A review of population trends in length and age of lake whitefish (*Coregonus clupeaformis*) harvested from Great Slave Lake between 1972 and 1995

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R.F. Tallman and M.K. Friesen. 2007. A review of trends in length and age of lake whitefish (*Coregonus clupeaformis*) harvested from Great Slave Lake between 1972 and 1995. Can. Manuscr. Rep. Fish. Aquat. 2819: v + 27 p.

Commercial fisheries can be responsible for substantial changes in fish populations. Typically, average fish size and age in the catch decline as the fishery progresses. We present evidence of a contrary trend for the Great Slave Lake lake whitefish, *Coregonus clupeaformis*, fishery between 1972 and 1995. Average length of fish caught increased from 377 mm to 425 mm during this period. Average age of fish caught increased from 7.7 to 10.6 years during 1972 to 1994. Analysis of covariance of length by year with age as a covariate was highly significant ($p = 0.0001$) suggesting that the increase in length during the study period was independent of the increase in age of fish in the catch. Trend analysis of six administrative areas of Great Slave Lake employed by fishery management showed that increases in size and age occurred in all areas except age in area 1W, suggesting that fishery management was highly effective during this time. The positive and significant regression slopes from the trend analysis indicate that the fishery could have remained stable at even higher exploitation rates. It appears that the management actions of that period of quota and spatial structuring by administrative areas was able to sustain the fishery and perhaps improve fishing conditions in the manner expected by fisheries theory. We examine this possibility and alternative explanations for the observations such as sampling error and environmental change.

RÉSUMÉ

R.F. Tallman et M.K. Friesen. 2007. Changements de la taille et de l'âge moyens des grands corégones capturés commercialement dans un grand lac subarctique sur une longue période 1972 - 1995. Rapp. manus. can. sci. halieut. aquat. 2819: v + 27 p.

Les pêches commerciales entraînent des changements importants dans les populations de poissons. Habituellement, on observe dans les captures une baisse de la taille et de l'âge moyens des poissons avec le temps. Nous présentons ici des résultats montrant l'existence de la tendance inverse dans le cas du grand corégone (*Coregonus clupeaformis*) du Grand lac des Esclaves pour la période 1972-1995. La taille moyenne des poissons capturés est passée de 377 mm à 425 mm durant cette période, et leur âge moyen, de 7,7 à 10,6 ans. L'analyse de covariance de la longueur selon l'année, avec l'âge comme covariable, a donné un résultat hautement significatif ($p = 0,0001$), ce qui indique qu'il y a eu un accroissement de la longueur durant la période d'étude qui était indépendant de l'effet associé à l'âge des poissons capturés. L'analyse des tendances dans les sous-unités de gestion de la pêche établies pour le Grand lac des Esclaves a montré qu'il y a eu accroissement de la taille et de l'âge dans toutes les sous-unités sauf pour ce qui est de l'âge dans la sous-unité 1 W, ce qui laisse penser que la pêche a été très bien gérée durant la période considérée. Les pentes de régression positives et significatives tirées de l'analyse des tendances indiquent que la pêche aurait pu demeurer stable à des taux d'exploitation encore plus élevés. Le quota et la structure de pêche imposés auraient amélioré la pêche. Nous examinons cette explication ainsi que d'autres explications pour les observations rapportées.

INTRODUCTION

Fisheries have caused great changes in many aquatic systems. Additional mortality imposed by fisheries will often cause target species to undergo substantial changes in demographic characteristics (Cushing 1981). It is typical for the average size of fish in the catch to decline after the initial few years of the fishery due to the "fishing up" effect described by Ricker (1975). Subsequently, equilibrium should be reached but in many, fisheries size continues to decline due to over-exploitation (Ricker 1975). Fisheries in the Arctic and sub-Arctic are no exceptions. For example, the Arctic charr, *Salvelinus alpinus*, in the Sylvia Grinnell River, Baffin Island, have dropped to half their former size due to over-fishing (Kristofferson and Sopuck 1983).

The Great Slave Lake whitefish fishery is the largest freshwater fishery in the northern territories of Canada. Until recently Great Slave Lake accounted for approximately three quarters of the commercial fish landings in the Northwest Territories and Nunavut. The annual harvest has been between 1,000 and 1,500 metric tonnes from the mid 1970s until the present. There has been a fishery on this lake since the mid 1940s when fishermen moved up from Lake Athabasca (Keleher 1962). During the early phases of the fishery the target species were lake trout (*Salvelinus namaycush*) and lake whitefish (*Coregonus clupeaformis*) (Keleher 1972). Since the collapse of the commercial lake trout fishery in the late 1960s, lake whitefish has been the sole target species for harvest. As a large lake fishery, Great Slave Lake is unique to other North American commercial fisheries. Since its inception in 1945, it has had annual monitoring of both production and biological parameters for harvested species, has remained relatively unpolluted and has not experienced introductions of non-native species. From the 1970s to the present, the Department of Fisheries and Oceans (DFO) has conducted systematic sampling of the landings to determine if the population characteristics had reached stability. This information, however, has not been analyzed for publication until this report.

BACKGROUND ON THE FISHERY

Commercial fishing began late in the summer of 1945 (Kennedy 1953). The most important commercial fish in the lake was, and is, the lake whitefish, *C. clupeaformis,* which currently makes up 93% of the commercial catch. In contrast, other species such as lake trout, *S.*

namaycush, walleye, *Stizostedion vitreum*, inconnu, *Stenodus leucichthys* and northern pike, *Esox lucius* combined, only constitute about 5% of the commercial catch. Annual production of all species peaked in 1949 at 4,055 tonnes and declined steadily to approximately 1,250 tonnes by the early 1970s where it remained until the early 1980s when it decreased to 900 tonnes. Production climbed steadily during the later half of the 1980s to 1,500 tonnes, but from the early 1990s to the present, production has declined steadily to approximately 900 tonnes.

The history of this lake and management of its fishery are unusual relative to other commercial fisheries because: 1) from the onset of the fishery to the year 2000, commercial fishing has been done only with 133 mm (5.25 inch) and 140 mm (5.5 inch) stretch mesh gillnets, 2) the production and biological parameters of commercially caught species have been monitored on an annual basis, 3) there have been no successful introductions of non-native species and 4) the lake has remained relatively unpolluted.

Considering the size of Great Slave Lake, (2,719,500 hectares), the fishery for lake whitefish is remarkably simple. There is only one gear type - gillnets, and fishing vessels are under 13 metres in length. There are four types of transport used in the fishery – skiffs (vessels under 8 metres), whitefish boats that average 13 metres in length, skidoos and bombardiers. Whitefish boats (summer) and bombardiers (winter) employ much longer gangs of nets than the others and account for the majority of the catch. Even so, the percentage of use for each type of fishing transport is about equal between management areas on the lake. Thus, there is near uniformity in fishing power and catchability throughout the fishing fleet among management areas compared to most marine fisheries on bottom dwelling fish. According to Day and Low (1992) the number of fishing transports increased a great deal in the first few years of the fishery but has not varied greatly since the 1950s. The total number of fishermen has also stayed relatively stable from the 1970s to the mid 1990s but has declined steadily in the last 10 years. There has been only one significant change in the whitefish fishery from its outset. The sole known perturbation in the Great Slave Lake fishery has been a mesh size change from 140 mm stretched mesh to 133 mm stretch mesh in 1977 to increase the efficiency of the fishing fleet (Moshenko et al. 1978). Other than this, fishing effort has been relatively constant.

Since 1971, Great Slave Lake has been divided into seven administrative areas for fisheries management (Figure 1). Each area has a separate commercial quota except area VI in the eastern arm of the lake which is closed to conserve lake trout for sport fishing enterprises. Most of the catch is landed in Yellowknife, Hay River and Moraine Bay for shipping or processing. Landed fish are usually sold at southern markets.

Fishery statistics are collected by DFO fishery enforcement officers in cooperation with fish plant managers and the Freshwater Fish Marketing Corporation (FFMC). The fishery quota is managed based on purchase slip information from the processing plants. These have been summarized in a series of reports (Bond 1975, Davies et al. 1986, Moshenko and Low 1978).

The management quota on Great Slave Lake has changed over time. A lake-wide quota of 4,082.9 tonnes (1.5 kg/ha) was set in 1949 and remained in effect until 1971 (Keleher 1972). Based on a comprehensive analysis of the effects of a 20 year period of commercial exploitation (1945-1964) on Great Slave Lake, the quota was reduced to 2,261.5 tonnes (0.83 kg/ha) in 1971 and further reduced to 1,545.5 tonnes (0.57 kg/ha) in 1977 (Day and Low 1992). Moshenko et al. (1978) stated that the quotas in areas II, IV and V were perceived by management biologists to be too high but until the change in mesh size from 140 mm to 133 mm, these quotas had never been filled and, therefore, it had not been necessary to reduce them. In the 1978-79 fishing year, when area III was formed with an accompanying quota of 44,643 kg and area V's quota was increased to 22,321 kg, the total lake quota increased to 1,612.5 tonnes (0.59 kg/ha). The next year the quota was increased to 1,681.8 tonnes due to an increase to the area V quota. Some further changes were made to balance the quotas for allocation purposes to a total of 1,727.4 tonnes (0.63 kg/ha) which remains to the present.

Harvest of lake whitefish over all areas has never exceeded the total lake quota for this species. In the same manner, quotas of each area have generally not been filled and there has been only one instance (area II in 1989) where the quota was exceeded.

In this paper we examine catch per unit effort (CPUE) and changes in average length and age between the years 1972 and 1995 to determine if stability has been reached in this fishery.

METHODS

THE STUDY AREA

Great Slave Lake lies in the southwest corner of the District of Mackenzie, Northwest Territories, Canada (Figure 1). It is the fifth largest lake in North America having a surface area of 27,195 km^2 and a drainage area of 985,300 km^2 (Day and Low 1992). Stretching 440 km from its extreme east end to the outlet of the Mackenzie River, the lake straddles two physiographic regions. The northeast shore of the north and east arms lay within the Precambrian Shield and have irregular precipitous margins. The western portion of the lake overlies the alluvial plain known as the Mackenzie Lowlands and has few islands and gently sloping shores. Rivers entering the lake from the Shield are cold, clear and rapidly flowing while those entering from the lowlands to the south are slow flowing brown water streams laden with silt during spring and early summer. The western basin has a maximum depth of about 165 m and a mean depth of 42 m, while a maximum depth of 625 m has been recorded in the east arm. Physical and biological characteristics of the lake have been described previously in detail by Rawson (1950, 1951, 1953a, b). The lake supports 25 species of fish with the most well represented families being coregonidae, salmonidae (*Salvelinus* spp) and cottidae (Rawson 1951, McCart 1986).

1972 TO 1995 PERIOD

The period of 1972 to 1995 was chosen for analysis because it followed the establishment of the use of the administrative areas on the lake and therefore allows analysis of each area separately. As well, it was thought that the fleet was relatively stable during that period. Subsequently, the number of vessels participating in the fishery has declined and it is likely there has been a significant drop in effort.

CATCH PER UNIT EFFORT (CPUE)

To calculate CPUE we made the assumption that fishermen would only be able to manage a certain number of nets at one time and that they would have immediately employed the maximum that they could retrieve and remove fish from within a 24 hour period. Thus, overall fishery fishing effort could be crudely approximated by estimating the total number of fisherman days in a season.

To get effort information we went back into the files of the FFMC to determine the number of fishing days executed each year. Within the database we sub-divided fishermen into full-time participants and part-time participants. Full-time participants made up about three quarters of the total. They participated about 120 to 125 days per year whereas the part-time fishermen fished around 20 days per year. The number of nets varied between these groups, also. We multiplied the number of full-time fishermen times their average number of fishing days times the length of nets normally set in one day and added this to the same statistic for the part-time fishermen to get a total length of gillnet set for the season. The depth of net was not considered as it is generally kept standard (6 m). A CPUE statistic was made for each year by dividing the landings by the total length of gillnet set for the season (kg/m).

$$\text{Annual Effort} = (N_F \times \overline{X}_{DFF} \times \overline{X}_{NLF}) + (N_P \times \overline{X}_{DFP} \times \overline{X}_{NLP})$$

Where :

i = 1972, 1974,…. 1995

N_F = The number of full-time fishermen year i

$\overline{X}_{DFF}$ = The mean days fished in year i by full-time fishermen

$\overline{X}_{NLF}$ = The mean length of net deployed per day in year i by full-time fishermen

N_P = The number of part-time fishermen year i

$\overline{X}_{DFP}$ = The mean days fished in year i by part-time fishermen

$\overline{X}_{NLP}$ = The mean length of net deployed per day in year i by part-time fishermen

CPUE per year = Annual Catch / Annual Effort

BIOLOGICAL SAMPLING

The catch was sampled by DFO personnel at the fish processing plants. Each year a random sub-sample of the catch was sampled for fork length (mm) and age determination structures (see sample sizes in Appendix 1). Ages used in the analysis were determined from scales but otoliths were also sampled and compared to scales periodically for consistency. In both cases, the surface of the structure was examined using a compound microscope to determine the age (Day and Low 1992).

AGE DETERMINATION

Scale ages are problematic because scales have been noted as sometimes underestimating the age of older fish (Ken Mills, Research Scientist, DFO, Central and Arctic, 501 University Crescent, Winnipeg, MB R3T 2N6, pers. comm.). However, the majority of the related literature on lake whitefish dynamics in northern Canada and elsewhere is based on scale ages (eg. Cucin and Regier 1965; Healey 1975, 1978, 1980; Kennedy 1953; Rawson, 1947, 1951; Day and Low 1992; Amtstaetter 2002; Gile and Mohr 1995; Salojärvi 1991, 1992a, 1992b, 1992c). In some key papers, such as Jensen (1981), the issue of age determination errors is not considered. Johnson (1976) in reviewing the ecology of northern fish populations, noted that in Great Bear Lake there was good agreement between scale and otolith in the ages determined in various samples of lake whitefish taken over a considerable number of years. In some cases, Miller and Kennedy (1948) used scales, Johnson (1976), used scales and otoliths and Falk et al. (1974) used only otoliths. They found that for fish up to 20-25 yr of age, agreement was good between scales and otoliths, but in older fish, otoliths tended to give higher ages. In most cases, the validity of the various methods has not been tested in northern situations but Johnson (1975) was able to compare two fish that had been tagged and recovered eight and nine years later, respectively. There was very little growth in length and Johnson (1976) stated that this casts doubt on whether annuli are laid down in the otolith when there is essentially no growth in length. Plant sample scale ages in the present study averaged between 7 and 10 years and were rarely greater than 18 years, thus we consider it reasonable to use otolith and scale ages interchangeably in our analyses.

STATISTICAL ANALYSES

We used trend analysis to examine the change over time in fork length and age by management area. Trend analysis is a time series technique that allows for the auto-correlation inherent in time series data. The linear component of trend is used to test whether there is an overall increase (or decrease) in the dependent variable as the independent variable increases (Lane and Scott 2000). A test of the linear component of trend is a test of whether the increase in length and age is significant.

We calculated the linear model of the trend as

$y = \beta o + \beta 1 + \varepsilon$ (Lane and Scott 2000)

where the co-efficient $\beta 1$ represents the linear increase of age or length with time and the coefficient βo is zero intercept. To measure the accuracy of the fitted values we calculated Mean Absolute Percentage Error (MAPE), Mean Absolute Deviation (MAD) and Mean Squared Deviation (MSD) as follows:

$MAPE = (\Sigma \left| (y_t - y^{hat}{}_t)/y_t) \right| / n) \times 100,$

Where y_t equals to the actual value and $y^{hat}{}_t$ equals the forecast value.

$MAD = (\Sigma \left| (y_t - y^{hat}{}_t) \right|)/ n,$

$MSD = (\Sigma \left| (y_t - y^{hat}{}_t) \right|)^2/ n,$

MSD is very similar to the mean squared error (Lane and Scott 2000).

To determine if length changes were independent of age changes we employed analysis of covariance (ANCOVA) of length on year with age as the covariate. Since length and age must meet at the origin we did not employ an intercept in the model. The model was:

$y_{ij} = b1X1j + Ai + e_{ij}$

Where:

y_{ij} = length

b1X1j = covariate (age)

Ai = treatment (years)

RESULTS

The landings were highest during the initial stages of the fishery when the inevitable "fishing up" of the stock was occurring (Figure 2). Fishermen were catching large old whitefish from a mature standing stock. The highest catch in the time series was over 2,500 tonnes in 1949. Landings from the inception of the fishery to the late 1960s were generally above 2,000 tonnes but showed a declining trend until the 1970s. Catches leveled off by the 1970s to 1990s and generally fluctuated between 1,000 and 1,500 tonnes. Unlike the early period of the fishery there was no apparent downward trend and the catch was quite stable. Catch per unit effort suggests that the stock size was also relatively stable during this time period (Figure 3).

Visual examination of the plots of fish length versus year suggested that fish size tended to remain stable or increase over time in the fishery (Figure 4). However, when we examined individual administrative areas using trend analysis we found that length and age appeared to be increasing and all areas showed a positive trend (Table 1). The consistency of the trends across areas suggests that there was a real increase in fish size in the landings. When we combined data from all areas the average length of fish caught increased from 368 mm (S.E. = 17.01) to 425 mm (S.E. = 3.89) between 1972 and 1995.

Table 1. Results of trend analysis by length and age of lake whitefish (*Coregonus clupeaformis*) for Great Slave Lake administrative areas. Measures of error included Mean Absolute Percentage Error (MAPE), Mean Absolute Deviation (MAD) and Mean Squared Deviation (MSD).

Area	Trait	Trend Model	MAPE	MAD	MSD
1E	Length	400.15 + 0.82 t	2.94	11.70	274.45
1W	Length	427.73 + 0.75 t	2.93	12.57	245.70
2	Length	395.73 + 1.09 t	3.79	14.82	517.34
3	Length	359.48 + 2.85 t	5.16	18.87	908.79
4	Length	393.69 + 0.82 t	2.35	8.87	276.11
5	Length	403.60 + 0.72 t	3.84	15.05	477.54
1E	Age	9.12 + 0.06 t	6.02	0.56	0.54
1W	Age	10.23 + 0.00 t	3.94	0.40	0.25
2	Age	8.00 + 0.11 t	7.32	0.65	0.63
3	Age	8.33 + 0.11 t	7.25	0.68	0.98
4	Age	9.35 + 0.08 t	4.11	0.42	0.35
5	Age	10.02 + 0.07 t	7.35	0.76	0.96

Average lengths for several administrative areas during the early 1980s were noticeably low (Figure 4). However, there are no recorded events that could account for these unusually low lengths. These data may be a result of problems in sampling at the fish plants in those years (George Low, DFO biologist Hay River (retired), pers. comm.). Given that these data points are in the middle of the time series they do not have a great deal of influence on the trend lines.

Average age clearly increased during the study period (Figure 5). Based on data combined from all areas, average age of captured fish increased from 7.7 (S.E. = 0.78) to 10.6 (S.E. = 0.34) years between 1972 and 1994 . When trend analysis was applied to the areas, all areas except area 1W showed a marked increase in average age in the catch (Figure 5, Table 1).

Although the strong increase in average age could be responsible for the increase in average size, the ANCOVA of length by year with age as a covariate was highly significant ($p = 0.0001$) suggesting that a portion of the increase in length was independent of the increase in age in the catch.

The results from the ANCOVA of length by year with age as covariate showed a significant effect of year ($p = 0.0001$). While length increased independently from growth, a portion of the length increase was also likely due to the increase in average age as the age coefficient was also significant ($t = 165$, $p = 0.0001$). Therefore, although increases in length were positive as indicated by the trend analysis, the increases in observed age were more pronounced.

DISCUSSION

These results suggest that fishery management was effective in controlling changes in the size and age structure during this time period. The fishery is probably operating below the maximum sustainable yield. Thus, natural trends in size and age, both up and down, can dominate the demographics of the stock. The increase in length suggests that growth is actually increasing under fishing pressure. This represents the ideal situation in managing a fishery. The stock is reduced just enough that growth is stimulated. The increase in average age suggests that mortality is lower than in the earlier years of the fishery; more fish are living longer.

There are several events that could be responsible for the observed increases in size and age of lake whitefish in this fishery:

1) One obvious possibility is a change in gear selectivity that may have resulted from the mesh size reduction from 140 mm (5.5 inch) stretch mesh to 133 mm (5.25 inch) mesh in 1977. However, this is unlikely since a mesh size reduction should result in more smaller and younger fish in the catch and we observed the opposite trend.

2) There has been a decrease in fishing pressure over time through either reduced effort or a greater standing stock due to good recruitment leading to greater numbers of older (and correspondingly larger) fish in the fishery.

3) Increased fishing pressure has lowered the population density resulting in an increase in growth rate. Thus, fish may have a greater size at age and may also have been aged older due to greater visibility of annual rings on scales.

Fish in northern waters are notably slow growing (Miller and Kennedy 1948, Grainger 1953, Johnson 1973, Falk et al. 1974) so that age determination presents some difficulty. Johnson (1976) noted that this is particularly so with fish over 25 years of age. Thus, it is possible that age determination methodology could have played a role in the change in average age. However, Great Slave Lake lake whitefish do not appear to be slow growing and during the years used in this study the average age in the catch did not exceed 12 years. In reviewing the growth of lake whitefish populations in North America, Healey (1975) concluded that growth was rapid in populations north of the 60°N. Perhaps, the population never did have many older age fish or it has reached a new equilibrium under long term harvest. In any case, the age of fish in the catch was well within the bounds (up to age 20-25 yr) where Johnson (1976) had recorded that age agreement was good between otoliths and scales. Within the time series it is possible that age reading interpretation could have changed. Age determination has a subjective component and can be affected by changes in the age reading personnel. However, in this case the same person aged the entire series. Also, there were regular checks for consistency of age determination undertaken within and between years using a reference collection. Therefore, a time series bias due to changing interpretation is probably not a significant factor.

As already mentioned, most fishery studies on lake whitefish utilize scales for age determination. Presently the North American Laurentian Great Lakes fisheries are managed using scales (Gile and Mohr 1995). We believe that methodological consistency with other studies will make our conclusions more widely appreciated by the fishery assessment community.

Harvest by sport and subsistence is considered negligible compared to the commercial harvest (Bill Bond, DFO biologist (retired), pers. comm.) although no quantitative studies have been done for the time period in question. There is no sport fishery for lake whitefish but there is a subsistence fishery which is small compared to the commercial harvest (George Low, DFO biologist Hay River (retired), pers. comm.). The total subsistence harvest is thought to have been stable from the 1970s onward (Robert Moshenko, DFO, Fisheries and Marine Mammal Management (retired), pers. comm.). Recent evidence suggests that the subsistence harvest is less than 5% of the total for the commercial harvest (Chris Day, biologist, DFO, Central and Arctic, 501 University Crescent, Winnipeg, MB R3T 2N6, pers. comm.). We observed that during the 1990s the number of subsistence fishermen declined in the Fort Resolution area of Great Slave

Lake. If this was the case over a longer period, then there could be a small drop in the fishing mortality experienced by the stock and fish could live longer. This would be consistent with our results.

Why did this fishery remain comfortably below maximum sustainable yield? Many factors probably allowed fishing below maximum to occur. First, as a lake located a long way from many conveniences, it had only a limited fleet capacity. Second, the lake is very large and the boats are limited in size so extended pursuit of whitefish has not been possible. The fishing power of the fleet is under capacity. Third, the price for whitefish does not make it a high profit venture. Fishermen fish for lifestyle and enough money to get by. Fourth, the lake is surrounded by aboriginal fishermen who tend to have a long term approach to harvesting which is based less on economics and more on sustainability and need. Fifth, because there are relatively few players there has been a reasonably amiable and close working relationship between harvesters and the fishery management agency. Currently, management decisions are discussed in the Great Slave Lake Advisory Committee meetings with stakeholders and DFO participating. There is a long history of unofficial co-management on the lake.

The sustainable yield recommended by D.S. Rawson at the onset of the fishery was based on his research and subsequent observation that the limnology, invertebrate and fish communities of Great Slave Lake were very similar to those of the Laurentian Great Lakes. He concluded that sustainable commercial fishing harvest rates of Great Slave Lake should therefore, also be similar to those demonstrated by the lower great lakes. Subsequently, Rawson assigned a quota of 3 to 5 million pounds (1,360.9 to 2,268.3 tonnes) to Great Slave Lake which to this day has proven to be sustainable. When Rawson's recommended quota was greatly exceeded in the early years of the fishery, sizes and ages of whitefish sampled from the commercial catch decreased dramatically (Keleher 1972). Quotas were reset in the 1960s to those recommended by Rawson. Subsequently, sizes and ages of whitefish sampled from the commercial catch, although lower than those observed during the early years of the fishery, stabilized and have remained so to the present. Sustainability and the stability of this fishery has also been aided by the fact that harvest has been spread throughout the lake to prevent over-exploitation in localized areas by the use of management areas. Each, with its own sub-quota and mesh size, has been relatively large, providing good escapement for mature fish. For example, modal age classes (first age of full recruitment into the fishery) of commercially caught lake whitefish have averaged between 10 and 12 years since the early 1970s and the first age of maturity for Great Slave Lake lake whitefish is at approximately 7 years. Finally, many of the management areas of the lake have not been fished to full quota from the early 1970s to the present, with the exception of Area I W and Area IV (for only a few years).

One other point to consider is whether there have been changes in abiotic or biotic factors in the lake that might have contributed to changes in size and age independent of the fishery. For example, if the nutrient load in the lake had increased substantially as is the case in many central European lakes, then the whitefish population might experience reduced mortality and increased growth due to the higher productivity. Unfortunately, on-going monitoring of lake chemistry and species diversity has not taken place so it is difficult to determine if nutrients or other factors such as climate change might be influencing the fishery. Data from Spence et al. (2006) shows that the Yellowknife River, entering the north part of the lake, had a slight upward trend in dissolved phosphorous over the time period of our study. However, this river contributes a relatively small volume of water to the lake compared to other tributaries such as the Slave River. Annual precipitation also appears to be increasing in the area. Lockhart et al. (2005) examined mercury levels and found whitefish had low concentrations compared to other species. There was no evidence that there was an increase.

As far as biological changes in the system, it is difficult to assess since there has been no consistent monitoring of other species. The only notable change is that the lake trout fishery collapsed in 1949 (Keleher 1972). However, there are no data during the time period of the collapse to determine if other species responded by changing their abundance. While they cannot be ruled out, substantial biotic and abiotic changes to the system are unlikely since there are not other directed fisheries on the lake and there has been no significant industrial development. The human population has increased somewhat but it remains a large lake with few humans living in its environs.

Thus, it seems that our results do represent a genuine increase in size and age with commercial exploitation. Age determination errors and other causes of spurious results can be ruled out as contributing factors. What is interesting, also, is that an increase in length was observed even though our data were from commercial catches which were sampling with a single mesh size. One would expect the selectivity of the gear to mask any minor changes in size in that the commercial gear selects a narrow size spectrum of animals.

The size measure we used was fork length and thus it is possible that given a set mesh size, the increase in length and age we observed was due to the fish becoming more slender over the time period. However, Day and Low (1992) showed no change in condition factor during this time period.

Additional analyses are required to understand the development of the lake whitefish population and the effects of fishing. Changes or lack thereof, in population size, mortality rates, age structure and growth would be best studied for this time series by using an age structured population model such as virtual population analysis (VPA).

Usually, attempts at understanding the effects of exploitation on fish communities have been mired by the confounding effects of pollution, foreign species introductions, changes in lake morphology and/or trophic state, incomplete harvest records, an absence of historical information on the type and amount of fishing effort employed and the absence of historical data on the structure, relative abundance and biological parameters of the fish community. The Great Slave Lake fishery has, to a large extent, none of these confounding problems. All difficulties encountered in managing and understanding the dynamics of exploited fish communities in Great Slave Lake have originated from a lack of scientific knowledge and from the characteristics of the lake itself. These characteristics include its vast size, mosaic environment and complex fish community.

It is interesting that, although Great Slave Lake has had a rather fitful history of quota assignments and changes implemented for a variety of economic and biological reasons, the lake quota during the period of study lies within the limits recommended by Rawson in 1945.

The Great Slave Lake lake whitefish fishery appears to be a rare success story where application of the theory of fishing in management has been effective in increasing the productivity of the lake while maintaining the resource at a stable level. However, we cannot definitively conclude that fishery management has increased the productivity of the lake because the analysis is too superficial at this point. Further work such as calculating fishing mortalities, yield-per-recruit, and examining the development of the lake whitefish stock/spawning stock abundance during the study period need to be done to fully analyze the harvest strategy on this system.

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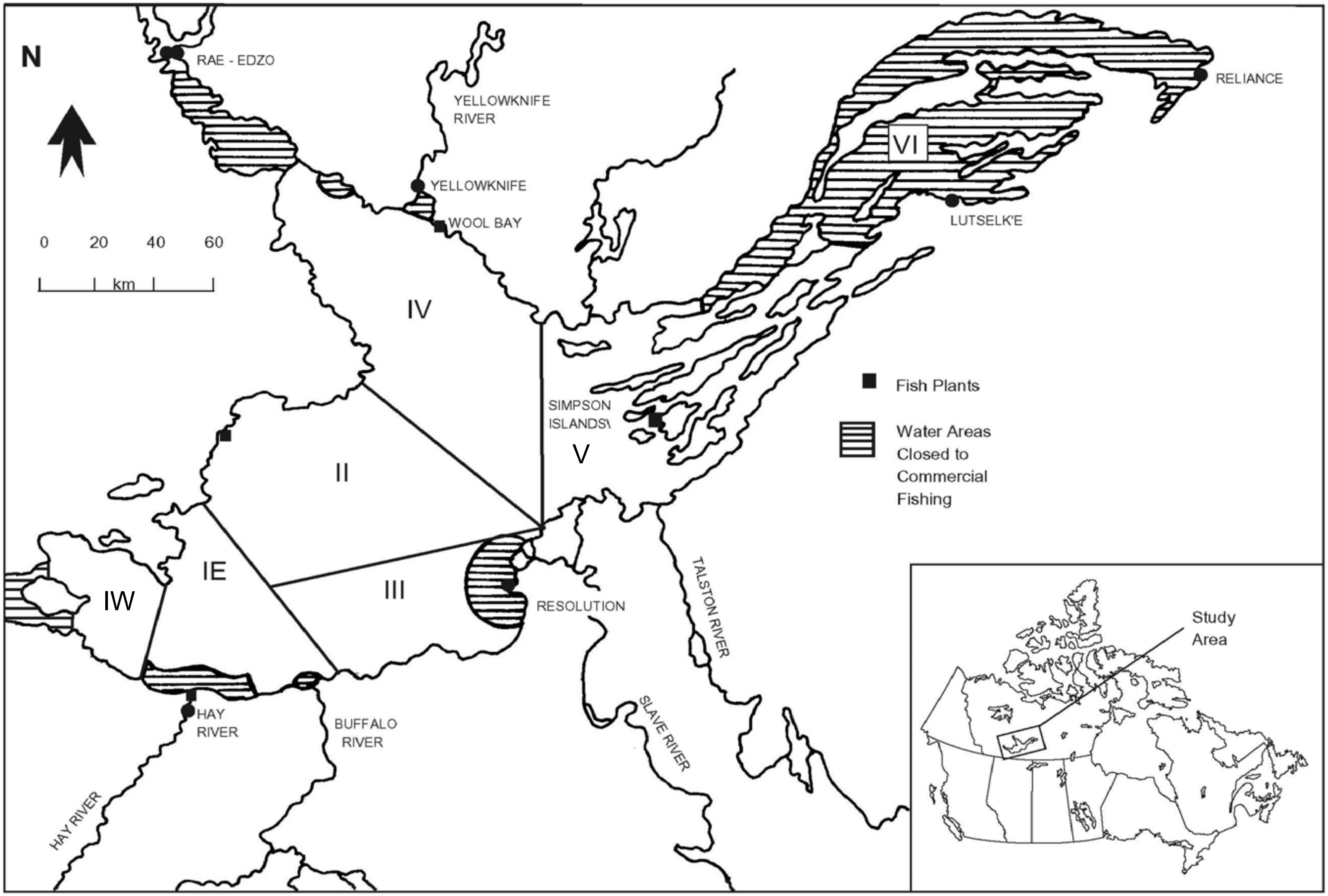

Figure 1. Map of Great Slave Lake showing administrative areas (modified from Read and Taptuna 2003).

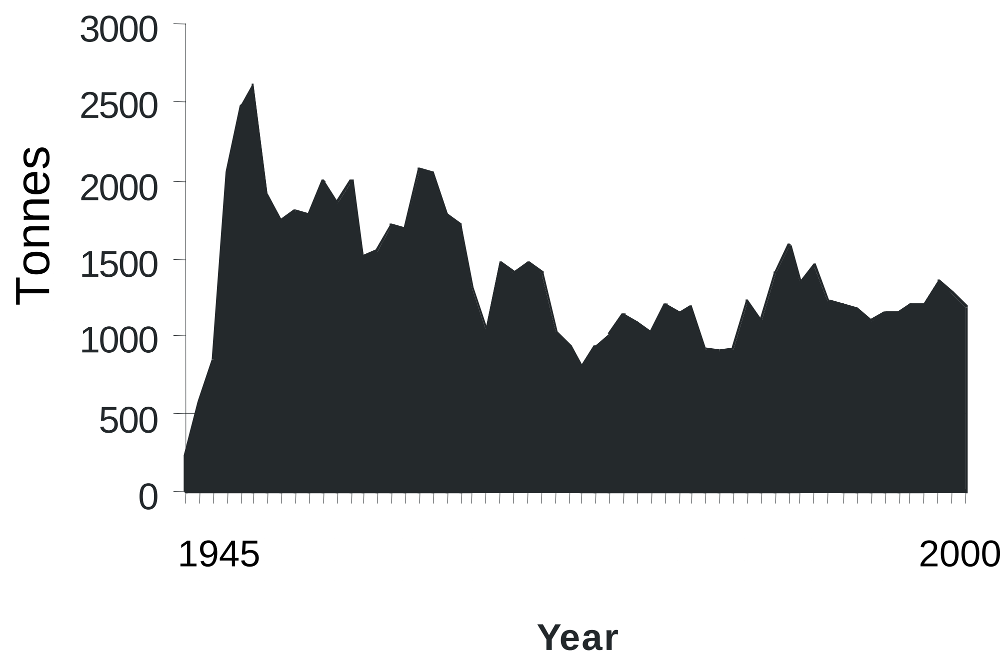

Figure 2. Landings of lake whitefish (*Coregonus clupeaformis*) from the Great Slave Lake commercial fishery for 1945 to 2000.

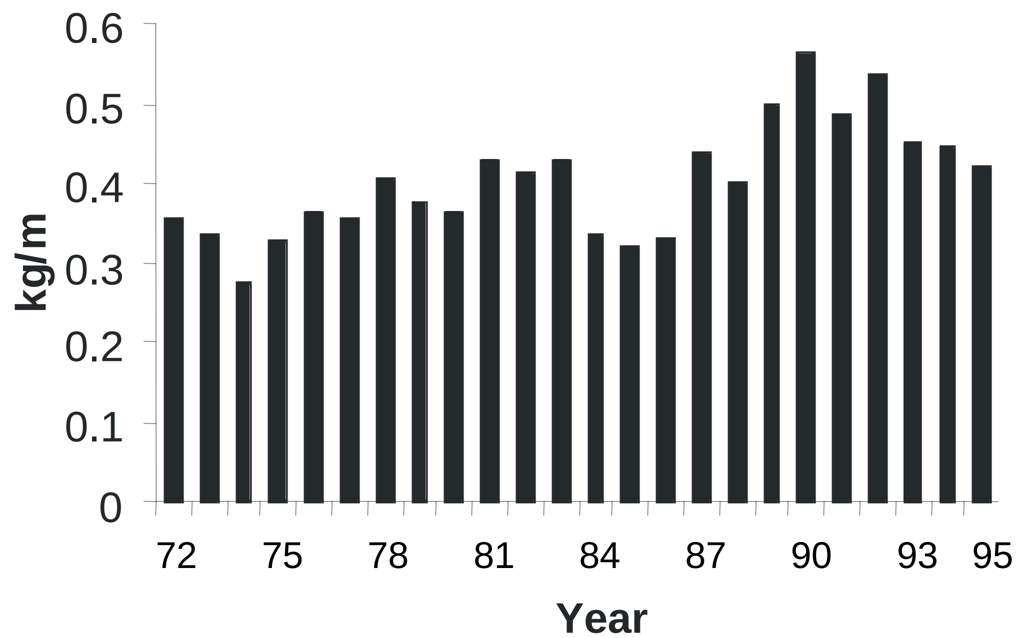

Figure 3. Catch per unit effort of Great Slave Lake lake whitefish (*Coregonus clupeaformis*) between 1972 and 1995.

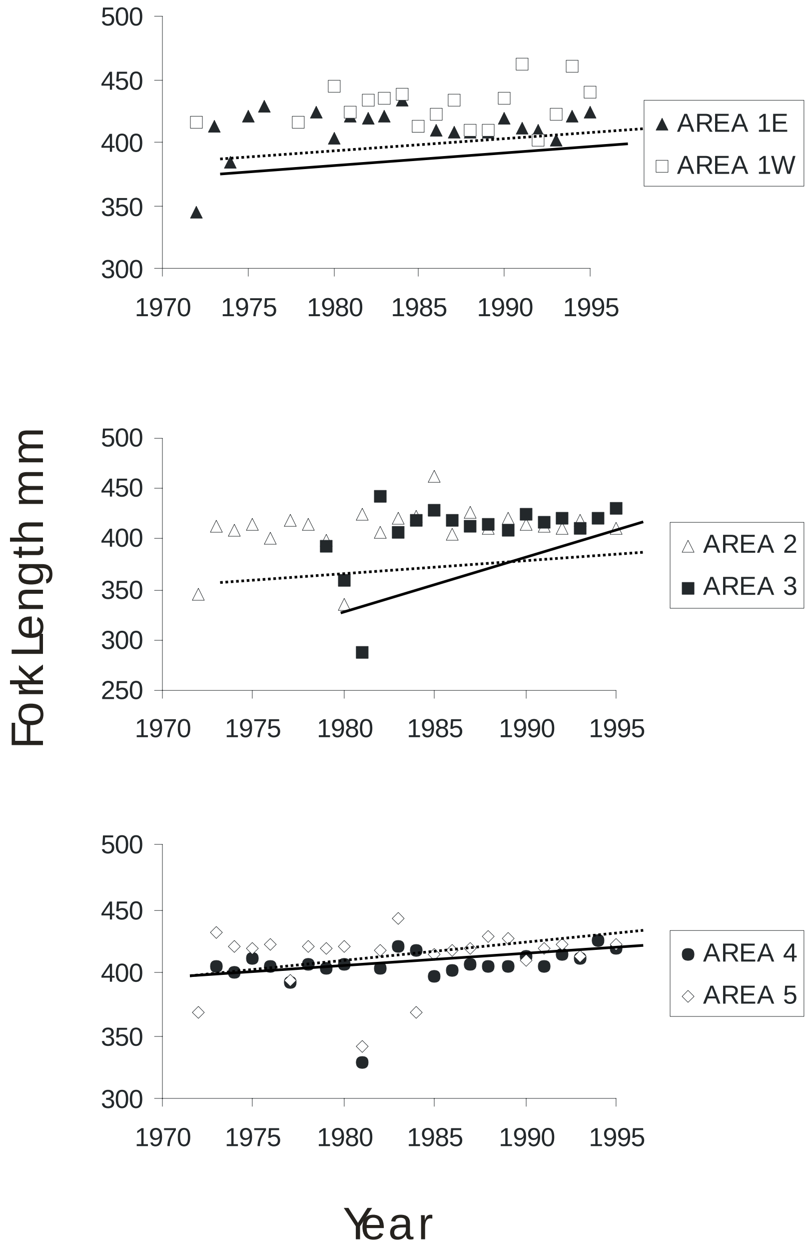

Figure 4. Average fork length by administrative area in the Great Slave Lake lake whitefish (*Coregonus clupeaformis*) commercial fishery 1972 to 1995.The trend line is dotted for open symbols and solid for the solid symbols.

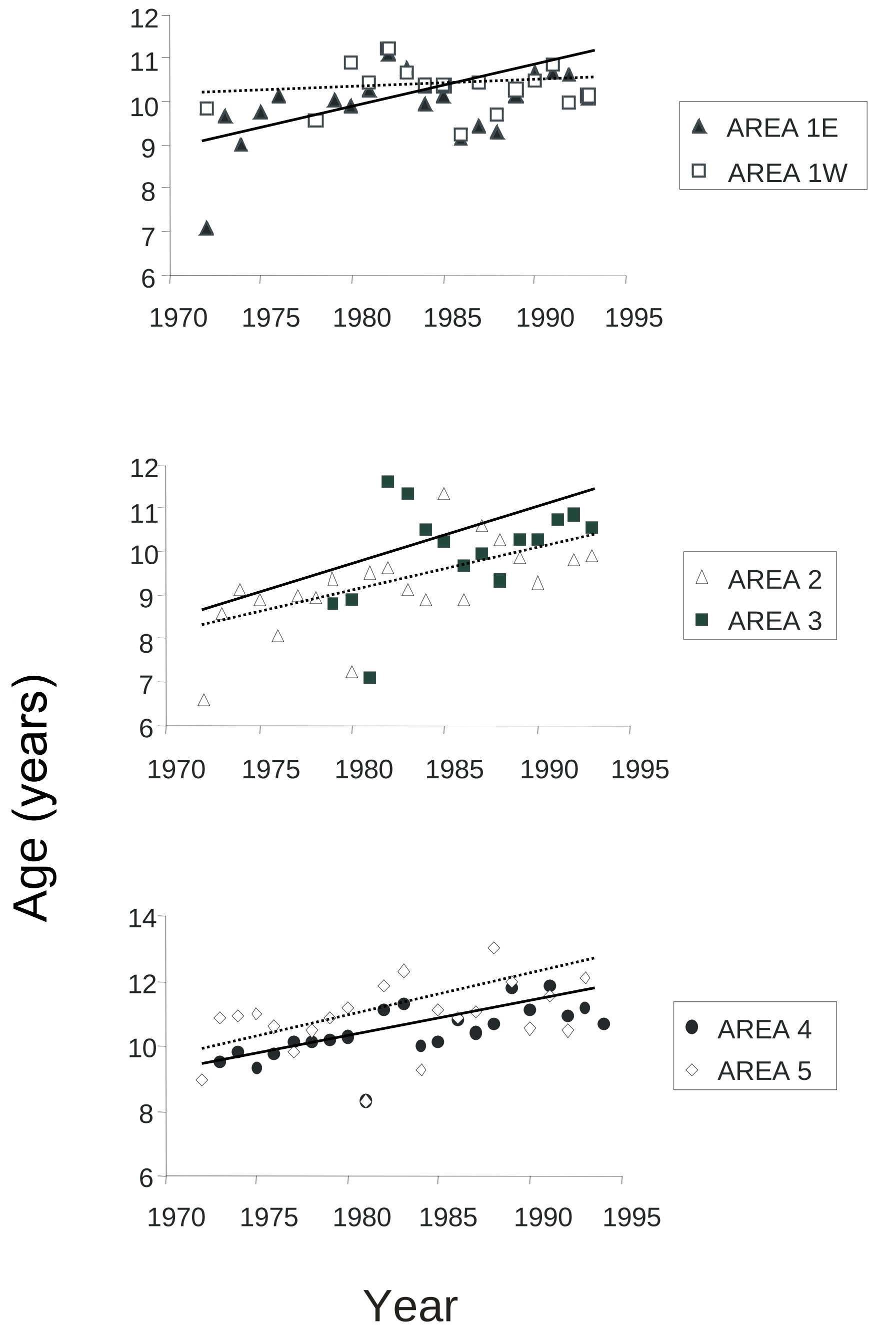

Figure 5. Average age by administrative area in the Great Slave Lake lake whitefish (*Coregonus clupeaformis*) commercial fishery 1972 to 1994. For areas 1E, 1W, 2, and 3 data only available to 1993. The trend line is dotted for open symbols and solid for solid symbols.

APPENDIX 1

Appendix Table 1. Sample sizes by year for age and fork length for Great Slave Lake lake whitefish (*Coregonus clupeaformis*), 1972 to 1995.

Year	Number sampled for Age	Number Sampled for Fork Length
1972	389	399
1973	872	2232
1974	1189	1227
1975	1156	1216
1976	1029	1093
1977	870	924
1978	1509	1645
1979	809	999
1980	1570	1603
1981	597	645
1982	791	843
1983	595	629
1984	216	418
1985	218	420
1986	330	614

Appendix Table 1 continued

Year	Number sampled for Age	Number Sampled for Fork Length
1987	218	420
1988	317	419
1989	213	418
1990	220	418
1991	220	416
1992	212	420
1993	171	328
1994	470	539
1995		539

Appendix Table 2. Analysis of Covarience (ANCOVA) of the effect of year on length with the covariate of age for Great Slave Lake lake whitefish (*Coregonus clupeaformis*), 1972 to 1995.

Source	DF	ADJ SS	MS	F	P
Covariates	1	42716416	42716416	27225.24	0.0001
YEAR	21	5402073	257242	163.93	0.0001
Error	****	50550528	1569		
Total	****	104779312			

Covariate	Coeff	Stdev	t-value	P
AGE	18.10	0.110	165.0	0.0001