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Science Advisory Report 2023/025

DEVELOPMENT OF A LAKE-WIDE MULTI-SPECIES FISHERY-INDEPENDENT SURVEY FOR GREAT SLAVE LAKE

Lake Whitefish (Coregonus clupeaformis)

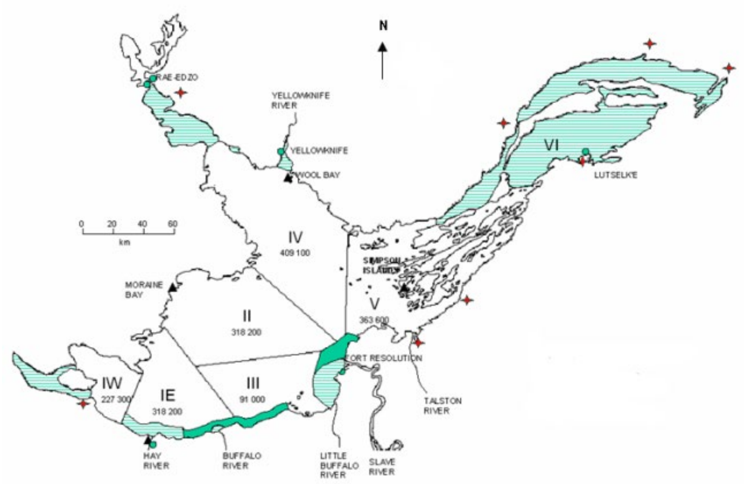

*Figure 1. Map of Great Slave Lake (GSL), showing the designated administrative areas for managing GSL commercial fisheries such as Lake Whitefish and Lake Trout (*Salvelinus namaycush*). Shaded areas are closed to commercial fishing and symbols indicate locations of fish plants (▲) and fishing lodges (✦) (after Day 2002).*

Context:

Great Slave Lake (GSL) is the largest freshwater ecosystem in Canada's sub-polar ecoregion. Managed by Fisheries and Oceans Canada, with input from the GSL Advisory Committee, Lake Whitefish in GSL support the largest commercial and subsistence fisheries in the Northwest Territories, Canada. Given the magnitude and significance of the fisheries to the ecoregion, the communities, and the Northwest Territories, there is a need to assess Lake Whitefish population productivity and establish sustainable harvest level recommendations. Until now, there has been no appropriate information on population sizes of either target or by-catch fish species.

A series of emerging cumulative anthropogenic activities have prompted the adoption of an integrated decision-making framework that incorporates the precautionary approach and ecosystem-based fisheries management into ongoing fisheries protection provisions. To approach this framework, two science advisory meetings were planned. The first meeting, held in January 2011, reviewed information available for this fishery from 1972 to 2004 to better understand the population dynamics on temporal and spatial scales. The second meeting, held in April 2013, reviewed and discussed quantitative approaches to determining sustainable harvest levels and updated integrated fisheries stock assessment plans by incorporating ongoing multispecies interactions and cumulative impacts.

This Science Advisory Report is from the April 25–26, 2013 regional peer review on the Great Slave Lake Stock Assessment Approach for Sustainable Fisheries Development Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

July 2023

SUMMARY

- A lake-wide depth-stratified summer fish survey using multi-mesh experimental gillnets was developed as a fishery independent sampling program for Great Slave Lake.
- To support assessments of stock productivity, a suite of biological data (e.g., fish length, weight, sex, condition, health attributes) and samples (e.g., ageing structures, stomachs, genetic samples) will be collected for individual fishes.
- Otoliths, pectoral fin rays, and scales will be collected for fish ageing.
- Otoliths are the preferred ageing structure, and it is unclear whether fin rays or scales are the preferred alternate; additional research on ageing accuracy and consistency with fish fin rays and scales in Great Slave Lake is needed.
- In addition to fish sampling, zooplankton nets and benthic grabs will be used at each site to provide data on lower trophic levels to support ecosystem assessments.
- Environmental data (e.g., depth profiles for dissolved oxygen, chlorophyll *a*, pH, water temperature and turbidity, weather and wave conditions) will be recorded at each site.
- This survey is Fisheries and Oceans Canada’s first ecosystem-level survey program for Great Slave Lake and was developed without previous estimates of variability or species distributions; therefore, the sampling program will need to undergo a preliminary review after three years and a full review after five years.
- To establish empirical relationships between additional environmental variables and stock production:
  - Water samples should be collected for nutrient analyses so that probe-derived chlorophyll *a* data can be related to phytoplankton composition.
  - Secchi disc and water colour measurements should be taken at all stations to allow comparison with historical data.
  - Data could be obtained from existing weather buoys and temperature loggers could be deployed on fishing nets.

INTRODUCTION

Great Slave Lake and its fisheries

Great Slave Lake (GSL; Figure 1) is the second largest lake in Canada. GSL has a surface area of 28,568 km^2 and a volume of approximately 2,088 km^3 of water (MRBB 2004). It is the deepest lake in North America with an average depth of 73 m and a maximum depth of 614 m. Geologically, it straddles two distinct physiographic regions: the erosion-resistant Precambrian Shield to the east; and the Interior Plain to the west. The Shield features open, stunted taiga forest and hundreds of lakes, while the Plain is characterized by a more dense boreal forest in a landscape that was sculpted and smoothed by continental glaciers. As a result of geological and vegetative differences between the two regions, annual rainfall is greater in the Shield than the Interior Plain. The Slave River accounts for 82% of the water inflow into GSL, drawing water from many lakes and tributaries along its course (Rouse et al. 2008). Over the past 50 years, the monthly average inflow from the Slave River has varied remarkably, decreasing in summer (e.g., June) and increasing in winter (e.g., February; Figure 2). Terrestrially-derived nutrients are transported into GSL, in particular from June to September, stimulating prey production, enhancing predator-prey interactions throughout the food web, and nurturing fish growth

(Kennedy 1953). In addition, seasonal variation in inflows drives the circulation and vertical mixing of water masses, modifying fish habitats during the life history periods of growth and over-wintering.

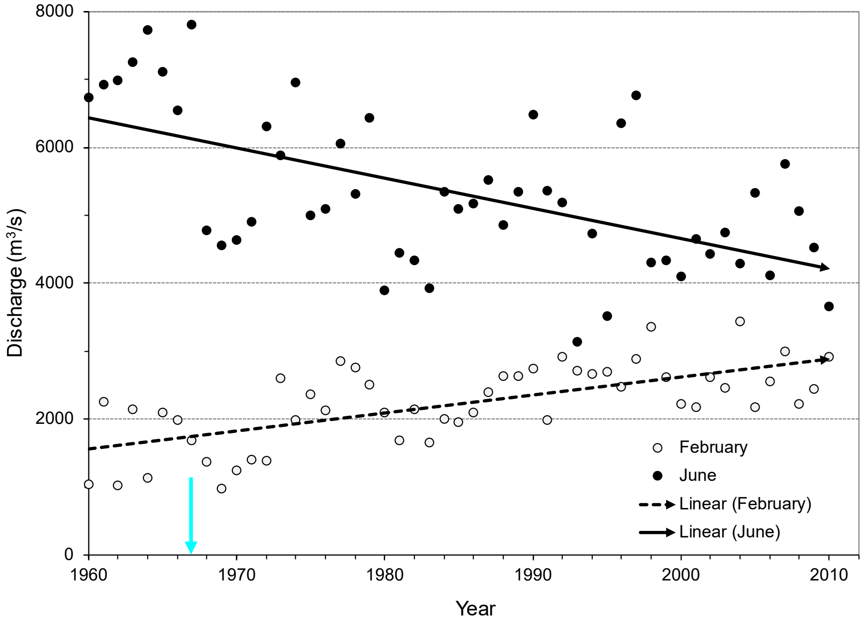

Figure 2. Changes in monthly average riverine inflow from the Slave River in February (open circles) and June (solid circles) over 50 years with linear fits (lines). The blue arrow indicates the inception of water regulation at the W.A.C. Bennett Dam in the headwater of the Peace River.

As a result of this river-lake interaction, GSL once sustained the largest Lake Whitefish and Lake Trout fisheries for commercial, recreational, and aboriginal (CRA) uses in the Northwest Territories. Commercial fisheries for both target species accounted for more than 4,000 t in 1947–1948 (Figure 3). When the Lake Trout population declined in the lake's main basin in the early 1970's, commercial Lake Whitefish catches fluctuated vastly from 2,600 t in 1949–1950, to 1,450 t in 1990–1991, to 230 t in 2006–2007. The increase in the proportional contribution of Whitefish to the total harvest from GSL was essentially due to a decline in the Lake Trout population in the western basin of GSL (Figure 3; Day 2002, Read and Taptuna 2003, Tallman and Friesen 2007). Since 2005, low market values for commercial fish products have unintentionally resulted in the closures of fish plants around the lake and fishers have abandoned the commercial fishery to continue subsistence fishing only. Thus, these noticeable changes in the GSL commercial fisheries may be mixed with multidisciplinary and cumulative impacts, but are not well documented and addressed to date.

Starting in 1972, Fisheries and Oceans Canada implemented a long-term fish plant sampling program for GSL that continued until 2010 when several fish plants closed. In addition, several research programs were undertaken by DFO scientists that focused on their particular interests, such as gillnet selectivity (Bond and Turnbull 1973, Bond 1975, Moshenko and Low 1978, Roberge et al. 1985a), the Lake Whitefish fall spawning run (Roberge et al. 1985b), and the effect of gillnet mesh size on capture efficiency (Day 2002). The lack of a dedicated survey vessel, limited funds, and a short open-water season (June–October) have substantially limited long-term fishery-independent research activities, especially integrated fisheries stock assessment.

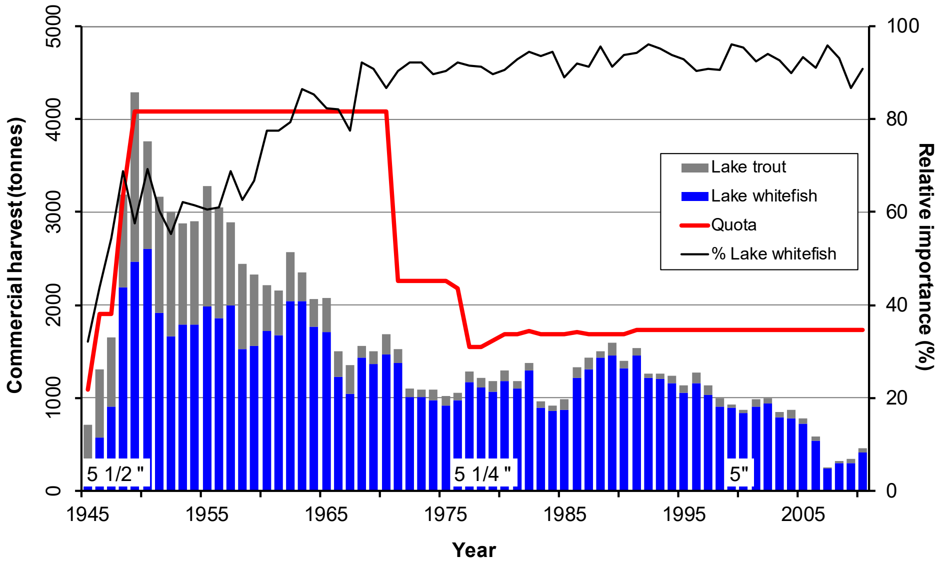

Figure 3. Commercial harvests (bars) of Lake Whitefish (blue) and Lake Trout (gray), and their combined quota (red line) in GSL from 1944 to 2010. The relative proportion (black line) of Lake Whitefish to the total harvest increased steadily until 1970 and has remained above 90% since then. The legal minimum mesh size changed from 140 mm (5½") in 1944 to 133 mm (5¼") in 1977 and 127 mm (5") in 1998.

In order to address the relationship between potential cumulative changes to affected fish and habitats in the context of impacts to the productivity of CRA fisheries, Koops et al. (2012) identified four possible consequences for fisheries and visualized them as quadrants of a 2-dimensional plate. Quadrant 1 is a low risk scenario characterized by low cumulative changes to fish and habitats and low impacts on the productivity of CRA fisheries. Quadrant 2 illustrates a low impact to CRA fishery productivity but significant cumulative changes to fish and habitats. Quadrant 3 includes low cumulative changes to fish and habitats but larger changes to CRA fisheries productivity. Quadrant 4 includes situations with increased changes to CRA fisheries production that are linearly related to increased cumulative changes to fish and habitats. Associated with these possible scenarios, the newly introduced Fisheries Protection Provisions (FPP) outlined in Koops et al. (2012) required:

1. development of adaptive management strategies in terms of the measurable nature and extent of cumulative impacts,
2. evaluation of the sustainability of fishable populations, and;
3. integration of uncertainties and environmental risks.

GSL provides an ideal ecological platform for researchers, Aboriginal communities, and decision makers to work together to address the effects of cumulative impacts, including cause-effect mechanisms governing the sustainability and ongoing productivity of impacted fished populations. Owing to a lack of long-term monitoring of biological productivity potentials, it is urgent to develop and implement an integrated monitoring and research program to assess the sustainability of ongoing CRA fisheries productivity in GSL.

Objectives of an integrated fishery stock assessment

An integrated fisheries stock assessment is best defined as the use of traditional and contemporary statistics to make quantitative predictions about the reactions of fish populations to alternative management choices (Hilborn and Walters 1992). Quantitative predictions require the routine collection of demographic information, definition of the potential contribution and variability of fisheries population production, and recognition of possible management actions under which all possible risks and outcomes will be well incorporated (Hilborn and Walters 1992, Quinn and Deriso 1999, Methot 2009). As Walters and Martell (2004) advocated, the central objectives of modern fisheries science, combined with all possible risks and outcomes, are to help decision makers make the right choices among options that might make a difference, to manage the probabilities of the outcomes, and to expose tradeoffs among conflicting objectives successfully (Mangel 2000).

There are some conflicting objectives in the GSL fisheries, especially among the CRA fisheries users, water regulators, mining and gas explorers, and decision makers. For example, commercial fisheries can be regulated by controlling fishing licenses, setting area-based quotas, and specifying a minimum legal mesh size, but Aboriginal subsistence fishers are exempt from these conditions. To help overcome this information gap, an integrated eco-monitoring and assessment framework for the GSL fisheries ecosystem was developed. Within this framework, objectives for the short-term (5 years) and long-term (10–15+ years) were developed. The short-term objectives focus on establishing a baseline of Lake Whitefish population status, multispecies associations with environmental variables, as well as a snapshot of the eco-trophic dynamics of the GSL ecosystem. The long-term (10–15+ years) research objectives include quantitative assessment and sustainable management of ongoing Lake Whitefish productivity, maintenance of stability and diversity in this multispecies community, and application of ecosystem-based fisheries management (EBFM).

ASSESSMENT

Framework for an Integrated Fisheries Stock Assessment Science Plan (IFSAP)

In addition to the research objectives mentioned above, a wide range of influences relating to the fishery, its stakeholders, and the aquatic environment were reviewed when developing the IFSASP following a pathway approach, and focusing on three inter-connecting components:

1. understanding the management context;
2. respecting the stock assessment process, and;
3. contributing to the fisheries management process.

These three components are independently formed but have interdependent relationships with each other (as indicated by directional arrows in Appendix 1).

The management context component included legal supporting documents that are fundamentally important to the way in which the fishery is regulated, including land claim agreements or treaties, provincial and federal regulations, and Acts. For the management approach in GSL, Lake Whitefish is the sole target for CRA fisheries. By-catch species, such as Lake Trout, Inconnu (*Stenodus leucichthys*), and ciscos, however, are important to the harvest because they interact with each other by sharing food-web pools or habitats. The governance regime is also changing from top-down government control to a co-management regime, where communities become proactive in regulating their fishery with the government.

The stock assessment and research component provides the sound scientific and technical basis for producing advice to fisheries management. To better resolve the issues, concerns, and advice requests, the main objectives of the stock assessment process can be accomplished by:

1. collecting key and related information,
2. applying the right assessment tools to provide a quantitative basis,
3. modeling indicators and reference points, and;
4. formulating management advice for decision makers.

Methodologies for integrated stock assessment and information requested

There are a wide variety of quantitative methodologies used for fisheries stock assessment. Six types of statistical methodologies are categorized for fisheries assessment and management (Appendix 2). Summarized with these methodologies, model complexity varies with the questions addressed, data availability, underlying assumptions, fisheries indicators, and reference points required to contribute to the fisheries management context (Smith and Addison 2003). Each model is therefore unique and shines a different light on population abundance, distribution, and health, taking into account a variety of different parameters. Each set of models has its own advantages and disadvantages, which are embedded within each model's complexity.

Of all factors considered, the time series of catch and abundance indices have become essential for nearly all selected models. Excluding the biomass dynamics model (Hilborn and Walters 1992), growth and mortality are essential parameters for the delay difference model (Quinn and Deriso 1999), equilibrium length-based cohort analysis (Jones 1981), and age-structured model (Pope 1977). Associated with life-stage separation, the age-structured fish population dynamics model can be assessed in relation to production, consumption, recruitment, and exploitation. The mass-balanced ecosystem model, Ecopath with Ecosim (EwE; Christensen and Walters 2004), creates a static snapshot of trophic dynamics of the ecosystem; where functional groups of the ecosystem are represented by biomass pools, connecting them through prey-predator relationships represented by sets of linear equations of each group. Most importantly, this model's capacity greatly benefits from studying the effects of fishery management policies in both marine and freshwater systems. As indicated in Appendix 2, (Table A2), the disadvantages of ecosystem modeling with EwE are rather apparent. There is still an ongoing debate on what combinations of indicators would be best suited to monitor the state of the ecosystem, to measure the effectiveness of management options, or to track the combined influences of environmental change and fisheries on ecosystem dynamics (Shannon et al. 2009).

Implementation of integrated fishery stock assessment in GSL

Available information

- *Commercial harvest* information has been collected since the fisheries exploitation of the 1950s. There is no information on recreational and subsistence uses.
- *Fishing effort*, despite being commonly used for GSL fisheries, is not available. This includes information on numbers of nets, net dimension, soak time, number and size of vessels, and labor and days used for CRA fisheries.
- Some scattered experimental *fishery-independent surveys* have addressed fishery-related research of interest including fisheries production (Rawson 1949), gillnet selectivity (Moshenko and Low 1978), spawning run in summer time (Roberge et al. 1985a), and effect of mesh size reduction on fishing efficiency (Day 2002).

- Information from the long-term *fishery-dependent survey* and monitoring program run through the fish plant since 1972 (Read and Taptuna 2003) gives insight into historical population health, fishery observations, and data methods. During this program, a total of 200 Lake Whitefish were sampled for both summer and winter fisheries in each administrative area of GSL each year. As the commercial market for Lake Whitefish downsized, some fish plants have been closed (since 2010), and the monitoring program suspended.

Proposed plan for integrated fisheries stock assessment

The proposed work plan for integrated fisheries stock assessment aims to 1) conduct fishery-independent experimental studies to *establish the baseline* of Lake Whitefish population production and their spatial variation, 2) explore effective indicators to *characterize the sustainability* of ongoing *fisheries productivity, biodiversity*, and *healthy ecosystem integrity*, and 3) *develop* a *benchmark* for capacity building with a *community-based eco-monitoring* module (CBEM) and *ecosystem-based fisheries management (EBFM)* so as to support co-management decisions within a precautionary framework.

To meet these planned research targets and required multidisciplinary information, the following major research components were suggested:

- Ecological environmental variables, primarily including temperature, dissolved oxygen, turbidity, and pH, will be measured in conjunction with a series of fish net samples to represent the environmental association with aquatic productivity and multispecies fish communities. Daily or monthly average riverine inflow and water level of major connecting rivers can be monitored through related websites.
- Low-trophic level producers including chlorophyll a, zooplankton, and benthos, do not directly contribute to CRA fisheries, but fundamentally support ongoing fisheries production through food webs. In the salmonid-dominated GSL ecosystem, two main food-chains were proposed: plankton-cisco-piscivores like Lake Trout and Burbot (*Lota lota*), and plankton-benthos-benthivores like Lake Whitefish (Healey 1975).
- Multispecies fish community attributes are mainly concerned with some direct community structure-providing species for CRA fisheries and some indirect but highly-connected species for the fisheries, such as:
    - ***Keystone species*** which have a disproportionate influence on community structure, e.g., predator of a highly fecund and competitive species that has dominance potential.
    - ***Wasp-waist species*** which dominate biomass at an intermediate trophic level, and are important prey of higher trophic levels, as well as important predators on lower trophic levels (Bakun 2006). These species represents a transition point between top-down and bottom-up control, and are usually schooling species with dense local aggregations available to predators but patchy over the entire area.
    - ***Key prey or forage species*** are low trophic level species and are important for energy flow to higher trophic levels.
    - ***Apex predators*** crop down other species and decrease dominance (i.e. top-down control).
- Respective metrics of fisheries stock assessment usually encompass a very broad array of datasets mainly used for fisheries stock assessment, including species-specific abundance trends, life history characteristics, and catch and effort.

Abundance trend data are derived from fishery-dependent or -independent sampling. To standardize relative abundance or catch-per-unit-effort (CPUE), multiple sets of statistical analyses and models can be applied to account for uncertainties relating to gear-specific catches from different capture efficiency, such as gear types, mesh sizes, soak time, vulnerability, spatial extent, and fishing behaviors. The trend analyses require that enough relative long time series data or absolute abundance estimates are available (Hayes et al. 2007).

Fish life-history characteristics mainly include information on age and growth, size- and age-dependent structure, mortality, recruitment and reproduction of fish populations of interest. All of these require measurements of fish samples from both fishery-dependent and fishery-independent studies. There has been recent interest by fisheries scientists to investigate ageing precision and reliability of multiple age structures of studied fish populations. Mortality accounts for different sources of death and removals from the fish populations and is estimated quantitatively. Natural mortality combines death by disease, starvation, predation, lethal environment, and old age. Fishing mortality combines the fishing removals and related effects indirectly linked to the fishing process. Recruitment parameters are size- and age-dependent, and by using multi-mesh gillnets or some other non-commercial gears, the quantities of recruitment of fish populations can be obtained. To generate a relationship between recruitment and spawners, long-term data collection of both variables is necessary (Maceina and Pereira 2007).

Catch and effort information best reflects the history of fisheries development, and forms the backbone of most stock assessments. In conjunction with a multispecies fishery-independent study, a fishery-dependent monitoring program should be simultaneously carried out, such as a logbook program, to give a complete picture of the exploitation history of the fishery. Other possible methods to gather commercial catch and effort data include onboard observer programs and port sampling (Hilborn and Walters 1992).

Progress made to date supporting net design and integrated fisheries management

Establish fishery-independent gillnet study (FIGS)

The FIGS developed for the multi-species sampling program was carried out by constructing an experimental gillnet with ten different mesh sizes ranging between 13–140 mm (½–5½”) knot to knot stretched (Figure 4), which followed a geometric constant of 1.3053 (Zhu et al. in prep[1].). The depths of the nets were 3.66 m (12’) and 1.83 m (6’) for pelagic and benthic sets, respectively. The lengths of panels varied with mesh size, 11 m (36’) for smaller mesh sizes (13–38 mm; ½–1½”) and 22 m (72’) for larger mesh sizes (51–140 mm; 2–5½”), in order to reduce the catch/mortality of small-sized fishes in small mesh size panels. The selection of sampling locations was based on a depth stratified random approach.

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[1] Zhu, X., Leonard, D., Howland, K.J., VanGerwen-Toyne, M., Gallagher, C., Carmichael, T.J., and Tallman, R.F. In prep. Fishery-independent gillnet study (FIGS) sampling protocol used for multi-species ecology study in Great Slave Lake, Northwest Territories, Canada. Can. Sci. Advis. Sec. Res. Doc.

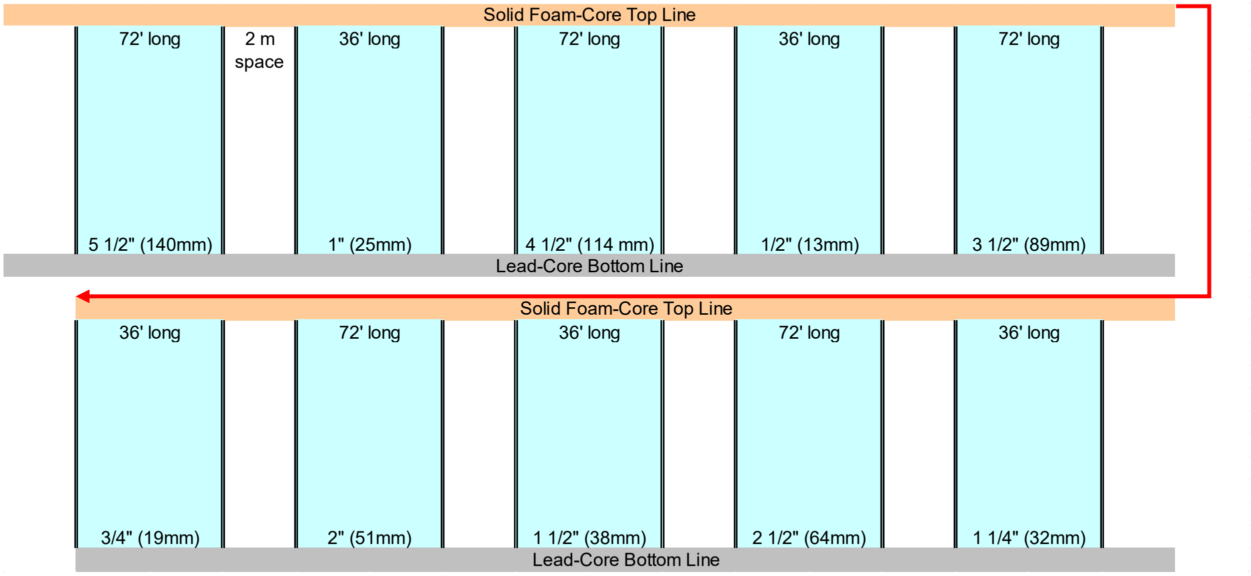


Figure 4. Profiles of a gang of experimental gillnets used for the GSL fisheries-independent gillnet study indicating panel lengths, mesh sizes, order and spaces between panels. Panel depth is 1.83 m (6 ft.) for benthic and 3.66 m (12 ft.) for pelagic gillnets, respectively.

Gillnet selectivity

Gillnet selectivity was estimated indirectly by applying log-linear SELECT methods and between-set analysis. The increase of Biomass Per Unit Effort (BPUE) with mesh sizes directly related to the rising capture efficiency by species enmeshed (Figure 5). For example, smaller mesh size panels seemed more efficient for the cisco group, although the fish species can be caught by full mesh size panels. Mesh sizes 64–114 mm (2½–4½") can be highly efficient for Lake Whitefish, while 89–140 mm (3½–5 ½") can be highly efficient for Longnose Sucker (*Catostomus catostomus*) and Burbot. The normal fixed spread selection curves resulted in the best fit for three select fish - Lake Whitefish, Longnose Sucker, and Burbot; significant model residuals largely resulted from sampling sizes and bias (Figure 6). These results could be used to design future research on the abundance estimates of fish species. It is recommended that greater accuracy is required for size distributions corrections (separation of entangled portion from the wedged or gilled), otherwise interpreting results from current gillnet sampling can be somewhat misleading especially when including fish from < 51 mm (2") mesh size panels.

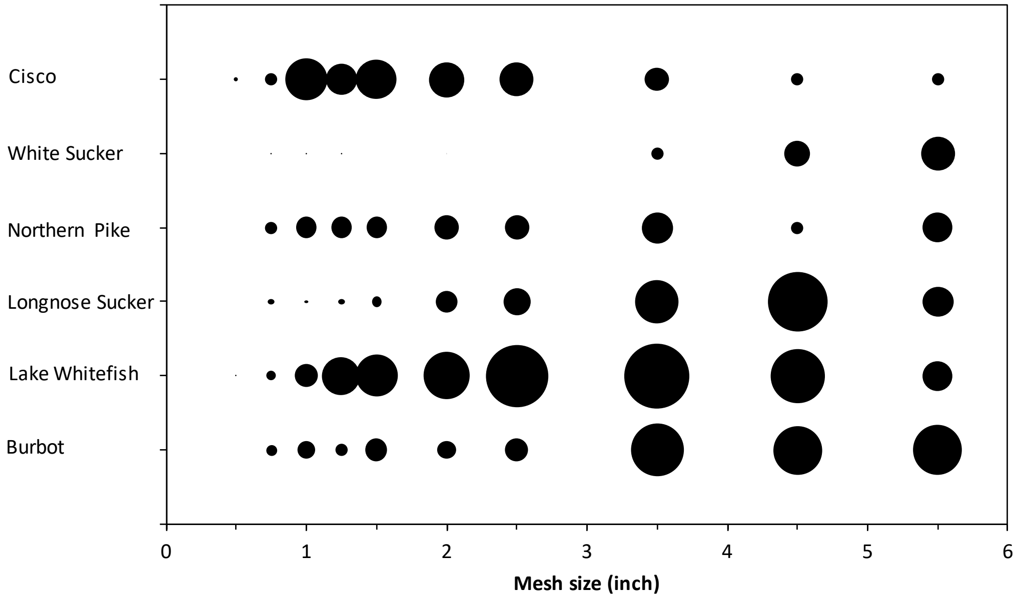
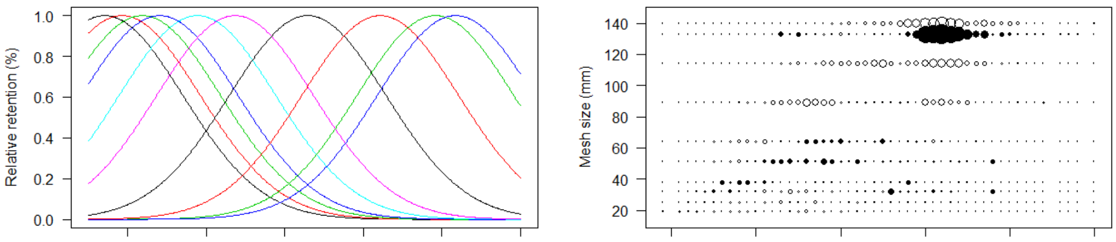


Figure 5. Variation of major species-specific BPUE (kg/1000 m^2) against the mesh sizes of experimental gillnets

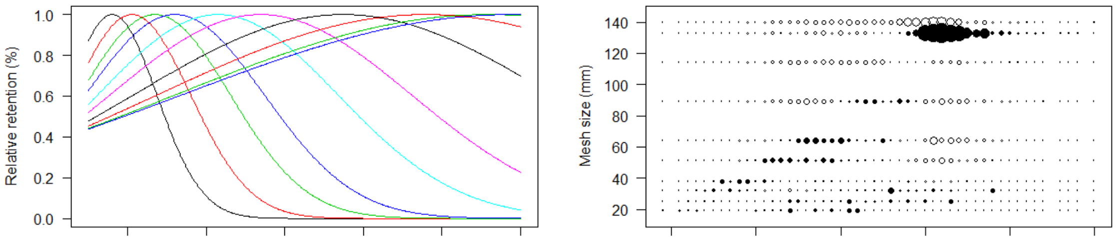
Age estimate comparison for Lake Whitefish

Suitability of three age structures to determine growth and mortality of Lake Whitefish, was evaluated (Zhu et al. 2017). Otoliths, pectoral fin rays, and scales of 307 fish collected from 32 benthic experimental gillnets in GSL between July 10 and August 15, 2012 were used to assess annular assignments, precision bias, and reader's uncertainty. Of the three structures, the greatest age range was identified from pectoral fin rays (1–27 years), with the median age range from otolith readings (1–25 years), and the smallest age range from scale readings (1–20 years). Mean age was greatest from otolith readings (10.88 ± 0.16 years, CV = 43%), which differed significantly from those of pectoral fin rays (9.82 ± 0.13 years, CV = 38%; $t = 9.667$, $p < 0.001$) and scales (9.66 ± 0.13 years, CV = 40%; $t = 7.420$, $p < 0.001$). Overall, ageing of Lake Whitefish by scales underestimated their true age and the level of disagreement with age increased linearly (Figure 7). Combined with processing efficiency, ageing precision, and bias of age structures for Lake Whitefish populations in GSL, it was determined that otoliths were the most appropriate structure for age estimation. However, the differences in age estimates from all three structures in this study highlighted the importance of validating ageing structures to provide accurate age estimates for integrated fisheries stock assessment.

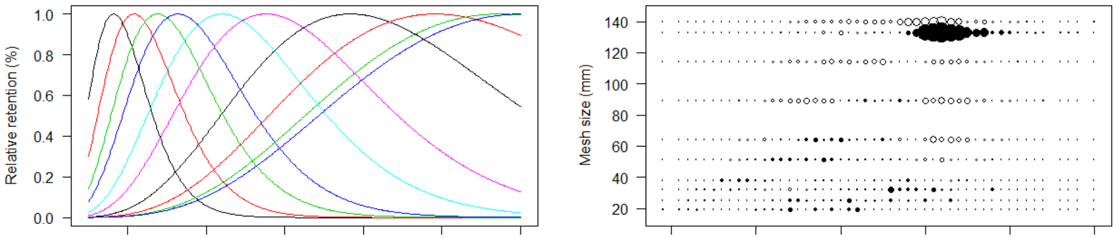
Normal fixed spread



Normal spread



Gamma spread



Lognormal spread

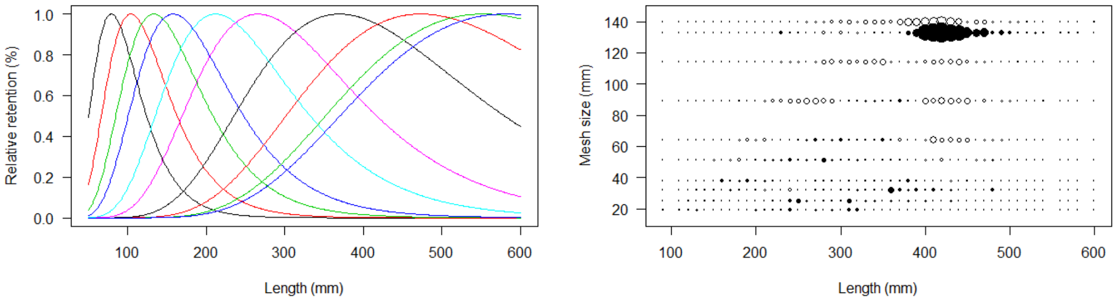


Figure 6. Retention curves and deviance residuals with equal capture efficiency fitted by normal fixed spread (first row), normal spread (second), gamma spread (third) and lognormal spread (fourth) for Lake Whitefish in GSL.

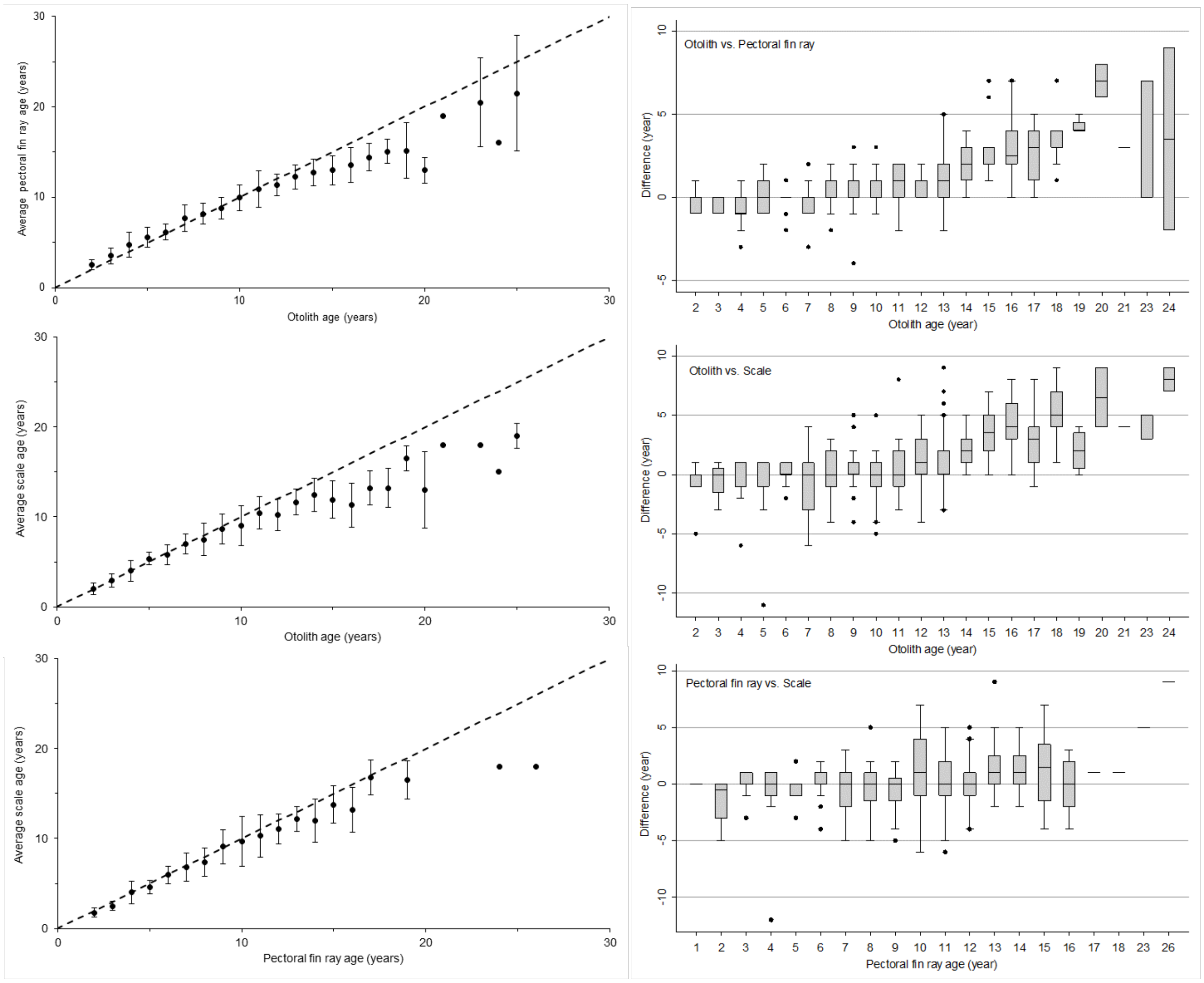


Figure 7. Paired comparison of age bias from the third read with the average values of the individual structures (left), actual reads (middle), and box-and-whisker plots of age differences between age structures (right). Error bars indicate one unit of standard deviation about the mean. Regression lines (broken) were added to fit the pairwise points and compare with 1:1 equivalence lines (solid line).

Sources of Uncertainty

- The planned survey will be conducted during only two months of the year (July and August); this will provide a snapshot of summer conditions but will not be representative of the entire year. Fish migrations will affect the survey results and subsequent analyses.
- The maximum depth of fish sampling is limited by logistical constraints such as vessel size and therefore data from deep areas is particularly poor. Linkages between near-shore and offshore habitats have not been examined.
- Catchability may not be linear with net area; net area differs between large and small meshes and it may be difficult to integrate and reconcile the data.
- There may be differences in age interpretation between otoliths collected in July and August because of the timing of annulus formation (which is unknown). Similarly, other metrics such as fecundity and maturity may be affected by the seasonal sampling and species phenology.

- With the lack of historical survey data, the current sampling intensity may not be sufficient for the desired analyses and an assessment of intensity will form a critical component of the preliminary and full reassessments.
- A fundamental understanding of the factors that affect the limnology and productivity of GSL is lacking. Feeding ecology, spawning habitats, and winter refugia for fish species needs to be studied further.

Uncertainty, in this context, is best defined as “the incompleteness of knowledge about the state or processes (past, present, and future) of nature” (FAO 1995). In other words, lack of knowledge causes risk (Francis and Shotton 1997). Uncertainty is inherent in all forms of integrated stock assessments and ecosystem studies. Here we mainly deal with three aspects of uncertainties closely related to integrated fisheries stock assessment which are sampling variability in the form of observation error, uncertainty in model performance in the form of the model preparatory process and parameterization, as well as scenario modeling feedbacks (Figure 8). Due to the underlying assumptions and conditions of probability distribution functions (PDFs) of model parameters, all aspects of uncertainties interact to influence outputs, summary statistics, and variance and covariance of model parameters (conventional statistics), as well as posterior PDFs (Bayesian statistics).

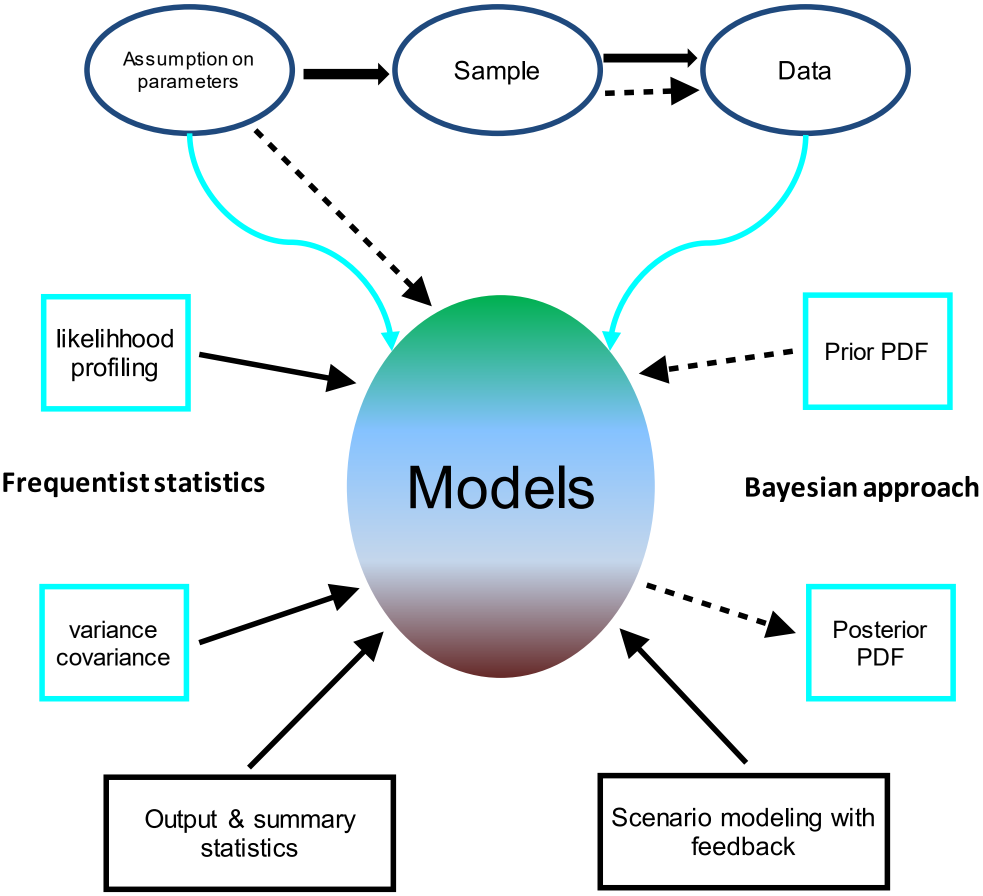


Figure 8. Schematic representations of frequentist and Bayesian statistical processes for evaluating uncertainties in integrated stock assessment and projection. Dashed lines showed stochastic processes. PDF stands for probability distribution function.

CONCLUSION AND ADVICE

- The survey that has been developed is appropriate as an initial protocol to develop a fishery-independent tool for integrated stock assessment of commercial fisheries and ecosystem management.
- This survey is Fisheries and Oceans Canada's first ecosystem-level survey program for GSL and was developed without previous estimates of variability or species distributions; therefore, the sampling program will need to undergo a preliminary review after three years and a full review after five years. The survey will be reexamined once sufficient data are available and refined as appropriate.
- The lake may be affected by further developments in the southern watershed (e.g., nutrient loadings and contaminants, invasive species).
- A fishery-independent survey is required for stock assessment on GSL which would include:
  - Collection of biological data (e.g., fish length, weight, sex, condition, health attributes) and samples (e.g., ageing structures, stomachs, muscle, and genetic samples) from individual fish to support stock productivity using multi-mesh gillnets
  - Collection of low trophic samples using zooplankton nets and benthic grabs in order to support ecosystem assessments
  - Collection of environmental and limnology data and samples such as water samples, water clarity and colour measurements, weather and wave conditions, and depth profiles for a suite of environmental factors including dissolved oxygen, chlorophyll *a*, pH, water temperature, and turbidity.

GSL is confronted with increasing challenges from a mixture of cumulative impacts from hydroclimate changes, to CRA fisheries fluctuation, and exploration of natural resources. All external variables interact with the biological producers, Lake Whitefish productivity and multispecies fish community, and the integrity of the lacustrine ecosystem. Because of the interactive nature of water, fish, and the ecosystem, multidisciplinary investigations and integrated fisheries stock assessments are fundamentally important to;

1. establish a baseline for Lake Whitefish population dynamics and spatial distribution,
2. characterize the sustainability of ongoing fish population production, and;
3. build up the capacity of community-based co-management of fisheries resources in the Canadian north.

To explore the feasibility, a comprehensive multispecies monitoring program was developed with an integrated fisheries stock assessment framework to facilitate our short-term (5 years) and long-term (10–15+ years) research targets to ensure the sustainability of GSL fisheries productivity and multispecies fish community dynamics. Progress to date includes a fisheries-independent gillnet study sampling protocol, evaluation of capture efficiency and gillnet selectivity, as well as age estimate comparisons for Lake Whitefish. These results have greatly supported the pursuits of the underlying framework, but caution should be taken to attend to the number of uncertainties and constraints when working in the northern great lakes.

LIST OF MEETING PARTICIPANTS

Name	Affiliation/Organization
Kevin Hedges (Chair)	DFO – Science, Central and Arctic Region
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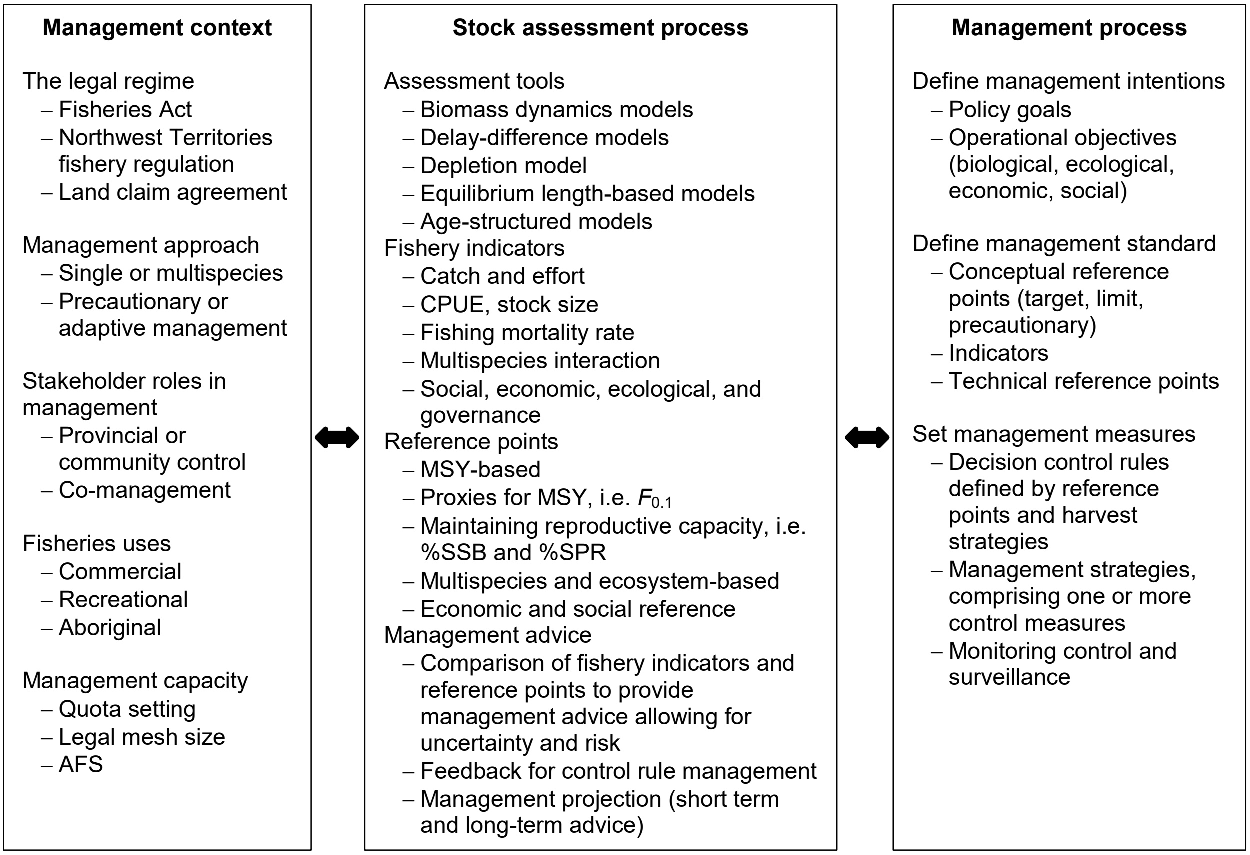
APPENDIX 1



Management context

The legal regime
- Fisheries Act
- Northwest Territories fishery regulation
- Land claim agreement

Management approach
- Single or multispecies
- Precautionary or adaptive management

Stakeholder roles in management
- Provincial or community control
- Co-management

Fisheries uses
- Commercial
- Recreational
- Aboriginal

Management capacity
- Quota setting
- Legal mesh size
- AFS

Stock assessment process

Assessment tools
- Biomass dynamics models
- Delay-difference models
- Depletion model
- Equilibrium length-based models
- Age-structured models

Fishery indicators
- Catch and effort
- CPUE, stock size
- Fishing mortality rate
- Multispecies interaction
- Social, economic, ecological, and governance

Reference points
- MSY-based
- Proxies for MSY, i.e. $F_{0.1}$
- Maintaining reproductive capacity, i.e. %SSB and %SPR
- Multispecies and ecosystem-based
- Economic and social reference

Management advice
- Comparison of fishery indicators and reference points to provide management advice allowing for uncertainty and risk
- Feedback for control rule management
- Management projection (short term and long-term advice)

Management process

Define management intentions
- Policy goals
- Operational objectives (biological, ecological, economic, social)

Define management standard
- Conceptual reference points (target, limit, precautionary)
- Indicators
- Technical reference points

Set management measures
- Decision control rules defined by reference points and harvest strategies
- Management strategies, comprising one or more control measures
- Monitoring control and surveillance

Figure A1. A framework for fishery assessment and management, using different components to be addressed showing the general key information towards the provision of management advice (after Hoggarth et al. 2006).

APPENDIX 2

Table A2. Summaries of methodologies, data requirements, advantages, and disadvantages of quantitative models used for fisheries stock assessment.

Methodologies	Data requirement	Advantages	Disadvantages
Biomass dynamics model or surplus production model	– Time series of catch and abundance indices	– Simple concept – Minimal data request – Easily extended	– Interactions between growth, recruitment, and mortality ignored – Need contrast data to get meaningful fit – Unable to address age-/size-based issues – Time delay between recruitment and sexual maturity is ignored
Delay difference model	– Time series of catch and abundance indices – Growth and recruitment – Natural mortality	– Explicit consideration of age structure in models – More biological realism and temporal structures	– Parameter confounding common – Some parameters fixed or estimated externally – More data requested
Depletion model—closed system	– Time-series catch and abundance indices, usually taken in short period	– Minimal data requirement – Simple assumption	– Snapshot estimate without account of dynamics – Closed system assumed limit applicability – Fishing intensity must be high enough
Depletion model—open system	– Time series of catch and abundance indices – Recruitment index, or age-structured data	– Useful for discontinuous growth stage – Error can be partitioned into observation and process parts	– More data required – Sensitive to assumption of natural mortality, relative catchability and size- / age-specific recruits
Equilibrium length-based cohort analysis and virtual population analysis	– Length-based catch composition, – Growth model parameters – Natural mortality	– Relatively low data requirement – Convergence of population numbers and fishing mortality if F is high relative to M	– Equilibrium assumption may often be violated, which can produce misleading results
Age-structured model—virtual population analysis	– Time series of catch-at-age data – Assumed M at age – Terminal population of F – Selection assumed fixed in separable VPA	– Age and time structured estimates of numbers and fishing mortality – Convergence of population numbers and F's at age if F is high relative to M	– High data requirement – Catch-at-age data assumed are exact – Assumption regarding M and terminal numbers may not apply
Statistical catch-at-age model	– Time series of catch-at-age data and abundance indices – Assumed M at age	– Age-structured models and able to include extra data – Statistical consideration of error on variables	– Many assumptions – High data and technical knowledge requirement – Parameter confounding may occur if the data do not have contrast
Ecopath with Ecosim	– Structuring full trophic components ranging from primary and secondary producers, to fish, waterfowls and detritus – Time series of age-structured biomass – Species-specific diet and consumption rate – P/B or Z ($=M+F$) – Ecotrophic coefficient	– Improved understanding of ecosystem functioning – Evaluate ecosystem effects of fishing – Explore management policy options – Evaluate effects of environmental changes	– Highly data intensive – Equilibrium taken as the starting point is never a true reflection of reality – Ignore the evidence that feeding habits change in response to depletion of some prey species and environment alteration – Linear relationship between recruitment and consumption is not always true – No direct linkages with abiotic environmental variables included in the model structure

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