AN ASSESSMENT OF
THE POTENTIAL IMPACT
OF THE RAINBOW SMELT
ON THE FISHERY RESOURCES
OF LAKE WINNIPEG

BY
RICHARD A. REMNANT

A PRACTICUM
SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE
MASTER OF NATURAL RESOURCE MANAGEMENT

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AN ASSESSMENT OF THE POTENTIAL IMPACT OF THE RAINBOW SMELT ON THE FISHERY RESOURCES OF LAKE WINNIPEG

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RICHARD ARTHUR REMNANT

A practicum submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF NATURAL RESOURCES MANAGEMENT

ABSTRACT

Once restricted to the eastern coast of North America, the Atlantic form of rainbow smelt (Osmerus mordax) are now found throughout much of Ontario, including waters of the Winnipeg River drainage basin. Three specimens collected in 1990 and two more taken in 1991 support the statement that rainbow smelt are now present in Lake Winnipeg. The colonization of lakes by rainbow smelt often has occurred with concomitant changes in native fish populations. The recent arrival of the rainbow smelt in Lake Winnipeg is viewed with apprehension by fishery managers and resource users alike, given the information available regarding their interactions with native species.

Winnipeg River drainage basin lakes of Manitoba and northwestern Ontario were surveyed for the presence of rainbow smelt in 1989 and 1990. Walleye were sampled from the Lake Winnipeg commercial fishery in 1990, and stomachs were examined for the presence of rainbow smelt. Literature dealing with lakes Erie and Simcoe, and other smelt-impacted lakes was reviewed to predict the potential impact of rainbow smelt on the fishery resources of Lake Winnipeg, and recommend management measures.

Rainbow smelt were collected from a number of locations in Winnipeg River drainage basin waters of Ontario. One rainbow smelt was identified from 508 walleye stomachs with identifiable contents from Lake Winnipeg. Rainbow smelt are predicted to colonize Lake Winnipeg, however, their success may be limited by the sub-optimal habitat offered. Anticipated effects on the native fish community include declines in lake whitefish and lake herring stocks due to predation by, and competition with rainbow smelt, and increased mercury levels in the flesh of walleye and sauger as they switch to a diet of smelt. These interactions will affect the commercial, sport and subsistence fisheries to varying degrees, depending upon the amount of success rainbow smelt have in colonizing Lake Winnipeg.

In conclusion, it is suggested that consistent monitoring of the colonization of Lake Winnipeg by rainbow smelt is integral to the proper management of Lake Winnipeg's changing fish community. Other management measures recommended at this time are designed to reduce the potential for further introductions into other bodies of water.

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Chapter I

INTRODUCTION

1.1 BACKGROUND INFORMATION

The range of the rainbow smelt (Osmerus mordax) in the inland waters of North America has been increased substantially as a result of planned introductions by fishery managers, intentional or unintentional introductions of fish waste or unused baitfish by anglers, or dispersal from a point of introduction. Once restricted to the eastern coast of North America, it occurs naturally in both landlocked and anadromous forms (Scott and Crossman 1979). First taken from the Great Lakes in the 1920s, rainbow smelt are now found throughout much of Ontario (Evans and Loftus 1987).

Rainbow smelt were first reported from waters of the upper Rainy River in 1972 (Campbell et al. 1991). It is presumed that they gained access to this tributary of the Winnipeg River by an unauthorized introduction of fish waste or unused baitfish. Rainbow smelt recently have been collected from several other water bodies in the upper Winnipeg River drainage basin (Barton et al. 1990). Three specimens taken in 1990 support the statement that rainbow smelt are now present in Lake Winnipeg (Campbell et al. 1991).

The colonization of new bodies of water by the rainbow smelt often has occurred with concomitant changes in native fish populations. Evans and Loftus (1987) contend that smelt are opportunistic, omnivorous feeders utilizing a range of food types from zooplankton to fish through their life history, thereby interacting with native fishes both directly (predation) and indirectly (competition). Lake whitefish (*Coregonus clupeaformis*) and lake herring (*C. artedii*) are among the more frequently cited examples of species which have reacted negatively to the introduction of smelt. Evans and Loftus (1987), using the Ontario Lake Inventory Database found recruitment declines of native lake whitefish in 13 of 24 lakes which had recently been colonized by rainbow smelt. Other species for which growth rate and recruitment may be adversely affected by the introduction of smelt include lake trout (*Salvelinus namaycush*), walleye (*Stizostedion v. vitreum*), burbot (*Lota lota*) and emerald shiner (*Notropis atherinoides*) (Evans and Loftus 1987). Simultaneously, smelt are utilized as food by virtually all coexisting predators, and improved growth rates of Atlantic salmon (*Salmo salar*), lake trout and walleye are well documented (Evans and Loftus 1987).

Loch et al. (1979) examined the potential effects of exotic species expected to gain access to Manitoba via the Garrison Diversion Unit. They hypothesized that smelt would cause the collapse of lake herring populations in Lakes Winnipeg, Manitoba and Winnipegosis; would have a major negative impact on the lake whitefish fishery in the north basins of Lakes Winnipeg and Manitoba; and negative effects on walleye fisheries in certain locales of the three large lakes (Loch et al. 1979). Decreases in fishermen's incomes due to the reduced abundance of native species and replacement by the lower-valued smelt also could be expected (Loch et al. 1979).

1.2 PROBLEM STATEMENT

The potential impact of an introduction of rainbow smelt on the commercial fish resources of Manitoba has been addressed previously by Loch et al. (1979). In the twelve years that have passed since this work was published, smelt have spread much further west in northwestern Ontario and recently have appeared in Lake Winnipeg. Over the same period of time, the literature dealing with the rainbow smelt's potential for interaction with the native fish community has grown. The recent arrival of the rainbow smelt, combined with the information available regarding their interaction with native species generates a number of questions for fishery managers and resource users alike. Specific components of the problem which need to be addressed include:

What is the means and rate of dispersal of the rainbow smelt?

Which Manitoba bodies of water can the rainbow smelt be expected to colonize?

What will be the consequences of the colonization of Lake Winnipeg by the rainbow smelt?

What steps should be taken to best manage the Lake Winnipeg fishery resource given the arrival of the rainbow smelt?

1.3 OBJECTIVES

The primary objective of this study is the prediction of the potential impact of the rainbow smelt on the existing fishery resources of Lake Winnipeg, and the potential of the rainbow smelt as a resource. Specific objectives include:

1) to delineate the present distribution of the rainbow smelt in the Winnipeg River drainage basin of northwestern Ontario and Manitoba, including Lake Winnipeg proper, and the predicted distribution in Manitoba bodies of water;

2) to assess the potential for impact on Lake Winnipeg's commercial, sport and subsistence fisheries;

3) to recommend management measures based on the findings of the investigation.

1.4 LIMITATIONS

It is recognized that the scope of the research objectives are bold and broad. The extent of the existing literature has influenced the degree to which the objectives have been met. This study does not lend itself to quantification, therefore the latter portion of objective 1, objective 2 and hence objective 3 have been realized based on qualitative observations and predictions.

1.5 IMPORTANCE OF THE PROJECT

The recent arrival of the rainbow smelt is viewed with apprehension by fishery managers and resource users alike. Several questions have been raised. Where and to what extent will rainbow smelt colonize Manitoba? What will be the consequences? Can the rainbow smelt be utilized as a resource? With this practicum I have attempted to answer these questions and recommend measures to be taken to best manage the fishery resources of Lake Winnipeg in the face of a changing fish community.

Chapter II

REVIEW OF RELATED LITERATURE

2.1 INTRODUCTION

The discussion of the relevant literature follows in three parts. These three sections are based upon the four questions or sub-problems which were identified within the problem statement. The first section contains a brief examination of the life history of the rainbow smelt with particular reference made to the type of water bodies it favours. The second section is a discussion of the interactions between smelt and other species and the consequences of colonization of water bodies by the rainbow smelt. The final component of the literature review deals with strategies for managing the rainbow smelt.

2.2 LIFE HISTORY OF THE RAINBOW SMELT

Historically, the Atlantic form of North American rainbow smelt (Figure 1) were primarily anadromous, but with landlocked populations in coastal drainages (Scott and Crossman 1979). Smelt are now known to tolerate and succeed in a variety of freshwater environments. Rainbow smelt are generally considered to favour oligotrophic waters (Jaiyen

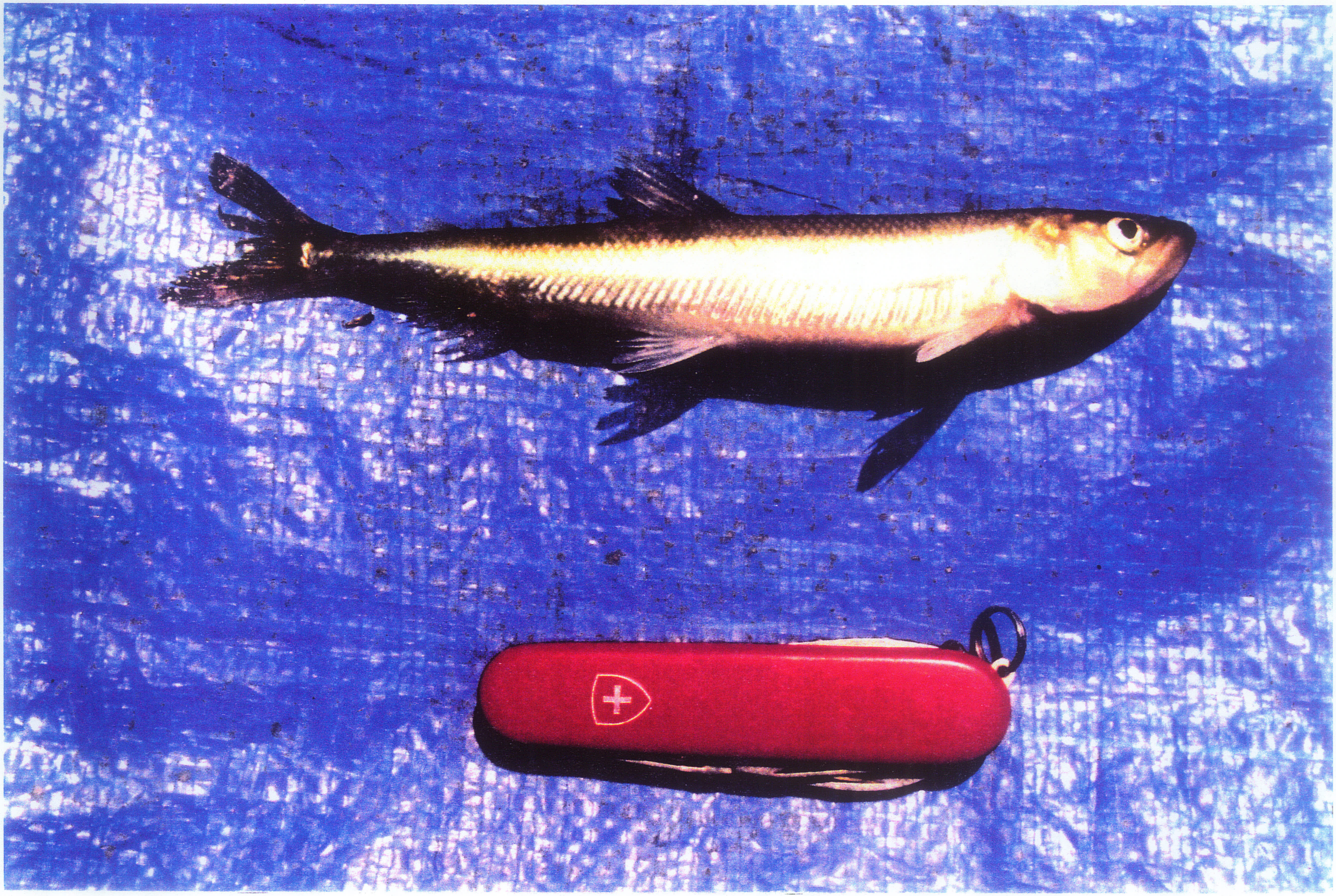

FIGURE 1. RAINBOW SMELT (OSMERUS MORDAX) FORK LENGTH = 155MM.

1975, Swain 1976, Johnson et al. 1977), however, they have colonized virtually all of the lake types found in Ontario, from shallow to deep, small to large, productive to nonproductive, and having sparse to rich fish communities (Evans and Loftus 1987).

Generally smelt only utilize streams or rivers for spawning (Scott and Crossman 1979), but exceptions to this have been documented (Rupp 1959, Burr and Mayden 1980, Gould 1981). Upriver spawning migrations are generally less than 0.5 km in distance (Baldwin 1948), and reference to other upstream travel by rainbow smelt is almost nonexistent in the literature. Exceptions to this are the probable movement by smelt into Lake Superior from Lake Huron and perhaps more notably the specimen taken from the Missouri River 225 km upstream of Lake Sakakawea, considered an upstream migration (Gould 1981). Smelt are considered poor swimmers and have difficulty ascending rapids or small falls with a drop of 20-30 cm (Baldwin 1948, McKenzie 1964).

Rainbow smelt will spawn in streams of almost any type or on shallow gravel shoals and beaches in lakes (Scott and Crossman 1979). They use most types of natural lotic environments for spawning including lake outlets and inlets, upper tributary streams and marshy headwaters (Rupp 1959). Spawning migrations are usually made only a short distance upstream, with the adults moving back to the lake by daybreak (Swain 1976). Rupp (1959) found that while coarse sand and gravel in riffles appear to be the preferred spawning substrate, smelt eggs were also deposited on sand, boulders, mud, aquatic vegetation, brush, flooded grasslands, concrete or wooden sluicebeds and on all types of debris.

Smelt usually are stream spawners, but spawning on gravelly beaches of lakes is common, particularly in stormy weather (Scott and Crossman 1979). Rupp (1965), observed roughly the same mean survival to hatching success rate for beach spawning as for stream spawning in a quantitative study of lakeshore spawning on gravel beaches in Maine. This, he concluded imputed no intrinsic disadvantage on shore spawners, the success depending instead upon site-specific conditions. Deepwater spawning has been reported from Lake Erie (MacCallum and Regier 1970) and from Lake Champlain, New York, where egg deposition was found offshore over a depth range of 14-29 m with concentrations at 17-21 m (Plosila 1984).

Rainbow smelt are nocturnal late-winter or early-spring spawners, usually around the time of ice-out (Swain 1976). Water temperature is generally cited as the release mechanism for spawning, but a wide range of temperatures are indicated by various authors (Swain 1976). It has been suggested that abiotic factors such as photoperiod, water temperature and water chemistry, combined with biotic factors such as overall density of smelt in a spawning school, and the presence of a critical proportion of females interact to initiate spawning (Rupp 1965).

Summarizing the work of various authors, Swain (1976) found survival-to-hatching of smelt eggs in stream sites to vary from 0.05% to 3.70% depending upon the density of eggs. Development takes about 20-30 days at normal water temperatures (4-10°C) and 10 days at 15.6°C (Scott and Crossman 1979).

Rainbow smelt display a eurythermal life history in large, stratified lakes. The nearshore water column to a depth of 60 m is partitioned into three strata, warm-, cool-, and cold-water habitats; utilized by young-of-the-year (YOY), yearlings and adults respectively (Evans and Loftus 1987). Temperature may be an important factor, however, MacCallum and Regier (1970) suggest that the spatial distribution of smelt is governed by a complex interaction of factors rather than any one parameter. Scott and Crossman (1979) report on the sensitivity of smelt to light.

Smelt larvae are about 5.0 mm in length upon hatching, and due to their inability to propel themselves, they immediately drift downstream (Scott and Crossman 1979). Growth is fairly rapid and by the end of August YOY smelt measure roughly 50 mm in length (Scott and Crossman 1979). Larval smelt are pelagic and appear tolerant of a wide range of temperatures (MacCallum and Regier 1970, Brandt et al.

1980), but in midsummer are found most commonly in epilimnetic waters (Ferguson 1965, Dunstall 1984, Evans and Loftus 1987). Brandt et al. (1980) observed a diel movement from the epilimnion to the hypolimnion by larval smelt in Lake Michigan. This movement may be in response to a change in temperature or to a similar migratory pattern displayed by food organisms. The diet of YOY smelt in Lake Huron was found to be comprised almost exclusively of copepods and cladocerans, with the latter being favoured later in the summer when the smelt were larger (Gordon 1961).

Evans and Loftus (1987) state that yearlings generally are found in an intermediate position between the young and adult fish. Rainbow smelt usually do not reach sexual maturity until their second year, although MacCrimmon et al. (1983a) found that yearlings comprised 1.63% of the spawning runs in Lake Simcoe over a fifteen year period. Copepods and cladocerans remain an important part of the yearling smelt diet, but insects and fish also are eaten (Evans and Loftus 1987).

After spawning, adult rainbow smelt move away from nearshore areas (Nellbring 1989). Adult smelt in large, stratified lakes generally occupy the hypolimnion in summer (Swain 1976, Evans and Loftus 1987). The diel movement of adult smelt in stratified lakes from the lake bottom up into the water column at night, often up through the thermocline into the epilimnion, has been well documented by many workers

(Brandt et al. 1980, Heist and Swenson 1983, Evans and Loftus 1987). Following the breakup of thermal stratification in the fall/early winter, adult smelt move into shallower water, probably as a response to declining temperatures (Rupp 1959, Dryer et al. 1965). Midwinter distribution is often widely scattered throughout a lake (Jaiyen 1975). Adult smelt begin to school tightly in late winter/spring and move towards shore prior to spawning (Jaiyen 1975).

Adult smelt utilize a variety of food items such as crustaceans, insects and fishes (Gordon 1961). However, smelt are opportunistic feeders and will select the largest and most abundant food items available (Evans and Loftus 1987). Growth rates of smelt are variable (Scott and Crossman 1979), the variation probably being attributable to a number of factors. In some small inland lakes smelt may only attain a maximum length of 100 mm whereas in Lake Ontario smelt have been taken up to 356 mm (Scott and Crossman 1979).

Many smelt populations exhibit post-spawning mortalities, with resultant dead smelt littering beaches during May and June. These mortalities are considered natural and generally are attributed to post-spawning exhaustion (Nepszy and Dechtiar 1972). Rainbow smelt play host to a microsporidian parasite _Glugea_ _hertwigi_, which also may contribute to post-spawning mortality. Nsembukya-Katuramu et al. (1981) found significantly higher _G_. _hertwigi_ counts in 1976 die-off stocks along Lake Erie's north shore than in spawning stocks, but in 1977 found no significant difference. An extensive mortality of YOY smelt in Lake Erie during fall 1969 was attributed primarily to *G. hertwigi* (Nepszy et al. 1978).

G. hertwigi was first found in Lake Erie smelt in 1960, steadily increased in prevalence to a peak at 87% infestation of sampled fish by 1971, and steadily decreased after that so that by 1982 prevalence of infestation was 6.5% in eastern basin smelt and 10% in central basin smelt (Dechtiar and Nepszy 1988). A mass mortality occurred in lakes Michigan and Huron in 1942-43 that eliminated nearly the entire population of smelt (Van Oosten 1947). The cause of the mass mortality was assumed to be a communicable viral or bacterial disease, and by 1946 or 1947, stocks had rebounded to a pre-mortality level (Van Oosten 1947).

A number of factors contribute to the success of the rainbow smelt. The utilization of the spatial, thermal and food resources of the lake bottom and entire water column minimizes intraspecific interactions (Evans and Loftus 1987). As an opportunistic feeder, it has essentially an unlimited diet. Jaiyen (1975) lists the high biotic potential of smelt as a factor contributing to its success. He explains high biotic potential as having early age at first maturity, annual spawning thereafter throughout life and high fecundity.

2.3 INTERACTIONS WITH OTHER SPECIES

As the rainbow smelt has expanded its range across Ontario, concomitant changes to the indigenous fish fauna of various lakes have taken place. The effects of smelt introductions on native fish stocks have been a matter of controversy for many years. The speed or longevity with which smelt colonized the Great Lakes and other bodies of water has been attributed partly to the degree of environmental resistance they encountered (Christie 1974). Several authors have suggested that smelt gained a foothold in a particular body of water at a time when indigenous piscivorous stocks were low (Van Oosten 1937, Smith 1972, Christie 1974). It also has been suggested that increased eutrophication of the Great Lakes and other nearby bodies of water favoured rainbow smelt and alewife (Alosa pseudoharengus) over the existing benthic predators because they were able to make better use of the resultant higher nutrient levels (Ryder et al. 1974, MacCrimmon et al. 1983a).

Studies on the role of the rainbow smelt as a predator and competitor of native fishes were initiated by Creaser (1929) in Lake Michigan. He concluded that smelt were:

> "... an enemy of all smaller fishes, including the young of the commercial species, as well as a competitor for the food of the adults of the larger species."

Christie (1974) postulated that the sheer magnitude of the numerical abundance of smelt makes it almost certain that their colonization has had at least locally significant effects on the indigenous fishes of the Great Lakes. Case studies of smelt invasions indicate instances where relatively neutral coexistance with indigenous species occurs, others where harmonious interactions ensue and still others where possibly malevolent interactions follow. The evidence for these, however, often is correlative and qualitative (Swain 1976, Evans and Loftus 1987).

2.3.1 Smelt as Prey

Rainbow smelt are utilized as food by virtually all coexisting predators, including larger smelt (Evans and Loftus 1987). Following the establishment of smelt in the Great Lakes they became important in the diet of lake trout (Schneberger 1936), and remain an important component in the diet of lake trout and other salmonids of the Great Lakes (Christie et al. 1987, Evans and Loftus 1987). Smelt are equally important in the diet of lake trout in inland lakes (Bridges and Hambly 1971, MacCrimmon and Pugsley 1979, Hassinger and Close 1984). Rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*) and Atlantic salmon also have been shown to utilize rainbow smelt as forage (Bridges and Hambly 1971). Walleye and northern pike (*Esox lucius*) are known to make use of smelt as forage, especially during the spring (Wagner 1972, Berard 1978, Mathers and Johansen 1985). Other documented predators of smelt include brook trout (Salvelinus fontinalis) (Ryan and Kerekes 1988); burbot (Wagner 1972); yellow perch (Perca flavescens), sauger (Stizostedion canadense), white bass (Morone chrysops), and occasionally rock bass (Ambloplites rupestris) and lake whitefish (Evans and Loftus 1987).

Evans and Loftus (1987) state that smelt introductions have had their greatest effect on predator growth rates in small lakes where an alternative prey is limited or lacking. The condition factor of both Atlantic salmon and lake trout in Quabbin Reservoir, Massachusetts was found to vary directly with rainbow smelt abundance (McCaig and Mullan 1960, Bridges and Hambly 1971). Ryan and Kerekes (1988) found that the presence of rainbow smelt in two of six lakes in Newfoundland contributed to greater biomass, larger fish and greater individual growth rates of brook trout in those lakes with smelt. Some walleye stocks in the Great Lakes exhibited good growth rates following the introduction of smelt (Schneider and Leach 1977).

Rainbow smelt were introduced into Lake Sakakawea, North Dakota in 1971 to provide forage for native walleye (Berard 1978). Hiltner (1983) found that walleye had a higher weight/length relationship and a much higher condition factor than in any previous studies on the lake. He found smelt in 84% of the walleye stomachs examined, and attributed the increased growth in the walleye to increasing densities of rainbow smelt in the lake.

The degree of use of rainbow smelt by walleye in a food-poor environment has been demonstrated by Goettl (1990) in Horsetooth Reservoir, Colorado. Prior to the introduction of smelt, walleye fed on crayfish (<u>Oronectes</u> sp.), rainbow trout and small invertebrates. Five years after their introduction, smelt were found to make up 83% of the diet of walleye by volume. While growth rates of walleye have improved from 25-35% for age-classes 1-5, size at age still lags behind the state average, demonstrating further the poor state of the pre-smelt environment (Goettl 1990).

Evans and Loftus (1987), summarizing the works of other authors, report on the elevation of mercury levels in the white muscle of lake trout as they switch to a diet of smelt, particularly in softwater areas. Figure 2 presents the relationship between lake trout length, and percentage of lakes where the mercury level in lake trout is above the acceptable level for any consumption (1.5 ppm), in lakes with and without smelt. Lake trout are shown to contain 1.5 ppm mercury in a greater proportion of lakes with smelt, than in those without, for all length intervals of lake trout.

MacCrimmon et al. (1983b) observed a pronounced acceleration in growth rate and an increase in mercury accumulation as lake trout switched to a piscivorous diet (rainbow smelt), from a diet of invertebrates in Tadenac Lake, Ontario. Akielaszek and Haines (1981) reported that lake trout

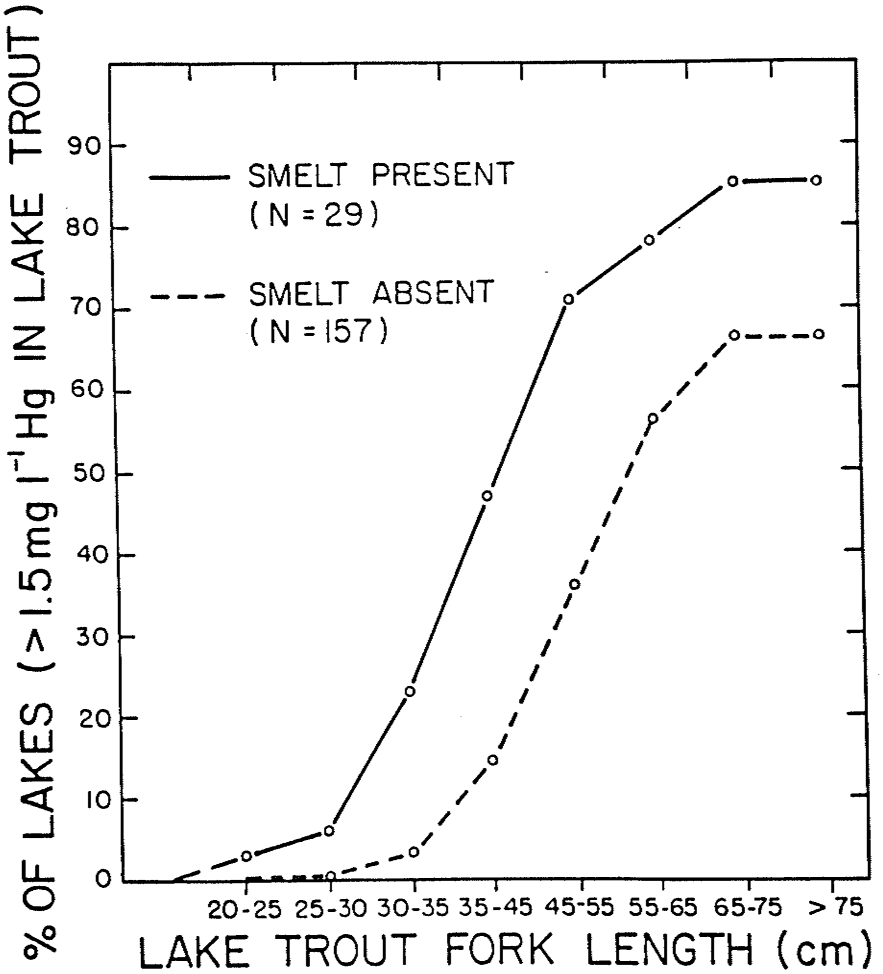

FIGURE 2. THE RELATIONSHIP BETWEEN LAKE TROUT LENGTH AND PERCENTAGE OF LAKES WHERE LAKE TROUT MERCURY LEVEL IS ABOVE 1.5 PPM, IN ONTARIO LAKES WITH (N=29) AND WITHOUT (N=157) RAINBOW SMELT (FROM EVANS AND LOFTUS UNPUBLISHED).

taken from lakes containing smelt exhibited higher mercury levels than lake trout taken from nearby lakes where smelt were absent, and concluded that smelt were an important vector of mercury uptake by lake trout. Mathers and Johansen (1985) concluded that walleye in Lake Simcoe, Ontario, accumulated higher levels of mercury than did pike, primarily because smelt was a much more important item in the diet of walleye as compared to pike. Recent work by Rasmussen et al. (1990) has shown that each additional trophic level contributed about a 3.5 fold biomagnification factor to PCB concentrations in lake trout. The authors concluded that species introductions that lengthen food chains lead to increased contaminant levels in top predators.

Another area of concern is a possible link between a diet of rainbow smelt and low reproductive success in lake trout. The hypothesis behind this is that smelt, and even moreso alewife, possess high levels of thiaminase, an enzyme which may inhibit lake trout reproduction. This link was reportedly developed during the 1960s as a possible explanation for the failure of lake trout reproduction in Lake Michigan (D. Evans, Ontario Ministry of Natural Resources, pers. comm.), but its absence from the primary literature appears to indicate that it fell out of favour. Dorr et al. (1981) make no mention of the link between a smelt or alewife diet and lake trout reproductive failure in their discussion of five hypotheses which may explain the lack of natural recruitment of lake trout beyond the fry stage in Lake Michigan. The issue currently is being re-addressed through research at the University of Minnesota. A smelt diet earlier was implicated in the reproductive failure of mink (D. Evans, Ontario Ministry of Natural Resources, pers. comm.), again due to high levels of thiaminase. Wolfert (1981) cites the failure of ranched mink to successfully reproduce when fed a diet of uncooked smelt, as a reason why a commercial fishery for rainbow smelt never really became established in U.S. waters of Lake Erie.

2.3.2 Smelt as a Predator

There is strong circumstantial evidence that the establishment of smelt in some lakes has caused a shift in the makeup of the zooplankton community (Evans and Loftus 1987). Smelt are known to prey on forage fishes such as shiners, sticklebacks, sculpins and darters but the specific effects of smelt predation on these species is not known (Evans and Loftus 1987). Crowder (1980) implicates alewife and to a lesser extent rainbow smelt predation on emerald shiner eggs and larvae in the demise of the latter from their role as an important forage species in Lake Michigan. Smelt have also been found to make use of fishes such as suckers, yellow perch and burbot (Wagner 1972). Several authors have reported on the incidence of cannibalism by smelt (Gordon 1961, Jaiyen 1975, Evans and Waring 1987). Berard (1978) examined 40 smelt from a spawning run in Lake Sakakawea and found smelt eggs in 78% of them. Little evidence for predation by rainbow smelt on larval lake trout or walleye has been found (Swain 1976), however, because smelt often occur in very large populations, even minor individual predation could be very significant (Scott and Crossman 1979). Larval lake trout were found in 2 of 2,991 smelt stomachs examined from West Bearskin Lake, Minnesota (Hassinger and Close 1984).

Loftus and Hulsman (1986), working on Twelve-Mile Lake in Ontario have shown, perhaps, the first concrete evidence of predation on larval lake whitefish by rainbow smelt. For seven weeks in 1984 they observed heavy predation by post-spawning smelt on emerging coregonid larvae. During the week when the larvae were most abundant, they occurred in 93% of the smelt stomachs containing food, and corresponding average daily consumption was 8.4 larvae per smelt (Loftus and Hulsman 1986). They observed that little or no recruitment of young whitefish to the population had taken place since 1975, and suggested that natural mortality (including the effects of heavy predation) could have been 100%.

Loftus and Hulsman (1986) proposed that the primary cause of the recruitment failure of the whitefish population in Twelve-Mile Lake was predation by smelt, and that their study is the first recorded case of direct predation by smelt on larval lake whitefish. They partially attributed this observation to the fact that Twelve-Mile Lake is small, with little refuge available for larval lake whitefish. However, they suggested that because smelt are opportunistic feeders, they probably feed on lake whitefish larvae in large lakes as well, when they are available. Rainbow smelt predation on larval lake herring also has been observed in the Great Lakes (Anderson and Smith 1971, Selgeby et al. 1978, Crowder 1980).

2.3.3 Smelt as a Competitor

The evidence for competition between rainbow smelt and indigenous species has been largely circumstantial, based on habitat and diet overlaps, and comparisons of changes in growth, survival, and abundance of species, pre- and post-smelt (Evans and Loftus 1987). Smelt have been implicated as a competitor of a variety of native species including lake whitefish (Berst and Spangler 1972, Wells and McLain 1973, Evans and Waring 1987), lake herring (Anderson and Smith 1971, Berst and Spangler 1973, Wells and McLain 1973), walleye (Forney 1965, Wells and McLain 1973, Schneider and Leach 1977), and lake trout (Dryer et al. 1965, Hassinger and Close 1984). Evidence of competition with fishes of the Great Lakes followed from the disease-induced mass mortality of smelt in 1942-43 (Van Oosten 1947). Smelt successfully invaded lakes Michigan and Huron by the late 1930s when many of the native fish stocks were low (Jaiyen 1975). Strong year-classes of lake whitefish and lake herring were produced in both Lakes Michigan and Huron, and a strong year-class of walleye was produced in Lake Michigan following the smelt crash (Evans and Loftus 1987). The decline of the deepwater cisco (*Coregonus johannae*) in Lake Ontario (Christie 1972), the extirpations of the shortnose cisco (*Coregonus reighardi*) in lakes Michigan and Ontario (Parker 1988), and the shortjaw cisco (*Coregonus zenithicus*) in lakes Michigan and Huron (Houston 1988) are tied to a series of factors including increased eutrophication, overexploitation and competition/predation from the introduced alewife and rainbow smelt.

Invading smelt do not always bring about the total collapse of lake whitefish or lake herring populations. Whitefish stocks in Lake Superior increased in the face of a prospering smelt population and in Lake Ontario whitefish persisted long after the smelt invasion (Christie 1974). In two of the four Ontario lakes with indigenous populations of smelt, good populations of coregonids now exist and smelt are almost absent (Evans and Loftus 1987).

2.4 MANAGEMENT OF THE RAINBOW SMELT

2.4.1 Commercial and Sport Fisheries

As invasion of Manitoba waters by the rainbow smelt appears imminent, potential uses of the resource and management schemes must be considered. Commercial, and to a lesser extent, recreational smelt fisheries were established after smelt became abundant in the Great Lakes. Some commercial production had begun in the Great Lakes by the early 1930s (Christie 1974), and in 1952 2.7 million kg were harvested (Frick 1965). A successful trawl fishery for smelt in Lake Erie began in 1959 (MacCallum and Regier 1970). Smelt ranked first in weight among all Great Lakes fishes in Canadian commercial landings in 1966 (Scott and Crossman 1979). Types of gear used in the commercial smelt fisheries of the Great Lakes have included small mesh gill nets, pound nets and bottom trawls (MacCallum and Regier 1970, Jaiyen 1975). The market demand for smelt as human food was high during the 1950s, but much of the catch was used as animal food (Jaiyen 1975).

Sport fisheries for rainbow smelt also have developed in Ontario. Sport fisheries are usually dipnet fisheries conducted during spawning, but some hook and line fisheries for rainbow smelt do exist. In 1973, 36,810 sport fishermen spent 95,850 angler-days in the Michigan waters of Lake Michigan dipping for smelt, yielding 0.8 million kg of smelt, about twice the commercial catch (Jaiyen 1975).

The value of the smelt catch generally has not served to replace pre-smelt catches. When smelt first colonized Green Bay, Lake Michigan, their abundance was so great that some commercial fishermen ceased fishing to avoid the nuisance (Schneberger 1936). Christie (1974) stated that the shift from the historic coregonine and lake trout commercial fisheries in the Great Lakes to yellow perch, rainbow smelt and alewife fisheries has brought higher associated capture costs and lower market values. The general result of species composition changes has been a reduction in gross revenue and failure of many commercial fishing ventures (Christie 1974).

Conflicting opinions exist on the value of recreational harvest of smelt during spawning. Laundergan (1976), in a survey of smelters in the Duluth, Minnesota area during the years 1971-1974 found that the economic benefit of recreational smelt fishing on the Duluth economy was negligible, while economic and social costs were fairly high. Social costs of smelt harvesting include the public expense of increased law enforcement, provision of sanitation facilities and garbage cleanup, while private expenditures include damage to residents' property. Raab and Steinnes (1979), using traditional benefit-cost analysis found the benefits to the residents of Duluth to be in excess of $150,000, while the costs were estimated at less than $20,000. Benefit-cost analysis clearly indicated that the recreational smelt fishery provides an overall benefit to the community of Duluth. It did not determine, however, whether those benefits were properly distributed to those bearing the costs, the landowners (Raab and Steinnes 1979). The environmental cost due to a reduction in stream habitat quality also was not considered in this analysis.

An economic benefit that was enjoyed by many communities of the Great Lakes following the arrival of smelt were annual smelt-dipping festivals that attracted fishermen and thousands of other visitors every year (Van Oosten 1947, Jaiyen 1975). Jaiyen (1975) reported that although the sport fishery was still important, the smelt-dipping festivals were much less common by the 1970s.

2.4.2 Management Strategies

Rainbow smelt populations are subject to large, apparently natural fluctuations. It has been demonstrated that no clear relationship exists between stock size and recruitment (Kircheis and Stanley 1981, Henderson and Nepszy 1989). At the same time, smelt have been found to exhibit intraspecific density-dependent effects to limit abundance (Evans and Waring 1987, Henderson and Nepszy 1989). These somewhat contradictory statements illustrate the complexity of management of the rainbow smelt, and perhaps indicate why there is very little literature available on the management of the species.

Jaiyen (1975) developed a decision-making framework for the management of a fish species. He applied the framework to the rainbow smelt population in Lake Michigan, but no thorough management strategy was developed. He found the smelt population to be underexploited and increasing in size, but recommended no change due to: 1) contemporary low market demand, 2) expected increase in fishing pressure, and 3) expected increase in predation by piscivorous species.

The Northwestern Region of the Ontario Ministry of Natural Resources (OMNR) currently is dealing with the management of introduced populations of rainbow smelt in both the Red Lake and Kenora Districts. The recommended strategy at this time is to control the introduction of smelt into other water bodies by increasing public awareness of the potential effects of smelt introductions through a variety of media sources (OMNR 1988a, 1988b). Most recently OMNR has put into place a total ban on all fishing for smelt, and the use of live or dead smelt as bait in four fishing regulation divisions of northwestern Ontario (OMNR 1990a). This is an attempt to prevent smelt from becoming established in waters where they presently don't exist.

Smelt numbers in some of the Great Lakes recently have begun to fall, and in some cases rebounding salmonid populations are probably the cause of the declines (Christie et al. 1987, Evans and Waring 1987). Evans and Waring (1987) suggest that lake trout in particular appear to have a profound effect on species composition, and by manipulating lake trout density the structure of the fish community can be managed, at least to some extent. Recent quota reductions in the Lake Erie smelt harvest (OMNR 1990b) suggest that overexploitation may be responsible for the decline of smelt stocks in that lake.

2.5 APPLICABILITY OF THE LITERATURE TO THE STUDY

The review of the existing literature in the three categories presented is intended as a discussion of the major issues facing Manitoba's fishery managers. The literature presented underscores the importance of the project. This review provides the base upon which to build and develop the study.

Chapter III

METHODOLOGY

3.1 INTRODUCTION

In this chapter the methodology used in the study is documented. Methods are discussed based upon the specific objectives to which they refer.

3.2 DISTRIBUTIONAL DATA

The present distribution of the rainbow smelt in the Hudson Bay drainage basin waters of northwestern Ontario and Minnesota is reported in Barton et al. (1990) based on work conducted in 1989. This author was a member of that team and therefore the methods used and results obtained from the Canadian portion of that study are presented here. Lakes chosen for surveying were selected using a number of criteria. Consultation with staff from the Ontario Ministry of Natural Resources yielded a number of candidate lakes with reported or suspected smelt populations. Beyond that, lakes were chosen primarily on the basis of suitable habitat or proximity to a previously confirmed location. Regardless of the suitability of the habitat, lakes located downstream of known populations were sampled.

Once chosen, lakes were sounded to locate suitable fishing sites using a Micronar M-700 electronic depth sounder/ fish finder mounted on a 65 H.P. outboard-powered 5.9 m aluminum boat. Vertical temperature profiles were conducted using a YSI 42SC tele-thermometer, generally in the deeper parts of the lake as determined from bathymetric maps and sounding. Gill nets (1.5 m deep, 8, 10 and 13 mm bar mesh), were set overnight at or below the thermocline, if one existed. If large schools of forage fishes were identified on the fish finder at, or below the thermocline, nets were set at that level. Large floats were used to suspend the net at the thermocline, or at depths of fish abundance as determined by sonar. Occasionally nets were set diagonally from the surface to the bottom, with progressively depth-graded floats in between to cover as much of the water column as possible. Bottom trawling, using a 6 m otter trawl was carried out where depth and substrate permitted. Seine hauls were conducted along beaches at a few locations.

The 1990 survey consisted of lakes chosen primarily to fill gaps in the existing data. One lake sampled in 1989 was re-sampled in 1990 because it appeared to be a very suitable candidate for smelt colonization. The survey was expanded in 1990 to include suitable Manitoba bodies of water located on the Winnipeg River proper. Initially Lake Winnipeg was not to be included in the survey due to its size, however, upon capture of a rainbow smelt in commercial gear in September 1990, the small mesh gear was fished in the area from which the specimen was captured. A local commercial fisherman was hired to fish the small mesh gear. One body of water not within the Winnipeg River drainage basin, but on another east side Lake Winnipeg tributary was tested because it was road accessible from Red Lake, Ontario, a lake with an existing smelt population. Techniques employed in 1990 were essentially the same as in 1989 except that one gill net gang consisted of five panels with mesh sizes ranging in size from 6 mm bar to 16 mm bar. Other nets used in 1990 were the same as those used in 1989. No trawling or seining were conducted.

The potential presence of spawning runs of rainbow smelt in five Lake of the Woods tributary creeks was monitored over a two night period during the anticipated spawning season. Rush Bay Creek was chosen because smelt had been reported from that system the previous year. The others were chosen primarily for ease of access and to give a broad spatial representation of sites around the northeastern portion of the lake. At two of the sites, small mesh hoop nets with 1 m openings and 6 m leading wings were set overnight to catch any upstream migrants. The other three sites were visually inspected after dark with flashlights to check for any upstream fish movement.

The potential presence of smelt in Lake Winnipeg also was investigated by examination of the stomach contents of commercially caught walleye in the spring. The majority of walleye caught in the spring Lake Winnipeg commercial fishery arrive at the Freshwater Fish Marketing Corporation plant in Transcona in the round. Fish from all parts of the lake therefore could be sampled at one location.

The number of walleye stomachs containing smelt in a sample (x), is a function of the proportion of walleye stomachs containing smelt in the population (p) and the sample size (n). The probability (Pr) of not detecting smelt in the sample can be expressed as Pr(x=0). The probability of detecting at least one smelt in the sample can therefore be expressed as Pr(x≥1) or 1-(Pr(x=0)). This last expression can be rewritten as an equation,

$$Pr(x \geq 1) = 1-[1-p]^{n},$$

where Pr = the probability of detecting at least 1 smelt,
x = the number of walleye stomachs containing smelt in a sample,
p = the proportion of walleye stomachs containing smelt in the population, and
n = sample size.

In Lake Simcoe, for example, Mathers and Johansen (1985) found the mean annual proportion of walleye stomachs containing smelt (p) to be 68%. If p = 0.68 is inserted into the equation and a sample size of 10 is assumed, the resulting probability of detection of at least one smelt is 0.9999887.

Applying this equation to the Lake Winnipeg situation it must first be assumed that smelt are present, but that the proportion of walleye stomachs containing smelt in the population is low. If a value of $p = 0.01$ is inserted into the equation, it follows that a sample size of 500 is required to obtain a 99% probability of detecting at least one smelt. This can be reworded to state that a sample size of 500 stomachs with identifiable non-smelt contents predicts with 99% confidence that rainbow smelt abundance in walleye stomachs is less than 1%.

Stomachs from adult walleye were extracted in May and June 1990. Whenever possible walleye were sampled representatively from all areas of the lake. Stomachs were fixed in 10% formalin and after a two week period were transferred to 70% ethanol. They were examined for their contents between September and December 1990. Fish remains were identified using a number of anatomical characteristics as permitted. These included whole body appearance (when applicable), size and type of scale, number of vertebrae, vertebral form and appearance, presence or absence of lingual teeth, location of point of attachment of ribs on individual vertebrae, ratio of rib length to standard length, and characteristics of the caudal skeleton. Suspected rainbow smelt were submitted to Dr. K.W. Stewart, an ichthyologist at the University of Manitoba for verification.

The future distribution of the rainbow smelt within Manitoba was predicted using topographical maps indicating which bodies of water were directly accessible from the Winnipeg

River. Lakes also were considered to be candidates for smelt colonization if they were located in areas of cottage development or sport fishing activity. Information on lake location, morphometry, presence or absence of lake trout and walleye, and resource use was obtained from the Fisheries Habitat Section, Manitoba Department of Natural Resources. This information was compared with ideal and satisfactory conditions for smelt as described in the literature in order to predict future distribution.

3.3 POTENTIAL FOR IMPACT ON THE FISHERIES OF LAKE WINNIPEG

As mentioned, it has previously been predicted that rainbow smelt will colonize Lake Winnipeg (Loch et al. 1979). The potential impacts on the commercial, sport and subsistence fisheries of Lake Winnipeg were examined by first presenting in detail case histories of smelt colonization, and accompanying changes in species composition and the related fisheries in relatively similar smelt-impacted lakes Erie and Simcoe. The physical, chemical and biological characteristics of these lakes were examined in light of how they suit the life history of the rainbow smelt. The role of smelt in commercial, sport and subsistence fisheries also was examined.

Physical, chemical and biological characteristics of Lake Winnipeg were analyzed. The degree of similarity between Lake Winnipeg and lakes Erie and Simcoe was used as one tool in predicting the success of the rainbow smelt in Lake Winnipeg. The potential impact of smelt on the native fish community was then translated to a range of impacts on the commercial, sport and subsistence fisheries.

Three analyses were carried out with existing data sets. Unpublished mercury survey data from the Department of Fisheries and Oceans, Inspection Services Branch was used to determine the relationship between mercury and weight or length of walleye and sauger caught in the Lake Winnipeg commercial fishery. Regression analyses of mercury versus weight, and mercury versus length were computed for each species. Fish from 1980 to the present were selected for analysis, 1980 being arbitrarily chosen as a cut-off date to attempt to avoid any mercury-contaminated fish from the early 1970s.

To determine if a relationship existed between lakes containing walleye with, and without smelt, similar to that presented in Figure 2 for lake trout and smelt, the Ontario Lake Inventory Database (OLID) and the Guide to Eating Ontario Sport Fish (OME/OMNR 1990) were consulted. All lakes with either walleye and no smelt, or walleye and smelt, were selected from OLID. All lakes in the above two categories which had walleye mercury data available in the Guide to Eating Ontario Sport Fish were selected for analysis. The cumulative frequency of lakes where walleye mercury levels reached 0.5, 1.0 and 1.5 ppm by walleye length range were plotted for lakes with, and without smelt.

To determine an economic relationship between a decreased harvest of lake whitefish and an increased harvest of rainbow smelt in Lake Winnipeg over time, a range of hypothetical scenarios were created. Lake Winnipeg whitefish harvest at year zero was determined by using the mean whitefish harvest over the last 5 years (ManDNR various). Decline in whitefish harvest was continued for twenty years, based on the Lake Erie example (Baldwin et al. 1979). Landed value (price/kg) of the whitefish harvest in Lake Winnipeg was determined by using the mean landed value for Manitoba whitefish during the last 5 years (DFO 1987,1988,1989,1990a,1991).

Rainbow smelt harvest in Lake Winnipeg was modelled after that of Lake Erie. Harvest of smelt in Lake Erie began roughly 5 years after the beginning of the final whitefish decline, initial harvest accounted for 2.15% of the total catch and increased for a 10 year period, followed by a 5 year period of relatively constant harvest (Baldwin et al. 1979). The landed value (price/kg) of rainbow smelt harvest in Lake Erie (R. Loblaw, Ontario Ministry of Natural Resources, pers. comm.) was used for Lake Winnipeg.

Annual total landed value was calculated by multiplying the harvest by the landed value (price/kg). Annual present value of the landed value was calculated by dividing the annual total landed value by the discount factor,

$$(1+r)^t$$

where r = discount rate (interest rate)
t = any future year t

as per Mishan (1972). Present value of the landed value is used because it incorporates the value of money over time (discount or interest rate) into the analysis, and therefore allows direct comparison of a stream of values. Present value was summed so that benefits over time could be compared using a single value. Annual present value assuming a constant harvest of whitefish at a quantity equal to year zero over a twenty year period also was calculated. The sum of the present value of the whitefish and smelt harvest over twenty years was compared with the sum of the present value of constant whitefish harvest.

3.4 MANAGEMENT STRATEGIES

The primary literature was further searched for any remaining information dealing with the actual management of the rainbow smelt. Letters requesting information were sent to the respective officials responsible for fisheries management in all provinces (6) and states (18) that were known, or expected to contain rainbow smelt, in order to gather whatever information was available. An example of the letter sent is enclosed as Appendix 1. The resultant information available was then summarized and presented.

The management techniques and strategies available were then examined for their applicability to Lake Winnipeg.

Management measures for Lake Winnipeg were recommended based upon the results of the investigation.

Chapter IV

RESULTS AND DISCUSSION

4.1 DISTRIBUTIONAL DATA

The lakes surveyed for rainbow smelt during 1989 and 1990 in the Winnipeg River drainage basin waters of Manitoba, northwestern Ontario and Minnesota are illustrated in Figure 3. A summary of the selected results of those lakes surveyed for rainbow smelt in northwestern Ontario and Manitoba during 1989 and 1990 are presented in Table 1. Ten of the forty nine lakes surveyed were found to contain smelt. The complete results of the lake surveys including effort and numerical catch by species are displayed in Appendix 2. The remaining lakes within the Winnipeg River drainage basin known to contain rainbow smelt are listed in Table 2 with year of collection and reference. Rainbow smelt are present in Lake Winnipeg as mentioned previously, although they were not detected by lake surveys. The distribution of rainbow smelt in the Winnipeg River drainage basin, including Lake Winnipeg proper, is illustrated in Figure 4.

Figure 5 shows the Lake of the Woods locations sampled for spawning runs in the spring of 1990. The results of the spring investigation are presented in Table 3. No rainbow smelt were caught or observed in any of the creeks.

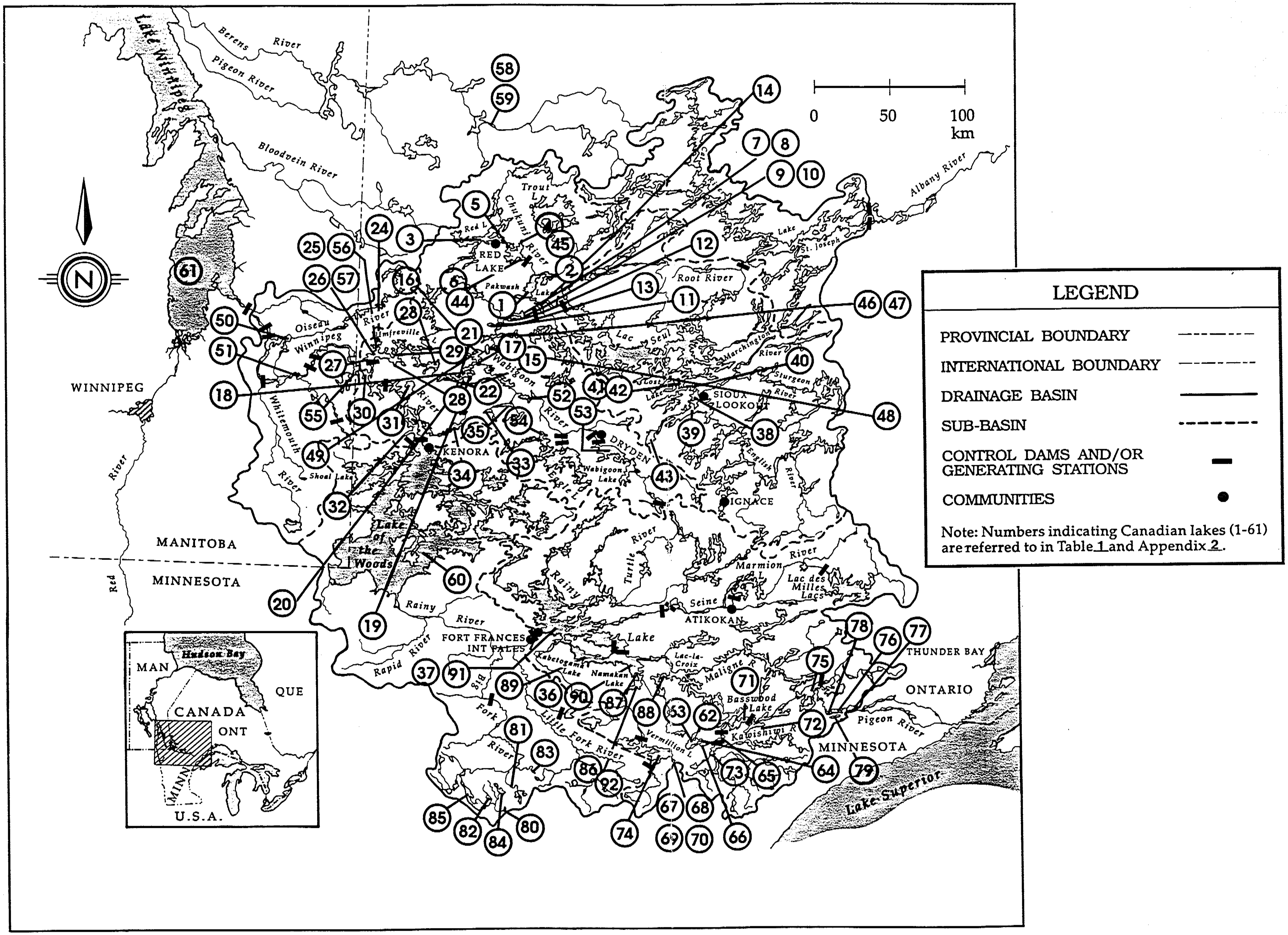

FIGURE 3. LAKES SURVEYED FOR RAINBOW SMELT DURING 1989 AND 1990 IN WINNIPEG RIVER DRAINAGE BASIN WATERS OF MANITOBA, NORTHWESTERN ONTARIO AND MINNESOTA.

TABLE 1. A SUMMARY OF THE RESULTS OF THE LAKE SURVEYS FOR RAINBOW SMELT IN NORTHWESTERN ONTARIO AND MANITOBA DURING 1989 AND 1990

DATE	NUMBER ON FIGURE 3	LAKE NAME	SURFACE TEMP°(C)	BOTTOM TEMP°(C)	MAXIMUM DEPTH (m)	SMELT
89/06/06-10	1	PAKWASH	17.0	11.0	15.0	YES
89/06/11	2	BRUCE	18.5	18.5	3.0	NO
89/06/15	3	RED	14.0	7.0	31.0	YES
89/06/18	4	GULLROCK	19.0	11.0	13.5	YES
89/06/17	5	KEG	20.0	12.0	12.0	YES
89/06/19	6	TWO-ISLAND	18.0	12.5	9.5	YES
89/06/29	7	BARNSTON	18.5	18.5	8.5	NO
89/06/30	8	CLEAR	21.0	4.5	16.5	NO
89/06/30	9	JOHNSON	22.5	10.0	11.0	NO
89/07/01	10	WEGG	24.5	16.5	11.0	NO
89/07/02	11	UNEXPECTED	22.0	13.5	13.5	NO
89/07/02	12	GOOSE	21.5	18.5	10.0	NO
89/07/02	13	WILCOX	21.5	18.5	5.0	NO
89/07/04	14	CAMPING	22.5	20.5	7.0	NO
89/07/08	15	GRASSY NARROWS	23.0	8.5	15.0	NO
89/07/09	16	TIDE	21.5	21.0	18.5	YES
89/07/09	17	BALL	21.0	20.5	12.5	NO
89/07/09	18	INDIAN	21.5	19.5	18.5	YES
89/07/10	19	LITTLE FOX	21.0	20.5	15.0	NO
89/07/10	20	SHOE	23.5	12.0	6.0	NO
89/07/10	21	BIG FOX	21.5	20.5	9.5	NO
89/07/11	22	LOUNT	21.5	20.5	13.0	NO
89/07/11	23	SEPARATION	21.5	21.0	17.0	NO
		UMFREVILLE				
89/07/21	24	(TWELNOR LAKE)	27.0	5.5	29.5	NO
89/07/21	25	(GIB LAKE)	26.0	8.0	21.5	NO
89/07/21	26	(MAIN BODY)	24.5	10.5	22.0	NO
89/07/22	27	(POWERLINE BAY)	26.0	4.5	30.5	NO
89/07/22	28	(GOSHAWK LAKE)	18.5	8.5	18.5	NO
89/07/22	29	(ONEMAN LAKE)	24.0	9.5	26.0	NO
89/07/23	30	TETU	23.0	21.0	15.0	NO
89/07/24	31	BIG SAND	25.0	6.0	40.0	NO
89/07/25	32	LULU	27.0	9.5	12.5	NO
89/07/31	33	FAVEL	23.0	7.0	24.5	YES
89/08/01	34	SILVER	24.0	6.5	28.0	NO
89/08/01	35	CANYON	24.0	10.0	16.5	NO
89/08/08	36	NAMAKAN	22.0	9.5	23.0	NO
89/08/09	37	RAINY	25.5	10.5	31.0	NO
89/08/14	38	ABRAM	21.0	7.5	29.0	YES
89/08/15	39	MINNITAKI	21.0	9.0	25.0	NO
89/08/16	40	PELICAN	-	-	13.0	NO
		LAC SEUL				
89/08/16	41	(ITALIAN BAY)	23.0	5.0	19.5	NO
89/08/16	42	(KEEWATIN BAY)	23.0	7.0	18.0	NO
89/08/17	43	SANDYBEACH	21.0	7.0	35.0	YES
89/08/18	44	TWO-ISLAND	21.5	20.0	10.0	YES
89/08/19	45	GULLROCK	21.0	20.0	13.0	YES
89/08/28	46	OAK	20.0	6.0	21.0	NO
89/08/29	47	OAK	20.0	5.0	30.5	NO
89/09/01	48	MAYNARD	20.0	14.0	16.5	NO
89/09/02	49	DUMPY	20.5	4.5	25.0	NO
90/06/18	50	LAC DU BONNET	20.0	11.0	14.0	NO
90/06/19	51	NUTIMIK	17.0	17.0	11.0	NO
90/06/20	52	CLAY	19.0	8.0	19.0	NO
90/06/21	53	WABIGOON	17.0	15.0	13.0	NO
		EAGLE				
90/06/22	54	(VERMILLION BAY)	18.5	11.0	20.0	NO
		EAGLENEST				
90/06/23	55	(GREEN LAKE)	22.0	16.0	8.0	NO
		UMFREVILLE				
90/06/24	56	(GIB LAKE)	20.0	6.5	21.0	NO
90/06/24	57	(MAIN BODY)	20.0	8.5	25.0	NO
90/07/31	58	BERENS	21.5	5.5	9.5	NO
90/07/31	59	BERENS	22.0	22.0	7.5	NO
		LAKE OF THE WOODS				
90/08/28-29	60	(NEAR MORSON)	22.5	22.5	8.0	NO
90/10/09,16,21	61	WINNIPEG (NEAR ARNES)	-	-	10.0	NO

TABLE 2. A SUMMARY OF THE KNOWN OCCURRENCES OF RAINBOW SMELT IN THE WINNIPEG RIVER DRAINAGE BASIN

PROVINCE/ STATE	LAKE (WATERSHED)	YEAR COLLECTED	REFERENCE
MANITOBA	WINNIPEG	1990	CAMPBELL ET AL. (1991)
ONTARIO	ABRAM (LAC SEUL)	1989	BARTON ET AL. (1990)
	BEAVERHOUSE (RAINY RIVER)	1983	GJTC (1990)
	EVA (RAINY RIVER)	1972	CROSSMAN (1976)
	FAVEL (WABIGOON RIVER)	1987,1989	BARTON ET AL. (1990)
	FRENCH (RAINY RIVER)	1972-1976	CROSSMAN (1976)
	GULLROCK (CHUKUNI RIVER)	1989	BARTON ET AL. (1990)
	INDIAN (ENGLISH RIVER)	1989	BARTON ET AL. (1990)
	KEG (CHUKUNI RIVER)	1989	BARTON ET AL. (1990)
	LITTLE EAGLE (WABIGOON RIVER)	1962	CAMPBELL ET AL. (1991)
	PAKWASH (CHUKUNI RIVER)	1989	BARTON ET AL. (1990)
	PICKEREL (RAINY RIVER)	1977	GJTC (1990)
	RED (CHUKUNI RIVER)	1987,1989	BARTON ET AL. (1990)
	SANDYBEACH (LAC SEUL)	1989	BARTON ET AL. (1990)
	SEPARATION (ENGLISH RIVER)	1988	CAMPBELL ET AL. (1991)
	TIDE (ENGLISH RIVER)	1989	BARTON ET AL. (1990)
	TROUT (RAINY RIVER)	1980	GJTC (1990)
	TWO-ISLAND (CHUKUNI RIVER)	1989	BARTON ET AL. (1990)
MINNESOTA	BURNTSIDE (RAINY RIVER)	1972	CAMPBELL ET AL. (1991)
	EAGLENEST 1 (VERMILLION RIVER)	1980	GJTC (1990)
	EAGLENEST 2 (VERMILLION RIVER)	1980	GJTC (1990)
	GNEISS (RAINY RIVER)	1979	GJTC (1990)
	GUNFLINT (RAINY RIVER)	1977	GJTC (1990)
	HANSON (RAINY RIVER)	1989	BARTON ET AL. (1990)
	LAC LA CROIX (RAINY RIVER)	1989	BARTON ET AL. (1990)
	LITTLE LONG (RAINY RIVER)	1989	BARTON ET AL. (1990)
	MAGNETIC (RAINY RIVER)	1978	GJTC (1990)
	NAMAKAN (RAINY RIVER)	1990	GJTC (1990)
	RAINY (RAINY RIVER)	1990	GJTC (1990)
	SAGANAGA (RAINY RIVER)	1982,1989	BARTON ET AL. (1990)
	SHAGAWA (RAINY RIVER)	1979	GJTC (1990)

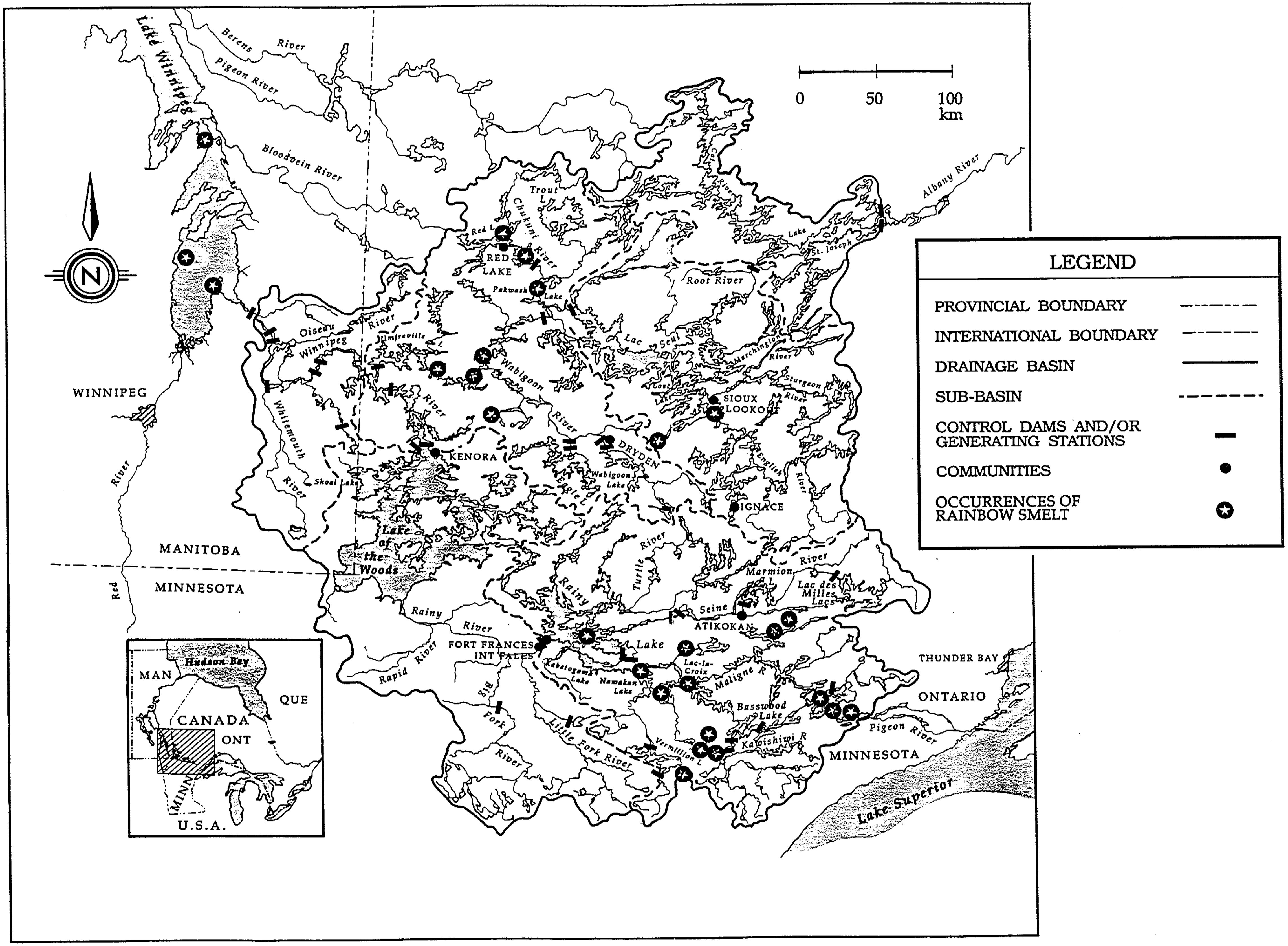

FIGURE 4. KNOWN OCCURRENCES OF RAINBOW SMELT IN THE WINNIPEG RIVER DRAINAGE BASIN.

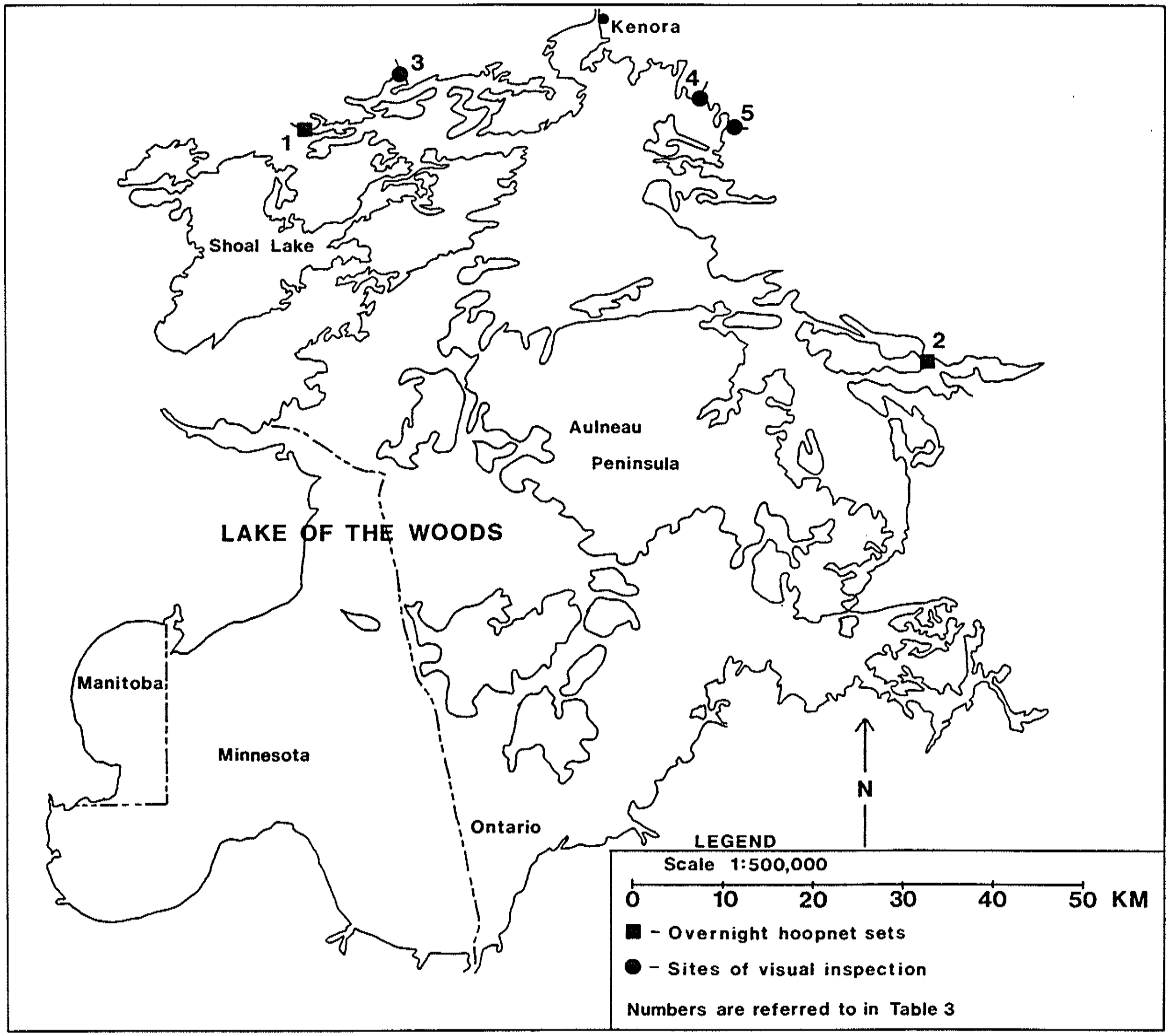

FIGURE 5. SITES SAMPLED FOR SPRING SPAWNING RUNS AROUND LAKE OF THE WOODS, ONTARIO.

TABLE 3. HOOPNET CATCHES FROM LAKE OF THE WOODS TRIBUTARIES (1990)

DATE	CREEK NAME	NUMBER ON FIGURE 5	WATER TEMP°(C)	WS	MM	NP	PK	YP	ID	SH
MAY 02	RUSH BAY	1	7.0	10	7	2	1	1	1	1
	BERRY	2	5.0	-	-	-	-	-	-	-
MAY 03	RUSH BAY	1	7.0	-	-	-	-	-	-	-*
	BERRY	2	8.0	4	-	-	-	-	-	1

* - large hole chewed in net
WS - White Sucker (Catostomus commersoni)
MM - Mud Minnow (Umbra limi)
NP - Northern Pike (Esox lucius)
PK - Pumpkinseed (Lepomis gibbosus)
YP - Yellow Perch (Perca flavescens)
ID - Iowa Darter (Etheostoma exile)
SH - Shiner (Notropis sp.)

Nine hundred and fifty two adult walleye were sampled from the Lake Winnipeg spring commercial fishery as presented in Table 4. The areas from which fish were sampled are illustrated in Figure 6. Although an attempt was made to sample as representatively as possible, only 14% of the walleye sampled were from north basin waters. This was primarily a function of the predominance of channel area and south basin walleye available at the Freshwater Fish Marketing Corporation plant. Five hundred and seven stomachs contained identifiable non-smelt remains, while 1 rainbow smelt was collected in a walleye stomach from a fish which came from the Riverton area. The collection of 1 smelt from 500+ stomachs with identifiable contents cannot allow prediction with 99% confidence that smelt abundance in walleye stomachs is less than 1%.

The specimen collected consists of the posterior 32 vertebrae including the caudal skeleton. Dr. K.W. Stewart verified the specimen as a rainbow smelt based on the following traits: (1) ural centra fused into a urostyle, (2) caudal vertebral centra with lateral sculpture consisting of two or three longitudinal ridges, (3) seven hypurals, with H_1 and H_3 slender and nearly equal, H_2 enlarged, H_4 and H_5 enlarged and subequal, and H_6 and H_7 slender and short, and (4) 20 or more vertebrae with closed hemal arches. This specimen has been retained by Dr. Stewart for future submission to the Royal Ontario Museum.

TABLE 4. COMPOSITION BY LOCATION OF WALLEYE STOMACH SAMPLES
TAKEN FROM THE 1990 LAKE WINNIPEG COMMERCIAL FISHERY

BASIN	LOCATION NAME	NUMBER ON FIGURE 6	N	N'	RAINBOW SMELT	LAKE HERRING	SHINERS	LAKE HERRING AND SHINERS	OTHER*
North	George's Island	7	63	47		35	6	2	4
	Assorted N. Basin	11	20	16		5	1		10
	Warren's Landing	12	25	16		11			5
	Grand Rapids	13	25	22		19	2		1
Channel	Matheson Island	2	156	78		27	25	4	22
	Princess Harbour	5	46	24		3	12	2	7
	Catfish Creek	8	108	58		27	15	6	10
	Pine Dock	9	92	46		28	3	1	14
South	Riverton	1	145	67	1**	23	25	3	16
	Gimli	3	122	71		20	39	7	5
	Red River Mouth	4	67	31		1	25		5
	Selkirk	6	68	26		10	10		6
	Traverse Bay	10	15	5		1	1		3
	Total		952	507	1	210	164	25	108

N - Number of walleye sampled
N'- Number with identifiable non-smelt remains
* - Included perch and invertebrates but most common was fish remains which could be identified as non-smelt, but no further.
** - Also contained one lake herring and numerous shiners.

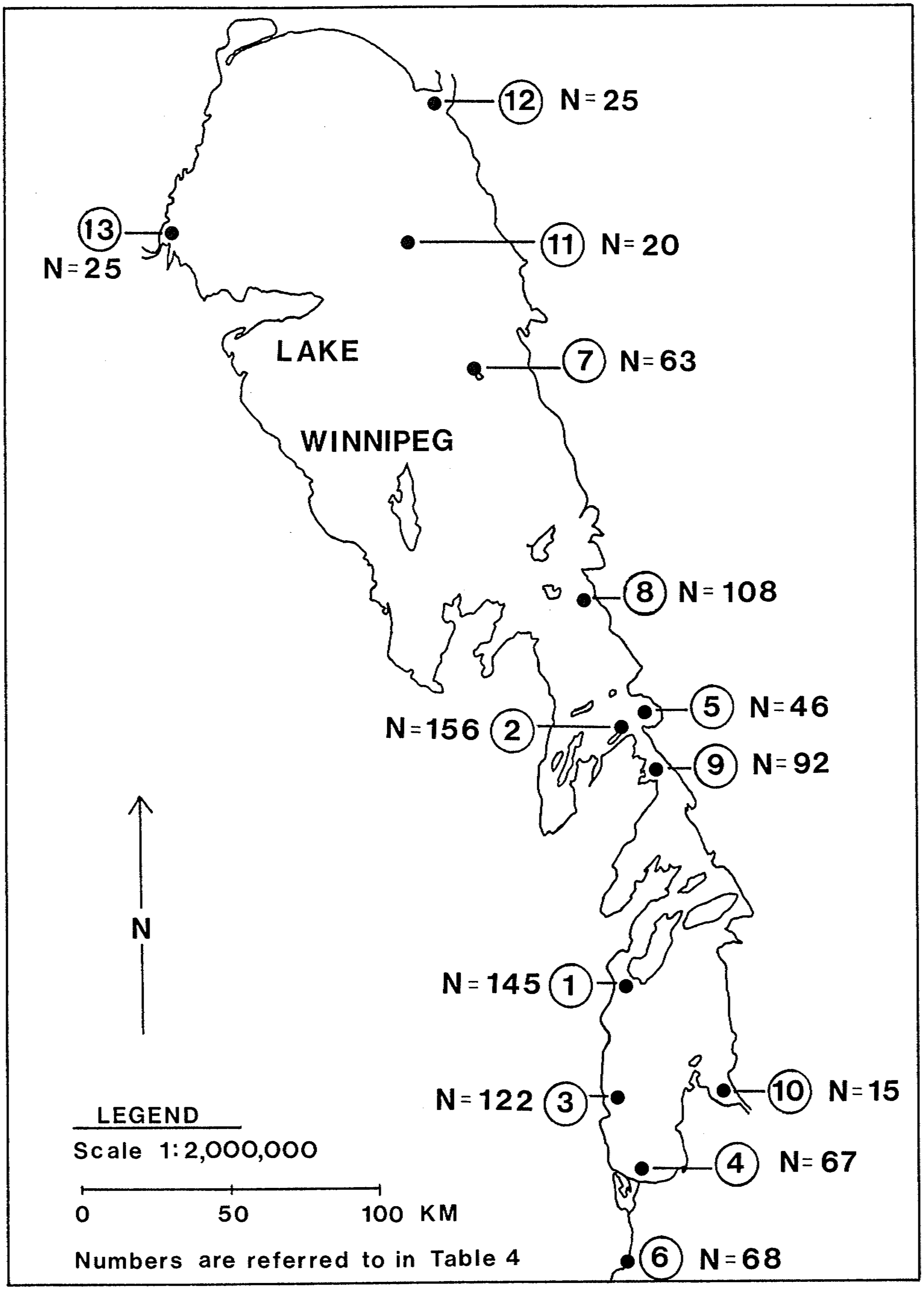

FIGURE 6. NUMBER AND LOCATION OF WALLEYE STOMACHS SAMPLED FROM THE 1990 LAKE WINNIPEG COMMERCIAL FISHERY.

The first detection of rainbow smelt in the Winnipeg River drainage basin was from Little Eagle Lake near Dryden, Ontario, dating back to at least 1962. This population was eradicated in 1978 at the request of the province of Manitoba (Campbell et al. 1991). The lake has no surface inlets or outlets, eliminating emigration by smelt as a means of dispersal. However, the possibility of dispersal into other water bodies via human transport, during the sixteen years that smelt were present in the lake cannot be discounted (Campbell et al. 1991). Apart from this record the first incidences of smelt in the drainage basin are from two sites on the upper Rainy River. They were collected from both Burntside Lake, Minnesota, and Eva Lake, Ontario, in 1972 (Table 2, Campbell et al. 1991).

Rainbow smelt are known from a number of discrete tributaries in the Rainy River system (Figure 4). They were discovered in Lac la Croix (#88 in Figure 3) in 1989 and could have reached this body of water by any one of four routes; from populations existing upstream on the Maligne River, from populations existing further upstream on the mainstem Rainy River, from established populations in Burntside Lake (#63), or from direct introduction into Lac la Croix. Smelt were discovered in both Rainy and Namakan lakes in 1990 and likewise could have reached Namakan Lake and hence Rainy Lake by any one of five routes; from populations existing upstream on the Quetico River, from populations existing upstream on the Vermillion River, from populations from Trout Lake, from populations existing in Lac la Croix and further upstream on the mainstem Rainy River, or from direct introduction into the lakes themselves.

The Rainy River exits from Rainy Lake and flows 130 km before entering into Lake of the Woods. Rainbow smelt were not detected in Lake of the Woods in either spring spawning surveys or late summer netting surveys. The failure to detect smelt in the spring spawning surveys is not significant. The timing of the investigation may have been off by a day or two, the selection of streams may not have been correct or shore spawning may have been favoured over stream spawning as has been found elsewhere (MacCallum and Regier 1970). The absence of smelt in the late summer netting survey does not signal their absence from Lake of the Woods but indicates a lack of abundance from that part of the lake.

Rainbow smelt were first confirmed in the English River system from Red Lake in 1986 (N. Ward, Ontario Ministry of Natural Resources, pers. comm.). Surveys in 1989 found smelt to be present in nine more lakes in the English River system. Smelt were reconfirmed in Red Lake and verified in Keg, Gullrock, Two Island and Pakwash lakes on the Chukuni River. Gullrock and Two Island lakes are both relatively shallow lakes which were first sampled in late spring of 1989. These unstratified lakes were resampled in August to verify the presence of smelt over summer. Smelt were also verified from Favel Lake on the Canyon River, a tributary to the lower Wabigoon River, and in Sandybeach and Abram lakes on the upper English River system. Single specimens were collected from both Tide and Indian lakes. These probably represent downstream migrants from one of the other three areas. A specimen was recovered from a northern pike stomach from Separation Lake by Ontario Ministry of Natural Resources personnel in 1988 (S. Lockhart, Ontario Ministry of Natural Resources, pers. comm.), but 1989 surveys of this lake did not yield any smelt. Separation Lake lies approximately 40 km downstream of Indian Lake on the English River.

Rainbow smelt are now known to be present in Lake Winnipeg. Two specimens caught by commercial fishermen in late September and early October had standard lengths of 117.6 mm and 124.0 mm respectively, and both showed one poorly defined annulus (Campbell et al. 1991). The portion of the specimen recovered from a walleye stomach measured 31.7 mm from its most anterior vertebra. Rainbow smelt contain from 58-70 vertebrae, usually 60-66 (Scott and Crossman 1979), therefore 32 vertebrae could be seen to constitute half a fish. Doubling 31.7 mm yields a fish with a length of about 63.5 mm (+ head length of about 5-10 mm). Late winter caught smelt from Lake Superior had mean lengths of 66 mm for yearlings and 151 mm for 2 year olds (Bailey 1964). Therefore, given a date of capture of about June 03, the Lake Winnipeg specimen probably was a yearling. The two specimens captured by commercial fishermen late in the season most likely were in their second season of growth. Therefore, these fish probably were all from the same year-class.

The origin of rainbow smelt in Lake Winnipeg is unclear. The furthest downstream location in the Winnipeg River system from which smelt were taken in 1989 and 1990 surveys was Indian Lake, 280 km upstream of Lake Winnipeg, while a previous record exists from Separation Lake (Campbell et al. 1991), 40 km downstream of Indian Lake. The effort expended in these surveys was not intensive, and therefore absence from the sample cannot be inferred to indicate absence of a population in a lake. Given the consistency of sampling gear and methodology, however, the absence of smelt from a sample indicates that smelt probably weren't abundant in a given lake. Therefore, while the possibility that the rainbow smelt caught in Lake Winnipeg are downstream migrants from Winnipeg River populations cannot be dismissed, given the absence of rainbow smelt in any of the nine surveyed lakes downstream of Indian Lake, it is unlikely. Umfreville Lake in particular, located downstream of Indian Lake on the English River, should offer suitable habitat for rainbow smelt colonization. Ten gangs of gillnets fished over two seasons failed to produce any smelt, strongly suggesting the lack of an established population in that lake.

Another potential source of rainbow smelt in Lake Winnipeg is via the Berens or Bloodvein rivers. An unauthorized or unintentional introduction of smelt from Red Lake into Berens Lake, Ontario, located 90 km north of Red Lake on the Nungesser Lake Road (Figure 3), and on the Berens River, would provide another source of supply to Lake Winnipeg. Berens Lake was surveyed during the summer of 1990 (Table 1), and no smelt were collected. Similarly, a potential point of fish transfer exists in flood conditions between some ponds feeding the northwest corner of Red Lake and the headwaters of the Bloodvein River (Figure 3). These potential avenues of introduction are not the favoured source of the smelt in Lake Winnipeg at this time.

Rainbow smelt have been captured in Lake Audubon, and the McClusky Canal in North Dakota, but are not known to be present in the Red River drainage basin (Sayler 1990). Surveys by the Minnesota Department of Natural Resources of upper Red Lake and other headwater lakes of the Red River system in Minnesota have not yielded smelt (Campbell et al. 1991). Therefore it would appear that smelt have not invaded Lake Winnipeg via dispersal from known Red River system populations. Manitobans are known to travel to Thunder Bay, Ontario to harvest spawning Lake Superior smelt (W. Franzin, Department of Fisheries and Oceans, pers. comm.). An unauthorized intentional or unintentional introduction of unused baitfish or fish waste into the lower Red River, or Lake

Winnipeg itself would appear to be a likely candidate for providing the source of smelt for Lake Winnipeg.

The length of time that rainbow smelt have been a resident of Lake Winnipeg remains a point of contention. A specimen was reported to have been angled from the Red River, immediately below the St. Andrews dam in May or June, 1975 (Campbell et al. 1991). This report cannot be substantiated with a specimen. Experimental trawl catches in the channel and south basin areas of Lake Winnipeg conducted during 1976-83 failed to turn up any rainbow smelt (Kristofferson 1985).

Rainbow smelt were first recorded from the south basin of Lake Winnipeg in 1990. By early July 1991 two more specimens had been captured by commercial fishermen. One specimen was caught near Pine Dock in the channel area (Figure 4), while the other was collected near Eagle Island at the north end of the north basin (A. Derksen, Manitoba Department of Natural Resources, pers. comm.). Rainbow smelt have spread beyond the south basin of the lake.

Eventual colonization of the north basin of the lake will give rainbow smelt access to the Nelson River. The movement of smelt down large river systems can be quite rapid and successful. In 1971, 7,440 gravid rainbow smelt were introduced into Lake Sakakawea, North Dakota and a few years later a self-sustaining population was present (Mayden et al.

1987). About seven years later smelt were being captured in the free-flowing lower Missouri River, after population build-up and passage through four major reservoirs (Mayden et al. 1987). The rapid movement may be explained by the lack of suitable lacustrine habitat and corresponding velocity of the system.

The rapid dispersal of smelt down the Missouri River probably will be repeated on the Nelson River, although possibly not until Lake Winnipeg is fully colonized. Much of the available lentic habitat along the Nelson River is less than ideal, with Playgreen, Pipestone and Cross lakes all having mean depths of less than 4.0 m (ManDNR 1989). Further downstream on the Nelson River lie Split and Stephens lakes (Figure 7). Mean and maximum depths of these lakes are displayed in Table 5. Thermal stratification does not occur in Split and Stephens lakes and data indicates that minimum summer water temperatures may reach as high as 18.5°C (Green 1990). Conditions for colonization by smelt are not ideal, however, given the scarcity of available habitat along the Nelson River some habitation of these water bodies may be expected. It is interesting to speculate, but impossible to forecast accurately whether rainbow smelt will colonize Hudson Bay upon reaching the Nelson River estuary.

If rainbow smelt have colonized Lake Winnipeg via the Winnipeg River system, they first had to pass through a num-

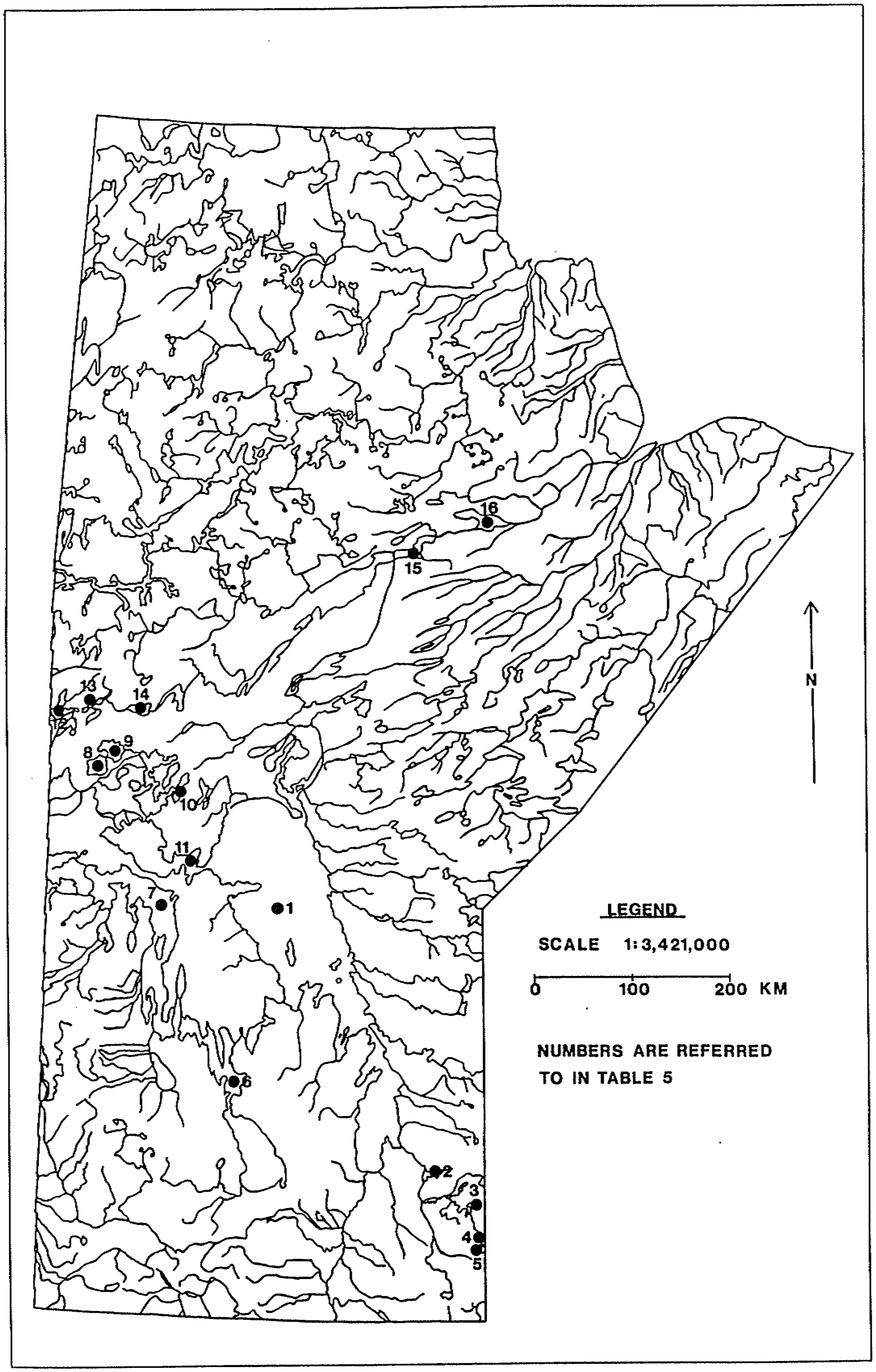

FIGURE 7. PREDICTED DISTRIBUTION OF RAINBOW SMELT IN MANITOBA.

TABLE 5. CHARACTERISTICS OF LAKES PREDICTED TO SUPPORT POPULATIONS OF RAINBOW SMELT[1]

				LAKE MORPHOLOGY		SPECIES		RESOURCE USE		
LAKE NAME	NUMBER ON FIGURE 7	LAT. (N)	LONG. (W)	MEAN DEP. (M)	MAX. DEP. (M)	LT	WE	LODGES/ OUTCAMPS	COTTAGES	ROAD ACCESS
WINNIPEG	1	52°00'	97°00'	12.0	36.0	N	Y	N	Y	Y
LAC DU BONNET	2	50°22'	95°55'	-	24.0	N	Y	Y	Y	Y
BIG WHITESHELL	3	50°05'	95°21'	4.9	8.2	Y	Y	Y	Y	Y
WEST HAWK	4	49°46'	95°11'	48.9	112.8	Y	Y	Y	Y	Y
FALCON	5	49°42'	95°15'	14.6	26.0	Y	Y	Y	Y	Y
MANITOBA	6	51°00'	98°45'	5.0	7.0	N	Y	Y	Y	Y
WINNIPEGOSIS	7	52°30'	100°00'	4.4	11.0	N	Y	Y	Y	Y
CLEARWATER	8	54°05'	101°00'	13.0	38.7	Y	Y	Y	N	Y
CORMORANT	9	54°10'	100°50'	-	33.5	Y	Y	Y	Y	Y
MOOSE	10	53°54'	100°04'	3.0	5.5	Y	Y	N	N	N
East Arm (Pre-flood)				7.9[2]	21.3[2]					
CEDAR	11	53°20'	100°10'	4.2	13.0	Y	Y	Y	N	Y
ATHAPAPUSKOW	12	54°33'	101°40'	14.9[3]	64.0[3]	Y	Y	Y	N	Y
SECOND CRANBERRY	13	54°37'	101°15'	22.3	52.1	Y	Y	Y	N	Y
REED	14	54°33'	100°30'	9.5	34.1	Y	Y	Y	N	Y
SPLIT	15	55°57'	96°11'	4.5[4]	23.0[4]	N	Y	N	N	Y
STEPHENS	16	56°26'	95°07'	7.6[4]	35.0[4]	N	Y	N	Y	Y

LT = LAKE TROUT WE = WALLEYE Y = YES N = NO

REFERENCES:
1. MANITOBA DEPARTMENT OF NATURAL RESOURCES (ManDNR) (1989)
2. HOWARD (1967)
3. DAY (1983)
4. CHEREPAK (1990)

ber of lakes in Manitoba. With the exception of Lac du Bonnet these lakes are essentially a widening of the river and offer very little off-current habitat. For this reason these lakes are not expected to harbour large smelt populations. Fieldwork conducted on June 19, 1990 revealed some degree of thermal stratification in the east basin of Lac du Bonnet (Table 1), suggesting an off-current area of potential smelt habitat. Smelt are predicted to colonize this body of water.

There are a number of lakes within the Whiteshell River system which may offer good habitat for smelt. The potential for upstream migration from the Winnipeg River, however, is limited to Heart Lake, as numerous rapids and small waterfalls are present below Betula Lake. Once smelt become abundant in the southern Manitoba area, Big Whiteshell, Westhawk and Falcon lakes, lake trout lakes with road access, become potential candidates for unauthorized introductions of smelt via introduction of baitfish or fish waste. With mean and maximum depths of 4.88 and 8.23, 48.9 and 113, and 14.6 and 26 m respectively, these lakes offer suitable habitat for rainbow smelt. Other lakes in the Whiteshell River system are not as favourable, but downstream migrants from West Hawk and Big Whiteshell lakes will pass through these lakes and may colonize some of them. A populated Falcon Lake will provide the opportunity for downstream migrants to enter Shoal Lake and Lake of the Woods.

From Lake Winnipeg rainbow smelt may be expected to travel upstream into Lake Manitoba via the Dauphin and Fairford rivers. This path of colonization previously has been forecasted by Loch et al. (1979). The fishway at the Fairford dam has been navigated by species such as white sucker (*Catostomus commersoni*), walleye and lake herring (Derksen 1988). Fish as small as 200 mm fork length were captured in a fishway trap, however, it was speculated that smaller fish could also successfully use the fishway (Derksen 1988). Under certain conditions the Fairford dam is not a barrier to fish movement. At flows of 300 m^3/s or more on the Fairford River, there is virtually no difference between water levels above and below the dam (Derksen 1988). In the period of record 1955-1986 mean monthly discharge exceeded 300 m^3/s twice in the month of May and three times during the month of June, while maximum daily discharge exceeded 300 m^3/s seven times in the period of record, twice in May (IWD 1987). Smelt could be expected to attempt to use the Dauphin and Fairford rivers for spawning, probably in late April or early May. In a highwater year, rainbow smelt could be expected to successfully navigate the Fairford dam fishway by using areas adjacent to the main current and enter Lake Manitoba.

Lake Manitoba is shallow, with mean and maximum depths of 5.0 and 7.0 m respectively. Warm summer water temperatures and high turbidity should preclude the establishment of large populations of rainbow smelt in the south basin. Smelt may be more successful in the north basin, where populations of lake whitefish and lake herring exist. From Lake Manitoba rainbow smelt will have unrestricted access into Lake Winnipegosis via the Waterhen River. Lake Winnipegosis is another shallow lake with a maximum depth of 11.0 m, but a mean depth of only 4.5 m. Lake Winnipegosis currently supports a weaker piscivorous population than does Lake Manitoba, so smelt may face less initial resistance in Lake Winnipegosis, thereby allowing a larger smelt population to develop (A. Derksen, Manitoba Department of Natural Resources, pers. comm.).

If smelt become abundant in Lake Winnipeg, many of the lake trout lakes in the northwest region of the province may be at risk to the unauthorized introduction of smelt. Lakes such as Athapapuskow, Second Cranberry, Reed, Clearwater and and Cormorant could all be expected to provide suitable habitat for smelt if introduced (Table 5). Downstream of Clearwater and Cormorant lakes lie Moose and Cedar lakes. Prior to flooding, the east arm of Moose Lake offered relatively deep (Table 5), apparently off-current habitat (Figure 7), however, it did not stratify (Howard 1967). Lake trout, however, have been harvested as an incidental catch in the east arm of post-flood Moose Lake, until at least 1977 (Sopuck 1979). The east arm of Moose Lake should therefore possess suitable habitat to support a population of rainbow smelt.

Cedar Lake, including Cross Bay was found to exhibit no thermal stratification in July 1973, with bottom temperatures fairly constant at about 15°C (Hughes 1974). In 1974, Saskatchewan River surveys were conducted in late June. Bottom temperatures in Cross Bay were found to be as low as 10°C (Hughes 1977). These temperatures would be ideal for smelt, however, expected higher temperatures later in the summer would not be as suitable. Lake trout are not reported from the commercial catch (DFO 1988), nor do any of the fishing lodges on Cedar Lake actively fish for lake trout (Travel Manitoba 1991). Cedar Lake does not therefore offer good habitat for colonization by rainbow smelt, however, given its position downstream of Clearwater, Cormorant and Moose lakes, some utilization of the lake by smelt may be expected.

There are a number of lake trout lakes on tributaries of the east side of Lake Winnipeg. None of these lakes are road accessible, but Wrong, Charron, Fishing, Moar, Aiken and Sasaginnigak lakes all support fly-in, sport lake trout fisheries and therefore some potential for introduction of, and colonization by smelt exists. Additionally, the latter four of these lakes lie on the Berens and Bloodvein Rivers, and therefore are provided with another potential source of smelt.

As discussed in chapter 2, long distance upstream movement of rainbow smelt or presence in lotic environments except during spawning is not common. For these reasons significant upstream movement of smelt on the Red and Assiniboine rivers is not predicted. The St. Andrews dam will serve as a further deterrent to upstream movement, although not an entirely unpassable barrier due to the presence of the boat locks.

4.2 POTENTIAL FOR IMPACT ON THE FISHERIES OF LAKE WINNIPEG

4.2.1 Case studies of smelt-impacted lakes

4.2.1.1 Lake Erie

Lake Erie is the southernmost lake in the Laurentian Great Lakes system, centered at 42°15'N and 81°15'W. It is 388 km long, 92 km wide at its maximum breadth, and has a surface area of about 25,690 km^2. The theoretical flushing time of Lake Erie has been calculated at 2.5 years (Hartman 1972). The lake is naturally divided into three basins - western, central and eastern; all with unique characteristics.

The following account of the morphometry and annual thermal regimes in the three basins of Lake Erie is modified from that provided by Hartman (1972). The western basin is the shallowest and smallest of the three, encompassing only 13% of the total lake surface area and 5% of the volume of the lake. Mean and maximum depths are 7.4 and 20.4 m respectively. It usually freezes over in mid-December with water temperatures under the ice isothermal at about 1°C.

The ice melts near the end of March and water temperatures rise gradually after that, reaching 10°C by May 1, 15°C by June and 24-26°C by early August. Due to wind action and currents, summer water temperatures in the shallow western basin are usually isothermal, but during extended periods of warm, calm weather, some stratification may occur. Fall cooling begins in August and proceeds gradually until ice is formed.

The central basin is deeper (mean and maximum depths of 18.5 and 25.6 m respectively), and much larger than the western basin, comprising 63% of the lake's surface area and volume. This basin rarely freezes over completely. Spring warming usually lags about one week behind that of the western basin. Temperatures reach about 13°C by late May and the water column is isothermal. A thermocline forms in June at about 12 m, and gradually sinks to about 18 m as the summer progresses. Water in the epilimnion warms to a maximum of 24-26°C by early August. Bottom waters during summer are much cooler in the central basin (9°C) than in the western basin. Water temperatures fall after that, with fall overturn usually occurring in late September. The water temperature in the central basin is isothermal at 1°C by late December.

The eastern basin is much deeper than the other two with a mean depth of 24.4 m and a maximum depth of 64 m. The basin is generally isothermal at 1°C in winter, although winter stratification may occur at depth. Ice cover in the eastern basin is minimal, however, as the western and central basins break up, prevailing winds carry the ice floes eastward into the eastern basin. This causes April and May surface water temperatures to lag roughly 18 days behind those of the western basin, and 11 days behind those of the central basin. Warming occurs gradually during April and May, with summer stratification occurring by June. The thermocline sinks as summer progresses. Surface waters reach 24°C by early August, while hypolimnetic waters may reach 7-9°C. Fall overturn usually takes place in November, with winter conditions being reached by late December.

Lake Erie, more so than any of the other Great Lakes, and perhaps most other North American lakes, has been altered through cultural eutrophication (Leach and Nepszy 1976). By virtue of its shallow depth and fertile drainage basin, Lake Erie was the most productive of the Great Lakes long before the arrival of European man. The vegetative cover and the dynamics of the drainage basin and lake were changed irreversibly as the basin was settled during the 1700s and 1800s. An increase in erosion and resulting siltation destroyed the spawning grounds and other habitat of many species (Hartman 1972). Other important spawning areas were made inaccessible by stream blockages, or destroyed by the large-scale drainage of marshlands (Leach and Nepszy 1976).

As the human population in the drainage basin increased, effluents from industries and communities entered directly into the lake or its tributaries in larger and larger amounts. Some of the changes attributed to cultural eutrophication that occurred in Lake Erie over the half-century ending in 1970 include: an increase in TDS from 133 to 198 mg/l, a threefold increase in sedimentation rate since 1850, a twentyfold increase in phytoplankton numbers and a shift in species dominance in the western basin from oligotrophic to eutrophic types, an increase in zooplankton abundance and a change in species composition towards eutrophic types, a decline in numbers and diversity of pollution-intolerant benthic organisms and an increase in abundance of pollution-tolerant species (Leach and Nepszy 1976).

The increased eutrophication or cultural enrichment of Lake Erie has led to a widespread decrease in dissolved oxygen. Dissolved oxygen levels as low as 0-2 mg/l were discovered during the 1950s and 1960s in the western and central basins (Hartman 1972). This only occurs during extremely rare stratification of the western basin, but low dissolved oxygen concentrations in the hypolimnion of the central basin are fairly common, and have been recorded as far back as the first survey of the lake in 1929 (Leach and Nepszy 1976). Critically low dissolved oxygen levels have not occurred in the hypolimnion of the eastern basin (Hartman 1972).

Lake Erie possesses a very diverse fish fauna, with a native composition of 24 families, 55 genera and 114 species (Christie 1974). The fish community of Lake Erie at the time of human settlement included inshore populations of smallmouth bass (*Micropterus dolomieui*), largemouth bass (*M. salmoides*), muskellunge (*Esox masquinongy*), northern pike, emerald shiner, spottail shiner (*Notropis hudsonius*), channel catfish (*Ictalurus punctatus*), and brown bullhead (*I. nebulosus*); and open water populations of lake sturgeon (*Acipenser fulvescens*), lake herring, longjaw cisco (*Coregonus alpenae*), lake whitefish, blue pike (*Stizostedion vitreum glaucum*), walleye, sauger, freshwater drum (*Aplodinotus grunniens*), white bass (*Morone chrysops*), white sucker and shorthead redhorse (*Moxostoma macrolepidotum*) (Leach and Nepszy 1976). A relatively small population of lake trout existed in the eastern basin.

Lake Erie has changed, and today some of those species have been extirpated, others remain at very reduced levels and several others have been added through introductions. Blue pike and lake trout have been extirpated, while numbers of lake sturgeon, lake herring, sauger and muskellunge are greatly reduced. The present Lake Erie fish community is dominated by native yellow perch, walleye, white bass, channel catfish, brown bullhead, freshwater drum, emerald shiner, spottail shiner, white sucker, shorthead redhorse and gizzard shad (*Dorosoma cepedianum*); and the introduced species rainbow smelt, common carp (Cyprinus carpio), goldfish (Carassius auratus), white perch (Morone americanus), coho salmon (Oncorhynchus kisutch) and chinook salmon (O. tshawytscha).

Rainbow smelt were first reported from Lake Erie in 1935, presumably having entered the lake via the Detroit River from populations earlier established in lakes Michigan and Huron (Leach and Nepszy 1976). The first observed spawning run was in 1940 and by the early 1940s smelt were spawning at Point Pelee (MacCallum and Regier 1970). Smelt were abundant in commercial fishing gear by the early 1950s.

The following brief life history of the rainbow smelt in Lake Erie is based primarily on works by Ferguson (1965) and MacCallum and Regier (1970). During the winter adults are fairly randomly dispersed throughout the lake. Mature fish begin to aggregate on the spawning shoals along the north shore of the lake during the first week of April, when spring warming begins. The peak of spawning activity takes place during the last two weeks of April around Point Pelee, but is somewhat delayed in the east-central and eastern basins due to the lag in vernal warming.

After spawning, adults move offshore into the waters of the hypolimnion. As the hypolimnion of the central basin became oxygen-reduced or anoxic, smelt were observed to vacate that area, moving up towards the thermocline or further east. Thermal preference of the adults during the summer was found to be about 6°C and few were found at temperatures above 15.5°C. Adults were generally found in waters deeper than 18 m by day, although they displayed a distinct diel movement into the thermocline and epilimnetic waters by night. Adults resume a more random distribution after fall turnover.

YOY smelt are abundant inshore, in 3-6 m of water after hatching in the spring. They are commonly found in epilimnetic offshore waters later in the summer, but also frequently occur in the metalimnion, appearing only to avoid the hypolimnion. Diurnal movement by YOY smelt from the epilimnion down into the hypolimnion by night as previously mentioned for Lake Michigan, was not documented for Lake Erie. By late fall YOY appeared to be fairly randomly dispersed throughout the east-central and eastern basins.

In early spring yearling smelt were found to be dispersed throughout Lake Erie in deep water. There appeared to be an onshore movement into shallower water as the adults moved offshore after spawning. Yearling smelt occupy the same habitat as YOY at this time. As summer warming begins yearlings were found to move out into deeper water, but generally remaining shallower in the water column than adults. Yearlings showed a temperature preference of 7-10°C during summer days (metalimnion), but moved up into 10-15°C epilimnetic waters by night.

The generalized pattern of distribution through the stratified water column in summer then is YOY in the epilimnion, yearlings in the metalimnion and adults occupying the hypolimnion. The nightly diel movement pattern by adults and yearlings results in some habitat overlap by all three size-classes of smelt. When the central basin hypolimnion becomes anoxic, both adults and yearlings may be found concentrated in the thermocline. Yearlings enter the adult size range by October and begin to assume the adult distribution in the water column.

In Lake Erie rainbow smelt are primarily shore spawners. Streams of suitable quality are available along the north shore of the lake and are used to some degree, but spawning runs always have been stronger along north shore beaches (LEFAU 1990). These appear to be favoured due to the presence of a gravel substrate and good current activity to aerate the eggs (LEFAU 1990). Traditional spawning areas are concentrated along Point Pelee and Long Point (Ferguson 1965), both prominent spits of land which protrude 15 and 35 km respectively out into the lake. The only offshore accumulations of surficial sand and gravel sediments in Lake Erie are restricted to areas extending southwest of Long Point and south of Point Pelee (Thomas et al. 1976). This may explain why these sites are favoured for spawning. MacCallum and Regier (1970) also report on observations made by commercial fishermen of deepwater spawning of smelt in Lake Erie at depths of 9-22 m.

Published information on the diet of rainbow smelt in Lake Erie is limited, but what information is available suggests that smelt are opportunistic feeders as in other bodies of water. Typically smelt feed on copepods, cladocerans, dipterans and amphipods, however, principal food items depended upon size of fish, season, and location in the lake (LEFAU 1990). Piscivory is common among adult smelt in Lake Erie, YOY smelt and yellow perch being the principal species consumed (LEFAU 1990). Henderson and Nepszy (1989) report that the primary items consumed by 1238 yearling smelt over the course of the summer of 1976 were copepods (65% frequency of occurrence) and cladocerans (58%). YOY smelt were identified in only 2% of the stomachs, while 5% contained smelt scales.

Rainbow smelt are preyed upon by a number of predators in Lake Erie, but given their role in the commercial catch they are not considered a forage species. Henderson and Nepszy (1989) state that smelt were an important prey for the following Lake Erie predators: yellow perch, walleye, coho and chinook salmon, and white perch, but frequency of occurrence values are not available. Knight et al. (1984), however, found that smelt were selected for only occasionally by walleye and yellow perch in the western basin of Lake Erie. Rainbow smelt are not commonly found in the western basin in the summer due primarily to unfavourable water temperatures. The resurgence of the walleye stocks in Lake Erie, which are concentrated in the western basin, and more recently in the western/central basin, are attributed primarily to factors other than the availability of rainbow smelt as a diet item (Nepszy et al. 1991).

The changes in fish community structure in Lake Erie have been attributed to three major phenomena; cultural eutrophication, exploitation, and the introduction of new species. Therefore it is difficult to link one effect to one particular cause. Hartman (1972), in a review of fish community changes in Lake Erie, surmised that eutrophication and exploitation were the dominant processes involved in the restructuring of the Lake Erie fish community. By the late 1950s most predaceous species had been greatly reduced. Reduced predation probably allowed rainbow smelt to become abundant. Regier et al. (1969) state that the predatory stress exerted on the young of other species by increasing numbers of smelt during the 1950s and 1960s played a large role in the severe reduction or extirpation of the young of the remaining stocks of lake herring, sauger, blue pike, lake whitefish and walleye.

Despite the fact that factors other than replacement by introduced species are responsible for many of the changes in Lake Erie's fish community, it is worthwhile to briefly explore some of the identifiable trends. While the commercial catch from a particular body of water does not necessarily reflect its fish community, it does present a reasonably accurate index of major changes in species abundances. Figure 8 presents the commercial fish landings from the Canadian waters of Lake Erie from 1931-1987. Data from 1978 onwards were available only from Canadian waters of Lake Erie, so for the sake of continuity only Canadian data were considered. Recently, Ontario has been a much larger harvester of most species, with almost no rainbow smelt being taken from U.S. waters (Baldwin et al. 1979). The year 1931 was chosen as a starting date because Lake Winnipeg statistics were only available from that date onward. All the major species commercially harvested are included in Figure 8. All of the species included are presently in Lake Winnipeg, with the exception of blue pike.

Historically, the two most important species in the commercial catch were lake herring and blue pike (Baldwin et al. 1979). Lake herring stocks collapsed precipitously in 1925 (Hartman 1972), and remained almost nonexistent in the commercial catch until a brief resurrection in the years 1945-47. Although not extinct, today lake herring are all but absent from the commercial catch. The near elimination of lake herring from Lake Erie is attributed almost entirely to overexploitation, although it also has been suggested that elevated temperature regimes following man's arrival made for a less suitable habitat for coldwater species such as the lake herring (Hartman 1972).

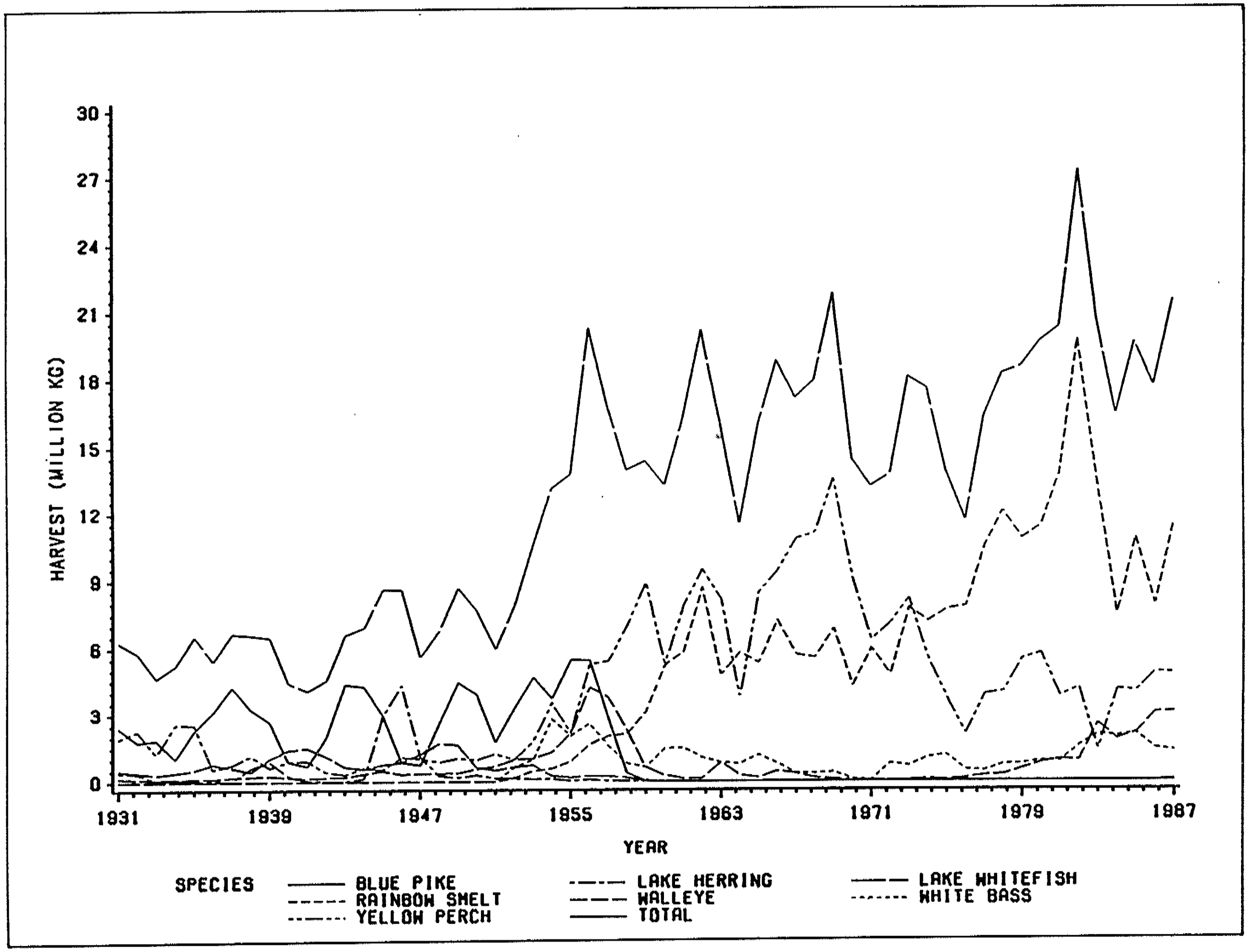

FIGURE 8. LANDED QUANTITIES (KG) OF MAJOR SPECIES FROM THE LAKE ERIE COMMERCIAL FISHERY 1931-1987 (FROM BALDWIN ET AL. 1979, OMNR VARIOUS).

Hartman (1972) stated that the 1954 year-class of blue pike was the last hatch of any importance. By 1961, blue pike had disappeared from the Lake Erie commercial fishery and now are considered to be extirpated from the lake. Its extirpation is linked to a combination of overexploitation, cultural eutrophication and finally hybridization with walleye (Hartman 1972). Regier et al. (1969), however, contend that predation pressure from rainbow smelt played a large role in the near extirpation of lake herring and the extirpation of blue pike.

Walleye increased in importance in the fishery during the 1940s and early 1950s until 1956, when a precipitous decline occurred. A moratorium on commercial and sport walleye fishing due to high mercury levels, combined with more restrictive management regulations triggered the rapid recovery of walleye stocks (Nepszy et al. 1991), as evidenced by the levels harvested during the 1980s. Harvest levels of whitefish have been below 100,000 kg since 1958, but stocks appear to have begun a gradual recovery. Sauger have never been a major component of the Canadian fishery in Lake Erie and now are virtually nonexistent.

White bass are native to Lake Erie but did not appear in the Canadian commercial catch until 1952. They have been harvested since at least 1899 from American waters (Baldwin et al. 1979). Their importance has varied over time, but during the 1980s about 1.5 million kg were harvested annually from Canadian waters. Freshwater drum, like white bass were harvested much earlier from American waters than on the Canadian side (Baldwin et al. 1979). They have remained an incidental catch, with their harvest probably not accurately reflecting their abundance in the lake, particularly in the western basin. Yellow perch have been one of the mainstays of the Lake Erie commercial fishery. They have contributed as much as 63% by weight of the annual catch, and over the last five years have averaged 25% of the harvest.

Rainbow smelt were first recorded from Lake Erie in 1935, but did not appear in the commercial catch until 1952. Initially they occurred as an incidental catch, but with the development of a trawl fishery and a market for them, catches in excess of 10 million kg were common by the late 1970s. The harvest of rainbow smelt peaked in 1982, with a catch of almost 20 million kg, representing 72.5% of the entire fish catch that year.

Rainbow smelt were first commercially exploited using specially modified poundnets and trapnets (Sand and Gordon 1960). As smelt became very abundant in Lake Erie during the mid-1950s, gillnetting was tried but was found to be uneconomical (MacCallum and Regier 1970). The decline in abundance of more valuable species during the late 1950s further stimulated the search for an efficient manner of harvesting rainbow smelt. The Canadian federal government conducted a developmental trawl fishery project for smelt in

1959, and in 1960 a number of Canadian trawlers were outfitted and fished successfully (Wolfert 1981). The trawls used in the Lake Erie smelt fishery are modified Biloxi shrimp trawls, varying in size according to the size of boat used to pull the trawl (Van West 1983). Trawl sizes range from 20 m across at the mouth, 13 m long and 4 m deep to 30 m X 20 m X 8 m (Van West 1983). By 1962 the catch reached 8.7 million kg but stabilized at a lower level for some time.

The large-scale harvest of smelt in Lake Erie depended upon securing a market. Presently, almost all Lake Erie smelt are processed for human consumption (R. Loblaw, Ontario Ministry of Natural Resources, pers. comm.), although wastes have been processed into fish meal and used as animal food (Howell 1972). In addition to the North American consumption of adult smelt, a large Japanese market for yearling smelt has been developed (Henderson and Nepszy 1989). There is very little domestic consumption of Lake Erie smelt, with larger smelt (>12.5 cm) shipped dressed primarily to the New York area, and smaller smelt (7.5-10 cm) shipped in the round to Japan (R. Loblaw, Ontario Ministry of Natural Resources, pers. comm.).

The vessels used for trawling in Lake Erie were modified gillnetters, some modified so that gillnetting was still possible (Van West 1983). The cost, in the late 1970s of retrofitting a Lake Erie tug from a gillnetter into a trawling vessel still capable of gillnetting, has been estimated at figures ranging from $5,000-$6,000 (exclusive of winch) (Van West 1983), to $10,000-$20,000 (R. Loblaw, Ontario Ministry of Natural Resources, pers. comm.). The measurements of a typical Lake Erie trawler are a length of 20.8 m, a breadth of 6.4 m and a depth of 2.2 m (Kolenosky 1975). Vessels are typically powered by 300 horsepower diesel engines (R. Loblaw, Ontario Ministry of Natural Resources, pers. comm.), and are equipped with echo-location equipment (Kolenosky 1975).

Bottom and mid-water trawls have been employed by trawlers, depending upon bottom type and location of schools of fish. Trawling has been carried out primarily in the central and eastern basins of the lake, and almost exclusively in Canadian waters. Bottom type in the central and eastern basins is predominantly post-glacial muds, followed in frequency of occurrence by areas of glacial till and soft grey mud (Thomas et al. 1976). The combination of very little bedrock, and a scarcity of large glacial erratics and uniform depth, especially in the central basin, makes the bottom of Lake Erie very suitable for trawling.

The importance of the smelt fishery in relation to the entire Canadian Lake Erie harvest is not typical of all the Great Lakes. Only lakes Superior and Michigan have provided sizable smelt harvests since 1977 (Baldwin et al. 1979). While Ontario was developing its gear testing program, similar research was going on in American waters of Lake Erie.

Tests conducted from 1958-1960 (Sand and Gordon 1960, Carr 1964), indicated that abundant quantities of smelt could be taken profitably on a commercial scale with trawling gear. Wolfert (1981) stated, however, that these earlier ventures were not carried through for economical and political reasons. A 1974 survey of the U.S. waters of Lake Erie found that commercially significant numbers of smelt could not be caught on a consistent basis (Wolfert 1981). Experimental trawling in Lake Ontario in 1968 and 1970, using Lake Erie gear, showed trawling to be marginally profitable (Kolenosky 1975). Experimental trawling permits for Lake Ontario were offered to fishermen, but those already established chose to remain on Lake Erie (Kolenosky 1975).

As earlier mentioned, decreases in overall value of the catch have been documented in the Great Lakes as the commercial fishery evolved from a coregonine and lake trout fishery to one primarily harvesting yellow perch and rainbow smelt. Lambert (1973) in an economic analysis of Ontario's Lake Erie fishery, found that total dockside value of the harvest was reduced by 50% in the late 1950s, due to the change in the species composition of the commercial catch. The average price per pound in 1959 fell 48% from the previous year's level, while the total landings remained essentially unchanged. The price per pound paid to all other Canadian inland fish producers meanwhile remained virtually constant from 1946-70 (Lambert 1973). To combat lower prices, landings per person increased rapidly so that landed value per person, although remaining near constant, has attained a level almost double that of any other Ontario fishery (Lambert 1973). To maintain this reasonably constant level of return on investment and labour, there was a gradual transition to a more capital intensive and efficient commercial fishery (Lambert 1973).

Berkes and Pocock (1990) examined seven types of commercial fishing operations in lakes Erie and Ontario and offered a number of economic comparisons. Eastern Lake Erie smelt trawlers were found to be less labour-intensive than gillnetters (usually 3 fishers per boat as compared to 6). Landed value per trawling vessel was less than half that of the larger gillnetting operations, and while investment per fishery was much lower than the larger gillnetters, investment per fishing job was the highest of any of the seven fisheries (Berkes and Pocock 1990).

Total value of the Lake Erie catch (1977-1989) has ranged from a low of $10 million in 1978 to a high of $42 million in 1988 (OMNR various, 1990b). The value of the smelt catch in the five years that value by species has been published (1985-89), has ranged from a low of $2.7 million in 1989 to a high of $4.2 million in 1987 (OMNR various, 1990b). Percentage of smelt value as a proportion of total value ranged from a high of 15% in 1985 to a low of 7.5% in 1989 (OMNR various, 1990b). The most important species by value in the contemporary catch is yellow perch. In the same five year period the value of the yellow perch catch has ranged from a low of $9.5 million in 1985 to a high of $22.5 million in 1989 (OMNR various, 1990b). Percentage of total value has ranged from a low of 47% in 1985 to a high of 61% in 1989 (OMNR various, 1990b).

The value of rainbow smelt, while being far from the most important species in the catch, annually has accounted for $3.25 million or 10% of the value of the catch over the last five years (OMNR various, 1990b). Landed values to Lake Erie fishermen in 1990 were roughly $4.00/kg for yellow perch, $3.00/kg for walleye and $1.00/kg for lake whitefish (R. Loblaw, Ontario Ministry of Natural Resources, pers. comm.). Landed values for rainbow smelt ranged from $0.44-0.48/kg, while market value ranged from $1.90/kg for the Japanese product to $3.39/kg for the North American product (N. Plumb, Omstead Foods, pers. comm.). The difference in market price reflects the additional processing required for the North American product. Lake Erie smelt retails in larger North American markets for about $7.00/kg (N. Plumb, Omstead Foods, pers. comm.).

Sport fishing for rainbow smelt in Lake Erie generally occurs in April or early May when adult smelt seek out streams and beaches on which to spawn. Beach seines and dipnets are the gear used to harvest smelt. Sport fishing first took place at Point Pelee National Park in 1948, and was monitored for the first time in 1959. At that time, an estimated 38,628 smelters with a fishing effort of 128,245 hours produced a harvest of 1,165,326 kg (Sztramko 1984). An estimated 22,323 smelters exerted an estimated 71,298 hours of fishing pressure in 1983 and harvested an estimated 407,402 kg (Sztramko 1984). The large reduction in harvest probably was due to poor weather (Sztramko 1984), rather than reflecting any trend in reduced harvest over time. Rainbow smelt also are angled in winter ice fisheries at various locations around the lake (Sztramko and Paine 1984).

The first management directed toward rainbow smelt in Lake Erie was done by the processors of the commercial catch (Wolfert 1981). The harvest was regulated according to contemporary market demand. Presently, management of smelt stocks is by a government-instituted quota allocation system (OMNR 1990b).

There are indications that the Lake Erie rainbow smelt population currently is not in excellent shape. There have been two extended periods where the catch has been marked by pronounced alternating year-class abundances; between 1963 and 1974, and more recently between 1983 and 1988. It has long been suggested that this alternating year-class abundance is evidence of cannibalism, probably yearlings preying upon YOY smelt (Regier et al. 1969). Henderson and Nepszy (1989) found evidence to support the hypothesis that cannibalism was an important mechanism for regulating recruitment of smelt, but found the actual evidence of cannibalism was weak. They conclude, however, that if cannibalism is responsible for the inverse relationship between recruitment to age 1 in any given year, and the abundance of yearlings during the previous year, then it can be inferred that cannibalism acts as a density-dependent and compensatory mechanism of mortality regulating recruitment to the adult population.

Henderson and Nepszy (1989) found no correlation between total mortality of smelt at ages 2 and 3 years, and fishing effort. They do, however, note that an increased harvest of yearling smelt from 1976 to 1983 coincided with the first period of alternate year-class abundance and suggest that the two may be related (Henderson and Nepszy 1989). Smelt quotas in the central basin have not been reached since 1985 (LEFAU 1990). Quota reductions currently being imposed upon the Lake Erie commercial fishery are aimed at reducing the magnitude of the fluctuation in harvest. Henderson and Nepszy (1989) found that in addition to year-class strength being affected by cannibalism from the preceding cohort or cohorts, natural mortality increased with stock density. They suggest from this that it may be appropriate to adjust fishing pressure so that strong cohorts are exploited intensively.

The Lake Erie commercial catch is dominated by yearlings and 2 year-old fish. Yearlings are recruited into the fall fishery. Yearling smelt made up less than 1% of an aged subsample of 341 smelt from a sample of 2383 stream-spawning smelt taken from two Lake Erie tributary creeks in 1976 and 1977 (Nsembukya-Katuramu et al. 1981). In periods of alternate year-class abundance, every second year the fall fishery is dominated by juvenile fish, a sign of population stress.

In summary, rainbow smelt have played an important role in Lake Erie since their arrival in 1935. The stock has increased in abundance, becoming an important source of prey for piscivores, a competitor with planktivores, and a valuable resource for both the commercial and sport fisheries. Predation and competition pressures exerted by a large population of rainbow smelt in the 1950s on the young of already low stocks of lake herring, blue pike, lake whitefish and walleye, played a role in the severe reduction or extirpation of these stocks. Changes in Lake Erie fish community structure attributed to the processes of eutrophication, exploitation and introduction of species have resulted in changes to the commercial fishery. The change from a larger percid and coregonid fishery to one harvesting primarily rainbow smelt and yellow perch has brought lower prices per unit of weight. To maintain a relatively constant level of return on investment and labour, there has been a gradual change to a more capital intensive and efficient commercial fishery. Catches of rainbow smelt greater than 10 million kg were common by the late 1970s due to the development of a trawl fishery, and a market for them. Past management of the rainbow smelt in Lake Erie has been minimal, but current cyclical fluctuations in the commercial catch are being treated with reductions in commercial quotas.

4.2.1.2 Lake Simcoe

Lake Simcoe is located in south-central Ontario (44°23'N, 79°18'W), has a surface area of 725 km^2, and mean and maximum depths of 17.2 and 41.8 m respectively (MacCrimmon et al. 1983a). It has a regular shoreline with two large bays, one of which is shallow (maximum depth 15 m) and eutrophic, the other being deep (maximum depth 41 m) and mesotrophic (Evans and Waring 1987). The central basin is mesotrophic, with Secchi disc readings varying from 2.5 to 5.0 m during summer (LSFAU 1987). The lake stratifies during summer and dissolved oxygen levels within 1-2 m of bottom in the hypolimnion often decline to $\leq$ 1 mg/l during late summer (Evans and Waring 1987). The watershed is largely agricultural, but the lake is fringed with cottages and recreational developments, and several large communities. Increased eutrophication due to agricultural and domestic nutrient inputs are reflected by increasing algal blooms, localized hypolimnetic oxygen depletion, and a gradual shift in benthic communities (MacCrimmon et al. 1983a). Lake Simcoe possesses a diverse fish fauna (13 families, 23 genera and 34 species) (LSFAU 1987), and supports warmwater and coldwater sport fisheries.

The source of the rainbow smelt population in Lake Simcoe is unknown but its origin is placed at 1960, and is almost certainly the result of accidental or intentional introduction by man (MacCrimmon et al. 1983a). MacCrimmon et al. (1983a) have described the naturalization of the rainbow smelt in Lake Simcoe and its life history in the lake. Most of what follows has been extracted from their work. Rainbow smelt were first reported from the lake in 1962 when three specimens were taken in the winter angling fishery. Smelt were not seen again until the 1964 and 1965 fisheries, when catches of 208 and 250 fish respectively were made.

The first spawning groups were seen in 1965 when large congregations of rainbow smelt gathered at stream and shore locations, signalling the buildup of the population. The appearance of a large population of spawning smelt around much of the shoreline in 1965, with equal numbers of mature fish of ages 1, 2 and 3 is evidence that successful spawnings took place in 1962, through 1964. The breeding population must have been very small in these years in view of their small contribution to the winter sport fishery, and the apparent absence of spawning concentrations prior to 1965. The abundance of smelt, as revealed by winter angling catches increased rapidly in succeeding years, to a peak in 1973.

In late winter, adult rainbow smelt gather around the periphery of the lake at depths of 3-10 m. At this time the lake is still unstratified, and temperatures in the epilimnion are constant at 3-4°C. The disappearance of shoreline ice and consequent warming of epilimnetic waters to 4-7°C triggers the onset of spawning, usually in late April. Shore spawning in Lake Simcoe occurred along sand beaches in water temperatures of 5-9°C for a period of up to two weeks. Spawning groups became dispersed, however, if wave action became pronounced, or if water temperatures remained above 11°C for any period of time. Stream sites appeared to support greater densities of spawners, but spawning occurred at about the same time in water temperatures of 7-11°C.

Adult smelt become less tightly congregated after spawning, and gradually move to deeper water. By mid-summer they are loosely distributed on, or near the lake bottom at depths between 18 and 40 m. During summer stratification, smelt generally were taken in waters ranging in temperature from 6-9°C, but they made diel movements into water as warm as 17.5°C at night. Following breakup of summer stratification in late autumn, smelt were found more closely associated with the bottom, apparently preferring the warmest water available. Few details are available on the life history of smelt yearlings or YOY from Lake Simcoe. Summer trawling in one season produced substantial numbers of YOY smelt near the bottom at depths of 10-14 m at various lake locations.

Adult smelt were found to feed throughout the year and at various water depths in Lake Simcoe, favouring zooplankton, but supplemented seasonally by small fish and benthic invertebrates (MacCrimmon and Pugsley 1979).

The principal environmental features that appear to have favoured the establishment of rainbow smelt in Lake Simcoe have been identified as, firstly, the presence of extensive creek and shoal spawning areas around the periphery of the lake; secondly, the availability of offshore areas with bottom water temperatures favourable for smelt feeding and growth (<11°C); and thirdly, an abundance and diversity of food available for year-round use (MacCrimmon and Pugsley 1979). The most notable changes which have occurred in the Lake Simcoe rainbow smelt population since their naturalization are a pronounced reduction in the percentage of yearling spawners, a reduced growth rate, and a gradual increase in population size to peak abundance by 1973, about thirteen years following introduction (MacCrimmon et al. 1983a). MacCrimmon et al. (1983a) documented the extreme variability in the size of the spawning population in Lake Simcoe, but stated that no apparent correlation between good and poor spawning years, and subsequent year-class strengths could be found. They postulated that year-class strengths in Lake Simcoe seemed to be determined by spawning success rather than the numbers of spawners.

Coincident with the colonization of Lake Simcoe by smelt has been a decline and near collapse of lake trout and lake whitefish populations (Evans and Waring 1987). Since the mid-1960s, the Lake Simcoe lake whitefish population has declined by 75 to 85%, angler catch has fallen 80 to 90%, and growth rate has increased 70% weight/age (Evans et al. 1988). While the exact cause or causes of these changes are not known, several hypotheses have been put forward, all dealing with three ecological stresses; eutrophication, increased levels of toxicants in the lake and the introduction of rainbow smelt.

Evans and Waring (1987) examined the winter angling fishery in Lake Simcoe from 1961-83 and summarized the changes in the fish community as follows. Lake trout initially declined from reproductive failure, possibly caused by poor survival of eggs and young due to eutrophication. Rainbow smelt were introduced into the lake during the period of declining lake trout abundance, and flourished possibly because of minimal lake trout predation. The lake whitefish population declined in numbers due to complete reproductive failure during the period of exponential growth of the rainbow smelt population. Competition between the two species for food and habitat resources or predation by adult rainbow smelt on young lake whitefish, or both, is the suspected cause.

Yellow perch increased in abundance as lake whitefish density declined. It is difficult to ascertain whether the dominance attained by yellow perch is due to a competitive advantage of yellow perch over lake whitefish in the presence of rainbow smelt, or is simply due to an increase in their abundance in the absence of competition from young lake whitefish. In either case, invasion by rainbow smelt has not had a negative effect on yellow perch. Lake herring abundance increased while lake whitefish were at their lowest density. Lake herring density subsequently has declined, as has the density of rainbow smelt, possibly due to increased predation by the lake trout trout population which has been augmented by introductions. Production of lake herring in Lake Simcoe does not appear to have been directly affected by the abundance of rainbow smelt (Evans and Waring 1987). This is significant in view of observations to the contrary in other lakes (Loftus and Hulsman 1986, Evans and Loftus 1987).

The recruitment failure of the Lake Simcoe lake whitefish population is well documented, but the actual cause is unknown (Evans and Waring 1987). Evans et al. (1988) state that whitefish recruitment diminished progressively over a period of a few years in the late 1960s and was minimal by 1970 or 1971. Spawning still is occurring and larvae are present in surface waters during May (Evans et al. 1988). Deterioration of habitat quality in Lake Simcoe has occurred, but the effect on whitefish reproductive success is unknown (Evans et al. 1988). Natural recruitment continues to be minimal, possibly nonexistent, and the whitefish population is maintained through the introduction of hatchery-reared progeny of native origin (McMurtry 1989).

The fact that the presence of abundant numbers of rainbow smelt does not appear to have had a significant effect on the recruitment success of lake herring, suggests that predation on coregonid larvae is not a major cause of early mortality in Lake Simcoe coregonids as was shown by Loftus and Hulsman (1986) in Twelve-Mile Lake. Young lake herring continue a pelagic existence throughout their first year, while lake whitefish become demersal at about six to eight weeks after hatching (Evans and Waring 1987). It can be presumed, therefore, that if smelt are having an effect on whitefish, it occurs after descent to the bottom by the latter. Recent introductions of hatchery-reared, yearling lake whitefish (1982-85) have survived and grown well in Lake Simcoe, suggesting that recruitment failure occurs due to mortality prior to the yearling stage (Evans and Waring 1987).

Evans and Waring (1987), in an analysis of interspecific interactions among species caught in the winter sport fishery on Lake Simcoe, found a statistically significant negative correlation between catches of whitefish, and catches of smelt four and five years earlier. Mean ages in the catch of 6-8 for whitefish, and 2-3 for smelt, suggest a negative interaction between year-classes originating in the same year. Evans and Waring (1987) postulated that rainbow smelt, being almost as large as YOY lake whitefish, and presumably much more abundant in the early 1970s, would have placed a huge additional load on the food and space resources of the deep epilimnetic zone. Competition at that time may have resulted in displacement of lake whitefish from their preferred habitat, resulting in elevated mortality.

Fish in Lake Simcoe have not been exploited with gillnets since about 1900 (Evans et al. 1988). Rainbow smelt are harvested in two sport fisheries; during spawning runs using seines or dipnets, and in a multi-species winter hook and line fishery. Since 1970, spawning aggregations of rainbow smelt have been harvested by nocturnal seine and dipnet fishermen. Annual spawning runs have not been quantified but general observations suggest a large variability in the extent and duration of both onshore and creek spawning runs (MacCrimmon et al. 1983a).

As mentioned previously, rainbow smelt first appeared in the winter fishery in 1962 and rapidly increased to reach a peak in 1973 (MacCrimmon et al. 1983a). The harvest of smelt since 1973 has ranged between 2800 and 3900 kg annually for a 70 day fishing season, varying substantially from year to year (Evans and Waring 1987). In an analysis of the winter fishery since the introduction of smelt, Evans and

Waring (1987) found that total catch in numbers of fish increased over the period 1961-83, reaching a level about 30% higher than during the "pre-smelt" period of the early 1960s. They found, however, that total yield in biomass declined during the survey period. This they attributed to a lower level of catchability of rainbow smelt as compared to lake whitefish, rather than a decline in total fish biomass in the lake. Annual variation in total yield also was found to increase coincident with the initial increase in smelt abundance. Over the same period of time, catch per unit of effort (CPUE) for lake whitefish in the winter angling fishery decreased from 0.377 fish/hr in 1965 to a low of 0.008 fish/hr in 1977, reflecting a decline in the estimated catch from 153,000 to 3000 fish. Following the introduction of hatchery-reared whitefish, catches increased to 14000-15000 fish per year (1981 to 1983), with a corresponding CPUE of 0.031 lake whitefish per angler-hour (Evans and Waring 1987).

McIntyre (1989) summarized the 1989 winter sport fishery catch of 558,552 fish in Lake Simcoe as 70% yellow perch, 21.2% rainbow smelt, 3% lake herring, 2.7% lake trout and 2.7% lake whitefish. Over 90% of the rainbow smelt caught were retained, resulting in a harvest of 3400 kg (McIntyre 1989). Lake whitefish were sought by 51.8% of anglers, followed by lake trout at 42.8% and yellow perch at 24.5%. Very few anglers had a specific interest in rainbow smelt, but harvested them opportunistically (McIntyre 1989). The fishery for rainbow smelt specifically is not managed for in Lake Simcoe, although increasing the number of lake trout re-introduced into the lake may serve to regulate the smelt population to some degree. The densities of rainbow smelt and lake herring have dropped, presumably in response to increased abundance of lake trout (Evans and Waring 1987), suggesting that a large predator may have a major influence on the structure of a fish community.

In summary, rainbow smelt have become an important part of the Lake Simcoe fish community since first collected in 1962. The population quickly increased in abundance, about thirteen years after introduction. As in Lake Erie, rainbow smelt have become an important source of prey for piscivores, a competitor with planktivores, and a substantial component of the winter sport fishery harvest. Coincident with the colonization of Lake Simcoe by smelt has been a decline and near collapse of lake trout and lake whitefish populations. It is felt that declines in these two species are due to a combination of three phenomena; eutrophication, increased levels of toxicants in the lake and the introduction of rainbow smelt. Stocks of lake herring in Lake Simcoe do not appear to have been affected by the abundance of rainbow smelt, in contrast to observations in many other lakes. The effect of smelt on whitefish is hypothesized to be competition for food and spatial resources between young-of-the-year of each species. Since the arrival of smelt, total catch (in numbers) in the winter sport fishery has increased, but total yield in biomass has decreased due to the lower catchability of smelt.

4.2.2 Lake Winnipeg

4.2.2.1 Physical, Chemical and Biological Features

Lake Winnipeg, centered at 52°00'N and 97°00'W, is the seventh largest lake on the North American continent. It is 436 km long, 111 km wide at maximum breadth, and has a surface area of 23,750 km^2. Lake Winnipeg can be naturally divided into two basins, north and south, with a third area, the channel, connecting the two basins.

Table 6 presents a comparison of selected morpho-edaphic characteristics of Lake Winnipeg and various smelt-impacted lakes. The surface area of Lake Winnipeg is very similar to that of Lake Erie. The mean depth of Lake Winnipeg is shallower than that of lakes Erie or Simcoe, but quite comparable to the mean value for the inland lakes containing smelt. A maximum depth of 36.0 m for Lake Winnipeg is misleading, as it occurs in a very small portion of the channel. The maximum depth in the north basin is 19.0 m.

Lake Winnipeg's shallow mean depth and high volume of inflow combine to produce a relatively short turnover time of 3.8 years. Brunskill et al. (1979a) stated that the

TABLE 6. CHARACTERISTICS OF LAKE WINNIPEG AND VARIOUS RAINBOW SMELT-IMPACTED LAKES

				ONTARIO INLAND LAKES CONTAINING SMELT[9]					
	WINNIPEG	ERIE	SIMCOE[8]	N	MEAN	MIN.	MAX.	LOWER QUARTILE	UPPER QUARTILE
SURFACE AREA (KM^2)	23750.0[1]	25690.0[4]	725.0	177	52.3	0.1	4480.0	1.2	9.6
MEAN DEPTH (M)	12.0[1]	18.5[4]	17.0	169	11.6	2.0	38.7	6.8	14.9
MAXIMUM DEPTH (M)	36.0[1]	64.0[4]	41.5	181	35.7	4.0	213.5	19.5	43.0
TURNOVER TIME (YEARS)	3.8[2]	2.5[4]	16.0	-	-	-	-	-	-
SECCHI (M)	-	4.5[5]	5.0	172	4.9	1.3	10.5	3.6	5.9
TDS (MG/L)	-	146.0[6]	208.0	135	49.4	5.5	231.4	27.0	57.9
MEI (TDS/MEAN DEPTH)	-	7.9[4,6]	12.2	128	5.9	0.6	45.3	2.2	7.6
NO. FISH SPECIES	48.0[3]	114.0[7]	34.0	179	11.3	3.0	63.0	8.0	12.0

REFERENCES:

1. BRUNSKILL ET AL. (1980)
2. BRUNSKILL ET AL. (1979a)
3. MANITOBA DEPARTMENT OF NATURAL RESOURCES (ManDNR) (1989)
4. HARTMAN (1972)
5. BEETON (1965)
6. MATUSZEK (1978)
7. CHRISTIE (1974)
8. LAKE SIMCOE ASSESSMENT UNIT (LSAU) (1987)
9. EVANS AND LOFTUS (1987)

water retention time is sufficiently short in Lake Winnipeg to allow water masses from the major rivers to retain considerable identity in the lake's basins. Further, they stated that the river plumes essentially control the seasonal distribution, variation and stratification in temperature, conductance and turbidity (Brunskill et al. 1979b). Brunskill et al. (1979a) found the turnover time of Lake Winnipeg to range from 2.9-4.6 years for the whole lake and 0.4-0.7 years for the south basin. The longer water renewal time of the north basin over that of the south basin suggests that there may be better habitat for smelt in the north basin.

Table 6 illustrates that Secchi, TDS and MEI are unavailable for Lake Winnipeg. Secchi readings and dissolved major elements are discussed at length in Brunskill et al. (1979a, 1979b), but mean values for Lake Winnipeg were not calculated. Lake Winnipeg is not a homogenous water body, and therefore mean values for these parameters would not be accurate (G. Brunskill, Department of Fisheries and Oceans, pers. comm.). Secchi readings averaged about 2.0 m in the open waters of the north basin and ranged from about 0.3 m near the mouth of the Red River to about 1.0 m at the northern end of the south basin in July of 1969 (Brunskill et al. 1979b). Water clarity values in July were the highest recorded through the open water season. Secchi readings of 2.0 m are much lower than most in Table 6. This reflects the very turbid nature of Lake Winnipeg compared to typical lakes containing rainbow smelt.

The south basin is shallower and smaller than the north basin, accounting for 12% of the total lake surface area and 9.5% of the volume of the lake (Brunskill et al. 1980). Differences in water temperatures between basins are not pronounced but due to its smaller size, the south basin warms up in spring and cools down in fall more quickly than the north basin. Brunskill et al. (1979a) found the south basin and channel to be 4-6°C warmer than the open waters of the north basin in early June. They found that Lake Winnipeg is vertically well-mixed and rarely shows any degree of summer stratification. Mixing is a function of the lake's mean depth, inflow and wind currents. Maximum depth in the south basin is 14 m. Water temperatures taken at a depth of 7-10 m in the open water zone of the south basin in 1969 ranged from 2.9°C in late April, to 11.0°C by early June, and 19.5°C by late July, before falling to 18.6°C by early September, 11.7°C by early October and 3.7°C by late October (Brunskill et al. 1979a). Surface temperatures of the south basin reached 20°C by the end of July. Inverse stratification occurs after freeze-up in both the north and south basins, with a thin layer of 3°C water right along the bottom, and most of the water column isothermal at ≤1°C (Brunskill et al. 1979a).

The north basin of Lake Winnipeg accounts for 74% of the surface area of the lake and 82% of its volume (Brunskill et al. 1980). Very little summer stratification occurs in the north basin, but Brunskill et al. (1979a) did observe a 4°C difference from surface temperature to bottom temperature at 15 m following an extended period of hot, calm weather. Maximum depth in the north basin is 19 m. Water temperatures taken at a depth of 13-16 m in the open water zone of the north basin in 1969 ranged from 2.3°C in early April, to 5.0°C by early June, 14.4°C by late July and 17.8°C by early September, before falling to 10°C by early October and 4.8°C by late October (Brunskill et al. 1979a). Surface temperatures in the north basin lagged behind those of the south basin by only 1-3°C (Brunskill et al. 1979a). Brunskill et al. (1979a) reported that other workers have found little or no oxygen depletion in either the north or south basins of Lake Winnipeg.

Brunskill et al. (1979a) found water temperatures in Lake Winnipeg to be relatively isothermal at about 17-19°C by late August/early September. The work conducted by Brunskill et al. (1979a) may be the most comprehensive water temperature data collected for Lake Winnipeg, but other data is available on the thermal regime of the north basin of Lake Winnipeg. Rybicki (1966) found bottom temperatures ≥16°C and no thermal stratification during mid/late July of 1963 and 1964. This concurs with the temperature regime described by Brunskill et al. (1979a). Kristofferson et al. (1975), however, found late July bottom temperatures as low as 10°C in 15 m of water, with a corresponding 10°C difference between surface and bottom temperatures. Partial thermal stratification was short-lived as a storm thereafter produced complete mixing of the water column in the north basin (Kristofferson et al. 1975). Pollard (1973) cautioned against the comparison of Lake Winnipeg water temperatures since temperatures vary with meteorological conditions. In summary, mean late summer water temperatures in Lake Winnipeg generally are isothermal at about 17-19°C, but extended warm, calm periods may produce varying degrees of thermal stratification.

Rainbow smelt generally are known to favour cool water and congregate at or below the thermocline in stratified lakes. In Lake Oahe, South Dakota, a stratified warmwater reservoir on the Missouri River, smelt were found only in areas with a hypolimnion in the summer (Nellbring 1989). The temperature preference of adult and yearling smelt in Lake Erie during summer was found to be 6-10°C. The normal summer water temperatures in Lake Winnipeg are well above those preferred by rainbow smelt under ideal conditions. Populations of smelt are known to occur, however, in non-stratified lakes where summer temperatures may exceed 20°C (Rupp 1959). Smelt were found in abundant quantities throughout the water column in Two-Island Lake during mid-

August in the present study (Figure 3). Corresponding water temperatures were found to range from 20°C at the bottom (10 m) to 21.5°C at the surface (Table 1).

There are also examples where populations of smelt have not become established although they are abundant in connected waters. Adult rainbow smelt are abundant in the central and eastern basins of Lake Erie. Adults generally are not found in the unstratified western basin after spawning, although YOY smelt are found throughout the summer (S. Orsatti, Ontario Ministry of Natural Resources, pers. comm.). Rainbow smelt are known to use the Detroit River for spawning, linking the western basin of Lake Erie with Lake St. Clair, thereby providing Lake St. Clair with a source of smelt. Lake St. Clair, an unstratified lake with a maximum depth of 6.0 m and a bottom temperature in the low- to mid-20s°C in late summer, does not support an abundant population of rainbow smelt (D. MacLennan, Ontario Ministry of Natural Resources, pers. comm.).

As previously mentioned, abundant populations of smelt are known to exist in lakes Sakakawea and Oahe, both thermally-stratified reservoirs on the Missouri River. Smelt also are known to drift down the Missouri River, and into the Mississippi River, particularly in winter (Burr and Mayden 1980, Mayden et al. 1987). Populations of rainbow smelt have not become established in the three unstratified reservoirs downstream of Lake Oahe (Johnson et al. 1990).

One of the three, Lake Francis Case, has a maximum depth of 42.6 m and a bottom temperature in late summer as low as 20°C (D. Unkenholz, South Dakota Department of Game, Fish and Parks, pers. comm.). Warm water temperatures during summer, and perhaps the short turnover time of the reservoir are felt to be the primary factors limiting the establishment of a population of rainbow smelt in Lake Francis Case (D. Unkenholz, South Dakota Department of Game, Fish and Parks, pers. comm.).

Smelt populations may exist in warmwater lakes, but there is evidence that the populations may be stressed. Nellbring (1989), in a review of smelt biology found that smelt from shallow, warm lakes mature early, live for only a few years and have populations which fluctuate to a greater degree than those in colder, deeper lakes. Additionally, high summer temperatures in shallower lakes may cause severe summer mortalities among smelt (Nellbring 1989). Given the preceeding review rainbow smelt probably will colonize Lake Winnipeg, but may exhibit high summer mortalities and fluctuating population numbers, as experienced in other lakes. Differences in water clarity, turnover time and temperature between Lake Winnipeg's two basins all suggest that smelt may favour the north basin during the summer.

Availability of stream sites for spawning probably will not be a factor limiting the success of rainbow smelt in Lake Winnipeg. Brunskill and Graham (1979) found silty-clays and clayey-silts to account for over 70% of the sediment samples taken in Lake Winnipeg. Coarse sediments such as sands, gravels and boulders were found concentrated along the shores of the lake, around most islands and in shallow areas. The largest area of offshore sand was found around Long Point (70% at one sediment station), an esker composed primarily of sand and gravel jutting 40 km into the north basin of Lake Winnipeg (Brunskill and Graham 1979). Given the availability of sand and gravel around the shore of Lake Winnipeg, shore spawning can be expected. Long Point on Lake Winnipeg is similar to both Long Point and Point Pelee on Lake Erie, sites of extensive smelt shore spawning; therefore Lake Winnipeg's Long Point may be expected to support spawning smelt. Spawning in the south basin may precede north basin spawning due to earlier vernal warming of the streams and the basin itself. It is doubtful, however, that north basin stocks will migrate to the south basin to spawn.

The original Lake Winnipeg fish community contained 16 families, 28 genera and 48 species. The native community is characterized by lower- or mid-trophic species such as white sucker, lake herring, lake whitefish, goldeye (Hiodon alosoides), emerald shiner, spottail shiner, troutperch (Percopsis omiscomaycus), yellow perch and freshwater drum; and the piscivores sauger, walleye and northern pike. No species have been extirpated from Lake Winnipeg but lake sturgeon have been reduced to an incidental catch in the commercial fishery. Lake trout occasionally have been caught in the commercial fishery but they have not been recorded since 1976. Lake Winnipeg has not received the same number of introduced species as has Lake Erie. Common carp and white bass appeared in the lake in about 1938 and 1963 respectively (Scott and Crossman 1979), followed by black crappie (*Pomoxis nigromaculatus*) (K. Stewart, U. of Manitoba, pers. comm.), and now rainbow smelt in 1990 (Campbell et al. 1991). Carp, black crappie and rainbow smelt function as lower- or mid-trophic species, while white bass tend to be a piscivore.

The principal piscivorous fishes in Lake Winnipeg are walleye and sauger, and more recently the white bass. Rainbow smelt probably will be preyed upon to some degree by all three species. Smelt probably will not utilize the south basin of the lake to the same degree as the north basin due to higher summer water temperatures. Walleye and sauger populations favour the bottom in shallow, turbid lakes (Scott and Crossman 1979). Smelt likely will favour bottom waters, precluding the presence of any bottom currents, and therefore probably will overlap spatially with walleye and sauger. White bass are epipelagic, with less potential for spatial overlap with smelt, at least in summer. Additionally, white bass presently are more abundant in the south basin and channel areas (Kristofferson 1985), so spatial overlap within the lake may be reduced.

The potential for increased mercury levels in the flesh of walleye and sauger as they switch to a diet of smelt may become an issue of concern. Fish found to contain mercury levels in excess of 0.5 ppm in their flesh cannot be sold in Canadian markets, and if mercury levels exceed 1.0 ppm, fish cannot be exported to U.S. markets (M. Hendzel, Department of Fisheries and Oceans, pers. comm.). Fish containing mercury levels in excess of 1.5 ppm in their flesh should not be consumed (OME/OMNR 1990).

The Lake Winnipeg commercial fishery was closed during 1970 and 1971 due to high mercury levels in the flesh of walleye and sauger (Lysack 1986a). Monitoring of the commercial catch has revealed that mercury levels currently are low (M. Hendzel, Department of Fisheries and Oceans, pers. comm.). Figure 9 presents the relationship between mercury level and weight of walleye caught in the Lake Winnipeg commercial fishery. This relationship was found to be statistically significant ($p<0.0001$), with an r^2 of 0.79.

Inserting a value of $Y = 0.5$ into the regression equation yields an X value of 2.48. The average walleye from the Lake Winnipeg commercial fishery does not contain 0.5 ppm of mercury until it reaches a weight of 2.48 kg. Lysack (1986a) found the mean weight of walleye harvested from the Lake Winnipeg commercial fishery in 1983 to be 1.107 kg from the north basin, 0.746 kg from the channel, and 0.731 kg from the south basin. Substituting these values into the

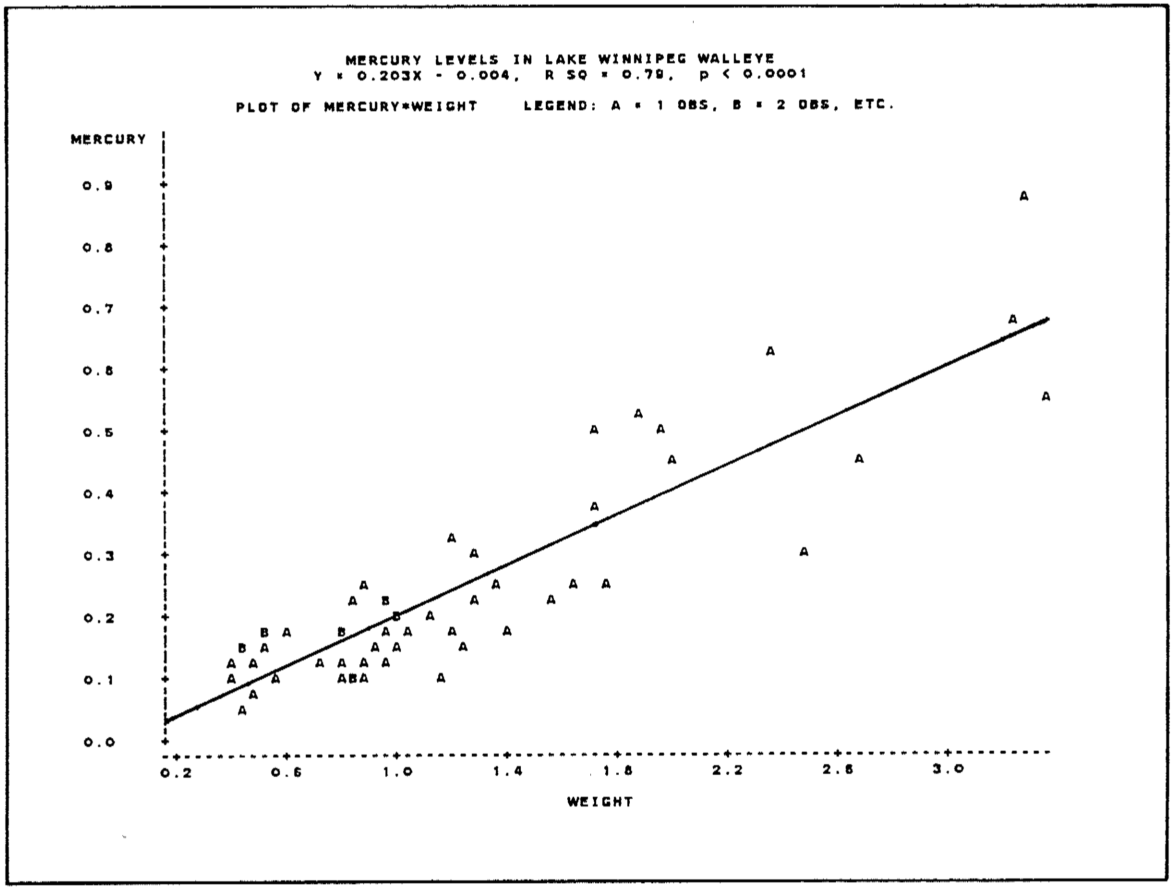

FIGURE 9. THE RELATIONSHIP BETWEEN MERCURY LEVEL (PPM), AND WEIGHT (KG), FOR WALLEYE (N=55) CAUGHT IN THE LAKE WINNIPEG COMMERCIAL FISHERY 1980-1990.

regression equation yields mercury values of 0.22, 0.15 and 0.14 ppm for north basin, channel and south basin walleye respectively. Mercury levels are currently very low in the walleye caught in the Lake Winnipeg commercial fishery. The relationship between mercury and length of walleye caught in the Lake Winnipeg commercial fishery had a lower r^2 value than that of mercury and weight, therefore it was not used. The relationship between mercury and weight or length of sauger was not significant.

The relationship between a diet of smelt and increased mercury levels in walleye has not been observed to the same degree as in lake trout. Mathers and Johansen (1985) found higher levels of mercury in walleye than pike, which they attributed to a higher frequency of occurrence of smelt in walleye stomachs. Figure 10 presents the relationship between walleye length and cumulative frequency of lakes where walleye mercury levels are above certain values, in lakes with, and without smelt. This figure illustrates that walleye reach a particular concentration of mercury contamination in a greater proportion of lakes with smelt, than in those without, for virtually any length interval of walleye at mercury concentrations of 0.5, 1.0 and 1.5 ppm. This is similar to the relationship presented earlier between smelt and mercury levels in lake trout.

Figure 10 does not indicate that walleye from any one lake with smelt will have higher mercury levels than in any

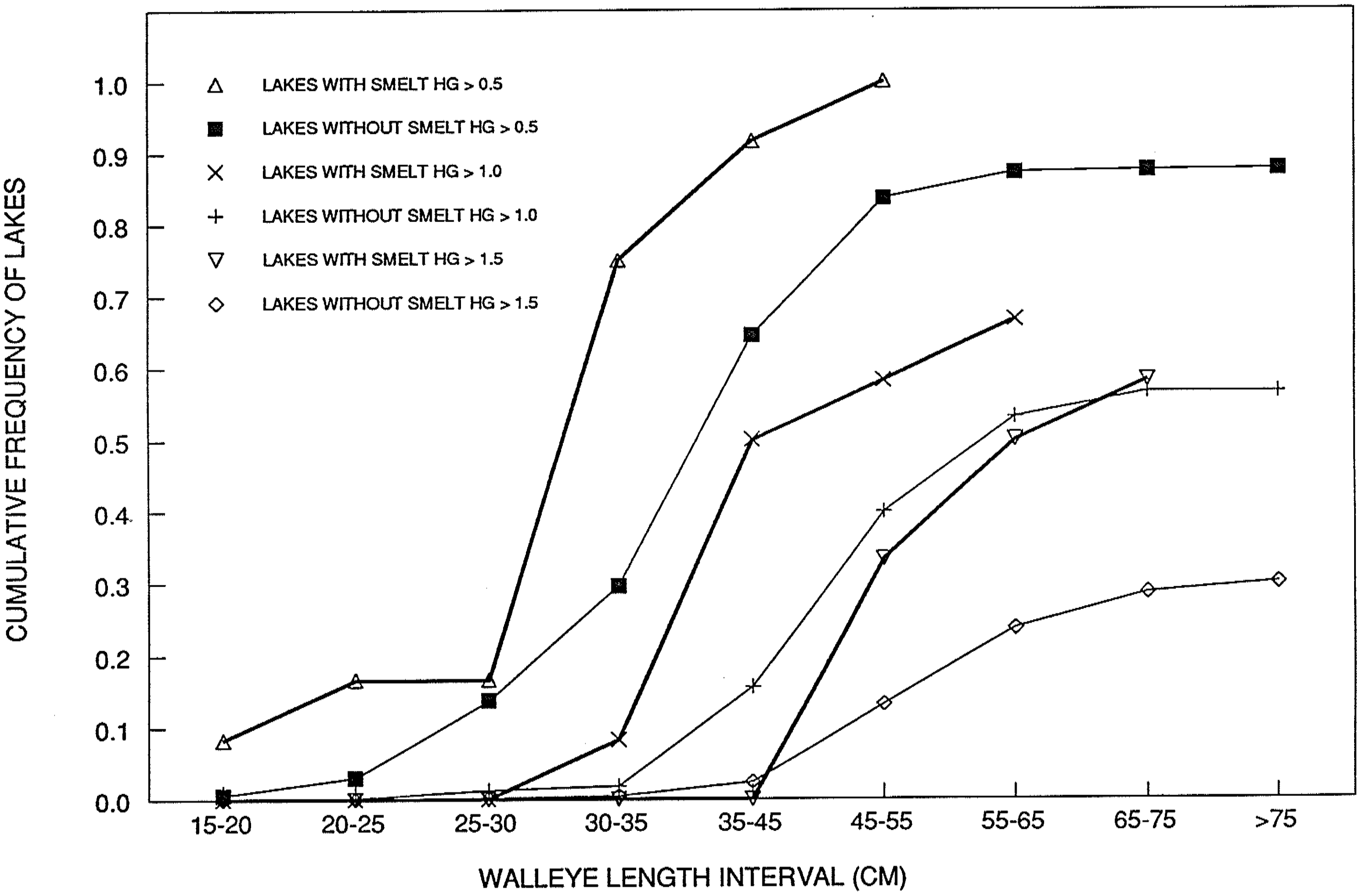

FIGURE 10. THE RELATIONSHIP BETWEEN WALLEYE LENGTH AND CUMULATIVE FREQUENCY OF LAKES WHERE WALLEYE MERCURY LEVELS ARE ABOVE 0.5, 1.0 AND 1.5 PPM, IN ONTARIO LAKES WITH (N=12) AND WITHOUT (N=493) RAINBOW SMELT.

otherwise comparable lake without smelt. It is included in the discussion of elevated mercury levels as one more piece of evidence to support the position that there is a overall relationship between presence of smelt and increased mercury levels in walleye. Rasmussen et al. (1990) showed that each additional trophic level contributed a 3.5 fold biomagnification factor to organic contaminant concentrations in lake trout, but their results may not be directly transferable to heavy metal contaminants. The principle, however, remains the same; species introductions that lengthen food chains increase contaminant levels in top predators.

Rainbow smelt are opportunistic feeders in most water bodies. Larger forms of zooplankton appear to be favoured among adult and yearling smelt in a number of lakes, including Lake Erie (Henderson and Nepszy 1989). A reduction in the abundance of large-bodied copepods and cladocerans following the introduction of smelt, resulting in a restructuring of the zooplankton and phytoplankton communities has been observed in at least two lakes (Reif and Tappa 1966, Siegfried 1987). Young-of-the-year emerald shiner, lake herring, lake whitefish, walleye and sauger in most lakes consume zooplankton during the first six weeks of their lives (Scott and Crossman 1979). Rainbow smelt therefore have the potential to compete for food resources with larval forms of all of these species. The latter three species migrate to the bottom and utilize different food resources after about six weeks, but smelt may compete for food resources with the former two species throughout their juvenile and adult lives.

The importance of lake herring and emerald shiners in the diet of Lake Winnipeg walleye is illustrated by the fact that 399 of 507 walleye stomachs with identifiable non-smelt remains contained lake herring and/or shiners (Notropis sp.). Walleye feed opportunistically, selecting abundant, vulnerable prey (Parsons 1971, Wagner 1972, Knight et al. 1984), and therefore smelt may be expected to form an alternate source of prey.

Because lake whitefish YOY become demersal at about six weeks and switch to a benthic diet, competition between smelt and whitefish for food does not appear to be a sound explanation for whitefish declines in other lakes. Overlap of spatial resources resulting in displacement of whitefish by the more abundant smelt was hypothesized as the explanation for recruitment failure of whitefish in Lake Simcoe (Evans and Waring 1987). In unstratified Lake Winnipeg, competition for spatial resources between smelt and whitefish also may be expected.

The reduction or elimination of lake herring and lake whitefish stocks have been observed frequently in Ontario lakes colonized by rainbow smelt. Fish communities have reacted in different ways to the introduction of smelt.

Lake herring and lake whitefish populations were nearly eliminated from Lake Erie due to both eutrophication and exploitation (Hartman 1972). Now, in the presence of a substantial population of rainbow smelt, lake whitefish numbers appear to be gradually increasing, but no such trend is apparent in lake herring. In Lake Simcoe, lake herring appear to have been unaffected by the invasion of rainbow smelt, while lake whitefish have reportedly suffered a near total collapse of the natural population (Evans and Waring 1987).

Predation of larval lake herring and lake whitefish was not viewed to be an important mechanism of population decline in Lake Simcoe (Evans and Waring 1987), while in nearby Twelve-Mile Lake smelt predation on coregonid larvae was found to produce total recruitment failure in lake whitefish and greatly reduced survival in lake herring (Loftus and Hulsman 1986). In unstratified Lake Winnipeg, there may be more spatial overlap between YOY coregonids and adult smelt, resulting in increased potential for predation by smelt.

Loch et al. (1979) considered the combined potential effects of rainbow smelt, gizzard shad and Utah chub (*Gila atraria*) on the Lake Winnipeg fish resources and predicted a 50 and 5% reduction in the lake whitefish populations of the north and south basins respectively, a 75 and 5% reduction in the lake herring populations of the north and south basins, and an overall 50% reduction in walleye and sauger populations of both basins as the most likely scenario. Upper and lower estimates of population reduction were also provided. Given the preceding account of the variability of coregonid declines following smelt introduction, I think it is unrealistic to attempt to quantify population declines. I feel confident in predicting that rainbow smelt will successfully colonize Lake Winnipeg, given the success of smelt in colonizing other sub-optimal habitats. How stable smelt populations will be, given the nature of some of Lake Winnipeg's morpho-edaphic parameters, is difficult to predict. I concur with Loch et al. (1979) in considering a range of possibilities so as to be ready for any potential scenario.

4.2.2.2 Commercial Fishery

Lake Winnipeg supports a large commercial gillnet fishery aimed primarily at walleye, sauger and lake whitefish. Walleye and sauger are harvested primarily in the south basin, while lake whitefish are harvested predominantly from the north basin (Kristofferson 1985). Annual yields of these species increased from the fishery's inception during the latter part of the nineteenth century until the 1950s and declined irregularly from 1950 to 1970, at which time the fishery was closed for eighteen months due to mercury contamination (Lysack 1986a).

Figure 11 presents the harvest of major quota species from the Lake Winnipeg commercial fishery from 1931 to 1987. Since the early 1970s catches of all three target species, walleye, sauger and whitefish, have fluctuated between 1 and 2 million kg annually each, with the total catch gradually increasing to about 6 million kg. These three species have generally constituted about 90% of the catch by weight during this period. The value of the catch has fairly steadily increased from $5.8 million in 1978-79 to $15.5 million in 1987-88 (ManDNR 1990). Walleye are the most valuable of the three target species, with summer 1990 prices to fishermen of $1.98/kg, followed by sauger at $1.54/kg and whitefish at $1.19/kg (FFMC 1990).

Evans and Waring (1987) found that coincident with the decline of lake whitefish and increase of rainbow smelt in Lake Simcoe has been a substantial increase in the angler catches of yellow perch, paralleling that of rainbow smelt. Whether the increase was due to reduced competition from lake whitefish, or a shift in competitive advantage in the presence of an external factor such as rainbow smelt could not be determined (Evans and Waring 1987). The initial dominance attained by yellow perch in the Lake Erie commercial fishery also paralleled the increase in the rainbow smelt population, and came at a time when coregonid stocks were very low.

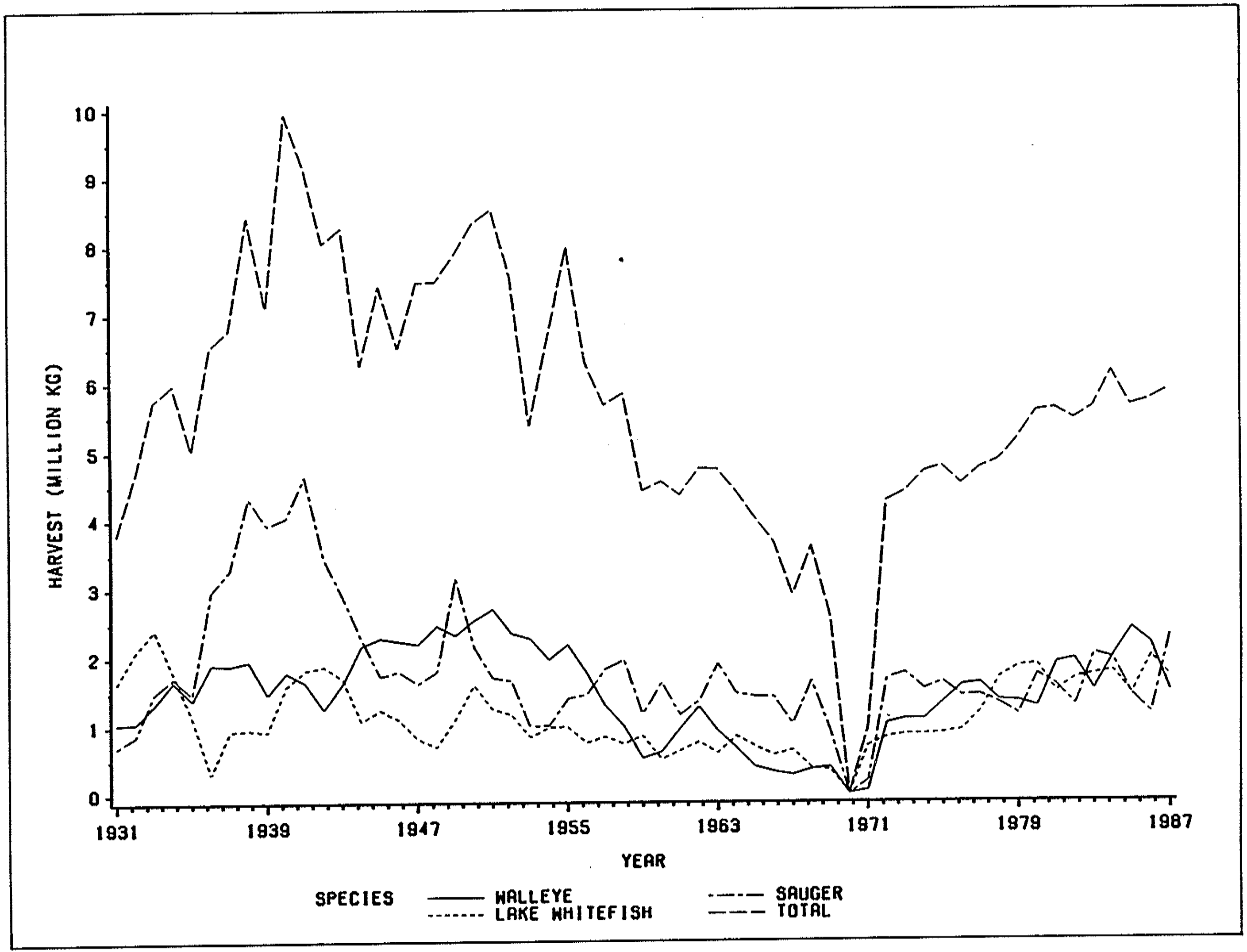

FIGURE 11. LANDED QUANTITIES (KG) OF MAJOR QUOTA SPECIES FROM THE LAKE WINNIPEG COMMERCIAL FISHERY 1931-1987 (FROM ManDMREM 1974, ManDNR 1983, VARIOUS).

If coregonid stocks decline in Lake Winnipeg in the presence of rainbow smelt, catches of yellow perch may increase similar to the situations in lakes Simcoe and Erie. Compounding this scenario, however, is the fact that increasing populations of perch in lakes Erie and Simcoe faced contemporary low and minimal populations, respectively, of piscivorous percids. This is not the current situation in Lake Winnipeg. The importance of yellow perch in the Lake Winnipeg commercial fishery has gradually increased over time, with the 1988-89 harvest accounting for 2% of the total catch by weight (DFO 1990a). The value of perch to fishermen is currently equal to that of walleye (FFMC 1990), making it a desired species.

Indicators show that the Lake Winnipeg commercial fishery, and the fish stocks on which it is based remain in relatively good shape. Catches continue to be fairly constant from year to year at about 85% of the 6.4 million kg quota set for the three target species (K. Campbell, Manitoba Department of Natural Resources, pers. comm.). However, Lysack (1986a) contends that rates of commercial exploitation of Lake Winnipeg's percid stocks are above the long-term sustainable yield of the lake. Long-term (1970-1986) increasing CPUE values in the lower Red River and south basin of Lake Winnipeg bait fishery suggest greater densities of forage fishes in the area, which may be due to decreased predation (Lysack 1987). The present density of piscivores in Lake Winnipeg becomes important when considering the potential invasion by rainbow smelt. It was shown that periods of rapid colonization by rainbow smelt coincided with reductions in predator density in several of the Great Lakes.

Depending upon the size that the rainbow smelt population assumes, and its attendant effect on the three principal species, the commercial fishery may be significantly affected. Some potential exists for the commercial exploitation of rainbow smelt in Lake Winnipeg, but this of course depends upon the population size they attain and its stability. In Lake Erie trawling was found to be the most economical method of exploitation. Physically, trawling may well be feasible in Lake Winnipeg. As previously described, over 70% of the lake's bottom is composed of silty-clays or clayey-silts with very few reefs or glacial erratics. Bathymetric maps reveal that much of the north basin and the central portion of the south basin is of uniform depth. Kristofferson (1985) has employed trawls successfully on an experimental basis. Exploratory work using commercial gear in Lake Erie was found to function and catch effectively to a minimum water depth of 4 m (Sand and Gordon 1960), suggesting that Lake Winnipeg would not be too shallow for commercial trawling.

The trawling season in Lake Erie's eastern basin extends from late March to December (Van West 1983). The open water season is much shorter in Lake Winnipeg, limiting the duration of trawling and perhaps affecting its economic viability. The vessels used in the north basin whitefish fishery should be suitable for trawling. With a reduction in Lake Erie smelt quotas and no apparent reduction in demand, it appears there is contemporary market demand for another smelt producer, particularly for American markets (N. Plumb, Omstead Foods, pers. comm.). A high quality, consistent and small product is required for Japanese and American markets, as smaller freshwater smelt are favoured over larger marine varieties (R. Loblaw, Ontario Ministry of Natural Resources, pers. comm.). Although current market demand appears high, distance from, and access to North American markets may further limit the economic potential of a Lake Winnipeg smelt fishery.

As previously mentioned, it is difficult and perhaps unrealistic to predict quantitative values of changes in existing fish stocks following colonization by smelt. The unpredictability of the success of smelt given the sub-optimal habitat offered by Lake Winnipeg again must be stressed. However, in order to demonstrate the economic impact of colonization of Lake Winnipeg by smelt on commercial fishermen, it is beneficial to create a range of hypothetical scenarios. The scenarios created are loosely based on the Lake Erie commercial fishery.

Table 7 presents the present value of the Lake Winnipeg lake whitefish and rainbow smelt harvest, pre- and post-rainbow smelt over a twenty year period for a range of scenarios. Detailed calculations are presented in Appendix 3. Lake whitefish harvest (5 year running average) declined an average of 27.7% annually from 1949-1969 in the Canadian waters of Lake Erie (Baldwin et al. 1979). Values of annual whitefish decline used for Lake Winnipeg were 5, 10 and 20%. Whitefish decline is not expected to be as rapid as that of Lake Erie due to the absence of cultural eutrophication as a contributing factor in Lake Erie.

Rainbow smelt catches were first recorded in 1952, harvests (5 year running average) increased an average of 24.7% annually from 1955-1964, and then remained relatively constant for the next five years (Baldwin et al. 1979). Values of smelt increase used were 10, 20 and 40%. The doubling of corresponding smelt increases compared to whitefish declines is explained by a projected decline in lake herring biomass equal to that of lake whitefish. Discount rates used were 5 and 10%. The model only takes into account the present value of whitefish and smelt harvest pre- and post-smelt. It does not look at changes in the value of percid catches, nor does it consider the capital cost required to convert to trawling.

Replacement of lake whitefish by rainbow smelt causes some loss to commercial fishermen under every scenario con-

TABLE 7. PRESENT VALUE OF LAKE WINNIPEG LAKE WHITEFISH AND RAINBOW SMELT HARVEST, PRE- AND POST-RAINBOW SMELT, OVER A TWENTY YEAR PERIOD

SCENARIO	Σ PRESENT VALUE WHITEFISH HARVEST	Σ PRESENT VALUE SMELT HARVEST	Σ PRESENT VALUE WHITEFISH AND SMELT HARVEST	Σ PRESENT VALUE WHITEFISH HARVEST PRE-SMELT	DIFFERENCE IN PRESENT VALUE PRE- AND POST-SMELT
1	$16,145,763	$983,731	$17,129,494	$23,566,891	-$6,437,397
2	$12,252,614	$551,034	$12,803,648	$16,654,409	-$3,850,761
3	$11,772,886	$1,874,199	$13,647,085	$23,566,891	-$9,919,806
4	$9,485,917	$994,547	$10,480,464	$16,654,409	-$6,173,945
5	$7,388,816	$6,812,567	$14,201,383	$23,566,891	-$9,365,508
6	$6,410,850	$3,377,229	$9,788,079	$16,654,409	-$6,866,330

ASSUMPTIONS OF SCENARIOS:

1 - 5% REDUCTION IN ANNUAL WHITEFISH HARVEST FROM YEAR 1 - 20, 10% INCREASE IN SMELT HARVEST FROM YEAR 6 -15, AND 5% DISCOUNT RATE.
2 - 5%, 10% AND 10%.
3 - 10%, 20% AND 5%.
4 - 10%, 20% AND 10%.
5 - 20%, 40% AND 5%.
6 - 20%, 40% AND 10%.

CALCULATIONS ARE SHOWN IN APPENDIX 3.

sidered. The loss ranges from $3.9 million to $9.9 million over a twenty year period. Calculated on a yearly basis, this translates to an annual loss to commercial fishermen ranging from $192,500 to $496,000. In 1991, the Lake Winnipeg commercial fishery lost $50,000-$80,000 of the annual freight subsidy paid out to commercial fishermen primarily to maintain the viability of the whitefish fishery (K. Campbell, Manitoba Department of Natural Resources, pers. comm.). Loss of this portion of the freight subsidy has some whitefish fishermen contemplating leaving the fishery (K. Campbell, Manitoba Department of Natural Resources, pers. comm.). Potential losses due to replacement of whitefish by rainbow smelt are larger than those of the reduction in freight subsidy allowance, and therefore may have greater ramifications.

4.2.2.3 Sport Fishery

Lake Winnipeg at present does not support a very substantial sport fishery. The site of one of the greatest concentrations of angler activity in the province, however, is the lower Red River (Lysack 1986b). Detailed stock analysis using morphometrics or electrophoresis have not been conducted on walleye or sauger stocks using the lower Red River to unequivocally determine if they originate from Lake Winnipeg. Biological characteristics (age-specific mean lengths and weights) of walleye and sauger stocks in the lower Red River were found to be very similar to those of southern Lake Winnipeg. Lysack (1986b), therefore postulated that Red River walleye and sauger stocks were not discrete, and originate from Lake Winnipeg. Tagging studies also have shown that walleye and sauger from Lake Winnipeg move into the lower Red River (J. O'Connor, Manitoba Department of Natural Resources, pers. comm.). Given the homogeneity of the percid stocks, the lower Red River sport fishery thus can be considered a Lake Winnipeg fishery.

Angling effort expended at Lockport, Selkirk and Netley Creek during the 1982-83 angling season was estimated at 336,626 angler-hours (Lysack 1986b). Anglers removed a total of 112,445 kg of fish during the 1982-83 season, with roughly 10% of the harvest being walleye and 20% being sauger (Lysack 1986b). More recent surveys of this fishery are not available, however, given the increased demand on sport fishing resources projected by Green and Derksen (1984), the current effort and harvest would be expected to be higher. Quantitative information for other Lake Winnipeg sport fisheries is generally not available, but important fisheries exist at the mouths of the Winnipeg, Fairford, Dauphin and Saskatchewan rivers, and effort and harvest estimates for the rest of the lake are thought to be about equal to that of the lower Red River (D. Fitzjohn, Manitoba Department of Natural Resources, pers. comm.).

The potential effects of rainbow smelt on the percid sports fishery range from recruitment declines in walleye and sauger populations and elevated mercury levels of the catch on the negative side, to increased growth rates and stronger year-classes on the positive side, with no apparent effect somewhere in between. The specific effects will depend primarily upon the extent to which smelt are able to colonize Lake Winnipeg and, as mentioned, this is difficult to predict.

Rainbow smelt may become a significant sport fishery resource of their own. Smelt are angled in winter hook-and-line fisheries in many lakes, including lakes Erie and Simcoe. This may not occur in the Lake Winnipeg area. Smelt are not likely to move upstream on the Red River and enter the winter angling fishery there. Sport smelt harvests probably will occur during spawning. As mentioned previously, there appears to be nothing precluding smelt in Lake Winnipeg from stream spawning, and shore spawning is anticipated.

The total value of the 1988-89 Lake Winnipeg commercial fishery including processing has been calculated to be $34.3 million (Scaife 1990). The total value of sport fishing on the Red River has been calculated at approximately $7.4 million using the value-added method and information from the 1985 Sport Fishing Survey (Scaife 1990). If it is assumed that the value of the Red River sport fishery in relation to the entire Lake Winnipeg sport fishery is the same proportion as that of effort (about 50%), then the total value of the Lake Winnipeg sport fishery approaches $15 million.

Under any of the scenarios presented in Table 7, the value of the commercial harvest drops with replacement of whitefish by smelt. A reduction in the size of whitefish stocks would require a reduction in the level of exploitation. This may encourage individual commercial fishermen to leave the industry.

In the American waters of Lake Erie, there has been a gradual decline in the size of the commercial fishery. Only Ontario reopened their commercial fishery for walleye following the two-year moratorium on commercial and sport harvest of Lake Erie walleye in 1970 (Hatch et al. 1987). The harvest of walleye became restricted to angling in Michigan and Ohio. Subsequently, gillnet fishing rights for yellow perch and white bass in Ohio waters of Lake Erie also have been purchased by the Ohio Department of Natural Resources and converted to angling quotas (Hushak et al. 1986). Commercial fishing in Ohio is now restricted to species not desired by sport fishermen.

A major charter boat industry has developed in Ohio around the expanding walleye population in the western basin of Lake Erie. The number of licenced charter captains increased from 34 in 1974 to about 700 by 1984 (Hushak et al. 1986). Greater political pressure generated by sport anglers as compared to commercial fishermen is primarily responsible for this. At the same time, it has been shown that summer sportfishing for walleye in Ohio's portion of Lake Erie generates larger economic impact relative to that generated by the commercial fishery (Hushak et al. 1986). The same study cautions that sportfishing may not hold an economic advantage over the commercial fishery for species for which prime angling season occurs in spring or fall.

A smelt-induced reduction of whitefish stocks causing commercial fishermen to leave the industry, combined with the ever-increasing demand for recreational fishing opportunities by resident and non-resident anglers (Green and Derksen 1984), may result in a future re-allocation of walleye and sauger quotas from commercial to sport fishermen. Presently, valuation of Lake Winnipeg's fisheries has shown the sport fishery to be worth less than half that of the commercial fishery on an annual basis (Scaife 1990). However, input/output analysis has shown the Lake Erie summer walleye fishery to be a more efficient revenue-generator (Hushak et al. 1986).

4.2.2.4 Subsistence Fishery

A survey of subsistence use of country foods by aboriginal Manitobans found average consumption of fish for three Lake Winnipeg bands to be about 50 kg annually per household, with an average household population of five people (Wagner 1986). If this level of consumption is indicative of the subsistence harvest around the entire lake, then the overall harvest is relatively small, but not insignificant to the individual resource user. Of the 115 households surveyed in the three reserves, 76% consumed walleye, 50% consumed lake whitefish, 38% consumed northern pike and 19% consumed sauger (Wagner 1986).

The principal species in the subsistence harvest may all become affected in some manner, depending upon how successfully rainbow smelt colonize Lake Winnipeg. Mercury levels in the flesh of walleye and sauger may increase, and catches of lake whitefish and lake herring may be reduced. Rainbow smelt may be difficult to exploit using traditional subsistence gear, except during spawning. Overall lake biomass has remained fairly constant in lakes Erie and Simcoe, although species compositions changed following the introductions of species. Wagner (1986) lists the consumption of twelve species by at least some residents of the three communities in Lake Winnipeg. The quality of the subsistence fishery may be reduced following the colonization of Lake Winnipeg by smelt, however, the harvested biomass may not be affected as other species are available.

4.3 MANAGEMENT STRATEGIES

4.3.1 General Review of Existing Techniques

4.3.1.1 Introduced Species

Programs designed to combat the threat of introduced species generally can be grouped into three categories: prevention, assessment and management (Shafland 1986). Prevention includes enforcement, resource-user education, and when possible, elimination of localized populations of the introduced species. Assessment is accomplished primarily through an active research program. The existing management practices for dealing with introduced species, such as sport and commercial fisheries and the introduction of predators, generally have been adapted from those developed for native species. If a sport or commercial fishery for an introduced species is seen to have beneficial effects it may serve to encourage illegal introductions into areas were they do not presently occur. The introduction of an exotic predator to control a previously introduced exotic species manifests opposing viewpoints. It has been shown, however, that on occasion, control of overly successful exotic species may require introduction of another exotic species when native species are unable to control them (Shafland 1986). The general philosophy behind the management of introduced species is to minimize the detrimental impacts while maximizing any intended or fortuitously beneficial attribute (Shafland 1986).

4.3.1.2 Forage Fish Management

Forage fish management has progressed from forage fish control to utilization of forage species. Management of forage fishes has included direct control of forage populations with toxicants, mechanical control such as seining, drawdown of water levels to increase forage availability, supplemental stocking and diversification of predators, and predator harvest regulations (Noble 1981). After careful analysis of fish populations in individual waters, the regulation of predator size limits can be used to affect the population structure of both predators and their prey. Minimum size limits adjust size structure of predator populations downward, thus favouring predation of small forage fishes (Noble 1981). Slot-sizes (protected size range) work to adjust the size composition of predators by reducing the number of small predators, protecting moderate-sized predators, and thereby shifting predation pressure from small forage to intermediate forage (Anderson and Weithman 1978). Anderson and Weithman (1978) discussed the successful increase of largemouth bass size using a protected slot size in a largemouth bass/bluegill (*Lepomus macrochirus*) community.

4.3.1.3 Management of the Rainbow Smelt

The lack of detailed management strategies for dealing with rainbow smelt has been a common theme in the literature and in the solicited provincial and state fishery information received. The lack of a management program in a state such as Michigan (W.C. Latta, Michigan Institute for Fisheries Research, pers. comm.), which borders on four of the five Great Lakes points to the scarcity of information available. Agencies in 5 provinces (83%), and 13 states (72%), replied to my requests for information, but only the states of Maine and New Hampshire had detailed management programs (Maine having separate anadromous and freshwater management plans). Even in Maine, however, where work has been going on for many years, it was noted that the erratic nature of fluctuating smelt populations has remained a perennial problem for fishery managers.

The general acceptability of rainbow smelt as a forage species has been commented on by some authors. Kircheis and Stanley (1981) state that the extreme fluctuations in the abundance of smelt limit their reliability as a primary forage species. The apparent decline of rainbow smelt in Lake Ontario due to rapidly increasing densities of salmonids, and their fluctuating abundance, has brought into question their reliability as a forage base for a multi-million dollar salmonid fishery. The re-introduction of one of the extirpated deepwater coregonids has been suggested as a precautionary measure (Christie et al. 1987). Similarly, it has been recommended that an additional coldwater forage species be introduced into Lake Oahe, South Dakota, to diversify the forage base and thus minimize the impacts of a fluctuating rainbow smelt population on salmonids (Stone and Nealson 1990).

Sport and commercial fisheries, and the introduction of predators have previously been mentioned as common techniques for managing rainbow smelt populations. Sport and commercial fisheries have been discussed in detail, and will only be touched upon here briefly. Rainbow smelt are considered one of the most important freshwater species in Maine and New Hampshire (Jordan 1986, NHFGD). Freshwater smelt generally are managed as salmonid forage in New Hampshire, while anadromous smelt are taken in sport and commercial fisheries. In Maine, freshwater smelt are managed as salmonid forage, for dipnet fisheries, hook and line fisheries and commercial bait fisheries. The allocation priority is salmonid forage, recreational fisheries and commercial bait fisheries (Jordan 1986).

The usual conflicts over use of the resource between recreational and commercial fishermen have developed. In Maine, it has been determined that single-use lakes are probably the best management strategy (Jordan 1986). Harvest of spawning smelt is not permitted in designated lake trout or other salmonid lakes in both Maine and New Hampshire (Jordan 1986, NHFGD). Streams are closed to fishing to protect the spawning stock, but also to prevent disturbance of the eggs, habitat degradation and vandalism. Limitations to control the number of smelters using the Lake Erie waters of Point Pelee National Park on a nightly basis have been in place since 1974 (Sztramko 1984). Reducing the congestion of smelters, rather than limiting the harvest appears to be the primary objective behind this management regulation.

The introduction of smelt eggs into other bodies of water to supplement or establish new populations has been experimented with for some time in New England (Kircheis and Stanley 1981). An experimental raceway was developed on a productive smelt spawning stream in New Hampshire. Burlap-covered spawning trays were used to collect the eggs. When the density of smelt was found to be low in the parent system, the eggs were left to hatch in-situ. When smelt densities were high, the eggs could be transferred to other water bodies. Presently, attempts are underway to develop the culture of rainbow smelt in Maine fish hatcheries (Jordan 1986). Attempts to regulate abundance by stocking to supplement the natural population, restricting fishing during low abundance, and killing eggs with chemicals during high abundance were successful in Quabbin Reservoir, Mass., but such practices were not considered effective as long-range planning tools because the extremes in population could not be recognized until after they occurred (Bridges and Hambly 1971).

The effective management of rainbow smelt as a forage fish requires the ability to recognize population fluctuations before predator growth is affected. At present it is difficult enough to indicate current population numbers, let alone predicted future trends. Gillnet catch per unit of effort (CPUE) and frequency of occurrence of smelt in walleye stomachs in Lake Nipigon have produced the same trends (B. Ritchie, Ontario Ministry of Natural Resources, pers. comm.), suggesting that indices of abundance can be used to monitor population abundance relative to past years. Hydroacoustic surveys have been used to estimate rainbow smelt biomass in Lake Superior (Heist and Swenson 1983), and in Lake Oahe (Burczynski et al. 1987). The estimate of smelt abundance in Lake Oahe was necessary to assess the effect of salmonid predators on the forage base, and allow fishery managers to predict the standing crop of predators that the forage base could sustain (Stone and Nealson 1990).

The elimination of a population of rainbow smelt, without the elimination of all species, has been attempted on at least one occasion (Bridges and Hambly 1971). The first step taken at Quabbin Reservoir, Massachusetts (surface area = 101 km^2), was to mechanically remove, using seines, as many spawning adults as possible. Tributaries were then treated with copper sulfate and in later years with a copper sulfate - sodium hydroxide mixture to kill the eggs. Five years later it was found that smelt were absent from predator stomachs. A combination of control measures, combined with lake trout predation and lower water levels to reduce shoal spawning apparently successfully removed smelt. Upon removal of smelt, however, lake trout growth rates decreased and smelt were immediately re-introduced, making it impossible to verify the success of the original eradication program (Bridges and Hambly 1971).

Rainbow smelt are not strong swimmers, and their upstream migrations are limited by their inability to ascend rapids and small falls over 30 cm in height (Baldwin 1948, McKenzie 1964). It has been suggested that this life history trait could be exploited by building control structures which would limit their dispersal. Smelt dispersed downstream through control structures in the Missouri River in a matter of a few years (Mayden et al. 1987). While control structures may limit natural upstream movement of smelt, they would not preclude movement by people.

4.3.1.4 Regulations concerning Rainbow Smelt

The regulations that were received and reviewed (Maine 1990, Michigan 1991, Minnesota 1990, North Dakota 1990/91 and Ontario 1991), generally concerned the harvest of freshwater rainbow smelt during spawning. The type of gear allowed varied among the jurisdictions, but consisted of dip nets, bow nets, small minnow seines, and minnow traps. Daily limits ranged from two liters per day in states such as

Maine which valued the resource more (MDIFW 1990), to no limit whatsoever. Seasons were either for one or two months duration at time of spawning, or they were unspecified. Smelt taken in the recreational harvest in Minnesota can be bought or sold at any time (MinnDNR 1990).

The non-commercial capture and use of live rainbow smelt as bait is legal in Maine (MDIFW 1990), and Michigan (MichDNR 1990). The non-commercial capture and use of smelt as bait in North Dakota is legal, but it is illegal to use live smelt for bait or to transport live smelt (NDGFD 1990). The possession of live smelt is illegal except below Garrison dam just outside of Lake Audubon (NDGFD 1990). Live smelt may neither be possessed or transported in Minnesota (MinnDNR 1990). Minnesota's regulations also carry a warning stating:

> "Smelt may cause problems to fish management in some waters, and to prevent their spread do not deposit fresh smelt or smelt eggs, or wash buckets used to haul fresh smelt in lakes or streams" (MinnDNR 1990).

Minnesota's concern regarding the introduction of smelt into new bodies of water appears inconsistent with their policy of allowing the recreational harvest to be bought and sold.

The Ontario regulations are the most conservative, not allowing any harvest of rainbow smelt in some areas of northwestern Ontario. They are designed to prevent further spread of the rainbow smelt. An OMNR publication reads as follows:

> "A total ban on fishing for or using live or dead smelt

> as bait in Northwestern Ontario is now in effect. This is to prevent smelt from becoming established in waters where they presently don't exist. Smelt compete with native cisco and whitefish, and, when lake trout feed on them, result in a less desirable tasting trout with elevated mercury levels" (OMNR 1990c).

The Ontario Sport Fishing Regulations Summary states:

> "It is illegal to possess live or dead smelt for use as bait or while sport fishing in Divisions 22, 24, 30 and 31 in Northwestern Ontario" (OMNR 1990a).

4.3.2 Management Considerations for Lake Winnipeg

The majority of the techniques described in the last section deal with the management of an existing population of rainbow smelt. Rainbow smelt are very early in their colonization of Lake Winnipeg and hence most of those techniques are not yet applicable.

The first consideration for Lake Winnipeg is to determine how well the smelt population succeeds in the lake. Due to the value of the Lake Winnipeg fishery and the potential effects of smelt, as have been documented, the rainbow smelt population must be consistently monitored to determine its success in the lake. The potential significance of the rainbow smelt in Lake Winnipeg simply cannot be ignored.

Whether or not to manage a particular fish species depends upon its economical, biological and natural importance in the fish community, its population condition, and the feasibility of management (Jaiyen 1975). The economical, biological and natural importance of any fish species depends greatly upon its population size. Consequently, the first step in a quantitative assessment of the impact of the rainbow smelt on Lake Winnipeg's fishery resources is to monitor accurately the colonization process.

Indices of abundance are techniques used to monitor the relative strength of a particular stock of fish over time. Bottom trawling for YOY percids is conducted in Lake Winnipeg during July and August to measure the strength of future year-classes which are recruited into the commercial fishery a few years later (Kristofferson 1985). Bottom trawling for YOY lake whitefish in the north basin has not been as successful, so future recruitment is determined using index gillnet sets (K. Campbell, Manitoba Department of Natural Resources, pers. comm.).

Indices of abundance will be the best way to determine the relative strength of the smelt population. This information, in combination with any trends in the commercially-harvested species can be used to forecast more accurately the apparent impact of smelt on native stocks. Any evidence of population stress over time among the three major commercially-exploited species as shown by biological or effort indicators, in concert with increased abundance of rainbow smelt, may lead fishery managers to consider a reduction in commercial harvest quotas. It may be possible to incorporate much of the index monitoring into existing Manitoba Fisheries Branch programs.

Trawling programs carried out in the north basin probably would be more beneficial than those in the south basin for monitoring the colonization of Lake Winnipeg by rainbow smelt, as smelt are likely to be more successful in the north basin. Bottom trawling to determine the abundance of YOY smelt in Lake Erie is conducted yearly, in October. If trawling in Lake Winnipeg were conducted later in the year, YOY lake whitefish might also be vulnerable to capture in the trawls, given their preference for the bottom later in the summer. Information on the strength of particular year-classes would be available two or three years earlier than is presently the case.

Other potential indices of abundance which could be used to monitor the strength of smelt stocks include the frequency of occurrence in walleye stomachs (as has previously been discussed), and the strength of spawning runs. Adult walleye stomachs could be taken and preserved for later detailed analysis, in conjunction with existing index netting programs. Van Oosten's (1937) figure of five years from the date of first capture in a lake to abundance and/or the presence of noticeable spawning runs appears to have remained fairly accurate over time. The first specimens were taken from Lake Simcoe in 1962, and spawning runs were first observed in 1965. Therefore, readily noticeable spawning runs may develop in Lake Winnipeg by about 1995. If and when spawning sites are identified index monitoring of streams can be carried out.

The invasion of rainbow smelt into Lake Winnipeg presents a good opportunity to study the potential increase in mercury accumulation by piscivores as a predator (walleye) switches from native planktivores (lake herring and shiners), to smelt, in one body of water. Additional walleye mercury level data would have to be collected soon, while the proportion of smelt in the diet of walleye is negligible.

Management of rainbow smelt population size may be attempted through the management of predators. It has been suggested that a predator can have a major effect on fish community structure (Christie et al. 1987, Evans and Waring 1987). Walleye feed opportunistically, shifting to vulnerable species when available (Parsons 1971, Wagner 1972, Knight et al. 1984). However, walleye also have been shown to feed selectively by species, and size, the latter criteria being selected for particularly when the abundance of forage species is high (Knight et al. 1984).

Protected slot-sizes have been demonstrated to be effective in the management of predator populations (Anderson and Weithman 1978), but their effectiveness in the management of prey populations is less conclusive. Even if it could be demonstrated that a particular size of walleye or sauger selected for adult smelt during periods of smelt abundance, it may be difficult to effectively institute a protected slot-size in a commercial fishery. Management of the predator population through the use of protected slot-sizes would appear to have limited application to the present Lake Winnipeg fishery. Regulation of commercial quotas of percid species may be used to manage predator, and hence prey, population size.

Changes to the existing Manitoba Fishery Regulations (1987) should be considered. Section 25(1) states that the use of previously frozen smelt as bait will be allowed (DFO 1990b). If spawning stocks become available, smelt undoubtedly will be harvested for this and other purposes. This creates two potential problems. First, there is an enforcement problem. How do you tell, and consequently enforce, whether or not bait has been frozen previously? Fresh smelt may or may not be more attractive bait, but they will be seen as such by some individuals. Unfrozen fresh smelt are a potential vehicle for introductions. Secondly, just by encouraging a fishery the possibility of further introductions is heightened.

A regulation similar to the one put into effect in northwestern Ontario should be considered at this time. A total ban on fishing for smelt or using any form of smelt, frozen or otherwise as bait would at least legally nullify the problems discussed above. This ban should perhaps better be seen as a moratorium on the use of smelt. It probably is best to be conservative at this time, until the potential of smelt in Lake Winnipeg is known. If large accessible spawning populations develop, smelt will become an attractive resource. As previously documented, the sport harvest of smelt can produce significant, seasonal local economic benefit. Subsistence fisheries for smelt which develop at spawning sites may offset some of the losses due to decreased lake whitefish and lake herring harvest. If large harvestable open water populations of smelt develop at the expense of lake whitefish, commercial exploitation of smelt may be considered. The commercial harvest of lower-valued smelt may offer an alternative income for commercial fishermen who may be displaced from the whitefish fishery.

If successful sport or commercial smelt fisheries are developed, and are seen to be beneficial by some people, then there is the potential for future unauthorized introductions aimed at duplicating these benefits in other lakes. The only Manitoba body of water from which rainbow smelt presently are known is Lake Winnipeg. Smelt have shown up in Lake Winnipeg much earlier than generally was anticipated. The occurrence of at least three discrete populations in the English River system, and at least six discrete populations in the Rainy River system of the Winnipeg River drainage basin attest to the role of introductions as a means of dispersal of the rainbow smelt. Once established in Lake Winnipeg, the introduction into other suitable water bodies becomes a distinct possibility.

Public education probably is one of the best tools available to minimize unauthorized introductions. A notice concerning smelt which appears in the 1991 Manitoba Sport Fishing Guide (ManDNR 1991), is included as Appendix 4. This is the type of message which has to reach the public, particularly the angling public. It is the angling public who are responsible for a great many of the unauthorized introductions of exotic species throughout North America (Shafland 1986). Educating the public as to the potential danger of introducing non-native species into water bodies with established fish populations will not solve the problem, but may lessen the likelihood of future unauthorized introductions.

Chapter V

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY

This study examined the present distribution of the rainbow smelt in the Winnipeg River drainage basin and the predicted distribution in Manitoba water bodies, assessed the potential impact of smelt on the fisheries of Lake Winnipeg, and recommended management measures based on the findings of the investigation. This study was undertaken because the range of the rainbow smelt is expanding, and its interaction with native species in other bodies of water has generated concern among Lake Winnipeg's fishery managers and resource users alike.

It has been demonstrated in this study that rainbow smelt have become well established in Winnipeg River drainage basin waters of northwestern Ontario. Three specimens collected from the south basin in 1990, and two more specimens collected in 1991, one from each of the channel and north basin, attest to the presence of rainbow smelt in Lake Winnipeg. Other Manitoba lakes which rainbow smelt are predicted to colonize include Lac du Bonnet, Big Whiteshell, West Hawk, Falcon, Manitoba, Winnipegosis, Clearwater, Cormorant, Moose, Cedar, Athapapuskow, Second Cranberry, Reed, Split and Stephens Lake.

The apparent absence of rainbow smelt from surveyed waters of the Winnipeg River proper, and the upper portion of the Red River drainage basin suggests direct introduction into the lower Red River, or Lake Winnipeg itself as the mechanism of dispersal into Lake Winnipeg. However, downstream migration from known Winnipeg River drainage basin collection sites (>200 km upstream), or headwater transfer into Berens or Bloodvein River systems and subsequent downsteam dispersal into Lake Winnipeg cannot be ruled out entirely. Van Oosten (1937) first suggested that it took roughly five years from the first capture to abundance and/or the presence of spawning runs in the Great Lakes, a figure that has remained reasonably accurate in other lakes. At that rate, Lake Winnipeg may support an abundant and readily noticeable spawning population of rainbow smelt by 1995.

It has been shown in the literature cited in this research that optimal conditions for rainbow smelt are deep, cool, clear lakes which thermally stratify in summer (Swain 1976, Evans and Loftus 1987, Nellbring 1989). Lake Winnipeg is a relatively shallow, turbid, unstratified lake, with late summer water temperatures generally isothermal at 17 - 19°C (Rybicki 1966, Brunskill et al. 1980). These temperatures are about 7°C above those preferred by adult rainbow smelt in Lake Erie. Rainbow smelt have been shown to have a very flexible life history, having colonized a wide range of lake types in Ontario. However, it has been stated in the literature that smelt populations in warmwater lakes are less stable than those in cooler lakes (Nellbring 1989). Given the plasticity of rainbow smelt, they are predicted in this study to colonize Lake Winnipeg. The population, however, may be subject to large summer mortalities and fluctuating levels of abundance due to habitat conditions that vary from the optimum.

The literature, as cited in this research, indicates that there are two major fish community implications associated with the invasion of rainbow smelt. The first is the potential restructuring of fish communities due to recruitment declines in native species (Evans and Loftus 1987, Nellbring 1989). The second is potential changes in energy flow and storage in the fish community due to changes in food web interactions (Evans and Loftus 1987). If smelt become well established in Lake Winnipeg, these interactions probably will be manifested primarily in the form of declines in lake whitefish and lake herring stocks due to predation by, and competition with smelt for food and spatial resources, and an increase in mercury levels in the flesh of walleye and sauger as they switch to a diet of smelt. The magnitude of these changes, however, are not quantifiable at this time.

The decline in whitefish stocks predicted in this study will result in a reduced commercial harvest of whitefish. This reduction, even if supplemented by harvest of rainbow smelt probably will result in an economic loss to commercial fishermen because of the price differential between whitefish and smelt. A range of hypothetical scenarios created in this study based on events which transpired in Lake Erie, examined the changes in the present value of the Lake Winnipeg lake whitefish and rainbow smelt harvest, prior to and after the establishment of rainbow smelt in the lake. These scenarios showed a loss to commercial fishermen ranging from $3.8 to $9.9 million over a twenty year period. These losses, calculated on an annual basis, are greater than current losses in annual freight subsidies paid out to maintain the viability of the north basin whitefish fishery, economic support fishermen say they cannot do without. These scenarios did not consider the capital cost required to convert to commercial trawling gear, nor did they look at any changes in the value of percid catches.

Lake whitefish and lake herring are not a major component of the sport harvest and therefore a reduction in these stocks should not adversely affect the sport fishery. A reduction in the availability of lake whitefish and lake herring may necessitate harvest of alternate species by the subsistence fishery, thereby reducing its quality. This study has found that the effect of smelt on the commercial, sport and subsistence harvest of walleye and sauger stocks will be determined primarily by the degree of smelt use by percids as a diet item, and the corresponding increase in walleye and sauger mercury levels.

Some potential may exist for the commercial exploitation of rainbow smelt in Lake Winnipeg. Smelt are shown to be lower-valued than any of the current target species, and have not proven to be as economically lucrative in existing fisheries. However, if whitefish stocks are severely affected, the commercial harvest of smelt may offer some alternative income for commercial fishermen displaced from the whitefish fishery. Physically, Lake Winnipeg appears to be suitable for commercial-scale trawling in the open-water season. The short season compared to that of Lake Erie, and distance from markets may further limit the economic potential of a trawl fishery. A substantial smelt population would produce the potential for an intensive sport fishery at accessible spawning sites. Subsistence fisheries for smelt which develop at spawning sites may offset some of the losses due to decreased lake whitefish and lake herring harvest.

Given the importance of the Lake Winnipeg fishery in economic and social terms, the potential significance of the rainbow smelt in Lake Winnipeg cannot be ignored. The overall objective of management of the rainbow smelt in Lake Winnipeg should be to minimize the detrimental effects while maximizing any beneficial attributes. The first management consideration is to determine how well rainbow smelt succeed in Lake Winnipeg. Other management strategies recommended in this study are designed to reduce the potential for further introductions into other bodies of water. These measures include banning the use of fresh or frozen smelt as bait, banning any future harvest of smelt until the success of smelt in Lake Winnipeg is determined, and implementing an extensive public education program, aimed at the angling public and designed to minimize future introductions into other water bodies.

5.2 CONCLUSION

Rainbow smelt are now resident in Lake Winnipeg and have been shown to have the potential to significantly alter its fishery resources in the future. The impact of rainbow smelt on Lake Winnipeg's native species, its existing fishery resource and the potential of rainbow smelt as a resource obviously depend greatly on the degree of success they have in colonizing Lake Winnipeg. This will be determined primarily by how well rainbow smelt are able to succeed in the sub-optimal habitat offered by Lake Winnipeg.

Literature dealing with the success of rainbow smelt in warm, unstratified lakes is inadequate to predict accurately the suitability of Lake Winnipeg for rainbow smelt. In this study it is recommended that quantitative data on the strength of the rainbow smelt population, and changes in lake whitefish and lake herring populations, and in walleye and sauger mercury levels be collected. This information is integral to the proper management of Lake Winnipeg's changing fish community and will enable user groups to respond more proactively to effects that the invasion of rainbow smelt have on existing fishery resources.

5.3 RECOMMENDATIONS

1. Index gillnetting programs for juvenile and adult populations of walleye, sauger and lake whitefish should be continued at the same intensity as present.

2. Fall index trawling programs should be established in the north basin to attempt to monitor the abundance of YOY lake whitefish, and the rate of colonization of the north basin of Lake Winnipeg by rainbow smelt.

3. Other programs designed to monitor indices of abundance of rainbow smelt, such as frequency of occurrence in percid stomachs, and their yearly abundance in any identified spawning streams should be established.

4. Mercury levels in walleye and sauger from Lake Winnipeg should be monitored more closely than at present, to determine the effect of smelt on background mercury levels.

5. The Lake Winnipeg Advisory Board, in consultation with representatives of Lake Winnipeg user groups must be kept informed of quantitative changes in coregonid populations and in percid mercury levels so that user groups are able to respond more proactively to rainbow smelt-induced changes in the existing fishery resource.

6. A ban on using any type of smelt as bait, including frozen, should be implemented.

7. Harvest of smelt in Manitoba should be declared illegal until it is determined how successfully rainbow smelt colonize Lake Winnipeg.

8. Public education programs, aimed particularly at the angling public should be expanded and continue to deliver the message that unauthorized introduction of aquatic species pose a very real and tangible threat to Manitoba's natural, economic and social fabric.

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APPENDIX 1. A COPY OF THE LETTER SENT IN JULY 1990 TO PROVINCIAL AND STATE OFFICIALS REQUESTING INFORMATION DEALING WITH THE MANAGEMENT OF THE RAINBOW SMELT

Dear Sir/Madam,

I am a student in the Master of Natural Resource Management degree program at the University of Manitoba, Winnipeg, Canada. As part of the degree, I am working on a practicum entitled "An Assessment of the Impact of the Rainbow Smelt on the Fishery Resources of Lake Winnipeg." From fieldwork conducted by myself and others, rainbow smelt are now known to be well established in several areas of the Winnipeg River drainage basin and can be expected to reach Lake Winnipeg at some point in time.

The issue at hand is when will rainbow smelt reach Lake Winnipeg and most importantly, what can be done about/with them? Are there ways to keep the rainbow smelt out of the province or at least slow them down?, or if not, in what way can the new fish community best be managed? This management aspect is the primary focus of my research at this time. I have been through the bulk of the relevant primary literature in my search, and am now hoping to gain access to any management information dealing with the rainbow smelt put out by state and provincial governments. Any literature, regulations, unpublished research or other material which you think might aid me in dealing with rainbow smelt management, produced by your agency which could be sent to me at the above address would be appreciated greatly.

Yours truly,

Richard A. Remnant

Appendix 2. Complete results of lake surveys conducted in northwestern Ontario and Manitoba (1989 and 1990).

DATE	NO. IN FIG 3	LAKE NAME	LATITUDE	LONGITUDE	SURFACE TEMP (C)	BOTTOM TEMP (C)	MAXIMUM DEPTH (M)	NET EFFORT NO. OF GANGS	TRAWLS NO./MIN.	SEINES	SMELT	RS	WE	SA	YP	BB	WF	LH	LT	TP	LP	SS	ES	RB	NP	WS	SR	JD	RD	SC	DS	GE	ME	NS	BS	BC	TM	LD	WB
												NUMBER OF FISH BY SPECIES																											
1989 CATCHES - GILLNET SETS: 1 GANG=3 PANELS, EACH 1.5M X 15M IN 8,10 AND 13MM BAR MESH FOR ~12 HOURS EXCEPT WHERE SPECIFIED. TRAWL = 6M OTTER TRAWL.																																							
JUN 6-10	1	PAKWASH	50°45'N	93°30'W	17	11	15	10	8/215	2	YES	9	10	167	221	6	11	1		118	5	189	182	2	10	4								1					
JUN 11	2	BRUCE	50°49'N	93°20'W	18.5		3	2			NO		19	45	150					15	1	2100			20		3												
JUN 15	3	RED	51°03'N	93°57'W	14	7	31	3	7/85	2	YES	51			8			1		16								7		4	3								
JUN 18	4	GULLROCK	50°58'N	93°40'W	19	11	13.5	1	5/72		YES	152		2	4	3	3	2		304		1	4				2	100	2										
JUN 17	5	KEG	51°00'N	93°41'W	20	12	12	1	2/30		YES	150	2			2		1								2													
JUN 19	6	TWO ISLAND	50°55'N	93°35'W	18	12.5	9.5	1	2/25		YES	92	4	1	30			6		473		50	1			3		2											
JUN 29	7	BARNSTON	50°35'N	93°30'W	18.5	18.5	8.5	1	1/13		NO		2	8				2					32																
JUN 30	8	CLEAR	50°34'N	93°35'W	21	4.5	16.3	1	3/50		NO		2	1	24		2	29		1					1														
JUN 30	9	JOHNSON	50°34'N	93°35'W	22.5	10	11	1	2/30	1	NO			3	4			17																					
JUL 1	10	WEGG	50°34'N	93°35'W	24.5	18.5	11	1	1/15		NO			25	6					21			18			1													
JUL 2	11	UNEXPECTED	50°30'N	93°32'W	22	13.5	13.5	3	2/30	1	NO			21	1			25		22		7			4	1													
JUL 2	12	GOOSE	50°32'N	93°40'W	21.5	18.5		1			NO			11	3			2				100	313		3								3						
JUL 2	13	WILCOX	50°31'N	93°47'W	21.5	18.5		1			NO		2	12	13			2		9	1	308	46		5														
JUL 4	14	CAMPING	50°36'N	93°25'W	22.5	20.5	7	1		1	NO		5	11						11		30	99										2						
JUL 8	15	GRASSY NWS	50°09'N	94°02'W	23	8.5	15	3		1	NO			6	275		28	136				10			5														
JUL 9	16	TIDE	50°20'N	93°58'W	21.5	21	18.5	1			YES	1		2			7	5		4			12																
JUL 9	17	BALL	50°18'N	94°00'W	21	20.5	12.5	1			NO			2			4	3		5			52																
JUL 9	18	INDIAN	50°14'N	94°05'W	21.5	19.5	18.5	1			YES	1		1			17	5		1		3	27																
JUL 10	19	LITTLE FOX	50°11'N	94°09'W	21	20.5	15	1			NO		1	3	1	1	34	7		2			22																
JUL 10	20	SHOE	50°08'N	94°10'W	23.5	12	6	1			NO				2		1	8		1		32			1														
JUL 10	21	BIG FOX	50°11'N	94°13'W	21.5	20.5	9.5	1			NO		3		1		8	3				2	54		3														
JUL 11	22	LOUNT	50°10'N	94°19'W	21.5	20.5	13	1			NO		2	2						2			9		1														
JUL 11	23	SEPARATION	50°14'N	94°24'W	21.5	21	17	2			NO		5	13			33	10		1		11	148		2														
		UMFREVILLE																																					
JUL 21	24	(TWELNOR LAKE)	50°23'N	94°57'W	27	5.5	29.5	1			NO							18		1					1														
JUL 21	25	(GIB LAKE)	50°21'N	94°57'W	26	8	21.5	1			NO		1	3			1	15																					
JUL 21	26	(MAIN BODY)	50°18'N	94°58'W	24.5	10.5	22	1			NO						19	58					2		1														
JUL 22	27	(POWERLINE BAY)	50°18'N	95°03'W	26	4.5	30.5	1			NO						1	4																					
JUL 22	28	(GOSHAWK LAKE)	50°15'N	94°48'W	18.5	8.5	18.5	1			NO							82							1														
JUL 22	29	(ONEMAN LAKE)	50°18'N	94°48'W	24	9.5	26	1			NO		1	5				5																					
JUL 23	30	TETU	50°11'N	95°02'W	23	21	15	2			NO		1	31	30		7	35		19			12			2													
JUL 24	31	BIG SAND	50°06'N	94°37'W	25	6	40	3			NO				15	2	2	37					3																
JUL 25	32	LULU	49°47'N	94°42'W	27	9.5	12.5	2	2/25		NO				1																								
JUL 31	33	PAVEL	50°00'N	94°00'W	23	7	24.5	3			YES	36			4			17																					
AUG 1	34	SILVER	49°53'N	94°11'W	24	6.5	28	3			NO				12			191			2					1												1	
AUG 1	35	CANYON	49°58'N	93°40'W	24	10	16.5	3			NO		1		30		3	147																					
AUG 8	36	NAMAKAN	48°27'N	92°35'W	22	9.5	23	3	1/25		NO		11	13	13		7	232		21								3		8									
AUG 9	37	RAINY	48°42'N	93°10'W	25.5	10.5	31	3			NO		10	3	2	2		136					7																
AUG 14	38	ABRAM	50°04'N	91°57'W	21	7.5	29	3	1/20		YES	1		9	1		7	166		2								6							1				
AUG 15	39	MINNITAKI	49°58'N	92°00'W	21	9	25	3	1/14		NO		4	11		1	1	196	3	35										14				2					
AUG 16	40	PELICAN	50°07'N	91°58'W					1/3		NO							1												1									
		LAC SEUL																																					
AUG 16	41	(ITALIAN BAY)	50°07'N	92°07'W	23	5	19.5	1			NO		4		11		1	5			1			1	1														
AUG 16	42	(KEEWATIN BAY)	50°07'N	92°07'W	23	7	18	2			NO						102	66																					
AUG 17	43	SANDYBEACH	49°49'N	92°21'W	21	7	35	3			YES	72						116	1																				
AUG 18	44	TWO ISLAND	50°55'N	93°35'W	21.5	20	10	1	4/75		YES	146	8	4	29		1			~1500		~1000				74		24											
AUG 19	45	GULLROCK	50°58'N	93°40'W	21	20	13	3 X 2.5 HRS	1/15		YES	12	8	2												2													
AUG 28	46	OAK	50°26'N	93°50'W	20	6	21	1			NO						5	83							1														
	47	OAK	50°26'N	93°50'W	20	5	30.5	1			NO		2		1		5	888							2														
SEP 1	48	MAYNARD	50°22'N	93°54'W	20	14	16.5	1			NO		10	6			1	129					6										1						
SEP 2	49	DUMPY	50°19'N	94°04'W	20.5	4.3	25	1			NO				1		2	221																					
1990 CATCHES - GILLNET SETS: 1 GANG=5 PANELS, EACH 1.5M X 15M IN 6,8,10,13 AND 16MM BAR MESH FOR ~12 HOURS EXCEPT WHERE SPECIFIED.																																							
JUN 18	50	LAC DU BONNET	50°22'N	95°55'W	20	11	14	3			NO		1	25	2		1	6		7	1		4																
JUN 19	51	NUTIMIK	50°09'N	95°41'W	17	17	11	1			NO		4	39	8					1		3	17	1	3														
JUN 20	52	CLAY	50°03'N	93°30'W	19	8	19	3			NO							35																					
JUN 21	53	WABIGOON	49°44'N	92°44'W	17	15	13	3			NO			80				15		5			8																
		EAGLE																																					
JUN 22	54	(VERMILLION BAY)	49°51'N	93°24'W	18.5	11	20	4			NO		2	39	1		3	285		1		22			6														
		EAGLENEST																																					
JUN 23	55	(GREEN LAKE)	50°06'N	95°23'W	22	16	8	1			NO		1		88							3	1		10														
		UMFREVILLE																																					
JUN 24	56	(GIB LAKE)	50°21'N	94°57'W	20	6.25	21	1			NO							2																					
JUN 24	57	(MAIN BODY)	50°18'N	94°58'W	20	8.5	25	3			NO			6		2		66																					
JUL 31	58	BERENS (SOUTH)	51°47'N	93°45'W	21.5	5.5	9.5	1			NO																												
JUL 31	59	BERENS (MAIN)	51°47'N	93°45'W	22	7.5	7.5	2			NO		31	106	5			136		4					5														
		LAKE OF THE WOODS																																					
AUG 28-29	60	(NEAR MORSON)	49°05'N	94°26'W	22.5	22.5	8	6			NO		25	228	714			3		209			27													96	1		
	61	WINNIPEG																																					
OCT 9		(NEAR ARNES)	50°48'N	96°52'W			8	4 X 48 HRS			NO	CATCH OTHER THAN SMELT NOT RECORDED																											
OCT 16		(NEAR ARNES)	50°48'N	96°52'W			10	2 X 48 HRS			NO	CATCH OTHER THAN SMELT NOT RECORDED																											
OCT 21		(NEAR ARNES)	50°48'N	96°52'W			10	2 X 48 HRS			NO		11		66			312		69			623																1

SPECIES: RS = Rainbow Smelt (Osmerus mordax) WE = Walleye (Stizostedion vitreum vitreum) SA = Sauger (S. canadense) YP = Yellow Perch (Perca flavescens) BB = Burbot (Lota lota) LW = Lake Whitefish (Coregonus clupeaformis)
LH = Lake Herring (C. artedii) LT = Lake Trout (Salvelinus namaycush) TP = Troutperch (Percopsis omiscomaycus) LP = Logperch (Percina caprodes) SS = Spottail Shiner (Notropis hudsonius) ES = Emerald Shiner (N. atherinoides)
RB = Rock Bass (Ambloplites rupestris) NP = Northern Pike (Esox lucius) WS = White Sucker (Catostomus commersoni) SR = Shorthead Redhorse (Moxostoma macrolepidotum) JD = Johnny Darter (Etheostoma nigrum)
RD = River Darter (Percina shumardi) SC = Slimy Sculpin (Cottus cognatus) DS = Deepwater Sculpin (Myoxocephalus thompsoni) GE = Goldeye (Hiodon alosoides) ME = Mooneye (H. tergisus) NS=Ninespine Stickleback (Pungitius pungitius)
BS = Brook Stickleback (Culaea inconstans) BC = Black Crappie (Pomoxis nigromaculatus) TM = Tadpole Madtom (Noturus gyrinus) LD = Longnose Dace (Rhinichthys cataractae) WB = White Bass (Morone chrysops)

APPENDIX 3. PRESENT VALUE (PV) OF LAKE WINNIPEG LAKE WHITEFISH AND RAINBOW SMELT HARVEST, PRE- AND POST-RAINBOW SMELT, OVER A TWENTY YEAR PERIOD

	LAKE WHITEFISH (LWF)			RAINBOW SMELT (RS)			Σ OF LWF & RS PV	PV OF CONSTANT HARVEST LWF	DIFF. IN PV
YEAR	KG	LV	PV	KG	LV	PV			
0	1716270	1750596	1750596	0	0	0	1750596	1750596	0
1	1630457	1663066	1583873	0	0	0	1583873	1667234	-83361
2	1548934	1579913	1433027	0	0	0	1433027	1587842	-154815
3	1471487	1500917	1296548	0	0	0	1296548	1512231	-215683
4	1397913	1425871	1173068	0	0	0	1173068	1440220	-267152
5	1328017	1354577	1061347	125000	60000	47012	1108359	1371638	-263279
6	1261616	1286848	920266	137500	66000	49250	1009516	1306322	-296806
7	1198535	1222506	868812	151250	72600	51595	920407	1244116	-323709
8	1138608	1161380	786068	166375	79860	54052	840120	1184872	-344752
9	1081678	1103312	711204	183013	87846	56626	767830	1128450	-360620
10	1027594	1048146	643471	201314	96631	59323	702794	1074714	-371920
11	976214	995738	582188	221445	106294	62148	644336	1023537	-379201
12	927403	945951	526741	243590	116923	65107	591848	974797	-382949
13	881033	898654	476575	267949	128616	68208	544783	928378	-383595
14	836981	853721	431187	294743	141477	71455	502642	884170	-381528
15	795132	834889	401596	324218	155625	74858	476454	842067	-365613
16	755375	770483	352967	324218	155625	71294	424261	801968	-377707
17	717606	731958	319351	324218	155625	67899	287250	763779	-376529
18	681726	695361	288937	324218	155625	64665	353602	727409	-373807
19	647640	660593	261419	324218	155625	61586	323005	692770	-369765
20	615258	627563	236522	324218	155625	58653	295175	659781	-364606
T			16145763			983731	17129494	23566891	-6437397

ASSUMPTIONS:
LV (LANDED VALUE) FOR LWF = $1.02/KG, LV FOR RS = $0.48/KG.
5% REDUCTION IN ANNUAL WHITEFISH HARVEST FROM YEAR 1 - 20, 10% INCREASE IN SMELT HARVEST FROM YEAR 6 - 15, AND 5% DISCOUNT RATE.

APPENDIX 3 (CONTINUED)

	LAKE WHITEFISH (LWF)			RAINBOW SMELT (RS)				PV OF CONSTANT HARVEST LWF	
YEAR	KG	LV	PV	KG	LV	PV	Σ OF LWF & RS PV		DIFF. IN PV
0	1716270	1750596	1750596	0	0	0	1750596	1750596	0
1	1630457	1663066	1511878	0	0	0	1511878	1591451	-79573
2	1548934	1579913	1305713	0	0	0	1305713	1446774	-141061
3	1471487	1500917	1127661	0	0	0	1127661	1315249	-187588
4	1397913	1425871	973889	0	0	0	973889	1195681	-221792
5	1328017	1354577	841086	125000	60000	37255	878341	1086982	-208641
6	1261616	1286848	726392	137500	66000	37255	763647	988166	-224519
7	1198535	1222506	627339	151250	72600	37255	664594	898333	-233739
8	1138608	1161380	541792	166375	79860	37255	579047	816666	-237619
9	1081678	1103312	467912	183013	87846	37255	505167	742424	-237257
10	1027594	1048146	404106	201314	96631	37255	441361	674931	-233570
11	976214	995738	349000	221445	106294	37255	386255	613573	-227318
12	927403	945951	301409	243590	116923	37255	338664	557794	-219130
13	881033	898654	260308	267949	128616	37255	297563	507085	-209522
14	836981	853721	224811	294743	141477	37255	262066	460987	-198921
15	795132	834889	199866	324218	155625	37255	237121	419079	-181958
16	755375	770483	167680	324218	155625	37255	201549	380981	-179432
17	717606	731958	144814	324218	155625	37255	175604	346346	-170742
18	681726	695361	125067	324218	155625	37255	153058	314860	-161802
19	647640	660593	108012	324218	155625	37255	133458	286236	-152778
20	615258	627563	93283	324218	155625	37255	116416	260215	-143799
T			12252614			551034	12803648	16654409	-3850761

ASSUMPTIONS:
LV (LANDED VALUE) FOR LWF = $1.02/KG, LV FOR RS = $0.48/KG.
5% REDUCTION IN ANNUAL WHITEFISH HARVEST FROM YEAR 1 - 20, 10% INCREASE IN SMELT HARVEST FROM YEAR 6 - 15, AND 10% DISCOUNT RATE.

APPENDIX 3 (CONTINUED)

YEAR	LAKE WHITEFISH (LWF) KG	LV	PV	RAINBOW SMELT (RS) KG	LV	PV	Σ OF LWF & RS PV	PV OF CONSTANT HARVEST LWF	DIFF. IN PV
0	1716270	1750596	1750596	0	0	0	1750596	1750596	0
1	1544643	1575536	1500510	0	0	0	1500510	1667234	-166724
2	1390179	1417983	1286152	0	0	0	1286152	1587842	-301690
3	1251161	1276184	1102416	0	0	0	1102416	1512231	-409815
4	1126045	1148566	944928	0	0	0	944928	1440220	-495292
5	1013441	1033710	809939	125000	60000	47012	856951	1371638	-514687
6	912097	930339	694233	150000	72000	53728	747961	1306322	-558361
7	820887	837305	595057	180000	86400	61403	656460	1244116	-587656
8	738798	753574	510049	216000	103680	70175	580224	1184872	-604648
9	664918	678216	437184	259200	124416	80200	517384	1128450	-611066
10	598426	610395	374729	311040	149299	91657	466386	1074714	-608328
11	538583	549355	321196	373248	179159	104751	425947	1023537	-597590
12	484725	494420	275311	447898	214991	119715	395026	974797	-579771
13	436253	444978	235981	537478	257989	136817	372798	928378	-555580
14	392628	400481	202270	644974	309588	156363	358633	884170	-525537
15	353365	360432	173374	773969	371505	178700	352074	842067	-489993
16	318029	324390	148607	773969	371505	170191	318798	801968	-483170
17	286226	291950	127377	773969	371505	162086	289463	763779	-474316
18	257603	262755	109180	773969	371505	154368	263548	727409	-463861
19	231843	236480	93583	773969	371505	147017	240600	692770	-452170
20	208659	212832	80214	773969	371505	140016	220230	659781	-439551
T			11772886			1874199	13647085	23566891	-9919806

ASSUMPTIONS:
LV (LANDED VALUE) FOR LWF = $1.02/KG, LV FOR RS = $0.48/KG.
10% REDUCTION IN ANNUAL WHITEFISH HARVEST FROM YEAR 1 - 20, 20% INCREASE IN SMELT HARVEST FROM YEAR 6 - 15, AND 5% DISCOUNT RATE.

APPENDIX 3 (CONTINUED)

	LAKE WHITEFISH (LWF)			RAINBOW SMELT (RS)					
YEAR	KG	LV	PV	KG	LV	PV	Σ OF LWF & RS PV	PV OF CON-STANT HAR-VEST LWF	DIFF. IN PV
0	1716270	1750596	1750596	0	0	0	1750596	1750596	0
1	1544643	1575536	1432305	0	0	0	1432305	1591451	-159146
2	1390179	1417983	1171887	0	0	0	1171887	1446774	-274887
3	1251161	1276184	958816	0	0	0	958816	1315249	-356433
4	1126045	1148566	784486	0	0	0	784486	1195681	-411195
5	1013441	1033710	641853	125000	60000	37255	679108	1086982	-407874
6	912097	930339	525152	150000	72000	40642	565794	988166	-422372
7	820887	837305	429670	180000	86400	44337	474007	898333	-424326
8	738798	753574	351548	216000	103680	48367	399915	816666	-416751
9	664918	678216	287630	259200	124416	52765	340395	742424	-402029
10	598426	610395	235334	311040	149299	57561	292895	674931	-382036
11	538583	549355	192546	373248	179159	62794	255340	613573	-358233
12	484725	494420	157537	447898	214991	68503	226040	557794	-331754
13	436253	444978	128894	537478	257989	74730	203624	507085	-303461
14	392628	400481	105459	644974	309588	81524	186983	460987	-274004
15	353365	360432	86285	773969	371505	88935	175220	419079	-243859
16	318029	324390	70597	773969	371505	80850	151447	380981	-229534
17	286226	291950	57761	773969	371505	73500	131261	346346	-215085
18	257603	262755	47259	773969	371505	66818	114077	314860	-200783
19	231843	236480	38666	773969	371505	60744	99410	286236	-186826
20	208659	212832	31636	773969	371505	55222	86858	260215	-173357
T			9485917			994547	10480464	16654409	-6173945

ASSUMPTIONS:
LV (LANDED VALUE) FOR LWF = $1.02/KG, LV FOR RS = $0.48/KG.
10% REDUCTION IN ANNUAL WHITEFISH HARVEST FROM YEAR 1 - 20, 20% INCREASE IN SMELT HARVEST FROM YEAR 6 - 15, AND 10% DISCOUNT RATE.

APPENDIX 3 (CONTINUED)

	LAKE WHITEFISH (LWF)			RAINBOW SMELT (RS)			Σ OF LWF & RS PV	PV OF CONSTANT HARVEST LWF	DIFF. IN PV
YEAR	KG	LV	PV	KG	LV	PV			
0	1716270	1750596	1750596	0	0	0	1750596	1750596	0
1	1373016	1400476	1333787	0	0	0	1333787	1667234	-333447
2	1098413	1120381	1076875	0	0	0	1076875	1587842	-510967
3	878730	896305	774262	0	0	0	774262	1512231	-737969
4	702984	717044	589914	0	0	0	589914	1440220	-850306
5	562387	573635	449458	125000	60000	47012	496470	1371638	-875168
6	449910	458908	342444	175000	84000	62682	405126	1306322	-901196
7	359928	367127	260910	245000	117600	83576	344486	1244116	-899630
8	287942	293701	198788	343000	164640	111435	310223	1184872	-874649
9	230354	234961	151458	480200	230496	148580	300038	1128450	-828412
10	184283	187969	115396	672280	322694	198106	313502	1074714	-761212
11	147426	150375	87921	941192	451772	264142	352063	1023537	-671474
12	117941	120300	66987	1317669	632481	352189	419176	974797	-555621
13	94353	96240	51038	1844736	885473	469585	520623	928378	-407755
14	75482	76992	38886	2582631	1239663	626114	665000	884170	-219170
15	60386	61594	29628	3615683	1735528	834819	864447	842067	+22380
16	48309	49275	22574	3615683	1735528	795065	817639	801968	+15671
17	38647	39420	17199	3615683	1735528	757205	774404	763779	+10625
18	30918	31536	13104	3615683	1735528	721148	734252	727409	+6843
19	24734	25229	9984	3615683	1735528	686807	696791	692770	+4021
20	19787	20183	7607	3615683	1735528	654102	661709	659781	+1928
T			7388816			6812567	14201383	23566891	-9365508

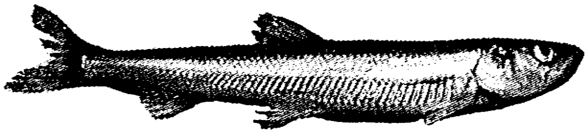
ASSUMPTIONS:
LV (LANDED VALUE) FOR LWF = $1.02/KG, LV FOR RS = $0.48/KG.
20% REDUCTION IN ANNUAL WHITEFISH HARVEST FROM YEAR 1 - 20, 40% INCREASE IN SMELT HARVEST FROM YEAR 6 - 15, AND 5% DISCOUNT RATE.

APPENDIX 3 (CONTINUED)

YEAR	LAKE WHITEFISH (LWF) KG	LAKE WHITEFISH (LWF) LV	LAKE WHITEFISH (LWF) PV	RAINBOW SMELT (RS) KG	RAINBOW SMELT (RS) LV	RAINBOW SMELT (RS) PV	Σ OF LWF & RS PV	PV OF CONSTANT HARVEST LWF	DIFF. IN PV
0	1716270	1750596	1750596	0	0	0	1750596	1750596	0
1	1373016	1400476	1273160	0	0	0	1273160	1591451	-318291
2	1098413	1120381	925935	0	0	0	925935	1446774	-520839
3	878730	896305	673407	0	0	0	673407	1315249	-641842
4	702984	717044	489751	0	0	0	489751	1195681	-705930
5	562387	573635	356182	125000	60000	37255	393437	1086982	-693545
6	449910	458908	259042	175000	84000	47416	306458	988166	-681708
7	359928	367127	188394	245000	117600	60347	248741	898333	-649592
8	287942	293701	137014	343000	164640	76806	213820	816666	-602846
9	230354	234961	99646	480200	230496	97753	197399	742424	-545025
10	184283	187969	72470	672280	322694	124413	196883	674931	-478048
11	147426	150375	52706	941192	451772	158343	211049	613573	-402524
12	117941	120300	38331	1317669	632481	201528	239859	557794	-317935
13	94353	96240	27877	1844736	885473	256490	284367	507085	-222718
14	75482	76992	20274	2582631	1239663	326442	346716	460987	-114271
15	60386	61594	14745	3615683	1735528	415472	430217	419079	+11138
16	48309	49275	10724	3615683	1735528	377701	388425	380981	+7444
17	38647	39420	7799	3615683	1735528	343365	351164	346346	+4818
18	30918	31536	5672	3615683	1735528	312150	317822	314860	+2962
19	24734	25229	4125	3615683	1735528	283773	287898	286236	+1662
20	19787	20183	3000	3615683	1735528	257975	260975	260215	+760
T			6410850			3377229	9788079	16654409	-6866330

ASSUMPTIONS:
LV (LANDED VALUE) FOR LWF = $1.02/KG, LV FOR RS = $0.48/KG.
20% REDUCTION IN ANNUAL WHITEFISH HARVEST FROM YEAR 1 - 20, 40% INCREASE IN SMELT HARVEST FROM YEAR 6 - 15, AND 10% DISCOUNT RATE.

APPENDIX 4. PUBLIC AWARENESS CAMPAIGN AIMED AT INFORMING THE ANGLING PUBLIC OF THE DANGERS OF UNAUTHORIZED INTRODUCTIONS OF RAINBOW SMELT (FROM ManDNR 1991).



Why should you be concerned about this little fish?

This is a rainbow smelt; usually 5 to 7 inches long and easily recognized by teeth on its tongue. It has been introduced to several lakes in northwestern Ontario, either accidentally as live bait, or intentionally without authorization.

The effects of introducing smelt to natural waters with balanced fish populations are difficult to predict, but in some cases they have been devastating to native species.

Unfortunately, it appears that rainbow smelt are now in Lake Winnipeg. It is unlikely that they migrated from Ontario. They were probably introduced as live bait. If they survive and reproduce, we will not see the effects until the population becomes large, which may take fewer than 5 years or as many as 20 years.

Other good fisheries in Manitoba are also at risk. Remember, in Manitoba it is illegal to possess or use live or fresh rainbow smelt as bait. You may only use smelt that has been frozen.