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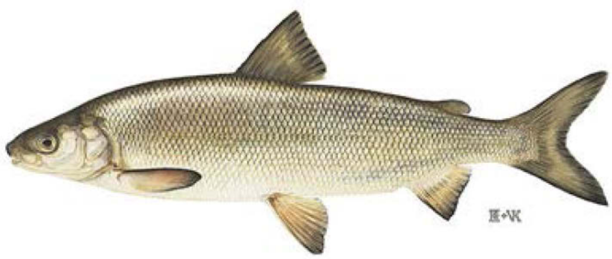
Central and Arctic Region

Canadian Science Advisory Secretariat
Science Advisory Report 2015/042

ASSESSMENT OF LAKE WHITEFISH STATUS IN GREAT SLAVE LAKE, NORTHWEST TERRITORIES, CANADA, 1972–2004



Lake Whitefish (Coregonus clupeaformis)

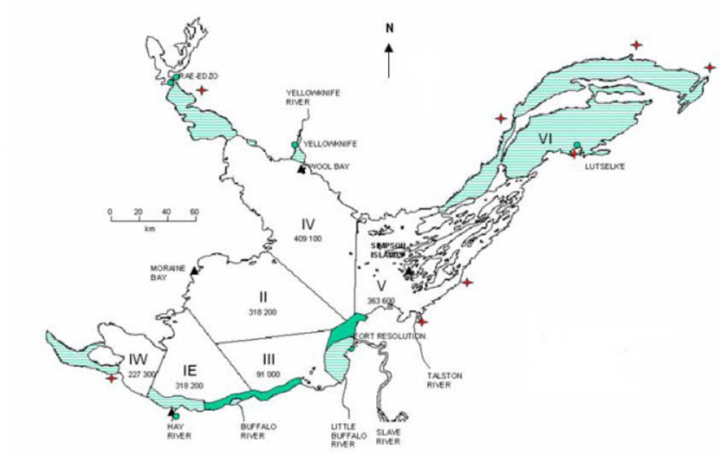


Figure 1. Map of Great Slave Lake, showing the designed administrative areas for fisheries management of Lake Whitefish and Lake Trout. Areas (coloured) were closed to commercial fishing and labels indicate locations of fish plants (▲) and fishing lodges(✦) (after Day et al. 2012).

Context:

The Lake Whitefish commercial fishery on Great Slave Lake, Northwest Territories, Canada, has been operating since 1945 and is managed by Fisheries and Oceans Canada (DFO) with input from the Great Slave Lake Advisory Committee (GSLAC). Lake Whitefish along with Lake Trout combined have accounted for 70 to 95% of the total annual commercial harvest. The Lake Whitefish fishery quotas are assigned to each of six management areas of the lake whilst the seventh area, the east arm, was closed to commercial fishing in 1974. Annual harvest levels of both species peaked in 1948-49 at 4,288 tonnes, declining steadily to approximately 1,500 tonnes in 1968-69 and remained at this level until the early 1990s. Since then, the annual harvest has steadily dropped to 340 tonnes in 2008-09. DFO has collected age structures from harvests in each management area and undertaken sporadic surveys to produce an abundance index to monitor the fished population dynamics. All available data collected from 1972 to 2004 are considered in this Lake Whitefish status assessment.

DFO Science was asked by Fisheries Management to provide science advice on the sustainable harvest level for Lake Whitefish for each management area. The primary approach to developing science advice was to integrate the accumulated biological and fishery-related information into a Lake Whitefish stock assessment dataset. A science advisory meeting was organized to review the historic information available and better understand biological characteristics and the effects of harvesting on Lake Whitefish in Great Slave Lake. A subsequent approach will be pursued to update the assessment with the results of ongoing research and to provide specific advice on sustainable harvest levels.

Canada

SUMMARY

- Lake Whitefish is ecologically, culturally and economically important in the Northwest Territories, Canada. A fishery-dependent sampling program was initiated in 1972 to collect biological data including scale age, fork length and dressed weight from all fished areas. The objectives of this study are to profile the spatiotemporal variations in biological characteristics and the potential association with cumulative impacts from localized hydrology, meteorology, and global climate changes during 1972-2004.
- Applying multi-model inference (MMI), a conventional linear regression model did not support the log-transformed pairs of fork length and round weight. Instead, the morphological relationships between log-transformed pairs of fork length and round weight were best described by a piece-wise regression model for fish in southern shallow areas and a cubic model for deep-water fish. The relative condition index, K_{LC}, was used to better reflect the effects of changing mesh sizes and fishing effort.
- The generalized growth model delineated length-at-age growth patterns and indicated that the growth traits of the fish changed along a southwest to northeast gradient in the lake.
- Commercial fisheries on Great Slave Lake commenced in the mid-1940s. The profound variation in Lake Whitefish population biological characteristics and the fishery yields corresponded to changes in social and economic factors. There was no indication of a decline in Lake Whitefish stock status among management areas. However, information gaps and uncertainties in the assessment were identified and further analyses recommended combining fishery-dependent and fishery-independent survey results.

INTRODUCTION

Lake Whitefish, *Coregonus clupeaformis* (Mitchell), is ecologically, culturally and economically important to structure Great Slave Lake (GSL) ecosystem (Figure 1). Records of Lake Whitefish harvest occur as early as 1929 and commercial fisheries commenced in the mid-1940s after a four-year feasibility survey and the construction of infrastructure, such as roads, for transportation, and the development of a fish processing facility. Five years later, a historical peak in harvest, over 4,000 tonnes of Lake Whitefish and Lake Trout (*Salvelinus namaycush*) combined, appeared as the largest commercial fishery in the Northwest Territories, Canada (Figure 2). The combined harvest declined to 1,000 tonnes in 1997 and further to 340 tonnes in 2008-09. The fishery became almost exclusively directed at Lake Whitefish due to the decline of Lake Trout populations in the west basin of GSL.

Despite the tremendous importance of the fish resources and evident decline in the fishery production in GSL, few studies have exclusively examined the relevance of changing biological characteristics. In fact, alterations in life-history patterns can be monitored by examining growth at age, population size-structure and condition, which may provide indications of the cumulative impacts from resource utilization and the effectiveness of management strategies. The objectives of this study were to:

(1) integrate available fisheries biology data from both fish plant sampling and experimental programs from 1972-2004,

(2) analyze temporal changes in length growth at age, size structure and condition index, and emphasize the capacity of population self-regulation under changing biotic and abiotic environments; and,

(3) examine changing environmental conditions as possible drivers of biological variation in Lake Whitefish population dynamics and life-history traits.

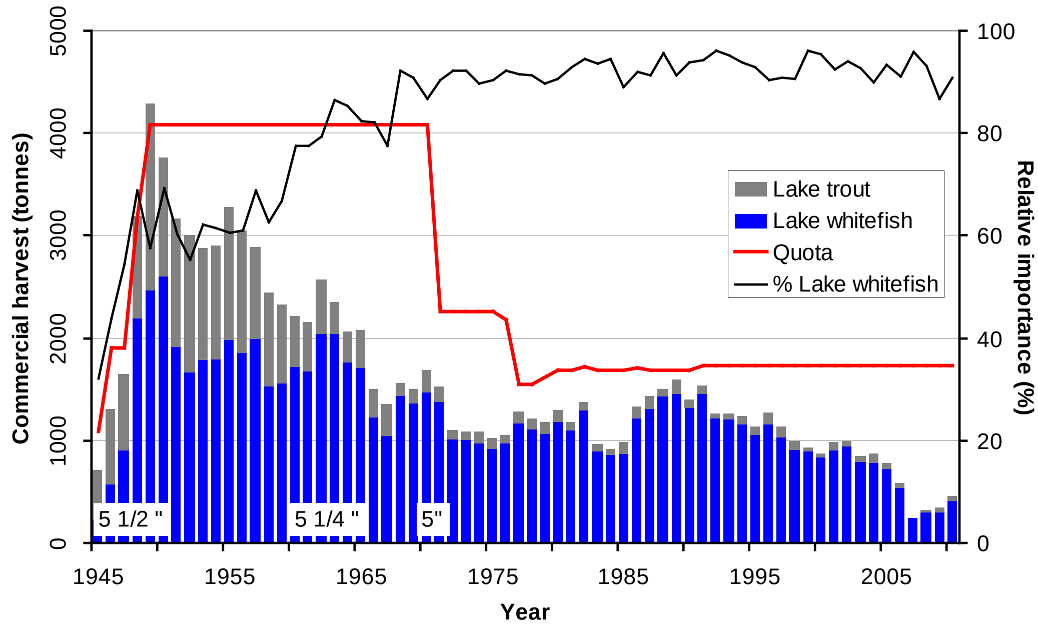


Figure 2. Temporal changes in commercial harvests and quotas (red line) for Lake Whitefish (blue) and Lake Trout (gray) in Great Slave Lake from 1944 through 2010. The relative proportion (black line) of Lake Whitefish to Lake Trout harvested was consistently elevated until 1970 and was maintained above 90% since then. The legal minimum mesh size changed from 140 mm (5½") in 1944, 133 mm (5¼") in 1977 and 127 mm (5") in 1998-2000.

ASSESSMENT

Relationships between fork length and round weight

Usually, relationships between fork length and round weight of fish are fit by using a power function. The log-transformed pairs of the length and weight can be statistically modeled by a linear regression. In this study, four regression models, linear, quadratic, cubic, and piecewise regressions as well as multi-model inference (MMI) were employed to select the best performance of the model fits. The piecewise regression model was the best representation of the relationships in the southern shallow areas (IW, IE, and III) while the cubic model was the best for deep-water areas (II, IV and V). An area-specific breakpoint was referred to the onset of maturation, suggesting the morphological changes during ontogeneic development. The classic linear regression model was not supported by MMI.

Condition index

Two condition indexes were used to measure the fish condition: Fulton's (K_F) and relative condition index K_{LC}. Combined with the corrected Akaike information criterion (AIC) weight, the average model was used to estimate theoretical values of round weight and K_{LC}. Using log-transformed fork length as a covariate, K_{LC} significantly varied with month, areas, and mesh size by means of ANCOVA. During 1976-1979, historically low condition index values were found across all areas. Since 1980, the condition index seemed to have declined steadily, except in area III.

Size composition

Fork length and round weight varied by years differently by area. In area IW they varied without trend, they increased slightly in area IV and decreased in areas IE and III (Figure 3). Average round weight decreased significantly over years in the eastern south shore areas.

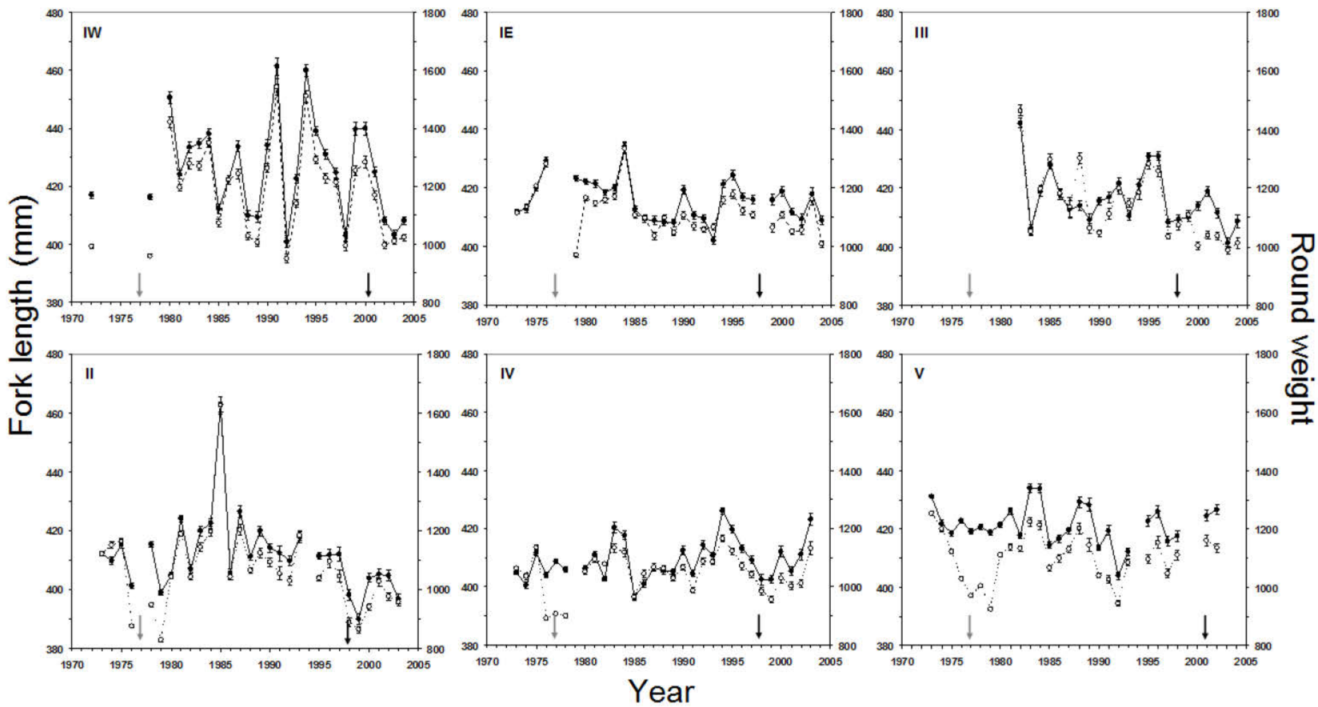


Figure 3. Spatiotemporal variations in fork length (mm; solid circles) and round weight (g; open circles) for GSL Lake Whitefish. Minimum legal mesh size for gillnets was initially set at 140 mm (5½"); this limit was reduced to 133 mm (5¼") (grey arrow) in 1976/77 and 127mm (5") (black arrow) during 1997-2000, respectively.

Over time, the average ages for Lake Whitefish varied by areas of the lake (Figure 4). Progressive increases in the average age were detected, especially in deep-water areas IV and V where there were significant positive relationships between the average age and year. Average age in the catch increased even with the reduction in commercial mesh during the time period examined. Over 1972-2004, the reduction in fishery production is likely;

1) only slightly related to a reduction in Lake Trout harvest, and
2) not related to a reduction in Lake Whitefish populations but rather reduced effort in the fishery.

To reflect the population status, multiple mesh sizes were necessary to obtain representative samples within the entire distribution areas. Single-mesh gillnet size selectivity made them unusable for this analysis.

Growth patterns

Three growth models: von Bertalanffy (VBM), generalized (GGM,) and logistic growth model (LGM), incorporated with four model scenarios: constant L_∞ and K (LCKC), constant L_∞ and varying K (LCKV), varying L_∞ and constant K (LVKC) and varying both L_∞ and K (LVKV) were used in the analysis. Combined with R-Based CODA for model convergence diagnosis and MMI of Deviance information criterion (DIC), GGM was the best growth model rather than VBM and LGM. Under GGM, the LCKV and LVKV scenarios better delineated the growth pattern of the fish in the southern shallow areas (IW, IE, and III) and deep-water area V. In the remaining deep-water area II and IV, GGM-LVKV better explained the growth traits for the fish (Figure 5). Throughout the time series there was a tendency for steady decrease in both growth parameters, but they did not statistically differ.

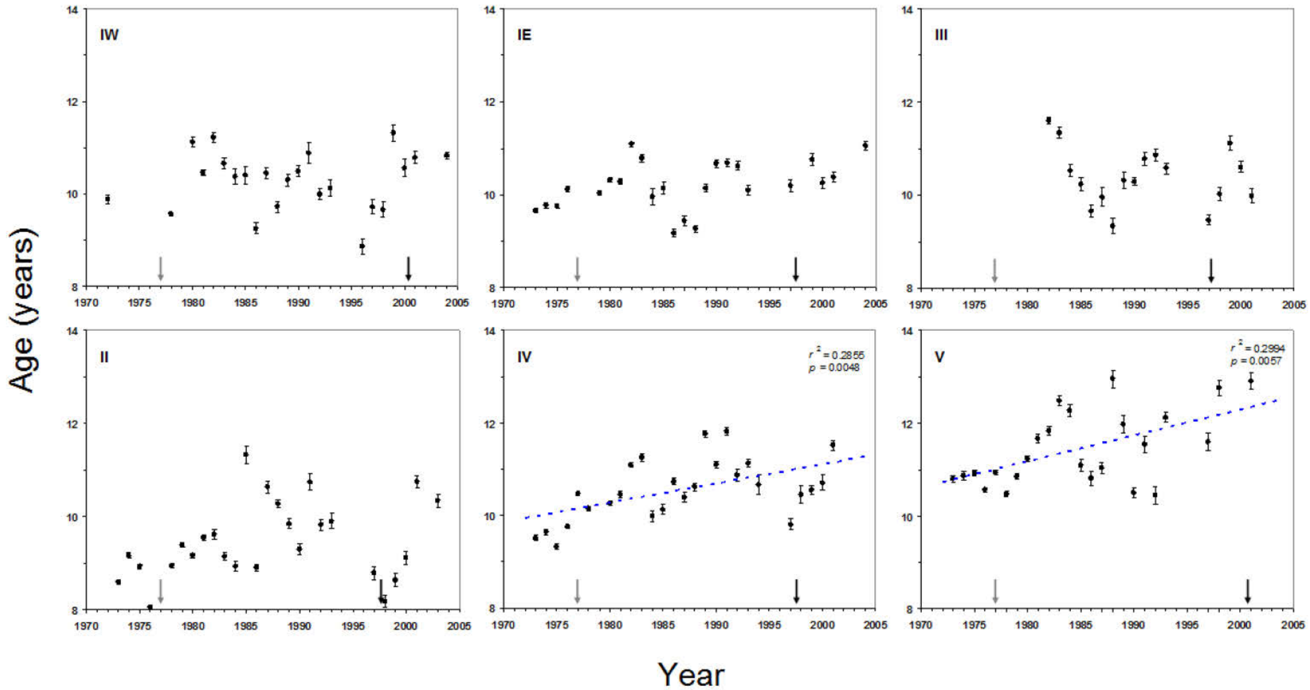


Figure 4. Spatiotemporal changes in the average age of Lake Whitefish collected from commercial fisheries on Great Slave Lake during 1972 through 2004.

Possible drivers of biological variation

At critical statistical levels (α=0.1, 0.05, 0.005), three clusters of influencing factors are considered for the possible drivers in variations of the population traits. Firstly, pair-wise correlation analysis indicated that the selected hydroclimatic variables (water level and riverine discharge) significantly influenced K_{LC}, K and L_∞. Especially in February, the correlation between riverine discharge and K_{LC} was significantly negative in area II; in June, growth parameter K positively related to water level in shallow area III. Accordingly, during 1960-2010, the riverine inflow tended to increase in winter (February), and gradually decreased in early summer (June). Both statistical results highlighted how hydro-climatic conditions impact the biological production. Increasing riverine discharge in winter may adversely impact prey production and overwintering habitat the fish required in deep water. In addition, higher summertime water level could stimulate the ecological turnover rates in productive shallow waters.

Positive correlations were detected between air temperature and K_{LC}, K, and L_∞ before May, and negative correlations during June through November, especially in shallow area III. In cold GSL, a moderate warming winter may result in good growing condition for overwintering schools. Warmer summer temperatures however likely retard the growth efficiency for Lake Whitefish, a cold stenotherm requiring cold temperatures and adequately oxygenated bottom waters for summer habitat. As a result, a warmer environment in summer can compress the optimal thermal habitat and force higher energy costs. As one of important weather condition parameters, precipitation in February varied by year and with higher amounts of rainfall in the mid-1980s. In August, historically higher precipitation occurred in the 1970s and mid-1990 through 2010. Pair-wise correlation detected the significant negative correlations between air temperature and precipitation versus population growth parameters of the fish in the summer. There is scare information available on the relationship between Lake Whitefish abundance and precipitation; our statistical results indicated the possible adverse impacts on the population growth by warmer and wetter summer weather.

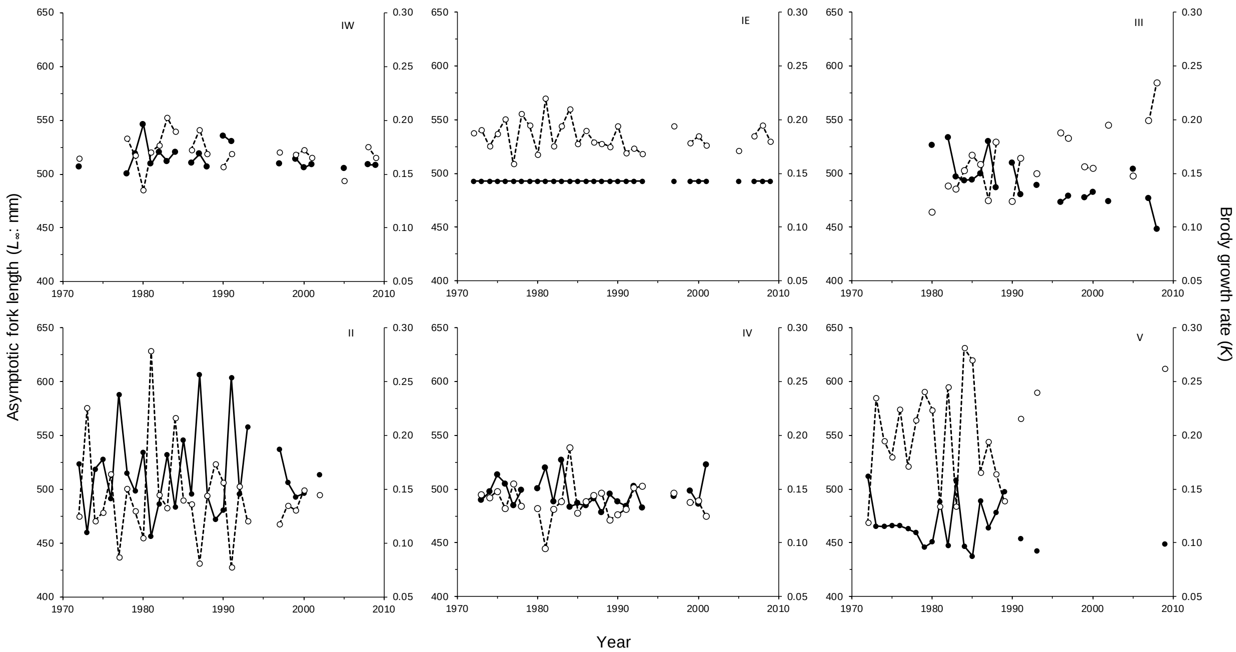


Figure 5. Temporal changes in posterior hyper-parameters of asymptotic fork length (L_∞: mm, solid circles) and the Brody growth coefficient (K: open circles) for Lake Whitefish across administrative areas of Great Slave Lake. The time periods for changing legal mesh size were labeled by arrows.

Over 1972-2010, commercial Lake Whitefish harvest only matched the quota in area IW, while constantly diminishing in the remaining areas possibly as a result of lowering market values and rising expenditure costs. In addition, commercial Lake Whitefish harvest was positively correlated with flow discharge especially in shallow area III but not to water level. Ice-fishing mostly occurred in the nearshore area with easy access to the fish plant. There were significant correlations between harvest, precipitation and temperature, but they varied by months and areas and may reflect effects of climate change on the fishery.

Sources of Uncertainty

There are a number of uncertainties related to the assessment of Lake Whitefish in GSL. In particular, the incomplete information about the state of the environment (past, present, and future) was involved during the study period. In accordance with Bayesian statistics framework, the underlying uncertainties can be partitioned into two categories: observation and process errors.

(1) Observation errors

- Gillnet samplings. Single mesh size gears provided the truncated size and age classes as a result of gillnet selectivity. Fish under age 5 or over age 18 were critically under-represented. For some multi-mesh experimental studies, the ranges of body-size samples were still biased because of the limited panels (<7 mesh sized panels).
- Dressed and round weight. Applying an old archived conversion factor, dressed weight was converted to standard weight, round weight. This might ignore the possible impacts from sex, size-dependent mortality, population density and seasonal variation. As shown by means of ANOVA and ANCOVA, K_{LC} varied by areas, month and years. For fish plant sampling, fish were gutted and the sexes were not distinguished by examining gonad tissues which did not allow determination of sexual differences in growth, mortality and recruitment.

- Ageing error from scale reading. The reliability of length-at-age analysis mostly relied on the accuracy of age determination. Scales have been used as a principal material for ageing GSL Lake Whitefish. Considerable discrepancies have been reported between scale and otolith ages. Scale ages underestimate otolith ages of western Labrador Lake Whitefish from age 4 or 5 on. For a slow growing whitefish, *Coregonus lavaretus* in Lake Tyrifjorden, Norway, the difference between scale and otolith estimates increased linearly. MMI was used to determine hyper-parameters of the hierarchical Bayesian growth model. The results of growth modelling are promising because the Bayesian framework incorporates the existing data as likelihoods, expert knowledge and references as priors, and generates the posterior estimations of model parameters. The derived estimation of growth rate seemed less sensitive to incorrect age determination than age distribution. The uncertainty for ageing GSL Lake Whitefish still existed especially for fish older than age 15. Beyond that age, the ageing errors from scale reading would linearly increase due to difficulties in separation of the condensed annuli marks.
- Incomplete observation. Despite the great efforts in collecting biological samples over 30 years, there were still incomplete biological data including age determinations by administrative areas.
- Stock definition. As a basic unit for fishery assessment, explicit deliberation of stock composition has become undermined because of insufficient scientific information. Out of necessity, this stage of analysis was solely based on administrative areas rather than discrete genetic stocks and ignored the movement patterns of discrete Lake Whitefish stocks among management zones.
- Social-economic development. Since the mid-1940s, the commercial fisheries underwent natural fluctuation in fish resources, market demands and fishing profits. To support commercial fisheries and enhance fishing efficiencies, the legal minimum mesh sizes were reduced from 140 to 133 mm in 1977 and 127 mm during 1997-2000, respectively. Sampling over three administrative areas by setting mesh sizes of 89-139 mm gillnets, researchers suggested that the reduction of legal minimum mesh size from 133 to 127 mm can significantly improve fishing efficiency by 46% for total round weight and 30% for total value catch-per-unit-effort (CPUE). Consequently, a mesh size reduction brought about the increase in smaller and younger fish in the catch and longer time to process the lower-valued products. Therefore, the further reduction of legal minimum mesh size did not stimulate the fisheries economy, instead fishing profits continued to drop as investment costs rose and some fish plants closed. There was missing information on the number of certificates, licenses, fishers, vessels, vehicles, fishing costs and trade values, which were needed to profile the fisheries economy under changing scenarios.

(2) Process error

- Environmental relevance. In this study, the proxy of fish habitat indicators was riverine discharge, water levels, air temperature, and precipitation data near the GSL rather than examining exact habitat inter-dependence on limnological conditions at specific fishing locations.
- Ecosystem model. Current growth models ignore the connection of environment and harvest influences. Future work is anticipated to take this interactive connection into account to examine temporal trends of biological patterns.
- Covariate analysis. In ANOVA and ANCOVA, log-transformed fork length was selected as a covariate and alternately weight may be adopted as a factorial approach to examine spatiotemporal variations and associated interactions with the population metrics.
- Isometric growth. To account for changes of morphological measures as fish grow, the exponential index, b, usually varies around 3, indicating isometric growth. For most aquatic animals, this index is less than 3 for negative growth or greater than 3 for positive growth. The negative growth can be observed as thinner more slender body shape whereas positive growth indicates the wider and fatter body measure. Applying a simple *t*-test can be used to test for isometric growth.

Gaps

A number of gaps have been identified through this process.

- Spatiotemporal variation in the conversion factor. New data are needed to re-assess spatiotemporal variation in the conversion factor between round and dressed weight of the fish.
- Differences in scale and otolith age estimates. A comparative study between scale and otolith readings is needed to eliminate ageing errors.
- Variations in population metrics. The population metrics should be associated with spatiotemporal changes in population density, recruitment, and environmental variables in the surrounding habitats, rather than administrative areas.

CONCLUSION AND ADVICE

Since the 1950s, GSL Lake Whitefish harvest has shown a steady decline, however, the decline is not uniform across all management zones. Fishing effort is believed to have declined markedly during the most recent 15 years of the fishery, likely because of socioeconomic constraints. Therefore, even though harvest has declined there is no indication of a decline in the whitefish stock over the course of the fishery.

Multi-model inference (MMI) indicated that the relationships between fork length and round weight can be best represented by piecewise regression for fish in the southern shallow areas and cubic regression for deep-water fish. A discontinuity or breakpoint was found to be varied with spatial areas and ontogeneic development. The traditional linear model for the log-transformed pairs of fork length and round weight was not supported by the MMI. Combined with von Bertalanffy, generalized, and logistic growth models, Bayesian hierarchical models showed the growth patterns in length-at-age over spatiotemporal scales were best described by a generalized growth model incorporated with hierarchical growth scenarios. While Lake Whitefish biological metrics (length, weight, age, condition index and length-at-age growth) tended to vary over years, there was no indication of a decline in stock status among administrative areas. Some temporal changes in the population biological metrics exhibited a reduction of the average fork length and round weight in shallow southern shore areas and increase of both quantities in the deeper areas. This may be related to an uneven distribution of fishing effort or a combination of varying environmental conditions. Area IW has been consistently harvested to its full quota, partially due to its proximity to the Hay River fish plant. Metrics in IW, however, were stable through the time series of 1972-2004. Changes in area-based average age of Lake Whitefish showed a significant positive relationship with year in areas IV and V, but no significant correlations were found in the remaining areas of the lake. We note that a noticeable spatiotemporal variation in size at age occurred over time, attributed to changing environmental conditions. Smaller L_∞ and larger K values appeared in deep-water areas (areas IV and V), while larger L_∞ and smaller K values were found in the shallow southern waters (areas IW, IE, and III). Pair-wise correlation analysis revealed that large amount of river discharge in winter may be negatively impacting prey production and overwintering habitat. In winter, increasing temperature stimulates energy cost for activity and swimming behaviour, but compresses the habitat ranges for the fish. Higher growth rate, measured by K, appeared in the higher water level in June, which benefited food consumption and growth. In summary, changes in environmental variables may potentially impact the biological production of the fish population, but no direct evidence presently indicates a decline in stock status.

There are a number of uncertainties and information gaps identified in this study. An ongoing fishery-independent survey is recommended. Standard multi-mesh gillnet survey techniques should be adopted. In addition, a logbook monitoring program should be implemented to record fishing effort and other statistics from the fishery. Within model-based procedures which set annual catch limits using constant exploitation rates and estimates of stock biomass, candidate models, such as surplus production model, catch-at-age statistics model, can be implemented and compared. In accordance with model-based procedures, candidate management scenarios are also tested in stochastic simulations against a series of operating model scenarios that reflect uncertainties about productivities and current status of GSL Lake Whitefish.

SOURCES OF INFORMATION

This Science Advisory Report is from the January 26-27, 2011 Regional Advisory Meeting on The Status of Lake Whitefish (*Coregonus clupeaformis*) in Great Slave Lake. Additional publications from this meeting will be posted on the DFO Science Advisory Schedule as they become available.

Day, A.C., VanGerwen-Toyne M., and Tallman, R.F. 2013. A risk-based decision-making framework for Buffalo River Inconnu (*Stenodus leucichthys*) that incorporates the Precautionary Approach. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/070. iv + 13 p.

Zhu, X., Day, A.C., Taptuna, W.E.F., Carmichael, T.J., and Tallman, R.F. 2015. Hierarchical modeling of spatiotemporal dynamics of biological characteristics of Lake Whitefish, *Coregonus clupeaformis* (Mitchill), in Great Slave Lake, Northwest Territories 1972–2004. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/038. v + 56 p.

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