitoba.** Lake Manitoba is a relatively shallow lake with a mean depth of 15 feet and higher nutrient levels than Lake Winnipeg. The maximum recorded catch of all species of fish from Lake Manitoba was 9.5 million pounds in 1940-1941. Walleye, sauger, and northern pike represented 65 percent of this catch (Green and Derksen 1984). Landings of these species from Lake Manitoba averaged approximately 2.2 million pounds per year from 1950 to 1980. Green and Derksen (1984) estimated the MSY of walleye, sauger, and northern pike for Lake Manitoba at approximately 2.2 million pounds annually. This estimate of MSY suggests that Lake Manitoba is currently being fished at
or near MSY. The long-term average catch indicates the contributions of walleye, sauger, and northern pike to be 43, 31, and 26 percent, respectively.

Lake Winnipegosis. Long-term annual harvests from Lake Winnipegosis average about 4.6 million pounds, but suckers make up a large proportion of the catch. Historically, combined harvests of walleye and northern pike have ranged from 3.7 million pounds per year in the mid 1950s to approximately 2 million pounds per year from 1976 to 1980. From 1950 to 1980, annual harvests of walleye and northern pike averaged about 2.2 million pounds per year. Since the late 1960s, northern pike have comprised about 70 percent of the combined walleye/northern pike catch. Green and Derksen (1984) estimated the MSY of walleye and northern pike at approximately 2.2 million pounds per year combined, suggesting the lake cannot support substantially higher levels of production.

Northern lakes. Northern Manitoba lakes are generally considered to be lakes north of the coniferous forest zone and north of the approximate limit of developed ground transportation routes, which roughly follows a line from the 57th parallel in the west to the 55th parallel in the east. Over half of the lakes in Manitoba are situated in the northern region, but almost all of them are smaller than 1,235 acres. In addition, many of these lakes are too shallow to support a population of large fish on a year-round basis (Green and Derksen 1984). Also, many of these small lakes lie in areas not serviced by roads or railways, and because of their small size, many are inaccessible by air. The potential harvest of these small lakes is, thus, effectively locked up until a road network is developed. Most of the lakes that have been surveyed in northern Manitoba lie between the 53rd and 57th parallels. This region is also the general area in which many of the commercial fisheries in northern Manitoba occur.
Growth in the northern Manitoba fishery resulted in an increase in walleye production from .8 million pounds in 1953 to 2.9 million pounds in 1962. A similar increase was observed with whitefish; northern pike; and, to a lesser extent, lake trout. Production by the northern fishery began to decline after the mid 1960s. From 1960 to 1984, the species composition of annual commercial catches by the northern fisheries remained comparatively stable despite fluctuations in catch volume. Walleye production in this period contributed approximately 22 percent of the annual landings.

The northern limit for yellow perch in Manitoba lies between the 55.4 and 58.1 °F July isotherms (Scott and Crossman 1973, cited by Green and Derksen 1984). The northern limit for yellow perch also probably represents the northern limit for commercially exploitable walleye populations. Although walleyes have been caught in areas north of the 55.4 °F isotherm, they are generally not present in large numbers. Furthermore, based on the observed distribution of large percids in northern Manitoba, the 62 °F July isotherm likely represents the northern limit at which walleye populations may be reasonably successful (Green and Derksen 1984).

Potential increased harvests in northern Manitoba lakes would likely be unsubstantial because of their small size, location near the limits of the walleye’s range, and the resulting low carrying capacity. In addition, the development of a road network supplying access to these lakes would also result in an increase in recreational fishing opportunities, likely restricting commercial harvests. Thus, it is unlikely that northern Manitoba lakes can contribute a notable amount to the total provincial walleye harvest.
Access to Fish Stocks

According to Manitoba Natural Resources, Fisheries (1994, P. 6), fish harvest allocations are determined according to the following priorities:

1. Fish stock conservation - ensuring the health and sustainability of fish stocks is prerequisite to protecting biodiversity, social, and economic values.

2. Treaty Indian domestic fish harvest-a constitutional obligation to Treaty Indians.

3. Resident recreation angling opportunity.

4. Commercial fishing harvest, including commercial net fishing, commercial sport fishing, bait fishing, and fish farming.

   It is important to note that resident recreational angling opportunity is not necessarily a consumptive allocation, but rather it is in recognition of a right to access for the purposes of recreational angling. It refers to the fact that Manitoba's fishery resources are public resources, and resident sport anglers have general access to angling opportunities. Angling opportunity will still exist when a creel limit of zero is regulated.

   Access rights or opportunities afforded by commercial use of fisheries will be allocated according to the value of the benefits generated to: 1) local, 2) regional, and 3) provincial economies.

   Where competing local interests are of similar economic and social benefits, long term biological sustainability will be the next priority in determining allocation.

   Established commercial fishermen are recognized as having proprietary rights in access to the fisheries resource. The proprietary rights that are recognized are those of access to, and not ownership of, some amount of the resource. Access rights are allocated via quotas, licenses, transfers, leases, and may be defined by zones and seasons.
Commercial fishermen who have access rights to the resource will be recognized as having developed tenure. When tenure has been established, reallocation to other commercial users without some form of compensation, determined through fair negotiation, will only occur if the tenured user fails to meet established performance standards. Re-allocation of access rights to the higher priority consumptive use of treaty domestic fishing, or to stock conservation will not be grounds for compensation.

Management approaches must ensure that the resource base receives adequate protection, a supply of fish adequate for the Treaty Indian food fishery is made available from the harvestable surplus, and the remaining surplus is appropriately allocated to other uses. Treaty Indian domestic fishing is the highest priority use allocation of the fish resource.

Treaty Indians have special fishing rights which are recognized and protected by the Canadian Constitution, various treaties, and provincial policy. Other Native American groups, including Metis, currently do not. Most Treaty Indian domestic fishing occurs in northern Manitoba, largely in remote areas where it is concentrated around native settlements such as Cross Lake, Oxford House, and Gods Lake. Domestic fishing is also thought to be essential to trappers, but again, largely in northern Manitoba. Therefore, competition between domestic fishermen, and sport and commercial users is likely a perceived rather than a real conflict (Cann 1997); however, future increases in domestic uses or sport fishing pressure could increase this competition.

**Harvest Quotas**

Quotas, mesh size, season timing and length, daily yardage, lake zones, and fishing effort have traditionally been used as tools to control commercial harvests throughout
Canada. In many of Manitoba’s commercial fisheries, due to pressures to provide economic opportunities and to make decisions quickly, the above controls have been set in the absence of monitoring programs or in spite of contrary indicators from monitoring programs. New management methods for controlling fishing effort, such as quota entitlement systems, have been based on past fishing effort rather than the productive capacity of a lake. Past differences among prices paid for various species have resulted in fishing effort that attempts to fill a multi-species quota with a single (most valuable) species. Increased fishing pressure on those more valuable species tended to focus concern and resulting management activities on a single species in spite of the existence of multiple species stocks (Manitoba Natural Resources, Fisheries 1994).

Commercial harvest quotas can be set based on the waterbody or region. For example, a set number of quota entitlements are issued on Lake Winnipeg and are based on community licensing areas. The number of commercial licenses available is limited, and all lakes open to walleye fishing are regulated by the use of quotas. Provided certain conditions are met, licenses are transferable from one individual to another. Furthermore, there may be a slight decrease in the number of licenses issued in the future. For example, the number of licenses available on Lake Manitoba is scheduled to be reduced from 650 to 400 over time (Cann 1997).

Costs

Operating, capital, and transportation costs for commercial fishing, relative to fish prices, can be a constraint. For the remote northern fisheries in particular, transportation costs limit economic viability. Currently, the only subsidy program available to Manitoba
commercial fishermen is the Northern Fishermen's Freight Assistance (NFFA) Program. It was established in 1976 to assist marginally viable commercial fishing operations through partial subsidization of the cost of transporting selected fish species from lakeside to Winnipeg. Fishermen pay the first $.09/lb of freight costs to the FFMC in Transcona; the province pays the next $.16/lb; and fishermen then pay any freight costs in excess of $.25/lb. The program's expenditures are capped at $250,000 annually. To ensure expenditures do not exceed the cap, fishermen receive an initial subsidy payment of 70 percent of the estimated full subsidy for which they are eligible. They receive a final payment at the end of the fishing year which may total the expected remaining 30 percent in a typical production year. However, in years of high production, final payments may be less than expected. In low production years, final payments may result in a higher subsidy rate than promised (Cann 1997).

Former federal and provincial programs for upgrading fish packing plants, docks, ice houses, and other infrastructure required for the commercial fishery have been discontinued, and there are no new programs to take their place (Manitoba Natural Resources, Fisheries 1994). However, there are fishermen loan programs in existence. For example, on Lake Winnipeg, quota entitlements can be used as collateral against fishermen loans (Cann 1997).

Pressures on Manitoba's fisheries have increased in recent decades because of increased accessibility due to a growing network of roads. Many waterbodies, particularly in the north, that were previously either untapped or lightly exploited, are now being intensively fished (Green and Derksen 1984). Improved access will continue to have a major impact on the exploitation of northern lakes.
Implications for the Manitoba Fishery

Due to a growing commercial fishing industry, concerns about stock abundance surfaced as early as 1884. Regulations limiting the number of nets per boat, restricting commercial fishing on Sundays, and confining fishing to the north basin of Lake Winnipeg were enacted by 1892 (Green and Derksen 1984).

Green and Derksen (1984) recognized that the trends of increased demand and constant supply of prime fish species during the 1880s were not sustainable. Most of this growth was expected to occur in the angling population. Manitoba’s commercial fishery is characterized by overallocation of fishing resources and is currently being harvested at or near MSY. Only marginal increases in production are possible, with decreases due to resource allocation losses to angling or other uses a long-term possibility.

Ontario

The Ontario commercial fishery is dominated by the fisheries of the Great Lakes. The Great Lakes make up the world’s largest freshwater system and contain the world’s largest freshwater fish resource (Jude and Leach 1993). Because they are distributed over such a large area, the individual lakes differ in climatic, physical, and chemical characteristics; and, consequently, in productivity and fish species diversity. Most native fish populations in the Great Lakes suffered dramatic declines between the mid 1800s and
the mid 1900s. These declines have been attributed to overfishing, degradation of habitat, and invasion of exotic species.

Of the Great Lakes, Lake Erie is by far the largest producer of walleye. From 1980 through 1999, the Ontario waters of Lake Erie produced an average of 6.8 million pounds of commercially caught walleye per year, followed by Lake Huron at 292 thousand pounds, Ontario at 22 thousand pounds, and Superior at 0.3 thousand pounds (GLFC 2002). The smaller lakes of northwestern Ontario also support a commercial fishery of less importance.

**Lake Erie**

For over a century and a half, the walleye has been valuable as a commercial and sport fish in Lake Erie. The first commercial hook and line fishery began in eastern Lake Erie in 1795 (Regier et al. 1969). Then, after the war of 1812, a commercial fishery using seines was established in the western part of the lake. During the nineteenth century, sauger, walleye, and smallmouth bass were the main species caught. The fisheries and the intensity of fishing increased during the late 1800s due to improved transportation, improved preservation techniques, and increases in the human population of the area. Fishing was also made easier by the introduction of steam boats in the 1880s, which also meant that the central region of the lake could be fished. In addition to being subjected to heavy fishing pressure, fish stocks were also exposed to a number of other changes including eutrophication; introduction of exotic species such as the sea lamprey through the Welland canal in about 1921 and the rainbow smelt (*Osmerus mordax*) in 1931;
tributary and shoreline development; an increase in siltation and turbidity; and the release of toxic materials from industry, vessels, and vehicles.

With the decline of yellow perch abundance and catch rates, the walleye is now the premier species of the commercial industry. The lake currently represents the largest source of commercially caught walleye in Canada.

There are at least two discrete populations of walleye in Lake Erie, the largest one occupying the western and central basins, and a relatively small one in the eastern basin (Leach and Schneider 1979). The western half of the lake has long sustained the best walleye fishery in the Great Lakes and possibly in the world.

The lake is shared by Michigan, New York, Ohio, and Pennsylvania in the United States and the province of Ontario in Canada. The recommended total allowable catch for walleye and yellow perch is determined by the Lake Erie Committee of the Great Lakes Fishery Commission, consisting of senior representatives of the resource agencies surrounding each lake.

Once a lakewide harvest level is determined, the allowable catch for Ontario and each state is determined using an internationally agreed upon sharing formula which is based on a combination of the surface area of Lake Erie within each jurisdiction and historic shares of harvest (Cooper 1997). Each jurisdiction allocates its portion of the harvest among user groups and is responsible for reporting all landings and enforcement. State, provincial, and federal fisheries agencies cooperate closely in implementing the quotas.
The 1996 walleye quota levels were the highest since the development of the international quota system in 1976, despite the fact that population numbers were down two-thirds since they peaked in 1988. While walleye population numbers have recently declined, sport and commercial harvests have remained relatively high (Cooper 1997).

Commercial harvest remained relatively stable at around 1,000 tons from 1885 to 1939, after which it increased steadily to a high of nearly 8,000 tons in 1956 (Baldwin et al. 1979). The increasing harvest in the 1940s occurred mainly in Ohio waters after the loss of the valuable lake herring fishery (Davies et al. 1991). In the 1950s, catches rose somewhat more rapidly as Ontario gill netters increased the amount and efficiency of their gear. The lake’s walleye stocks, especially those in the western and central basins, then collapsed with commercial harvests falling below 1,000 tons in 1960 (Baldwin et al. 1979).

Commercial fishing was temporarily banned in both U.S. and Canadian waters of the western basin in 1970 due to mercury contamination. In Ontario and Michigan waters, anglers also were prohibited from retaining walleye. This protection allowed walleye populations to recover, with the fishable stock in the western basin increasing from about 83,000 walleyes in 1970 to nearly 14 million in 1976 (Hatch et al. 1987).

With a decline in mercury contamination levels, the Ontario commercial fishery was reopened in 1974 under a limited permit system and expanded under the international quota system in 1976 (Davies et al. 1991). In Michigan and Ohio waters, the harvest was restricted to sport fishing only and has remained so.

Walleye landings in the central basin collapsed simultaneously with those from the western basin, but the recovery has not been simultaneous. Davies et al. (1991) suggested
several reasons for the slower recovery and continued relatively low levels of abundance in the central basin, including

1. changed limnological conditions,
2. pollution in spawning streams,
3. siltation of open lake spawning and nursery areas,
4. increasing populations of rainbow smelt (*Osmerus mordax*), and
5. a continuing small-mesh gillnet fishery for yellow perch (*Perca flavescens*).

In the Ontario waters of the central basin, commercial walleye catches increased from 2 tons in 1980 to over 1,147 tons in 1986 due to a combination of greater abundance and increased effort directed at that species. Harvest by anglers also increased in both Ontario and Ohio waters in the 1980s, with the sport harvest from Ohio waters alone increasing from 54,000 walleyes in 1982 to 1.1 million in 1988 (Davies et al. 1991).

Although sport and commercial harvests have increased in the central basin, the increased abundance of walleye is apparently due to dispersal from the western basin. The presence of mature, spent adults in May; larval walleye in late May; and juveniles in July is evidence of a reproducing population (Dunlop and Timmerman 1985), but the lack of prime spawning substrates on both shores of the central basin makes it unlikely that major contributions to the lake’s walleye population will come from these areas. Historic walleye population levels support this assumption as they were abundant in the central basin only when populations were strong in the western basin (Davies et al. 1991).

Prior to 1956, walleye were only caught incidentally in the commercial fishery of the eastern basin, with harvests ranging only from one to four tons annually. The fishery concentrated on lake herring in the 1940s, and blue pike and whitefish in the 1950s. After the simultaneous collapse of blue pike and whitefish populations in the late 1950s and the
collapse of the western basin walleye stock in 1957, the commercial harvest of walleye in New York’s eastern basin waters rose, ranging between 50 and 84 tons from 1961 to 1975. With the rehabilitation of the western basin stock, annual commercial landings from the eastern basin ranged from 32 to 47 tons from 1976 to 1983 and then rose to 158 tons in 1985 as the fishery expanded in Ontario waters. Since 1986, the commercial harvest of walleye in New York waters has been prohibited to allow for exclusive exploitation by angling (Davies et al. 1991).

Before 1970, regulations on the Lake Erie commercial fishery were mostly those favored by politically active commercial fishery operators. Generally, there were no limitations on the number of licenses issued, total effort applied, or quantity of walleye landed. Historic declines in walleye stocks have been related to overexploitation, with walleye stocks rebounding when exploitation was controlled (Davies et al. 1991). This relationship suggests that the lake cannot withstand long-term harvest rates at or near the historic highs. The closure of the commercial fishery in Ohio, Michigan, and New York; the establishment of exotic species; more intense regulation; and increased sport harvest make it very unlikely that Lake Erie’s commercial harvest can be increased substantially beyond current levels.

Lake Huron

Lake Huron is the second largest of the Great Lakes. Three-quarters of the lake’s shoreline is in Canada. Lake Huron is an oligotrophic lake, with a total dissolved solids level intermediate between Lake Superior and Lake Ontario.
Composition and abundance of the Lake Huron fish community have changed dramatically in this century. Large-scale commercial fishing began in Lake Huron during the mid 1800s. The total annual commercial harvest from Lake Huron (Canada and U.S. waters) was fairly constant from 1912 to 1940, averaging just under 20 million pounds. This time frame has been used as a “base period” for estimating historically stable yield prior to the collapse of the fishery. During this period, yields averaged 8.12 pounds per acre annually. Whitefish and herring, lake trout, and yellow perch and walleye made up 43 percent, 27 percent, and 13 percent of the harvest, respectively. The average annual walleye harvest for this period was 1.5 million pounds. During this period, the catch from Lake Huron was believed to at or near MSY (DesJardine et al. 1995).

Beginning in the late 1930s, total commercial harvests declined continuously with lake trout nearly becoming extinct and populations of whitefish, lake herring, and walleye all severely depressed by the mid 1960s. These declines were attributed to excessive fishing, habitat deterioration, and the introduction of exotic species. Habitat loss, combined with overfishing, was most instrumental in the collapse of lake herring and walleye populations in Saginaw Bay.

Historically, walleye was the dominant near-shore predator and an important species to both the commercial and sport fisheries of Lake Huron. Reckahn and Thurston (1991) reported that there were as many as 14 different stocks of walleyes in the Ontario waters of Lake Huron, but several have become extinct. The combined Ontario and Michigan annual walleye harvest ranged from as high as 3.5 million pounds in the early part of this century to as low as 77,000 pounds in 1972 (Baldwin et al. 1979). Current walleye harvests are split equally between sport and commercial fisheries, but the walleye
sport harvest from Michigan waters is starting to exceed the Ontario commercial harvest in some years.

DesJardine et al. (1995, P. 15) identified the overall management objective for Lake Huron: “Over the next two decades, restore an ecologically balanced fish community dominated by top predators and consisting largely of self-sustaining indigenous and naturalized species capable of sustaining annual harvests of 8.9 million kg (19.6 million pounds).” The 19.6 million pound harvest objective is the recorded annual harvest of all species between 1912 and 1940 as previously discussed. The walleye annual harvest objective is 1.5 million pounds, also the recorded annual harvest for that time period.

The 1.5 million pound walleye harvest objective is for the entire lake. If reached, the available harvest would have to be split up among the various users and jurisdictions, and would not all be available for commercial harvest. Furthermore, given the loss of habitat and the establishment of several exotic species, this goal appears unlikely.

**Lake Ontario**

Lake Ontario water quality is generally characteristic of an oligotrophic system (Kerr and LeTendre 1991), and it is second only to Lake Superior in terms of depth relative to size. Lake Ontario supports a commercial and recreational fishery. The commercial fishery is concentrated in the eastern portion of the lake and in the Ontario waters of the St. Lawrence River. The commercial fishery provides direct employment and income for 200 to 300 people.
Currently, the Lake Ontario commercial harvest is based primarily on whitefish, yellow perch, and brown bullhead (*Ictalurus nebulosus*) (GLFC 2002). Historically, the early Lake Ontario fish community was believed to be dominated by large individuals of native species, including lake sturgeon, lake trout, whitefish, burbot, and Atlantic salmon (*Salmo salar*). Atlantic salmon, lake trout, and blue pike have been eliminated or dramatically reduced due to the combined effects of habitat alteration, pollution, overfishing, and the introduction of exotic species (Flint and Stevens 1989).

Commercial yields peaked at 7.5 million pounds in the late 1800s and again at almost 6 million pounds in 1924. Due to overfishing, pollution, loss of habitat, and the establishment of exotic species, the native fish community of Lake Ontario has undergone dramatic changes over the past 100 years, resulting in the decline of the commercial fishery from historic levels. The western basin commercial fisheries were greatly reduced by the mid 1940s, with the eastern basin fisheries persisting through the 1950s because of greater species diversity (Kerr and LeTendre 1991).

Restoration efforts in Lake Ontario are focused on lake trout and Atlantic salmon. Due to the lake’s oligotrophic nature, it is unlikely that walleye populations could be increased to the point of supporting sizable commercial harvests. Furthermore, the presence of several exotic species, combined with habitat degradation, will likely prevent walleye populations from attaining historic levels.
Lake Superior

Lake Superior is oligotrophic with the lowest summer surface temperature and mean annual lake temperature among the Great Lakes. The lake’s commercial and sport fisheries are comprised primarily of cold-water species, but walleye populations do exist and are exploited in the shallow water areas and bays (Atkinson et al. 1991).

The lake’s several distinct walleye stocks have historically supported a commercial fishery, with harvests peaking at 378,000 pounds in 1966 (Baldwin et al. 1979), but the overall abundance of walleye in the lake declined primarily due to overfishing. The lake’s slow-growing stocks, dominated by old individuals, were unable to withstand high levels of exploitation. Commercial fishing is now eliminated except for a small incidental quota in Ontario and a Native American fishery in U.S. waters (Atkinson et al. 1991).

Although not as popular a sport fish as the lake’s salmonids, the walleye is actively sought by anglers. Agencies have responded to the demand for walleye fishing and are attempting to rehabilitate stocks through regulations and stocking. Despite management efforts and some rehabilitation success, walleye distribution and abundance in Lake Superior will continue to be limited due to the lack of suitable habitat (Atkinson et al. 1991). This limitation, coupled with more recent angling interest, suggests that the lake’s commercial production will remain at low levels and continue to be limited to incidental catches in Ontario and tribal fisheries in the United States.
Saskatchewan

In Saskatchewan, most commercial fishing effort takes place in lakes north of 54 degrees latitude. There are several lakes south of 54 degrees that support commercial whitefish fisheries, but no game fish harvest is allowed. Any game fish incidentally caught are collected by conservation officers for distribution to nonprofit groups. Commercial fishing has been an industry in the province since 1885, and most major fisheries have been active since the 1920s. There are very few lakes remaining that are not fished commercially (Adam et al. 1996).

In most cases, there are communities near lakes with major fisheries, and licenses are issued only to local residents. Most lakes have been fished by the same fishermen for many years, and these fishermen are given preference in licensing. In recent years, about 700 northern fishermen obtain licenses and employ about 1,500 helpers each year. Fishermen may fish several lakes, but a separate license is required for each water-body fished. The province sells about 2,000 commercial fishing licenses each year at $10 (Canadian) per 1000 meters of gill net. Most northern fishermen are of aboriginal ancestry and fish in lakes close to their place of residence (Adam et al. 1996).

Saskatchewan’s commercial fish production has decreased from a high of nearly 15 million pounds in 1965 to over 5 million pounds in 1994, and has exhibited noticeable fluctuations for all major species. Walleye harvests have dropped from a high of approximately two million pounds in 1965 to just over one million pounds in 1994 (Adam et al. 1996). When comparing harvest levels for lake whitefish, walleye, lake trout, and northern pike since the 1920s, fluctuations in harvest for each species appear to follow the same general pattern.
Various methods are used in Saskatchewan to determine allowable harvest levels, depending on the amount of information available regarding each lake. Although historic commercial harvest levels are often taken into consideration, most of these methods use ecological parameters and/or habitat data, including mean and/or maximum depth, total dissolved solids, standing crop of bottom fauna, lake size, and geographic location to calculate sustainable rates of harvest (Chen 1992). Once the allowable harvest levels have been determined, the government allocates the catch for each species among the various user groups according to the following priorities as identified by The Commercial Fishing Working Group (Adam et al. 1996, P. 25-26):

1. Conservation: The first priority is to insure that sufficient breeding fish are available to maintain the population. If the fishery is badly depleted, no fishing is allowed.

2. Treaty Indian Fishing: If a surplus is available, the first users considered must be Indians taking fish for food pursuant to treaty rights.

3. Subsistence Fishing: Mainly in northern areas, disadvantaged local residents who need fish for food are given access to the resource.

4. Sportfishing by Saskatchewan Residents: All Saskatchewan residents with valid sportfishing licences have access to all public waters for angling purposes, subject to seasons and catch limits.

5. Commercial Users: This includes sport and commercial fishing, and tourist outfitting. Preference in allocating the resource to these uses is based mainly on past fishing history on the lake in question.
All lakes with some portion of the harvest allocated to commercial fishing are managed through the use of quotas. Three forms of quotas are used. Lake limits are set as the total allowable harvest of fish on a lake, all species combined. Tolerance quotas are set as the percentage of the total catch which may be made up of game fish, the balance usually being whitefish. Species limits refer to separate quotas on each species harvested from a lake. Today, very few lake limits are used. Most lakes are now managed with species limits. These individual quotas are set as conditions of license for each fisherman. The fishermen do not own the quotas, but in most cases if a fisherman quits fishing, he can sell his equipment, and the purchaser will be allowed to fill the quota (Adam et al. 1996).

In the last 50 years, there have been dramatic increases in angling activity and the development of commercial tourist outfitting businesses in many areas. As a result of the increase in sport-fishing harvest, many commercial quotas were reduced or changed. Most lakes where reductions occurred are now fully or over-allocated to the various users. Reversing the reduction in commercial allocation would be difficult. However, quota levels are reviewed regularly or on request. If better information on the fish stocks is available or if harvests by other users prove to be lower than previously thought, quotas could be increased. However, substantial quota increases are very unlikely, with such increases rare and fairly minimal. While commercial harvests have been recorded consistently for over 70 years, data on harvests by other users are usually scarce (Adam et al. 1996).

Fifty major lakes account for about 90 percent of Saskatchewan’s annual commercial fish production and 76 percent of the annual walleye production. Of these
lakes, approximately 40 make up nearly all of this walleye production. Another 200 or so lakes, mostly small, provide the remainder of the catch (Adam et al. 1996).

Quotas for each lake are either the same as, or a percentage of, the total allowable harvest level for that lake. The total allowable harvest levels are based on ecological criteria. Since, in the case of Saskatchewan’s northern lakes, these criteria have not and will not likely change enough to increase the lakes’ carrying capacity for walleye, and since commercial fishermen have the lowest priority in allocation of the resource, it is very unlikely that quotas could be increased. Quotas will more likely stay the same or decrease due to increased competition for the harvest by other users.

Because many of the lakes in northern Saskatchewan are remote and difficult to access, transportation costs are a major constraint to commercial production. Fish first must be transported from each lake to an FFMC packing facility, where they are weighed, graded, and packed in standard weights for shipment. After being packed, they are transported to the FFMC processing plant in Winnipeg and then distributed to various markets (Adam et al. 1996).

Distribution of processed fish to the various markets is a factor in the fish prices established by the FFMC and is paid by all fishermen equally. Truck transportation is used exclusively in Saskatchewan to transport fish from the packing plant to the FFMC processing plant. This cost is deducted from the price paid by the FFMC in Winnipeg to the individual fisherman (Adam et al. 1996).

Transporting fish from the lake to the packing plant is usually done by the individual fisherman using boat, truck, or snowmobile. These costs have been increasing annually due to higher fuel, equipment, and maintenance costs. Many fisheries have
switched to the winter season because the catch from remote lakes can be hauled to the nearest delivery point by snowmobile and because fish prices are generally higher. In summer fisheries, air transportation, which was once common but now rare, is required (Adam et al. 1996).

Recognizing that transportation costs were a major constraint to production on remote lakes, Saskatchewan instituted a freight equalization and price support program in 1975. The program reimbursed fishermen for 90% of the cost of transporting their catch to Prince Albert, which was considered a common point for most fish being exported. Administration of the program proved to be very expensive and time consuming, and was turned over to the FFMC in 1983. The program was restructured in 1987 in response to severe budget constraints. Freight subsidy rates were reduced, and subsidy was no longer paid on walleye or lake sturgeon (*Acipenser fulvescens*). However, payments on compliments to walleye continue (Adam et al. 1996).

Administration of the program was transferred to the newly formed Department of Northern Affairs in the 1996/97 fiscal year. It is expected that the FFMC will continue to administer the payments to fishermen and that there will be no changes to the basic format of the program (Adam et al. 1996).

Most of Saskatchewan’s commercial fishing lakes that are readily accessible and close to services are already being fished at or near capacity. The main opportunities for increasing production are lakes which are remote, and this potential increase is very minimal. As the distance from services increases, the cost of fuel and supplies, as well as the cost of freight, increases until the potential profit margin disappears. Since most northern Saskatchewan lakes are relatively small, they cannot produce at or withstand the
harvest levels necessary to overcome these costs to make it profitable to fish them. Restoring the freight subsidy for walleye could result in an increase in fishing effort on northern lakes. However, similar to northern Manitoba lakes, they have a low carrying capacity and could not support noteworthy levels of harvest over the long term.

Occasionally, lakes with commercial fishing allocations are fished lightly or not at all by local residents or by the eligible fishermen. This underutilization may be due to lack of interest; lack of start-up capital; or availability of better paying employment in construction, mining, forestry, or fire fighting. Fishermen from other parts of the province have asked for access to unfished lakes. Presently, licenses may be issued to non-local fishermen on a temporary basis, but only after consultation with local fishermen. Occasionally, no agreement can be reached with the local fishermen, yet no locals fish the lakes commercially that year (Adam et al. 1996). A policy change allowing non-local fishermen more access to underutilized fisheries could result in a slight increase in total harvest. Walleye harvests probably would not be increased as much as harvests of other species. Higher relative prices for walleye suggest that they are being targeted more and that fishermen would be less likely to quit fishing a productive and accessible walleye lake in favor of some alternative source of income.

Saskatchewan’s commercial walleye harvest is less than half of what it was in the 1960s. Many quotas have been reduced because of competition from sport fisheries. Since walleye is the most sought after fish species by both sport and commercial fishermen, it is unlikely that quotas can increase. With walleye being the most valuable species in the province, any accessible lake that can produce is likely producing.
Future walleye quotas are likely to either remain relatively constant or be reduced due to allocation to other uses. Opportunities for increases in production, mainly in northern lakes, are minimal; would not have an appreciable effect on the total supply of commercially caught walleye; and, over the long term, would likely be offset by reductions in harvests in other areas.

**Alberta, Northwest Territories, and Quebec**

The provinces of Alberta, Northwest Territories, and Quebec account for only 0.9 percent, 0.6 percent, and 0.1 percent, respectively, of the Canadian commercial walleye harvest (Figure 5). These provinces are located at the outer limits of the walleye’s natural range, contain a limited amount of suitable walleye habitat, and do not have the productive capacity to maintain large populations of walleye able to withstand substantial harvest levels. Commercial harvests generally consist of incidental catches of walleye and small fisheries based on isolated populations.

**Alberta**

The province of Alberta accounts for less than one percent of Canada’s commercial walleye harvest. Commercial fishing for walleye is not as extensive in Alberta as it is in some of the other provinces. The Fisheries Management Division of the Department of Environmental Protection is responsible for fisheries management in the province (Berry 1997).
Sixty-four large river systems, their drainages, and an estimated 177 lakes throughout the province support walleye populations. These lakes represent 17 percent by number and 73 percent by area of the total fish-bearing lakes in Alberta. Eight lakes make up about 65 percent of the total area of lakes containing walleye, with approximately 75 percent of the lakes with walleye, 89 percent by area, located north of Edmonton. The distribution of walleye has been extended into southern areas, particularly reservoirs, but most of these populations have not become fully established (Berry 1995).

Despite stocking programs that have introduced 79 million eggs, 182 million fry, and 11 million fingerlings since 1938, walleye populations across Alberta have declined due to overharvest of the adult spawning populations, resulting in loss of natural production. Many walleye populations are currently in a vulnerable or collapsed status (Berry 1995).

Pressure from commercial fishing during the first half of the century contributed to the decline and loss of some walleye populations. Stricter regulations have reduced the effects of commercial fishing on walleye in the 1990s. Increased sportfishing pressure combined with improved fishing techniques and more knowledgeable anglers has contributed to recent reductions in walleye numbers. The growing popularity and increased occurrence of tournament fishing is also increasing the pressure on some populations.

The province has set management priorities that are to be used to make decisions concerning resource allocation. In the case of fisheries management, conservation of fish stocks takes the highest priority, followed by subsistence fishing for Native Americans, resident recreational use, and commercial fishing and tourist angling. However, these
priorities are negotiable to some extent. The actual allocation percentages are arrived at through a process of consultation with user groups to allocate the harvestable walleye production to various users according to policy priorities and the needs of these user groups. The harvestable supply of walleye for each water body is based on production values of 0.75 lb./ac. or the current 5-year average production, whichever is lower (Berry 1995).

Commercial fishermen on Alberta lakes generally target lake whitefish and lake herring, but are allowed a yearly quota of incidentally caught walleye. Once this quota is reached, they must stop fishing (Berry 1997). On a province-wide basis, Alberta’s commercial fishery currently takes about 15 percent of the yearly walleye harvest while the sport fishery takes more than 80 percent.

Three major lakes account for the majority of Alberta’s commercial walleye harvest. They are Lake Athabasca, Lesser Slave Lake, and Lake Bistcho. Of these lakes, Lesser Slave is the only one where there is a notable overlap between sport and commercial fishing. The lake is readily accessible, and the sport fishing harvest has been increasing over the last few years. Because of the increase in sport fishing on Lesser Slave, fishery managers are attempting to reduce and eventually eliminate the commercial harvest of walleye on the lake by reducing the quotas, implementing gear restrictions, setting seasons, and zoning (Berry 1997).

Lakes Athabasca and Bistcho are harvested almost exclusively by commercial fishermen. Lake Athabasca is difficult for anglers to reach and difficult to fish because of its large size and physical characteristics, with the Alberta portion of it accounting for 29 percent of the total area of lakes containing walleye. Lake Bistcho has developed a sport
fishery in recent years. This fishery, however, is limited to fly in fishing resulting in a relatively low harvest rate. Creel censuses are not done on these lakes because of the low rates of angling pressure they receive. The commercial harvest of walleye in these lakes is expected to be maintained at current levels (Berry 1995).

Alberta is near the northwestern limit of the walleye’s natural range. The ability of Alberta’s lakes to produce walleye is limited compared to those in more southern and eastern regions. Annual production is affected by the northern climate, which slows growth and age to maturity, contributes to size and maturity differences between the sexes, and causes weak and variable year-classes which makes the species susceptible to population declines. Alberta only has a small number of large lakes that are productive for walleye, and the majority of the lakes containing walleye can support only low rates of harvest.

In accordance with Alberta’s Fish and Wildlife Policy (Berry 1995, P. 14 and 16):

A viable commercial fishing industry will be encouraged. Target species are generally lake whitefish and tullibee (cisco), and reasonable access to these species will be maintained. Commercial use of the fish resources will be managed in consultation with commercial fishermen and recreational users to promote the following objectives:

a) Recognize commercial fishing as a viable industry and a valid user of the fish resource to meet the food-fish needs of the public;

b) Minimize the harvest of walleye, yet achieve allocated harvest levels for lake whitefish and tullibee; and

c) Minimize the commercial use of lakes having significant walleye conservation concerns, high angling pressure, and low commercial catches of lake whitefish with marginal economic returns.
At commercially fished lakes, a minimal tolerance limit for walleye in the commercial harvest will be the objective. Restrictions, such as timing of seasons and fishing zones, will be maintained to ensure that walleye harvests are within tolerance limits.

It is unlikely that commercial fishing will end in Alberta, but due to biological constraints, increased competition for walleye, and the already stressed condition of many walleye populations, it is doubtful that commercial harvests of walleye could increase. The commercial harvest will more likely decrease, or at least remain steady, due to lower quotas and more intensive management.

**Northwest Territories**

The extreme northwestern limit of the walleye’s range extends into the western half of the Northwest Territories. There are few sources within the Northwest Territories that can support commercial walleye harvests. Because of their relatively high prices, walleye in these lakes are highly targeted and fished to their sustainable limits (Colford 1997).

In 1993, 71 inland water bodies were opened for commercial fishing, of which 35 were fished. One hundred eighty-seven commercial fishing licenses were sold to 176 fishermen in 7 communities with total landings of 3,401,104 pounds. Of this total, lake whitefish was the most common species, making up 79 percent of the total, followed by northern pike at 9 percent, burbot at 5 percent, and lake trout at 3 percent. Walleye made up less than 1 percent of the total harvest. Great Slave Lake accounted for 97 percent of the total harvest of all species. Commercial production in other recent years has been similar to 1993 since harvest levels of most species tend to be fairly consistent (Colford 1997).
Three lakes account for almost all of the territory’s walleye harvest. Lakes Kakisa and Tathlina have walleye quotas of 44,100 pounds each. Great Slave Lake supports a walleye harvest that is small and somewhat inconsistent, but substantial relative to the other fisheries of the territory, and does not have a commercial walleye quota. In 1993, fisheries on these three lakes produced 56,245 pounds of walleye, accounting for all of the territory’s walleye harvest. Between 1978 and 1995, the territory averaged 83 thousand pounds (Craig 1997).

Fish allocation priorities are similar to other Canadian provinces, with subsistence use ranking higher than all other uses. Sport fishing pressure in the territory is light, and most anglers target species other than walleye (Colford 1997).

There are subsidies for certain species of fish, with whitefish export subsidies amounting to almost 50 percent of the value of the fish, but there are no subsidies for walleye harvest or transport. A lake freight transport subsidy exists for other species but is scheduled to be discontinued.

Overall, other than slight natural fluctuations, walleye harvests in the Northwest Territories are relatively stable. Commercial fishermen targeting walleye are not faced with increasing competition from other user groups as is the case in other parts of Canada, so quotas and harvest levels will not likely decrease. Conversely, given the fact that walleye are already being harvested at sustainable levels and since population levels are limited due to the biological constraints existing at the northern edge of the walleye’s range, it is not likely that harvests can increase.
Quebec

With an annual average commercial walleye harvest of approximately 19,000 pounds, Quebec accounts for roughly \(1/10\) of 1 percent of the total Canadian harvest (Figure 5). Lying in the outer reaches of the walleye’s range, Quebec contains marginal walleye habitat, and harvests are largely limited to incidental catches. The commercial catch of walleye in Quebec will remain low and continue to be relatively inconsequential to the total Canadian commercial walleye harvest.
V. COMMERCIAL WALLEYE SUPPLY

Past overexploitation of Canada’s fish stocks resulted in government intervention to remedy the common property resource market failure. This intervention included actions such as the introduction of licensing and harvest quotas, seasons and other harvest limitations, and regulation of the number of fishermen allowed on certain lakes. Initiation of these regulations introduced some inefficiencies to the industry, some of which were necessary to reduce the common property externality problem. Quotas are now widely used in the industry but are often not easily transferable. Fishing seasons, mesh size, limits on net length, zones, and other restrictions of fishing effort also contribute to industry inefficiency.

Equity and other social concerns may also have played a part in government intervention, attempting to ensure fishermen have some minimum income and/or spread out the perceived benefits over many users of the resource. The result may be higher prices than that of a perfectly functioning market, and certain gains in efficiency could be achieved by operating the industry at a harvest level below MSY (Figure 2), but the industry can be assumed to be operating nearly as efficiently as possible to prevent problems associated with common property resources.

Environmental and biological factors limit the amount of fish that can be harvested annually. This limited harvest causes a kink in the supply curve at the point where it becomes nearly vertical (Figure 6) due to the carrying capacity and MSY. This portion of the curve has a very low price elasticity of supply, i.e., production is unresponsive to price. The unresponsiveness of quantity supplied to changes in price suggests the fishery is at or near the maximum annual level of production when operating on this portion of the curve.
Figure 6. Hypothesized supply of Canadian commercially caught walleye.

The Manitoba fishery was overexploited in the 1960s, and certain areas were closed to commercial fishing due to mercury contamination in 1970 and 1971. The overexploited Lake Erie fishery was also closed in 1970 due to mercury pollution. It reopened in 1974 under a limited permit system and an expanded quota system in 1976. These events had a substantial impact on the Canadian fishing industry.
Figure 7 graphs the market equilibrium for the Canadian commercial walleye fishing industry with linear regression lines for the years 1955 to 1979 and 1980 to 1999. Assuming relatively constant demand during these periods, the market equilibrium is an approximation of the supply curves for commercially caught walleye.

Figure 7. Market equilibrium for the Canadian commercial walleye fishing industry, 1955-1979 and 1980-1999 (data from DFO 2002).
From 1955 through 1979, the proxy industry supply curve (i.e., market equilibrium) actually had a negative slope. This negative slope can be attributed to two factors. Harvest levels in excess of MSY in the 1960s caused reduced abundance and corresponding lower attainable harvest levels. Additionally, the temporary closure of portions of the fishery shifted the proxy supply curve to the left due to a decrease in the resource base available for exploitation. The effect of the closure is analogous to a reduction in carrying capacity, resulting in fewer fish available for harvest. The industry was unable to overcome these environmental influences and biological constraints to increase production despite increases in price, partially because the portion of the industry remaining was already operating at or beyond MSY.

After 1972, controls over the number of fishermen allowed were introduced on some Manitoba lakes, and the use of catch quotas increased. Gradual increases in the number of fishermen and quota levels on Lake Erie occurred after the limited reopening of the fishery in 1974. The fishery returned to “normal” in the early 1980s, having rebounded from overexploitation and mercury contamination. Many areas were now operating under new regulations and harvest quotas, which are unlikely to be relaxed in the future.

In the 20-year period from 1980 to 1999, the proxy industry supply curve is nearly vertical. This time frame is the most indicative of current and near future conditions. The fishery was operating under more current regulations; was not subject to partial closure; and had, for the most part, recovered from overexploitation.
Figure 7 indicates that the fishery is operating in the inelastic portion of the proxy supply curve (Figure 6) and is harvesting the MSY. At this point, the fishery is unresponsive to price changes and incapable of increasing harvests substantially.

In general, increases in price will cause a move along the supply curve up and to the right. However, since supply is inelastic due to MSY, an increase in price would cause little or no increase in quantity supplied. If prices were to decrease far enough, decreased profits would cause individuals to leave the industry, causing decreased harvests and a move along the supply curve down and to the left. Harvest levels would fall below MSY, causing the supply curve to become more responsive to price at that point (Figure 6). Decreased prices could also start a trend toward more native subsistence or small, hobby type operations as well as larger commercial fishing operations with lower per-unit costs.

There are several factors that can cause shifts in the supply curve. Fishermen rely on gasoline for outboard motors, snowmobiles, and transportation to market. Increased fuel prices would increase the cost of production, causing that portion of the supply curve below MSY to shift to the left. Increased transportation costs would also make it less likely that any additional remote lakes would be fished. If energy costs make up a larger proportion of the costs to the Canadian commercial fishery than a potential aquaculture industry, aquaculture may be increasingly competitive during periods of higher fuel prices.

Similarly, the Canadian government could increase subsidies, causing that portion of the supply curve below MSY to shift to the right. However, this shift would not affect current harvest levels, which are already at MSY. In addition, it may be advantageous for the government to reduce subsidies and commercial production, and to allocate that
portion of the resource to sport fishing, which would extract additional benefits from the
resource.

Commercial fishing for walleye inescapably requires the use of manual labor and
devices. Major advances in fishing technology are unlikely in the near future. Any
advances that may occur would likely be marginal, occurring in areas, such as electronics,
which do not have a direct effect on catch efficiency. Furthermore, with the existence of
quotas and the fact that the industry is currently at MSY, increases in total harvests would
not occur.

Prices of production complements, such as sauger, northern pike, whitefish, lake
herring, and lake trout, could potentially have an impact on walleye harvests. Income from
the sale of these species is an important part of a fisherman’s income. Depending on the
location and the proportion of a fisherman’s catch that is made up of production
complements, reductions in price could cause fishermen to exit the industry, shifting the
supply curve to the left and moving to that section of the curve below MSY. Increases in
the price of complements in production could increase profits, but would not have any
appreciable effect on walleye supply due to the current location on the supply curve.

Additional taxes and licensing costs are unlikely due to their unpopularity and the
relative low incomes of commercial fishermen. If imposed, these additional expenses
would be an increased cost of production. The effect could vary from no effect to
reductions in harvests and a shift in the supply curve to the left.

A portion of the resource becoming contaminated and unsuitable for human
consumption would have similar effects as mercury contamination in the 1970s, reducing
the available supply. Possibly the most probable factor affecting supply is the spread of
invasive exotic species that could have the effect of reducing the carrying capacity of infested water-bodies.

Since the fishery is currently operating at or near MSY, changes in any of the factors affecting supply would either result in no change or cause reductions in walleye harvests. Any potential increases would require a substantial increase in price and would only be marginal. Some potential exists for improvements in efficiency, but improved efficiency would not increase production and could also require reductions in harvests below MSY.
VI. DISCUSSION AND CONCLUSIONS

Historical harvest data indicate that Canadian walleye populations were, in some instances, harvested at unsustainable levels. This unsustainable harvest, combined with inelastic supply, suggests that recent harvest levels are at or near MSY. If this information and the conclusions drawn from it are correct, it is highly improbable that substantially higher harvest levels could be sustained.

Artificial means to increase supply, such as stocking to supplement natural reproduction and subsidies, will have no appreciable effect on harvest levels. In rare instances, stocking may help to offset reductions in population size due to overharvest, but will not increase growth rates or the carrying capacity of the individual lake stocked. There is also a trend towards relying less on stocking and more on habitat protection and better management of the resource, which often means reducing harvest levels.

Assuming the industry is operating at or near MSY, the industry may become somewhat more efficient by reducing effort. However, it is unlikely that harvest levels can increase and rather would likely decrease to a level below MSY.

Some potential for increased harvests may exist in very remote, hard to reach areas, however, these increases are unlikely to occur and would only be marginal. Additionally, most of these areas are near the outer limit of the walleye’s range and support relatively small population sizes with slower growth rates and less successful reproduction. Since there is also a higher cost associated with fishing remote areas, they would likely be fished only if prices increased substantially or if costs of inputs dropped. Fishing these remote lakes is also more time consuming and entails increased opportunity costs. Any potential
increases in harvest levels would be minimal and would likely be offset by losses to increased sport fishing effort.

Increased allocations to sport fishing and/or Native Americans presents a very real possibility. Allocating more of the resource to other users would decrease the amount of fish available for commercial harvest, causing a decrease in quantity supplied. Utilization of fish resources is linked to human population changes. Since most of the commercial walleye harvest in Canada is exported to foreign markets, primarily the United States, and since sport fishermen from elsewhere come to Canada, fishery exploitation is dependent upon outside population growth as well as internal population pressures. As world population increases, there will continue to be increasing demands placed on freshwater fish resources, by both the food industry and angling sources. As United States and Canadian populations grow and economic growth increases expendable incomes, sport fishing will likely consume a higher proportion of the available fishery resource.

The North American Free Trade Agreement (NAFTA), which was implemented on January 1, 1994, will affect the import of fish products from Canada. The provisions of the United States–Canada Free Trade Agreement (CFTA), in effect since 1989, were incorporated into NAFTA. Under these provisions, all tariffs affecting agricultural trade between the United States and Canada, with a few exceptions, were removed before January 1, 1998. The three NAFTA countries will work toward elimination of export subsidies in North America, and neither Canada nor the United States is allowed to use direct export subsidies for agricultural products being sold to the other (USDA 2002). The inclusion of the CFTA provisions in NAFTA ensure that current and future walleye imports will not be inhibited by tariffs or other similar trade barriers.
If future prices of walleye increase, demand could shift to substitutes such as chicken, pork, or other fish species. Concerning substitutes, one question of importance to consider is the possibility for development of a competitive fishery or aquaculture industry from an alternative species such as zander (*Stizostedion lucioperca*). Zander could conceivably be grown domestically or imported to the United States, marketed as “European walleye,” and compete with a domestic walleye aquaculture industry.

Zander is a relative of the walleye that originated in the Caspian-Black Sea region but now has spread throughout most of mainland Europe and much of Asia (Brown et al. 2001). Zander and walleye have evolved separately over the past several million years (Marshall 1977), but both are members of the same genus and have many similar characteristics. They are similar in appearance; shape; and, most importantly, taste (Anderson 1992).

In addition, zander have certain advantages over walleye. Both have similar lifespans, but zander exhibit substantially faster growth rates than walleye. The average length of 7 year-old walleyes in 16 U.S. populations was 19.5 inches total length, while the average length of 7 year-old zander in 4 rivers from the Azov-Black Sea basin was 26.6 inches standard length (Anderson 1992). Zander are also more tolerant than walleye to a wide range of environmental conditions, have a higher fecundity rate, and require a less specific set of spawning conditions (Marshall 1977).
Zander are an important commercial species in Europe and Asia (Marshall 1977). The extent to which this fishery could be increased is unknown. Recent discussions have taken place in various states to consider stocking zander as an alternative to walleye. The North Dakota Game and Fish Department has already begun an experimental zander program, stocking Spritwood Lake in 1989 with fingerlings hatched from eggs from Finland (Anderson 1992). Zander are well adapted to waters that are turbid, relatively warm, highly productive, or stagnant (Marshall 1977). Therefore, it may be likely that any stocked zander would occupy lakes offering different habitat than those supporting strong walleye populations, thereby avoiding direct competition.

Concerning a potential aquaculture industry, zander larvae have been found to have similar daily nutrition requirements as perch and walleye (Mehner and Worischka 1998), but less is known about the culture requirements of this species to food-sized fish. Artificial fertilization of zander eggs is difficult and less successful than walleye (Marshall 1977), but not impossible. Biological and technological advances in this area could conceivably attain higher success rates.

Given the current goal of most fishery management agencies of protecting or enhancing available habitat and accomplishing fish management with native fish species, the likelihood of additional zander introductions may be low, but it does exist. As demand for fish products continues to grow and aquaculture becomes more common, a zander aquaculture industry may become more likely as well.

Canadian commercial walleye harvests should remain steady or possibly decline over time. The industry can be expected to provide between 15 and 20 million pounds of walleye annually over the next 10 years. Annual harvests considerably over 20 million
pounds are likely not possible. If U.S. demand increases, there may be an opportunity for
development of a food-sized aquaculture industry, but other factors should play more of a
role in the decision-making process, such as questions concerning substitutes, the
consumer’s willingness to pay a higher price for walleye, and the possibility of expanding
the market for walleye products.

Additional research could be directed toward the likelihood of substantial future
decreases in the supply of walleye. For example, information concerning the potential and
likely spread of exotic species and their effect on walleye populations is incomplete. More
research is also needed on the demand side of the walleye food market. Is the market a
regional phenomena based on the walleye’s home range, or are there opportunities to
expand the market? What is the likelihood that an increase in price of walleye products
will cause a shift in demand to substitutes? The answers to these and other questions
remain unclear, however, they are important to a potential walleye aquaculture industry.
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APPENDIX A. LIST OF SPECIES

Alewife .......................................................... \textit{Alosa pseudoharengus}

Atlantic salmon ......................................................... \textit{Salmo salar}

Blue pike ............................................................ \textit{Stizostedion vitreum glaucum}

Brown bullhead ......................................................... \textit{Ictalurus nebulosus}

Burbot .............................................................. \textit{Lota lota}

Carp ................................................................. \textit{Cyprinus Carpio}

Emerald shiner ......................................................... \textit{Notropis atherinoides}

Lake herring ........................................................ \textit{Coregonus artedi}

Lake sturgeon ......................................................... \textit{Acipenser fulvescens}

Lake trout .......................................................... \textit{Salvelinus namaycush}

Lake whitefish ......................................................... \textit{Coregonus clupeaformis}

Largemouth bass ................................................... \textit{Microperus salmoides}

Northern pike ......................................................... \textit{Esox lucius}

Rainbow smelt ......................................................... \textit{Osmerus mordax}

Round goby ........................................................ \textit{Neogobius melanostomus}

Ruffe ................................................................. \textit{Gymnocephalus cernuus}

Sauger ................................................................. \textit{Stizostedion canadense}

Sea lamprey ........................................................ \textit{Petromyzon marinus}

Smallmouth bass .................................................. \textit{Micropterus dolomieu}

Suckers .. ............................................................. Family \textit{Catostomidae}

Tilapia ................................................................. \textit{Oreochromis niloticus}
Troutperch .......................................................... *Percopsis omiscomaycus*

Walleye ................................................................. *Stizostedion vitreum*

White bass ............................................................ *Morone chrysops*

White perch ......................................................... *Morone americana*

Yellow perch ......................................................... *Perca flavescens*

Zander ................................................................. *Stizostedion lucioperca*

Zebra mussel ......................................................... *Dreissena polymorpha*