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STOCK ASSESSMENT OF ANADROMOUS CHARRS (GENUS *SALVELINUS*) IN THE CENTRAL AND ARCTIC REGION.

by

R. F. Tallman, M. VanGerwen-Toyne, L. Harris, C. Gallagher, T. Carmichael, K. Howland and X. Zhu

Fisheries & Oceans Canada
Freshwater Institute
501 University Crescent
Winnipeg, MB
R3T 2N6

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ABSTRACT

Tallman., R.F, M. VanGerwen-Toyne, L. Harris, C. Gallagher, T. Carmichael, K. Howland and X. Zhu. 2012. Stock assessment of anadromous charrs (genus *Salvelinus*) in the Central and Arctic Region. Can. Manuscr. Rep. Fish. Aquat. Sci. 3007: v + 26 p.

We briefly describe stock assessment for fisheries on charrs (*Salvelinus* spp) with reference to the considerations in the Central and Arctic Region of the Department of Fisheries and Oceans. For reference, we provide simple descriptions of the purpose of stock assessment and fisheries management. For stock assessments, general considerations are that stock assessments must be quantitative, recognize that stocks are dynamic in time and account for uncertainty due to natural processes, measurement error and model error. We discuss model complexity and the importance of cross-comparison in stock assessment to reduce uncertainty in conclusions. Considerations for stock assessment in the Central and Arctic Region are discussed including the unique nature of Arctic fisheries, the biology of the species harvested and the pros and cons of sampling techniques and models for Arctic assessments. We present short descriptions of key fisheries to indicate when advice will be provided and to whom, the stock assessment model that is currently contemplated to be used in the provision of the advice, a description of the parameter(s) that we hope to estimate, the assessment program - i.e. plant sampling, annual collections of catch and effort, mark/recapture, aerial surveys etc., a description of the preferred stock assessment model (if the current model is considered less than ideal) and why it is preferred and the research needed to implement the preferred model.

RÉSUMÉ

Tallman., R.F, M. VanGerwen-Toyne, L. Harris, C. Gallagher, T. Carmichael, K. Howland and X. Zhu. 2012. Stock assessment of anadromous charrs (genus *Salvelinus*) in the Central and Arctic Region. Can. Manuscr. Rep. Fish. Aquat. Sci. 3007: v + 26 p.

Nous décrivons brièvement l’évaluation des stocks pour la gestion d’ombles, en référence aux considérations de la region Centrale et Arctique de Pêches et Océans, Canada. Nous offrons, en tant que référence, des descriptions simples du rôle de l’évaluation des stocks et de la gestion des pêches. Pour l’évaluation des stocks, les considérations générales sont que l’évaluation des stocks se doit d’être quantitative, de reconnaître que les stocks sont dynamiques dans le temps, et qu’il faut prendre en considération l’incertitude liée aux processus naturels, erreurs de mesure et des modèles. Nous discutons de la complexité des modèles et de l’importance d’inter-comparaisons dans l’évaluation des stocks afin de réduire l’incertitude des conclusions. Les considérations concernant l’évaluation des stocks dans la région Centrale et Arctique sont discutées, par exemple la nature unique des pêcheries arctiques, la biologie des espèces récoltées, et les aspects positifs et négatifs des techniques d’échantillonnage et des modèles d’évaluation des stocks arctiques. Nous présentons des descriptions courtes des principales pêcheries indiquant quand et pour qui un avis doit être offert, quel modèle d’évaluation des stocks doit être utilisé pour produire cet avis, une description des paramètres prévus pour l’estimation du modèle, le programme d’évaluation – i.e. échantillonnage des plantes, collectes annuelles de prises et effort, marquage et recapture, études aériennes etc., une description du modèle d’évaluation des stocks souhaité (si le modèle courant est considéré sub-optimal), et la justification du choix du modèle et de la recherche pour son implémentation.

INTRODUCTION

To facilitate the integration of the ecosystem and precautionary approach into fisheries assessment in Canada, the Department of Fisheries and Oceans (DFO) has developed the Sustainable Fisheries Framework (SFF) and Fisheries Renewal scheme (Bouffard 2010) The SFF summarizes DFO's approach to ecosystem based fisheries management which considers the system of stock and fishery as the center and analyzes the impacts of fishing on ecosystem components as well as the impacts of the state of the ecosystem on fisheries through its approach to integrated ocean management . The SFF serves to develop and articulate a series of policies to consider the effects of fisheries on sensitive benthic areas, forage fish and bycatch species (i.e. ecosystem impacts) as well as the precautionary approach policy for management of harvest rate. The sustainability checklist is a central tool in SFF and fisheries renewal that is being used to guide and coordinate the planning process for Science, Fisheries Management and Conservation and Protection (Bouffard 2010). The checklist provides a snapshot of the scientific information available for assessment including ecosystem factors such as bycatch, knowledge of forage species and basic ecosystem components. A gap analysis is done to guide the allocation of future resources to reduce the uncertainty in the system. Several aspects of Canadian policy development surrounding the SFF and Fisheries Renewal scheme are highly relevant to fishery developments in the North (Tallman et al. 2012).

While the sustainability checklist seeks to bring together a unified approach to all stocks and cover all the possible types of information and management systems, each species group and fishery type will need to focus on certain critical aspects of fishery assessment that are specific to their circumstances. For example, for charrs understanding the effect of harvest on the dynamics of the stock must be understood before collecting data on other ecosystem aspects such as the primary productivity in the system. The core of fisheries management remains the precautionary approach which requires scientific advice to support management actions (DF0 2006). Scientific advice will be based on suitable data analyzed using fishery models.

Fisheries management of Arctic and Dolly Varden Charrs (*Salvelinus alpinus* and *S. malma*) in the Central Arctic Region requires an integrated plan of research to provide high quality advice. In practice, all fisheries assessment operates with certain important limitations due to the nature of the problem of making predictions regarding stock sustainability where there is high uncertainty, limited resources for gathering information and a highly temporally dynamic renewable resource such as a fish stock. We will explore why we must consider uncertainty and dynamics and represent outcomes in quantitative terms such as mathematical models. These considerations are exaggerated with charrs in the Canadian Arctic.

The aim of this document is to: 1) provide general guidance and understanding of the principles of stock assessment; 2) classify and describe some of the current methodologies used to gather data and analyze charr fisheries in the Central and Arctic Region. These data gathering methods and analyses will evolve with time as new methodologies are developed. In some cases this will occur as time series are developed so that more precise and informative models can be used in assessment.

Ultimately, it is hoped that with better understanding of the challenges of stock assessment, particularly with northern charrs, that management will have greater clarity regarding scientific assessment methods and resulting advice. This will allow management to use scientific advice more effectively in developing management actions with stakeholders.

Stock assessment in Fisheries Science involves studying the status of a fish stock to understand the dynamics of exploited populations as well as the possible outcomes of different management alternatives. It tells us if the abundance of a stock or fishing mortality is below or above a given target point and by doing so lets us know whether the stock is overexploited or not; it also tells us if a catch level will maintain or change the abundance of the stock.

It should be kept in mind that the science of fisheries stock assessment is challenging. It is somewhat like forestry in that you are attempting to predict sustainability of a population by virtue of its growth, reproductive output and natural mortality patterns in the face of additional mortality imposed by a harvest, except you cannot see the trees and the trees move around.

THE PURPOSE OF STOCK ASSESSMENT IN FISHERIES SCIENCE

The objective of assessment for each stock in the Central and Arctic Region is to provide advice to fisheries management or aboriginal land claim wildlife management boards on the effect of the options for harvest strategies on abundance and other aspects of population dynamics.

Stock assessment makes use of diverse types of information to give managers advice about the status of a fishery and the possible outcomes of management actions (Appendix 1). This includes aspects not only related to the resource abundance such as whether the stock is depleted or close to its maximum biomass, but also in regards to other important aspects of fish population dynamics such as the current levels of mortality and expected levels of future recruitment, or even economically relevant factors such as likely changes in catch per unit effort. As well, in the Central and Arctic Region, for many species the basic model of the life cycle and key vital rates may be poorly described and research is required to understand these aspects in order to develop a quantitative assessment model.

Stock assessment has been defined in many ways, often in terms of its objectives. Sparre and Venema (1992) proposed that the basic purpose of stock assessment is "to provide advice on the optimum exploitation of aquatic living resources". Probably the best modern definition comes from Hilborn and Walters (1992): "Stock assessment involves the use of various statistical and mathematical calculations to make quantitative predictions about the reactions of fish populations to alternative management choices." The last definition is especially relevant because it explicitly says two important things, that *quantitative predictions* are needed in the process and that the objective is to provide *advice* to management *about choices*.

QUANTITATIVE PREDICTIONS, DYNAMICS, AND UNCERTAINTY

Fisheries science has naturally developed into using mathematical and statistical descriptions of these processes. The underlying assumption is that if we can understand how populations respond to different perturbations then we should be able to manage those fisheries according to our chosen objectives (Quinn and Deriso 1999). Ideally, assessments can benefit by having quantitative predictions of subsequent abundance. While in data limited assessments it may be all that can be done to indicate that a fishery resource is "abundant" or "overfished" without further detail. A more useful approach for shaping management decisions is to express the level of abundance or depletion as a quantity. For example, "the fishable stock is at 30% of its original virgin biomass". However, As Dempson (DFO pers. comm.) points out we know from the limited information on charr abundance in rivers, this can vary dramatically from one year to another and for reasons that we may not entirely understand. Thus, predictions in situations such as this could be fraught with error.

Equally important, stock assessment should be able to make *quantitative predictions* of the outcomes of different management regulations, such as how likely it is that an overexploited stock will recover to a target level in a specified time-frame under different catch or effort quotas. This is why modern stock assessment work is by necessity a *quantitative* discipline.

One of the most important roles of stock assessment is to understand the *dynamics* of fisheries. This follows because biological resources, the environment and harvesters are changing entities; they are dynamic, not static. Furthermore, fisheries will necessarily respond dynamically over time to management actions as well as to external factors such as environmental forces. Understanding all of these dynamics in order to make good predictions is the ultimate role of stock assessment. For example, variations in the harvest yield from a fishery arise through the combined effects of variations in effort, in recruitment, and in natural mortality and growth. Understanding which aspects of production are driving a fishery is the primary task of a stock assessment (Haddon 2001). The difficulty for the fisheries scientist is to decide whether a particular effort or catch level is sustainable for a given future time. This can be made especially difficult by the major sources of productivity varying naturally through time, such as time-varying recruitment.

Uncertainty is an intrinsic characteristic of stock assessment. First, natural systems have a lot of random variability that translates into uncertainty and which can be due to variations in fish growth (Fargo and Kronlund, 2000) and reproductive output, as well as to environmental effects (abiotic and biotic) on biological and ecological processes (Parsons et al., 1998). Other sources of uncertainty are the variations in the behavior of fishing fleets and gear, the errors and biases in data collection, and the often incomplete or less than ideal quality of the data sets available for performing stock assessment. Uncertainty also arises from the choice of model used for stock assessment; some models are better suited to capturing the underlying dynamics of a given resource than others but it is often impossible to determine which model is more correct for a particular stock. Considering all of the above, it is not surprising to find that the results of fisheries stock assessment are never precise metrics of biomass or mortality, but are in reality estimates that contain a certain degree of uncertainty and doubt. Dealing with uncertainty, acknowledging it and incorporating it into the decision-making process is something extremely important but this has only recently begun to be put into practice. Further reading on the need to embrace uncertainty and new methods to achieve this can be found in Punt and Hilborn (1997), Hilborn and Lierman (1998), McAllister et al. (1999), and Patterson et al. (2001).

MODEL COMPLEXITY AND THE IMPORTANCE OF CROSS-COMPARISON IN STOCK ASSESSMENT

Predictions are always based on the use of a model, whether the model is explicit or implicit. Even the simplest prediction about what will happen to a stock if effort is increased implies a set of assumptions or conceptual model. Formally, a model is just a representation or abstraction of a given system or process, which in the case of quantitative disciplines such as fisheries stock assessment takes the form of equations or sets of equations. The type and complexity of models depends on the field of research and the particular problem to be analyzed. In terms of Holling's (1978) classification, problems in population modeling generally lie in the area of low quality/quantity of relevant data. However, it is important to emphasize that the complexity of a model (understood as the number of variables included) is not always directly related to its performance and usefulness.

Models available for stock assessment range from the simple holistic models that intend to capture all biological processes in a simple equation such as surplus production models, to the detailed and elaborate age-structured, spatially-structured, multi-stock or even multi-species models that include several sets of equations and which intend to give a more realistic representation of fish population dynamics. However, while intuition tells us that complicated and detailed models should be better than simple ones because they more accurately represent "reality," research has shown that simple models can often perform better because they require fewer parameters to be estimated, and very frequently the uncertainty surrounding the estimation of some of these parameters only reduces the ability of models to produce useful information (Ludwig and Walters, 1985; 1989; Ludwig et al., 1988). Readers are encouraged to investigate this topic in more detail by referring to chapter 3 of Hilborn and Walters (1992) for an excellent discussion and further references on this topic. Starfield and Bleloch (1986) give an excellent accessible introduction to model building.

Perhaps the most important message that readers should take home is that while analyzing a fishery, it is advisable to avoid using a single “best” method. The idea that any given model is the best and only model to be used for fisheries stock assessment is risky since all models rely on certain assumptions being met. Instead, it is best where possible to employ a carefully chosen suite of methods—which are appropriate to the available data—and if possible including both simple and complex models. This will allow the cross-comparison of alternative results which will help detect coincidences and patterns as well as inconsistencies, often highlighting errors in data or guiding the acquisition of additional key information through additional research. In a similar fashion, conflicting results using the same model with different data sets should be carefully analyzed for possible biases in the data. Stock-assessment scientists should ask themselves why there might be differences in predictions about the status of the stock or about the outcomes of different management alternatives across models. An objective picture of the situation can only be obtained when we question the conclusions from one analysis with those of a different one and critically use the different results to gauge our conclusions and to identify which pieces of the puzzle are missing. Only this complete process will allow us to improve the data and methods, and therefore increase our capacity to perform better assessments in the future. The same principle applies also to different data sets that could be available to perform a particular stock assessment. Sound stock assessment is achieved only through healthy cross-comparison and exhaustive questioning of the results of alternative models and data sets.

Finally, it should be mentioned that the complex topic of model choice in stock assessment can nowadays be dealt with through the use of Bayesian approaches (Hammond and O’Brien, 2001) and decision analysis techniques (Punt and Hilborn, 1997; McAllister and Kirkwood, 1998). These methods offer quantitative ways to choose between different models and management options taking into account the uncertainty involved, and are the best way to make management decisions based both on the outcomes of the stock assessment and the probabilities of success of the proposed management options.

CONSIDERATIONS FOR STOCK ASSESSMENT IN THE CENTRAL AND ARCTIC (C&A) REGION

The Central and Arctic Region has some unusual fisheries relative to most other regions in Canada and for fishery organizations in the northern hemisphere. Due to the profound influence of aboriginal land claims in the region many fisheries are important solely for their subsistence value. Some are mixed fisheries with part of their value being for traditional subsistence and part for commercial purposes. Entry and gears used are often determined solely by what a single individual is capable of handling. Consequently, vessels are small, independent and difficult to track. Only a small number fit the pattern of most northern hemisphere fisheries under stock assessment and management of a modern industrial fishery. Thus, standardized methods of data collection worked out in other fisheries elsewhere may not apply. Regardless, the principles described above of using quantitative prediction while considering dynamics and uncertainty are still critical. Where possible the comparison of results from a variety of modeling approaches is still the best practice.

PRACTICAL APPROACHES TO DATA GATHERING AND MODELING

There is always an equation, either explicitly or implicitly that must be involved when developing data gathering approaches – in essence it computes how great an increase in accuracy and precision in our quantitative assessments will be attained per investment of time and money in data collection. Therefore, adequate thought on the type of model and data collection that is optimal for individual stocks must be considered before work begins. Commercial fisheries can utilize fishery-dependent data as well as fishery-independent data (research surveys and point estimates). Subsistence fisheries can utilize fishery-independent data (research surveys and point estimates) as well as harvest monitoring data. Each of these categories is described below. Figure 1 is a representation of a decision tree of data collection under the above considerations that covers the practices currently used by Central and Arctic.

FISHERY DEPENDENT DATA

Fishery dependent data can be collected from **small or large scale commercial fisheries**, produces a time-series of data which can project into the future, has a low relative cost, but a potentially high bias. This type of data monitors trends in the harvested stock (the catch), not the whole population.

With commercial fisheries, the harvesters bring the catch to a central point such as a fish processing plant to sell. Therefore, it is a cheap and convenient method to collect fishery-dependent data. The catch is the product of fishing mortality and abundance in situ, changes in catch over time may reflect trends of fishing mortality, abundance, or both (Quinn and Deriso 1999). Regarding fishing mortality, it can be separated into quantities of fishing effort and gear-specific catchability coefficient, a measure of fishing efficiency. In addition to fishing effort concerns, biological observation through fish plant sampling is also a necessary approach to monitoring commercially-fished population attributes to the fishery-dependent survey.

Catch and Effort

Catch can be relatively easily and cheaply obtained through summation of purchase slip information. The challenge in catch sampling is to make sure that there are systems to connect it to the biological sampling of the fishery in order to get a more precise picture.

Similarly effort can usually be obtained using a logbook system from the commercial harvesters. Fishing effort may be measured by counting the numbers of vessels, fishers, time of hours, days, and months, hooks, towing hours of trawls, sets of nets, length and mesh sizes of net, or other measurable variables related to fishing activities. However, the north presents special challenges as the harvesters have small operations and thus less familiarity to filling out forms, and may be unable to translate into English.

With charrs a further complication arises in that most stocks that are commercially fished are also harvested for subsistence purposes. Obtaining catch and effort information from these stocks is a challenge.

The collection of catch and effort data is the responsibility of Fisheries Management.

CPUE data can be used to monitor trends in the catch and thus infer some trend in the stock; however, if the stock is harvested during periods of congregation, the CPUE may not show a decline until the stock is severely depleted. Coupling CPUE with information on biological characteristics (which can be monitored in more detail) can provide a more complete assessment of stock status.

Biological Sampling (from a fish plant)

Biological sampling of fish processed in a central fish plant provides an economical way of determining the biological characteristics of the catch; and in the absence of research surveys is an indication of the state of the stock. Coupled with a good method of determining age and a time series of data, estimates of growth and recruitment can be made using modeling techniques such as cohort analysis. These statistics (and others) are important as fish stocks vary strikingly in their productivities and early detection of changes in the stock can be monitored. Thus, harvest rates can be adjusted more precisely with this information. Ideally, harvest rates should vary with time and with the basic demographic characteristics of the stock. Otherwise, advice will likely be overly cautious under the precautionary principle.

Fishery Types

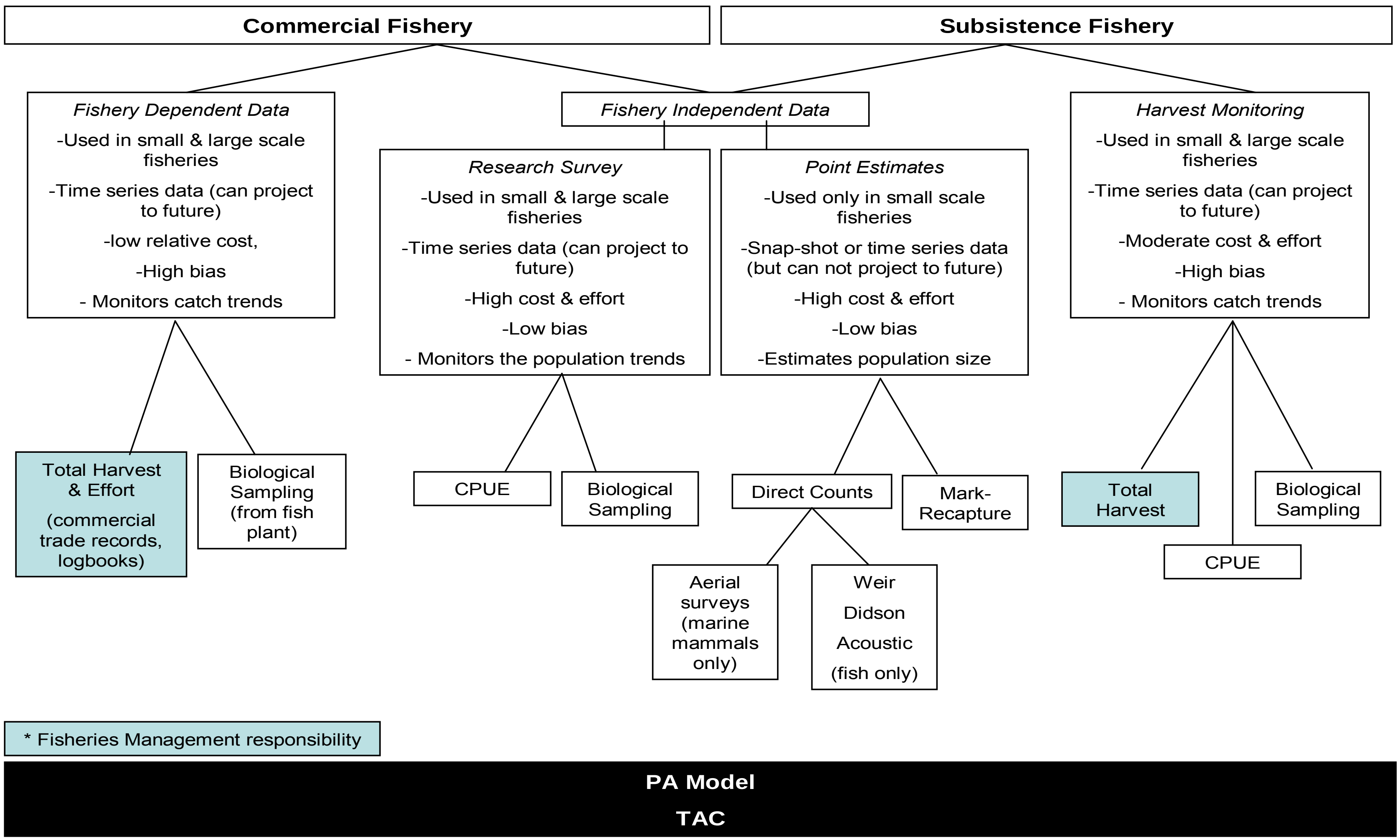


Figure 1. Heirarchal decision tree for fishery sampling for stock assessment.

FISHERY INDEPENDENT DATA

There are two main types of fishery independent data used by Central & Arctic Science; research surveys (CPUE and biological sampling) and point estimates (population size).

Research Surveys

Research surveys can be used in **large or small scale, commercial or subsistence fisheries**. They produce a time-series of data that can be used to project into the future. They have a high cost, but low bias. Contrary to the fishery-dependent data, research surveys monitor the trend of the population (not just the commercial catch).

Research surveys randomly sample a population using standard gear-based methods which remain consistent through time. While these surveys are an expensive method of determining stock status, they provide unbiased results. That is, these studies are designed to sample the population randomly. Conversely, all fishery-dependent statistics (catch, effort, biological samples) are potentially biased because the harvesters are not in the business of randomly sampling to determine stock size; their goals are to find the highest concentrations of fish and exploit them with the minimum effort. Thus, areas with few fish are not sampled and a straight “bumping up” of the totals will likely result in an over-estimate of the abundance of the fish. As well, the harvesters will likely change their behavior and the composition (and hence the fishing power) of the fleet will change with time. Much of the problems in the Canadian East Coast fishery have been caused by an overreliance on commercial fishery statistics. Furthermore, commercial catches are size biased whether taken with gillnet or trawl. Mesh size regulations (appropriate to preserve recruits) will mean that samples taken from the commercial catch are automatically biased. Research surveys can be designed for consistency and statistical validity which make for much more reliable estimates. As well, their results can be used to compare to the outcomes from commercial sampling. If trends are going in the same direction one has much confidence in the assessment of stock status (and vice versa).

Also, in commercial fisheries, the catch is limited to a specific gear type (i.e mesh size) which results in only a portion of the population being represented in fishery-dependent collections. Research surveys have the option to collect data using multiple gear types (i.e multi-mesh gillnets) and therefore collect information on the broader population (i.e juveniles). The more detailed the dataset can be, the more options there are for analyses and the more robust the assessment will be.

The weakness of research surveys is that since they are expensive for governments, they cannot do as many sampling attempts as the commercial operations. Commercial fisheries may take three to four orders of magnitude more samples (eg. 100 versus 100000 sets). Thus, the statistical power of research survey data may be a concern. However, quantity does not necessarily increase accuracy and discounting research surveys has repeatedly led to the failure of fishery management. The most spectacular example of this is the collapse of the Atlantic cod stocks on the Atlantic coast. The collapse was predicted by research survey data far before fisheries management took action. Unfortunately, both Science and Management clung to the belief that the fishery dependent data provided an unbiased indication of stock status. Catch rates remained high while the stock collapsed.

It should be noted that time series of both types of data need to span a sufficient number of years to provide a proper view of the situation. Please refer to Toyne and Tallman (2010) for a discussion of this topic.

Research survey CPUE data can be used to monitor trends in the population; however, coupling CPUE with information on biological characteristics can provide a more complete assessment of stock status.

Point Estimates

Point estimates are similar to research surveys in that they can have a high cost and effort, and low bias. However, they differ in important ways; point estimates are normally **only used in small scale commercial or subsistence fisheries**, and produce snap-shot results which can not project into the future. The studies do not monitor the population or stock, but provide an estimate of population size for a discreet period of time. However, if point estimates are performed regularly, they can appear to comprise a time-series of data, but ,at best, will be limited in their usefulness for prediction because the estimates produced are always historic and provide no information of what might be expected in the future (i.e there is no cohort that can be traced through time). Point estimate studies can be split into two types of data collections; mark-recapture and direct counts.

Mark-Recapture Experiments:

Mark-Recapture experiments can be used to get a point estimate of the stock size in the past. Thus, they are appealing because they require the minimum mathematical treatment to obtain an estimate. However, they also have some serious assumptions that probability of re-capture is the same for marked and non-marked fish and that sampling coverage is complete and unbiased. For example, assumptions regarding tag loss, recruitment patterns and differential likelihood of capture of marked and unmarked fish must be considered carefully. The difficulty in meeting these assumptions may result in an over-estimate of stock size.

Unlike the time series methods with fishery-dependent surveys and research surveys, a mark-recapture point estimate cannot predict anything about the future of the stock. Thus, we can learn that our harvest level was too high or low in the past but it does not account for changing stock dynamics. Mark-recapture estimates (ideally with several other time separated point estimates) is a good check on our other methods of estimation and so coupled with demographic and catch-effort survey time series information we can use it to ground truth our assumptions in other models.

Mark-Recapture experiments may be more attractive in small subsistence operations such as the Rat River but the caveats above still apply.

Direct Counts (Visual):

Visual counts are typically used for marine mammals and can occasionally be used for migrating fish if the water clarity is high and remains consistent.

Weir:

Weirs are effective when the system is of reasonable size, does not have large freshets that can destroy the weir and all of the population or some set proportion must pass through the weir. These estimation methods are extremely labor intensive and must occur before ,during and after the run of fish to be effective. Provided all of the conditions are met weirs, can provide the most detailed information of any technique as the entire population is available to be sampled. Unfortunately, the over-wintering behaviour of Arctic Charr may mean that an unknown percentage of the population migrated into another system for the winter and the assumptions of the method are not met.

Hydro-acoustic techniques (Didson sonar):

Hydro-acoustic techniques offer the advantage of generating large amounts of potentially comprehensive data (looking at the whole population). Heretofore analysis has been extremely complex and the failure of the 20 year program within the region on hydro-acoustics to provide a single piece of stock assessment advice should be noted. However, the Didson sonar is a revolutionary advancement that has been used effectively in Alaska for assessment of migratory salmonids. The streams of the western Arctic seem ideal situations to use this technique. However, like a weir a Didson sonar is most effective if it can function before, during and after the run and thus requires large human resource to ensure proper functioning.

Density estimation (visual marine mammals):

Sampling for marine mammals really falls into a different category altogether since they can be at least partially seen by researchers and harvesters, they have long complex lives, their growth is determinant compared to fishes (not as much variability between populations), they are harvested in a completely different manner and scientists cannot sample the same numbers that scientists working on fish and invertebrates can use. The sampling techniques and analyses have much more in common with large terrestrial wildlife assessments except that there is generally a problem similar to that of working with fish populations in that they disappear for periods of time below the water surface.

Regardless, one advantage is that they can be estimated by direct observation (visual counts). These methods have many assumptions about things going on when the marine mammals are not in view (both below the waves and at other times of the year) and thus much research into their biology is required.

HARVEST MONITORING

Harvest monitoring of subsistence fisheries are not as convenient as fishery-dependent data collections because the harvesters have little motivation to provide information and the catch is dispersed widely. The initial challenge with subsistence fisheries is that you have no controlled record of the catch through a central point such as a commercial fish processing plant.

The use of catch monitors, harvesters selected to record their catch and gather statistics (such as effort) and samples for analysis, is only an alternative when there is no central point such as a fish processing plant to gather information. The harvesters can extend the sampling effort into classes of fish not normally harvested (by using small mesh nets for example). The technique relies heavily on the monitors being consistent, appropriately educated or trained and reliable. The statistical concerns fall somewhere between those of commercial sampling and fishery independent sampling described above. In systems such as the Rat River Dolly Varden it can be effective as the community of harvesters are small and the fish must migrate up a discreet stream on the way to spawn or overwinter.

AGE DETERMINATION

The understanding of the dynamics of a stock is generally based on knowledge of the balance between growth and reproductive effort and mortality. Fisheries science divides mortality into that caused by fishing and that from natural causes. All of the work that involves understanding mortality, reproductive effort and growth is underpinned by accurate age determination. Age can be determined in temperate and Arctic fishes by counting the rings laid down on hard body parts such as scales, otoliths and fin rays. The reliability of the age determination requires validation usually by specialized mark and recapture studies.

COMPARISON OF TIME SERIES AND POINT ESTIMATE DATA COLLECTIONS

There are pros and cons to both time series and point estimate approaches to collecting data for stock assessment purposes (Table 1)

Time Series Data Collection

Time series data is produced in fishery dependent, research survey, and harvest monitoring data collection studies and are useful in both small and large scale commercial and subsistence fisheries. The positive feature of time series data collections is just that; it is collected over a period of time. Fishery-dependent and harvest monitoring record trends in the harvested stock and research surveys record trends in the broader population, but all produce a series of data that can be monitored (CPUE and biological characteristics). The ability to monitor through time in this manner improves the strength of the results because it allows for variation to be incorporated into the assessment. Variation can be caused by natural, environmental or anthropogenic sources, but result in a non-static population dynamic. Time series data can also be used to predict future events in the stock. For example, if age frequency distribution is monitored regularly and a strong year class enters the population, it can be expected that CPUE will increase when that age cohort reaches harvestable size.

Conversely, if some environmental condition causes poor recruitment in a year and it is tracked though time, it can be predicted that CPUE will decrease when that cohort reaches harvestable size. Being able to monitor and predict these types of things will provide more information to understanding why the stock is in the state that it is. It will also provide valuable information to resource managers who may be able to control harvest accordingly. The only truly negative feature of time series data is that it does take time, and time costs money.

Point Estimate Data Collection

Point estimate is an alternate approach that is useful in both commercial and subsistence fisheries, but normally only in small scale fisheries. Point estimate data collections include mark-recapture and direct count (weir, Didson, acoustic, visual surveys), all of which aim for the same thing; to estimate stock size/density. The positive feature of these approaches is that they can be performed independently in a relatively short period of time and thus produce a result much quicker than a time series approach. Also, this approach provides a way to collect information on the stock without lethal sampling; this is of utmost importance in situations where stock status is thought to be of concern, However, the result from a point estimate only provides information on what the population size/density was at a discreet point in time. The results provide no information of the amount of variability in the stock and have no predictive powers for the future. From this, resource managers must make decisions about the future of the stock based on historic information alone with no information on what the future might hold. A decision is made post-hoc rather than pro-actively. Because of this, management decisions made solely on point estimates are not as powerful as those made using information from time series data. That said, if point estimates are repeated regularly, the can take the form of a modified time series and allow for some incorporation of variation, but predictive powers remain low and management decisions are still made post-hoc.

The ideal situation for any fishery is one which involves multiple approaches; monitoring CPUE/harvest and biological characteristics through time, while periodically performing point estimates. To do all of these simultaneously would be incredibly expensive in both time and effort and is therefore rarely accomplished in Central & Arctic where there are several different priority stocks. Therefore, scientists are forced to look at each stock uniquely and decide which approach is 1) practical and 2) would provide the most valuable information for resource managers.

MODELS AND OUTPUTS

Index Based Assessment

The majority of Central and Arctic stocks are assessed at the present time using an index of abundance in the absence of a full population dynamics model. An index of abundance is something which does not tell one the actual population size but is thought to co-vary with it; for example, CPUE,width of the age structure (frequency) histogram, average growth rate, or average size.

Model Based Assessment

Each of these techniques provide an outcome for stock assessment (Table 2.) The ultimate goal is to provide advice on harvest strategies for fisheries management and land claim management boards.

CENTRAL AND ARCTIC PRIORITY STOCK PLAN

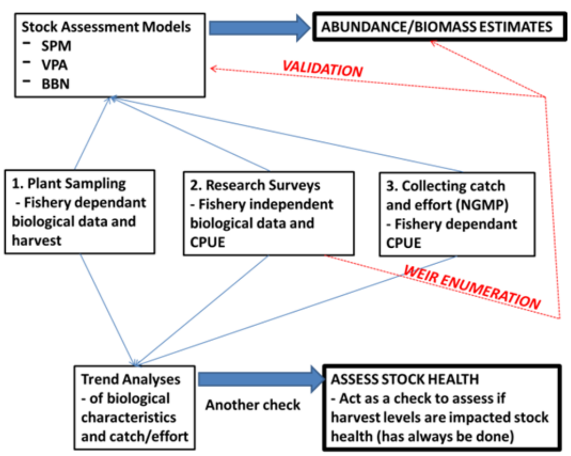
The following stocks are listed as C&A prioirity stocks: 1. Cumberland Sound Charr; 2. Cambridge Bay Charr; 3. Hornaday River Charr; 4. North Slope Dolly Varden .

Sample sizes and sources of data for priority stocks are listed in Table 3.

As a case study in the development of a science plan the Cambridge Bay stock assessment plan will be described in terms of 1) when advice will be provided and to whom; 2) the stock assessment model that is currently contemplated to be used in the provision of the advice; 3) a description of the parameter(s) that we hope to estimate; 4) the assessment program - i.e. plant sampling, annual collections of catch and effort, fishery independent sampling, etc; 5) a description of the preferred stock assessment mode (if the current model is considered less than ideal) and why it is preferred; 6) the research needed to implement the preferred model

CAMBRIDGE BAY CHARR (EXAMPLE)

Three types of data are needed for optimal stock assessment including: (1) plant sampling (fishery dependent) facilitating the collection of biological and harvest data from the fishery, (2) stock assessment research surveys (fishery independent) facilitating the collection of biological and catch and effort information independent of the commercial fishery and (3) the collection of commercial catch and effort data (e.g., through the Nunavut General Monitoring Plan (NGMP)). These data can then be incorporated into stock assessment models to provide estimates of biomass or abundance for the fishery or can be used in traditional trend analyses to assess the health of the harvested stock. Note, periodically weir enumerations can be used to provide population abundance and to validate estimates provided through modeling exercises (Figure 2).



SPM = Surplus Production Model, VPA = Virtual Population Analysis, BBN = Bayesian Belief Network, NGMP=Nunavut Government Monitoring Program, CPUE=catch per unit effort.

Figure 2. Conceptual model of stock assessment research objectives for Cambridge Bay Arctic Charr..

1) Timeline and Recipient for Advice

A regional advisory process (RAP) is typically conducted every five (5) years, or when specific requests for advice are needed, as a means to relay technical knowledge and advice to management and regulatory agencies within DFO and elsewhere. These requests for advice on the conservation requirements for Cambridge Bay Arctic Charr are typically led by the Stock Assessment section of Fisheries and Oceans Canada (DFO) Science and include the involvement of DFO Fisheries Management (FM), Nunavut Wildlife Management Board, Government of Nunavut, Kitikmeot Foods and the Ekaluktutiak Hunters and Trappers Organization (EHTO). All stakeholders are informed of, and engaged in, the assessment process. The advice resulting from the RAP is provided to FM with the aim identifying upper and lower limit reference points used to set and regulate commercial harvest quotas to ensure the sustainability of the stock. Additionally, the advice will be used for the development of an Integrated Fisheries Management Plan (IFMP) for Arctic Charr in the region, therefore considering all types of harvest. All requests for Science advice (eg. new assessments, updated assessments and special responses) are sent to the Science Advisory Coordinator.

2) Stock assessment model

A Precautionary Approach (PA) to management was followed using information provided by a surplus production model for the collective area of Cambridge Bay using pooled fishery dependent data (i.e., length, weight and age of commercially harvested Charr collected as part of the plant sampling program) from 1960-2008. Weight-based CPUE is an index of biomass (B_t); it is described by a functional relationship between the exploitation rate and fishable biomass. The exploitation rate can be further expressed by the product of the invested fishing effort at time *t*, E_t, and its catchability coefficient, q,

$$C_t = qE_tB_t \qquad (1)$$

$$I_t = qB_t \qquad (2)$$

where C_t and I_t are the reported harvest and CPUE at time *t*, respectively. The catchability coefficient specifies the retained proportion of the species captured by one unit of gear-specific effort (Hilborn and Walters 1992, Quinn and Deriso 1999).

Biomass dynamics model:

When only harvest and relative abundance or biomass data are available, surplus production models simplistically integrate the quantities of growth, recruitment, and natural mortality into a comprehensive part of surplus production. Dynamic changes in instantaneous biomass can be balanced between surplus production and harvest removals, which is commonly represented by the Graham-Schaefer logistic surplus production model (LSPM) (Schaefer 1957, Hilborn and Walters 1992, McAllister and Kirkwood 1998**)**

$$\frac{dB}{dt} = \mathrm{r}B(1-\frac{B}{\mathrm{K}}) - \mathrm{q}EB \qquad (3)$$

and the generalized surplus production model (GSPM) (Pella and Tomlinson 1969; Fletcher 1978),

$$\frac{dB}{dt} = \frac{\mathrm{r}}{z}B(1-(\frac{B}{\mathrm{K}})^{z}) - \mathrm{q}EB \qquad (4)$$

where, parameters r and K are the intrinsic population growth rate and virgin biomass or carrying capacity, respectively. An additional parameter, *z*, refers to a measure of production density dependence (Pella and Tomlinson 1969). When z=1, equation (4) is a logistic function of equation (3) (Polacheck et al. 1993). Otherwise equation (4) is a skew-asymmetric function with a shape parameter *z* (Prager 2002, Barker and Sibly 2008).

To reduce parameter confounding, such as between B_t and K (Meyer and Millar 1999a, b, Millar and Meyer 2000), the GSPM was re-parameterized using relative biomass (P_t=B_t/K) to express annual biomass proportional to K,

$$P_{t+1} = P_t + \mathrm{r}P_t(1-P_t^{z}) - \frac{C_t}{\mathrm{K}} \qquad (5)$$

Then, a grid of alternative parameters for precautionary management strategies can be derived, including maximum surplus production (MSP=(B_{MSP})×(F_{MSP})), fishing mortality at maximum surplus production (F_{MSP}=r/((z+1)$^{(1/z)}$), biomass at maximum surplus production (B_{MSP}=K/((z+1)$^{(1/z)}$), the relative fishing mortality rate (F/F_{MSP}), and relative biomass (B/B_{MSP}) at sampling series (Quinn and Deriso 1999).

Hierarchical Bayesian model

A hierarchical Bayesian paradigm can explicitly account for a smooth ‘signal fit’ from noisy data and pursue a plausible representation of nonlinear covariates in both the population dynamics model and observations (Millar and Meyer 2000, Buckland et al. 2004). Combined with relevant uncertainties for errors with respect to parameter estimation, two interactive processes are involved in model performance: *i*) a state process of underlying stochasticity in population dynamics is an unobserved vector, representing Arctic Charr population biomass, *ii*) a space process of data collection described by an observable vector, biomass-based CPUE from index surveys or covariate prediction, is a function of the unobserved state process (Francis and Shotton 1997, Meyer and Millar 1999a, Buckland et al. 2004, Thomas et al. 2005). Conceptually, the state process error also indicates uncertainty accounted for environmental noise or natural variability, assuming the observations are made without errors and all of the errors occur as a result of changes in population size (Polacheck et al. 1993, Bousquet et al. 2008). The observation process error estimator is made by assuming the population dynamics are deterministic and that all of the errors occur in the sampling procedures (Polacheck et al. 1993). In fact, these analytical errors may account for differences between expected and observed CPUE, and between model-derived and true biomass quantities.

As such, these stochastic forms for relative biomass (P_t) and CPUE (I_t) are obviously represented by a skewed and multiplicative lognormal distribution (Limpert et al. 2001) for t=1960,…2008,

$$\log(P_t) = \log(\hat{P}_t) + \mu_t \qquad (6)$$

$$LP_t = \frac{1}{\sqrt{2\pi}\sigma P_t}\exp(-\frac{(\log(P_t)-\log(\hat{P}_t))^2}{2\sigma^2}) \qquad (7)$$

$$\log(I_t) = \log(\hat{I}_t) + \upsilon_t \qquad (8)$$

$$LI_t = \frac{1}{\sqrt{2\pi}\tau I_t}\exp(-\frac{(\log(I_t)-\log(\hat{I}_t))^2}{2\tau^2}) \qquad (9)$$

Where μ_t and v_t are independent and identically-distributed (iid) normal probabilities of $N(0,\sigma^2)$

and $N(0,\tau^2)$, respectively. LP_t and LI_t are likelihoods for P_t and I_t, given $\hat{P}_t$ and $\hat{I}_t$, respectively.

Priors and posterior probability distributions

As was indicated earlier, a Bayesian-based GSPM (eq. 4) is determined by the conditional state process posterior pdf (eq. 5), the state process pdf (eq. 6-7), the observation process pdf (eq. 8-9) with an unobservable parameter set, $\Theta=\{K, r, q, z, \sigma^2, \tau^2\}$, and relevant priors. Overall, there are six model parameters in Θ, 49 unknown and derived state time series of relative biomass P_t, and predicted CPUE (I_t) where t = 1960,…2008.

Prior to model implementation, two categories of prior pdfs need to be specified, assuming the parameters in Θ are independent *a priori* (Meyer and Millar 1999a, b, Millar and Meyer 2000): informative and non-informative. Informative priors are primarily determined by intensive assessment of the parameter choices and expert judgment using knowledge-based information (Walters and Ludwig 1994, Punt and Hilborn 1997, McAllister and Kirkwood 1998). Non-informative priors refer to prior probability distributions created without any information or without favoring one parameter value over another (Carlin and Louis 2009). The resulting inferences are completely objective. In this study, we applied both categories of priors when specifying prior pdfs for model parameters, especially for estimates of K and r.

To define non-informative uniform pdfs for K and r, because of the scarcity of sufficient documentation, we estimated the bound quantities for K used in the models, combined with spatially-specific harvest history. Since 1960, total harvested biomass in the commercial Arctic Charr fisheries ranged from 5.77 metric tonnes in 1962 to 67.94 metric tonnes in 1978. The censored intervals for Arctic Charr biomass, uniform pdf U(100, 1500), were subjectively selected by incorporating historical harvest records with an approximate factor of twenty times. Model parameter r is interchangeable with similar biological characteristics among species and stocks (Hilborn and Walters 2002, Sibly and Hone 2002). Accordingly, we described parameter r as a randomized variation of the uniform distribution probability U(0.01,1.05). For catchability coefficient q, a non-informative flat normal pdf was initiated with a bound of (10^{-6}, 1.0). Similarly, the shape parameter z was specified by a non-informative flat normal pdf prior with a bound of (0.1, 10).

$$\begin{aligned} &\mathrm{K} \sim \mathrm{uniform}(100,1500) \\ &\mathrm{K} \sim \text{log-normal}(\mu_{\mathrm{K}},\tau_{\mathrm{K}})\,\mathrm{I}(100,1500) \\ &\mathrm{r} \sim \mathrm{uniform}(0.01,1.05) \\ &\mathrm{r} \sim \text{log-normal}(\mu_{\mathrm{r}},\tau_{\mathrm{r}})\,\mathrm{I}(0.01,1.05) \\ &\mathrm{z} \sim \mathrm{normal}(0.0,10^{-6})\,\mathrm{I}(0.1,15) \\ &\mathrm{q} \sim \mathrm{normal}(0.0,10^{-6})\,\mathrm{I}(10^{-6},1) \end{aligned} \qquad (10)$$

where μ_K and μ_r are the prior means for parameters K and r, respectively, and τ_K and τ_r are the corresponding prior precisions for parameters K and r, which are known as hyper parameters (Harley and Myers 2001). To incorporate time-varying effects, lognormal pdfs were employed to express random walk q priors (Wilberg et al. 2010),

$$q_{t+1} = \sqrt{\frac{\tau_q}{2\pi}}\frac{1}{q}\exp(-\frac{\tau_q}{2}(\log q - q_t)^2) \qquad (11)$$

Here, q_{t+1} and q_t were timely changes in q in year t+1 and t, and the precision term τ_q was specified by a non-informative prior as an inverse uniform pdf U(0.01,1.0).

To account for vaguely estimated quantities for subsistence use, the following formula is used for total harvest,

Total harvest=Commercial X (1+*HRR*) (12)

Here *HRR*, harvest report rate, is considered as the proportion of fisheries for subsistence use. Combined with a Nunavut wildlife harvest study (Priest and Usher 2004), an informative prior of 50% commercial harvest was applied to the normal pdf prior with the bound of (0.01,1.05),

$\mathrm{HRR} \sim \mathrm{normal}(0.0,10^{-6})\mathrm{I}(0.01,1.05)$ (13)

In a scenario associated with a half-Cauchy hyper prior distribution, the estimation is obtained as the ratio of a normal and square root of a X^2 distribution with one degree of freedom (Gelman 2006).

Process uncertainty variance, σ^2, was considered when modeling uncertainties of recruitment variability and environmental noise (Millar and Meyer 2000, Bousquet et al. 2008). Observation uncertainty variance, τ^2, was linked to uncertainties in data collection during sampling for the abundance index and fisheries statistics (Walters 1998; Meyer and Millar 1999b). Under the assumption of deterministic population dynamics, a reasonable range for observation error was 0.1 to 0.3 on the basis of a coefficient of variation (CV) on abundance-based CPUE (Hilborn and Liermann 1998, Walters 1998). A vague Gelman's prior, an inverse uniform pdf, U(0.01,100), was applied to σ^2 and τ^2 in the overall models (Carlin and Louis 2009

Stochastic simulation and model evaluation

Incorporated with a Markov Chain Monte Carlo (MCMC) simulation for a full range of uncertainties, Metropolis-Hastings within Gibbs sampling was explored for Bayesian nonlinear GSPM, defined in equations (3), (4), and (5). Under the computational framework of WinBUGS (http://www.mrc-bsu.cam.ac.uk/bugs/welcome.shtml), we adopted three groups of model scenarios: *i*) a general model pursuit using non-informative uniform pdfs for constants *K* and *r* (model UKR), *ii*) comparative models by applying lognormal and half-Cauchy lognormal pdfs for constants *K* and *r* (LNKR and HCLNKR), and *iii*) incorporation of time-varying effects on the catchability coefficient q (LNKRWQ). For each model scenario, we used MCMC to run two-chains of Gibb's sampling with 3,250,000 iterations each. Following a burnin period of 650,000 iterations, a total of 8,000 samples were obtained by sampling in a thin of the 325th iteration to avoid highly auto-correlated neighboring values (Spiegelhalter et al. 2002). Model convergence and stationarity were diagnosed using the R-based evaluation package CODA (Convergence Diagnosis and Output Analysis) for Gibbs sampling output, version 0.13-5 (Plummer et al. 2006, Ntzoufras 2009). Deviance information criterion (DIC) with *a priori* parsimonious predictive Bayesian statistics was employed to measure the relative goodness of fit of the structural models, which profile the complexity and instability resulting from particular parameterization (Burnham and Anderson 1998, McAllister and Kirkwood 1998, Millar and Meyer 2000, Spiegelhalter et al. 2002, Carlin and Louis 2009).

Biomass was calculated for the upper and lower harvest reference points. To assign individual river biomass from the overall total, a river specific proportion was calculated from long term proportional contributions to the entire Cambridge Bay harvest. It is unknown at this point whether a specific quota can be determined for each individual river system. At least 5 years of data collection for catch and effort (i.e., catch-per-unit-effort, CPUE), and abundance would be required at each commercial river system to run surplus production models for each. Measures to collect this information are currently underway. Prior to this, general trends in biological information (i.e., length, weight and age) were assessed for each stock to evaluate the sustainability of current harvests. The assessment of biological trends, in addition to monitoring age structure and recruitment (e.g., number of spawners and fecundity) remains an important tool for commercial Arctic Charr assessments.

In addition to evaluating stock health through assessments of fisheries dependent data (i.e., that collected through the plant sampling program) recent stock assessment surveys aimed at collecting fishery independent data have been initiated. These data will better reflect the population as a whole in terms of length, weight and age structure and such data can be assessed for trends as described above or be put towards refining and improving the accuracy of surplus production biomass models described above. The effectiveness of such models should increase with increasing resolution and accuracy of population demographics of commercially harvested Arctic Charr.

Age structured models such as cohort analysis or statistical catch at age will be employed if all types of necessary data are collected – catch, effort, size and age of harvested fishes, fishery independent CPUE and demographics.

3) Estimated parameters

The collection of length, weight, gender sexual maturity, gonads and age data, through both fishery dependent and independent programs, will facilitate the estimation of biological parameters such as growth rates, age at maturity and fecundity that can be used to assess the health of a population as well as providing an understanding of recruitment. Additionally, these data can be incorporated into a variety of stock assessment models used to estimate biomass and abundance (e.g., surplus production models). Additionally, having time-series data of these biological parameters will allow for continued trend analyses to assess population status. This has proved informative in the past and will likely continue to be important for Cambridge Bay Arctic Charr assessments.

The collection of CPUE data is vital for accurate assessments of stock health. In many areas, and especially in the Arctic, information on total abundance is difficult to collect. Accurate estimates of CPUE can provide a proxy for abundance and trends in this measure can be used to assess how populations are impacted by current harvest levels and whether these current harvest levels are likely to remain sustainable. The collection of commercial catch and effort data, to be collected by FAM from each commercially fished river, started in the summer of 2012. Fishery independent CPUE collected by science started in 2011.

Taken together, the collection of fishery dependent and independent data combined with information on catch and effort, will be used in more sophisticated modeling exercises that will allow for the estimation of biomass (and therefore abundance) and total allowable catch. Such models are currently being explored and implemented for these fisheries.

4) Assessment program

The assessment program for the Cambridge Bay commercial Arctic Charr fishery incorporates three aspects.

1. The collection of fishery dependant data. A long-term plant sampling program has facilitated the collection of length, weight and age data, and more recently the collection of genetics samples. This program is an inexpensive method for collecting a time series of biological information for Cambridge Bay Arctic Charr. The majority of past assessments have relied on these data.
2. The collection of fishery independent data. The majority of biological information on which management decisions are based and current harvest levels are implemented has typically only considered biological/catch information of commercially harvested fish (i.e., information collected as part of the plant sampling program). The limitation of this is that older and larger individuals are usually over-represented, resulting in a lack of biological information that accurately represents the population as a whole. Given these caveats, a fishery independent sampling program has been initiated to collect biological information on Arctic Charr from these fisheries that include all ages and sizes. Additionally, this program aims at collecting samples for future genetic assessments and ovaries for fecundity estimates to better understand recruitment. The collection of biological data, fecundity, catch and effort data on each commercial river system will be compared to the fish plant data to ascertain whether or not plant sampling data accurately describes plant sampling data predictions. These combined with accurate estimates of CPUE provided through these fishery independent surveys will promote the effective management of these fisheries. The Jayco and Halovik rivers in addition to one inland location (Little Surrey Lake) have at this time been sampled.
3. The collection of catch-per-unit-effort information from commercial fisheries. Little information on population abundance for Cambridge Bay waterbodies is currently available and those data that are available are drastically out-dated. In the absence of such data accurate estimates of CPUE can be used as a proxy for population abundance. A community-based monitoring program has been proposed and is currently in the review stage for consideration. The program aims at hiring local monitors to collect CPUE data where commercial fisheries are implemented for the duration of the fishery. This information will allow managers to determine the current status of a fishery and are factors in establishing sustainable harvest levels in support of Article V of the Nunavut Land Claims Agreement, specifically supporting the NWMB's authority to establish, modify and remove levels of total allowable harvest (S 5.6.16). In addition to catch information, the collection of fishing effort information can provide important insights into fisher behaviour and gear efficiency. There is, however, virtually no information available on the fishing effort of commercial fisheries, the main motivation behind this proposed program. Overall, the collection of a long term series of catch and effort information, to compliment fishery independent biological data collected as

part of stock assessment surveys, will be valuable in guiding future conservation and management strategies.

5) Preferred stock assessment model

The surplus production model listed above is useful and may be used to estimate limit reference points for individual stocks in the Cambridge Bay system once a time series of catch and effort are established for each system.

An alternative approach is to use age information to construct a population model. There is age information for each Cambridge Bay stock. The advantage is that age structured models can predict future population sizes and answer a wider variety of management questions (for example what would be the consequences of a mesh size change). It does not rely on the population being in a stationary state and thus best describes a dynamically changing resource, There are a wide variety of models to choose from such as C++ Algorithmic Stock Assessment Laboratory, Integrated Catch at Age, Instantaneous Separable Virtual Population Analysis, ADAPTive framework for stock assessment, Statistical Catch at Age Model, Extended Survivor Analysis to name a few (Tallman et al. 2012). An basic example of an age structured model is the virtual population model.

Virtual Population Analysis (VPA)

The VPA is also known as a cohort analysis because each cohort is treated separately. The method is based on the following equation:

N alive at beginning of next year = (N alive at beginning of this year) - (catch this year) - (natural mortality this year)

In this particular case recruitment is not considered because we are analysing only a single cohort. We can change the above equation to:

N alive at beginning of this year = (N alive at beginning of next year) + (catch this year) + (natural mortality this year)

Assuming that natural mortality, M, is known and that at some age x there are no more fish alive (that is, all fish in the cohort die after age x) we can iteratively calculate the number of fish alive each year, starting from the oldest age and moving backwards to the youngest.

The basis of the method is the assumption that if we know that this year we have zero fish of the oldest age left alive and we know how many of them we caught last year (in theory those were the last fish of that age left in the sea after those which died of natural causes) and if we know the instantaneous natural mortality rate then, for fisheries where the fishing period is short it can be assumed that there is no natural mortality during the short fishing period so that:

$$N_t = N_{t+1} + C_t + D_t \qquad (14)$$

where

$$D_t = N_t(1-S) \qquad (15)$$

so that

$$N_t - D_t = N_{t+1} + C \qquad (16)$$

$$N_t - N_t(1-S) = N_{t+1} + C_t \qquad (17)$$

$$N_t - N_t + N_tS = N_{t+1} + C_t \qquad (18)$$

$$N_tS = N_{t+1} + C_t \qquad (19)$$

$$N_t = (N_{t+1} + C_t) / S \qquad (20)$$

where N is number of fish, C is catch, D is the number of deaths, t is time (year) and S is the finite survival rate.

The last equation above is the key equation for VPA or cohort analysis, when fishing takes place in a single short period of time during which we can consider M to be negligible. This equation allows the calculation of the numbers alive last year from the numbers this year, the catch-at-age and natural mortality, but because we assume there were no more fish left of the oldest age this year (they were all caught or died) we can calculate the numbers last year with only catch and mortality as parameter values.

<u>6) Research required to implement the preferred model</u>

The collection of biological data through the plant sampling program needs to continue to allow for analyses of trends in fish population parameter (i.e., trend analyses in age structure) refine stock assessment models on a yearly based with updated biological information

- Annual and specific river data catch and effort data needs to be collected to establish surplus production biomass and to establish a data base on information to be used as a proxy for abundance.
- Fishery independent biological data needs to be collected on each river system to supplement that collected through the plant sampling program.
- Samples must be collected to facilitate genetics work aimed at resolving genetic stock contribution to harvest at each commercial waterbody

THE VALUE OF SCIENTIFIC ADVICE TO FISHERIES MANAGEMENT

Fisheries management will be called upon to manage fisheries within the Sustainable Fisheries Framework which encourages economic benefits to Canadians while ensuring biological sustainability or conservation. However, maximization of economic and social benefits and conservation goals oppose each other. A well managed fishery recognizes this problem and allows for trade-offs between fishery yield (an economic goal), stability of harvest (a social goal) and stock conservation (a biological goal). Fishery decisions are by definition “hard decisions (Clemens 1997) which must try to optimize between several opposing forces. Science analysis or stock assessment can provide a sound basis for making the optimal choice of how much harvest will sustain the resource while allowing the best possible economic and social benefits to stakeholders. Making decisions without scientific support leaves the decision maker with an unknown degree of risk.

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REFERENCES

Alverson, D. L., and Paulik, G. J. 1973. Objectives and problems of managing aquatic living resources. J. Fish. Res. Board Can. 30:1936-1947.

Barker, D., and Sibly, R.M. 2008. The effects of environmental perturbation and measurement error on estimates of the shape parameter in the theta-logistic model of population regulation. Eco. Model. 219: 170-177.

Bouffard, N. 2010. Canada’s sustainable fisheries framework. Presentation to the Fisheries Resource Conservation Council (FRCC), unpubl. 23 pp.

Bousquet, N., Duchesne, T., and Rivest, L.P. 2008. Redefining the maximum sustainable yield for the Schaefer population model including multiplicative environmental noise. J. Theoret. Biol. 254: 65-75.

Buckland, S.T., Newman, K.B., Thomas, L., and Koesters, N.B. 2004. State-space models for the dynamics of wild animal populations. Ecol. Model. 171: 157-175.

Burnham, K.P., and Anderson, D.R. 1998. Model Selection and Inference. Springer-Verlag, New York

Caddy, J.F., and Mahon R. 1995. Reference points for fisheries management. FAO Fish . Tech. Pap. 347, FAO, Rome.

Carlin, B.P., and Louis, T.A. 2009. Bayesian methods for data analysis. CRC Press, Boca Raton.

Clark, W.G. 1991. Groundfish exploitation rates based on life history parameters. Can. J. Fish. Aquat. Sci. 8:734–750.

Clemens, R.T. 1997. Making Hard Decisions: An Introduction to Decision Analysis. South Western Educational Publishing. 696p.

Fairlie, S. (ed.). 1995. Overfishing: its causes and consequences. Ecologist. 25(2/3).

Fargo, J., and Kronlund, A.R. 2000. Variation in growth for Hecate Strait English sole (*Parophrys vetulus*) with implications for stock assessment. J. Sea Res. 44 (1-2): 3-15.

Fletcher, R.I. 1978. Time-dependent solutions and efficient parameters for stock-production models. Fish. Bull. 76(2): 377-388.

Francis, R.I.C.C., and Shotton, R., 1997. "Risk" in fisheries management: a review. Can. J. Fish. Aquat. Sci. 54: 1699-1715.

Gelman, A., 2006. Prior distributions for variance parameters in hierarchical models. Bay. Ana. **1**(3): 515-533.

Gulland, J.A. 1968. The concept of maximum sustainable yield and fishery management. FAO Fish. Tech. Pap. 70. FAO, Rome.

Haddon, M. 2001. Modeling and Quantitative Methods in Fisheries. Chapman and Hall/CRC.

Hammond, T. R., and O'Brien, C. M. 2001. An application of the Bayesian approach to stock assessment model uncertainty. ICES J. Mar. Sci. 58:648–656.

Harley, S.J., and Myers, R.A. 2001. Hierarchical Bayesian models of length-specific catchability of research trawl surveys. Can. J. Fish. Aquati. Sci. 58: 1569-1584

Hayes, D.B. 2000. A biological reference point based on the Leslie matrix. Fish. Bull. 98:75–85.

Hilborn, R. and Liermann, M. 1998. Standing on the shoulders of giants: learning from experience in fisheries. Rev. Fish Biol. Fish. 8: 273-283

Hilborn, R., and Walters, C.J. 1992. Quantitative fisheries stock assessment, choice, dynamics and uncertainty. Kluwer Academic Publishers, Boston.

Hilborn, R., and Walters, C.J. 1992. Quantitative fisheries stock assessment: Choice, dynamics and uncertainty. Chapman and Hall.

Hayes, D.B., and Liermann, M. 1998. Standing on the shoulders of giants: learning from experience in fisheries. Rev. Fish Biol. Fish. 8:273-283.

Holling, C.S. (ed.). 1978. Adaptive environmental assessment and management. Wiley, Chichester.

Jakobsen, T. 1992. Biological reference points for North-East Arctic cod and haddock. ICES J. Mar. Sci. 49(2):155-166.

Larkin, P A. 1977. An epitaph to the concept of maximum sustainable yield. Trans. Am. Fish. Soc. 106:1-11.

Limpert, E., Stahel, W.A., and Abbt, M. 2001. Log-normal distributions across the sciences: keys and clues. Bioscience 51: 341-352.

Ludwig, D., and Walters, C.J. 1989. A robust method for parameter estimation from catch and effort data. Can. J. Fish. Aquat. Sci. 46:137-144.

Ludwig, D., and Walters, C.J.1985. Are age-structured models appropriate for catch-effort data? Can. J. Fish. Aquat. Sci. 42:1066-1072.

Ludwig, D., Walters, C.J. and Cooke, J. 1988. Comparison of two models and two estimation methods for catch and effort data. Natural Resource Modeling 2(3):457-498.

Mcallister, M.K., and Kirkwood, G.P. 1998. Applying multivariate conjugate priors in fishery- management system evaluation: how much quicker is it and does it bias the ranking of management options? ICES J. Mar. Sci. 56:884–899.

Mcallister, M. K., Starr, P.J., Restrepo, V.R., and Kirkwood, G.P. 1999. Formulating quantitative methods to valuate fishery-management systems: what fishery processes should be modelled and what trade-offs should be made? ICES J. Mar. Sci. 56:900–916.

Meyer, R., and Millar, R.B. 1999a. Bayesian stock assessment using a state-space implementation of the delay difference model. Can J. Fish. Aquat. Sci. 56: 37-52.

Meyer, R., and Millar, R.B. 1999b. BUGS in Bayesian stock assessments. Can. J. Fish. Aqaut. Sci. 56: 1078-1086.

Millar, R.B., and Meyer, R. 2000. Non-linear state space modelling of fisheries biomass dynamics by using Metropolis-Hastings within-Gibbs sampling. App. Stat. 49: 327-342.

Ntzoufras, I., 2009. Bayesian modeling using WinBUGS. John Wiley and Sons, New Jersey.

Parsons, L.S., Powles, H. and Comfort, M.J. 1998. Science in support of fishery management: New approaches for sustainable fisheries. Ocean Coast. Manage. 39 (1-2):151-166.

Patterson, K., Cook, R., Darby, C., Gavaris, S., Kell, L., Lewy, P., Mesnil, B., Punt, A., Restrepo, V., Skagen, D.W., and Stefánsson, G. 2001. Estimating uncertainty in fish stock assessment and forecasting. Fish Fish. 2: 125–157.

Pella, J.J., and Tomlinson, P.K. 1969. A generalized stock production model. Int.-Am. Trop. Tuna Com. Bull. 13(3): 419-496.

Polacheck, T., Hilborn, R., and Punt, A.E. 1993. Fitting surplus production models: comparing methods and measuring uncertainty. Can. J. Fish. Aquat. Sci. 50: 2597-2607.

Plummer, Martyn; Best, Nicky; Cowles, Kate and Vines, Karen (2006). CODA: convergence diagnosis and output analysis for MCMC. *R News*, 6(1), pp. 7–11.

Prager, M.H. 2002. Comparison of logistic and generalized surplus-production models applied to swordfish, *Xiphias gladius*, in the North Atlantic Ocean. Fish. Res. 58: 41-57.

Priest, H., and Usher, P.J. 2004. The Nunavut wildlife harvest study. Nunavut Wildlife Management Board. 818 p.

Punt, A., and Hilborn, R. 1997. Fisheries stock assessment and decision analysis: the Bayesian approach. Rev. Fish Biol. Fish. 7:35–63.

Quinn, T.J., and Deriso, R.B. 1999. Quantitative Fish Dynamics. Qxford University Press. New York.

Sainsbury, K.J., Punt, A.E., and Smith, A.D.M. 2000. Design of operational management strategies for achieving fishery ecosystem objectives. ICES J. Mar. Sci. 57:731–741.

Schaefer, M.B., 1957. A study of the dynamics of population important to the management of commercial marine fisheries. Bull. Inter-Am. Trop. Tuna Comm. 2: 247-285.

Sibly, R.M., and Hone, J. 2002. Population growth rate and its determinants: an overview. Phil. Tran. Royal Soc. B 357: 1153-1170.

Smith, S.J., Hunt, J.J. and Rivard, D. (eds.). 1993. Risk Evaluation and Biological Reference Points for Fisheries Management. Can. Spec. Publ. Fish. Aquat. Sci., no. 120.

Sparre, P., and Venema, S. 1992. Introduction to tropical fish stock assessment. Part 1. Manual. FAO Fish. Tech. Paper 306/1 rev 1. FAO, Rome.

Spiegelhalter, D.J., Best, N.G., Carlin, B.P., and der Linde, V. 2002. Bayesian measures of model complexity and fit. J. Royal Stat. Soc. Series B. 64: 583-639

Starfield, A.M., and Bleloch, A.L. 1986. Building models for conservation and wildlife management. Macmillan Publishing Company, New York.

Stevens, J.D., Bonfil, R., Dulvy, N.K., and Walker, P.A. 2000. The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. ICES J. Mar. Sci. 57:476–494.

Tallman, R.F., Cadigan, N., Cass, A., Duplisea, D., Healey, B., Trzcinski, K., and Wade, E. 2011. Techniques for the Provision of Advice in Information-Poor Situations. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/106. vi + 42 p

Tallman, R.F., Roux, M.-J. and Fisk, A. 2012. Management of Ecosystem Effects, Potential and Realized, in Emerging Arctic Fisheries in South Baffin Island. In: G.H. Kruse, H.I. Browman, K.L. Cochrane, D., Evans, G.S., Jamieson, P.A., Livingston, D., Woodby, and C.I. Zhang, (eds.), Global Progress in Ecosystem-Based Fisheries Management. Alaska Sea Grant, University of Alaska Fairbanks, Fairbanks.

Thomas, L., Buckland, S.T., Newman, K.B., Harwood, J., 2005. A unified framework for modelling wildlife population dynamics. Aust. N. Z. J. Stat. 47(1): 19-34

Toyne, M. and Tallman, R.F. 2010. Information in support of an Exploratory Fishery Protocol - Nunavut and Northwest Territories Anadromous Arctic Charr. Canadian Stock Assessment Secretariate Research Document 2010/077 38p.

Walters, C.J., 1998. Evaluation of quota management policies for developing fisheries. Can. J. Fish. Aquat. Sci. 55: 2691-2705.

Walters, C., and Ludwig, D., 1994. Calculation of Bays posterior probability distributions for key population parameters. Can. J. Fish. Aquat. Sci. 51: 713-722.

Wilberg, M.J., Thorson, J.T., Linton, B.C., and Berkson, J. 2010. Incorporating time-varying catchability into population dynamic stock assessment models. Rev. Fish. Sci. 18: 7-24.

APPENDIX 1. THE PURPOSE OF FISHERIES MANAGEMENT

What is the purpose of fisheries management? While early fisheries management had implicitly or explicitly MSY (Appendix 2) as it's most important objective (Gulland, 1968) presently MSY is considered only a biological concept and benchmark to guide management. Although MSY still plays an important role as a guiding light for fisheries management, often specific and multiple objectives of fisheries management may be more important than obtaining maximum yield in the long term (Alverson and Paulik, 1973). According to Hilborn and Walters (1992), the most widely accepted fundamental purpose of fisheries management is "to ensure the sustainable production over time from fish stocks, preferably through regulatory and enhancement options that promote economic and social well-being of the harvesters and industries that use the production".

In the modern world of fisheries, management tries to balance multiple objectives that span beyond biological concerns. Often times these multiple objectives are in opposition to each other, such that it is not possible to achieve all of them simultaneously. Managers have to make quantitative decisions about how many fish can be caught, what is the number of boats that will be allowed to enter a fishery, or what is the minimum size of a fish or a gillnet mesh that should be allowed. They also have to make decisions about how much should be spent on research, enforcement of regulations, administration, etc. Within this context, fisheries assessment is about giving advice on the status of the resource and the likely results of alternative measures. Once this is done, the choice of which action to take remains (usually a given amount of fish or quota that can be caught by many different combinations of effort and number and size of boats), and this is where choices have to be made by managers, usually on economic and social grounds. Below we consider the biological and conservation objectives of concern to stock assessment.

Biological and conservation objectives

By default the biological objective of fisheries management is to obtain MSY, or in other words achieving biological yield maximization. This concept has already been explained above. The standard indicator of biological yield is the annual weight or number of fish caught.

Resource conservation, as well as biological and genetic diversity, are also important biological objectives with an increasingly important role in fisheries management. Explicit directives to avoid putting stocks of target ***and*** non-target species at risk of extinction, and to develop plans for their recovery in case they are already endangered, play a very important role in fisheries legislation in many parts of the world. This is exemplified in the 1996 Magnuson-Stevens Fishery Conservation and Management Act of the USA. Even more recently, ecosystem-health objectives are beginning to take a very important role in fisheries management (Sainsbury et al. 2000; Stevens et al. 2000). Several fishery management plans already incorporate ecosystem objectives and it is just a matter of time until ecosystem-based objectives replace some of the more traditional biological objectives such as obtaining single- species MSY levels.

APPENDIX 2. THE CONCEPT OF MAXIMUM SUSTAINABLE YIELD (MSY) AND ITS EVOLUTION FROM AN OBJECTIVE TO A REFERENCE POINT.

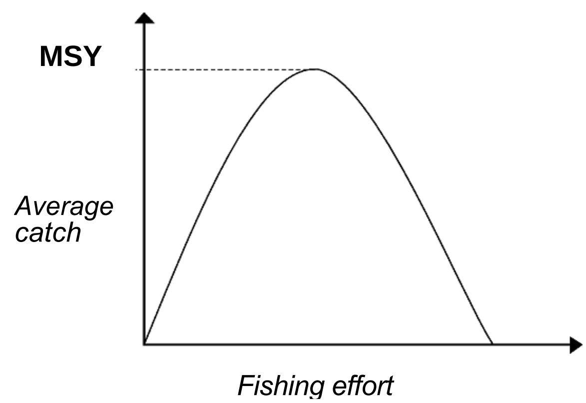

Figure 3. A graphical representation of the Maximum Sustainable Yield (MSY).

The traditional concept of the dynamics of fishery resources is that there is an underlying model according to which as fishing effort increases, catch will increase up to a maximum, and if effort continues to grow then catches (also known as yield) will decrease. This leads directly to the concept of maximum sustainable yield (MSY) which has been the holy grail of fisheries (Larkin, 1977). The specific shape of the yield curve shown in Figure 2 does not matter. The important principle always holds: zero effort means zero catch; too much effort leads to small or almost zero catch. Also, in theory there should be a point at which catch reaches a maximum—at least on average— and supposedly once the curve reaches the top, the MSY level has been found. For decades, finding MSY and keeping fisheries at this prescribed level of catch and effort became the sole objective and obsession of fisheries science, as was eloquently put by Larkin (1977).

There are several problems with this concept, the first practical problem being that natural systems have a lot of random variability. In practice, real data will always reflect this variability as "noise." The great danger of focusing stock assessment work solely on finding MSY and its associated optimum effort ($foptimum_{pt}$ defined as the effort level that produces MSY) is that we can seldom be totally sure that we have witnessed the MSY level. Even if managers try to be very careful and cautious by developing a fishery at a very slow pace it can never be guaranteed that the stock will not be overexploited or that opportunities will not be wasted. An excellent example of the difficulties in finding MSY comes from work on Atlantic Yellowfin Tuna (*Thunnus albacares*) published by FAO and cited by Hilborn and Walters (1992). When scientists performed the first assessment of this resource in the mid-1970s, they thought they had already arrived at the MSY level and calculated this at about 50,000 t. However, due to a lack of effective management the fishery continued to grow and a second analysis 10 years later suggested a different MSY level of more than 100,000 t, clearly indicating that the first assessment had led to a "false" MSY. The question remaining was if the second assessment was also an underestimate.

The real problem in the above example, and in most real fisheries is that in all cases and especially in situations of noisy data we would have to go beyond MSY to ensure that we had actually found it. In other words, until yield does not substantially decrease over a sufficient period of time at increased effort levels we cannot be sure that MSY has been observed. This effectively means that we can never prevent overexploitation, at least not a small amount of it in the best case. This is an important principle identified by Hilborn and Walters (1992): ***"You cannot determine the potential yield from fish stocks without overexploiting them."*** The secret is not to overexploit the stock beyond recovery in our effort to find MSY. An additional practical problem is that once fisheries have actually passed the MSY point and gone into the overexploitation phase, more problems arise. In such cases, the fishery has already entered the overcapacity side of the curve. This leads to another sad but important principle stressed by Hilborn and Walters (1992): ***"The hardest thing to do in fisheries management is to reduce fishing pressure."***

In an ideal situation a new fishery should start with all the mechanisms in place to assure, a) a quick detection of MSY after passing this point (i.e., a good monitoring and data acquisition system should be in place), and b) there should be mechanisms in place from the onset of exploitation, that will reduce effort effectively without detrimental effects (high taxes that can be later used to buy back boats or compensate for the lost catches and revenue of each boat).

Currently, MSY is a theoretical concept that should hold on average, but it is mostly useful as a *general concept* that helps us to guide our work; it is *not the aim* of fisheries assessment (Note that currently the European community has decided to use MSY as a target after moving through various types of goals. This is likely because most of their stocks are exploited well to the right side of Figure 2). In present times the MSY concept is used to derive management targets and limits or biological reference points (BRPs). Biological reference points are levels of total biomass, spawning stock biomass, fishing mortality rate or other measurable characteristics of a fish population and a fishery, which are either the target of management or a limit beyond which the fishery will not be permitted to go. Two common BRPs are the biomass at which the population can produce the maximum sustainable yield (BMSY) and the fishing mortality needed to achieve MSY (F_{MSY}). For additional reading about these and related concepts readers should refer to Clark (1991), Jacobsen (1992), Smith et al. (1993), Caddy and Mahon (1995), and Hayes (2000). A further important consideration is that MSY and any reference points based on it assume that the recruitment of the studied population and environmental conditions are constant. However, human-induced (habitat destruction, species depletion) and environmentally driven phenomena (climatic “regime shifts”), can all produce changes in MSY. This issue has commonly been either ignored or mishandled in fisheries science.

Table 1. Comparison of strengths and weaknesses for stock status analyses using time series and point estimate models.

Types of Analyses for Stock Status	Strength	Weakness	Effect of typical errors on fishery management
Time Series	1) Multiple indicators of stock health/ stock trends/ CPUE/ age structure/ size structure/ mortality rate/ sex structure 2) Projects forward (year class strength) 3) Measures inter-annual variation 4) Cross-checking (validation of trends) 5) Manage growth rate 6) Modeled population size estimate/ F/ yield	1) Age determination error 2) Costly in age determination/ sample processing	Underfishing
Point Estimates	1) Direct population size estimate 2) Direct calcualtion quota (TAH) 3) Possible direct estimation of exploitation rate	1) Single measure; no sense of stock trend 2) No info on inter-annual variation 3) Assumes complete (unbiased) recovery of tags, no tag loss, no differential mortality in marked animals, random mixing of tagged animals 4) Looks backward; no forward projection	Overfishing

Table 2. Fishery sampling to model applied. *Region - C&A Fishery :1. Cumberland Sound Charr; 2. Cambridge Bay Charr; 3. Hornaday River Charr; 4. North Slope Dolly Varden.

Sampling	Model Type	STOCK*	Outputs	Who Collects	Analysis
Catch	None	All	Time series Catch Record	Fish Management	Science
Effort	None	All	Time series Effort Record	Fish Management	Science
CPUE	Surplus - Production	All	MSY estimate	Fish Management	Science
Plant Sampling	None (Index)	1, 2	Time Series of Catch Age/Size Structure	Science	Science
Plant Sampling	Size at age - Catch	1, 2	Time series size at age of catch	Science	Science
Plant Sampling/CPUE/ Fishery Independent	Age Structured - VPA type	1, 2	Estimate Fishing Mortality	Science/ Management	Science
Plant Sampling/CPUE/ Fishery Independent	Age Structured - VPA type	1, 2	Estimate Population Size		
Plant Sampling/CPUE/ Fishery Independent	Age Structured - VPA type	1, 2	Estimate Cohort Strength	Science/ Management	Science
Plant Sampling/CPUE/ Fishery Independent	Age Structured - VPA type	1, 2	Project Forward	Science/ Management	Science
Fishery Independent Sampling	Regression	1, 2	Time Series - Growth (Catch)	Science	Science
Fishery Independent Sampling	Age Structured - VPA type	1, 2	Determine recruitment	Science	Science
Fishery Independent Sampling	Age Structured - VPA type	1, 2	As above	Science	Science
Fishery Monitor	Index Age/ growth series	3,4		Science	Science
Mark-Recapture	Point Estimate	All char		Science	Science
Didson	Current Year Point Estimate	4		Science	Science

Table 3. Sample sizes and source for key stock assessment information for Charr stocks.

Stock	Harvest	Effort	Catch Demographics	Fishery Independent CPUE	Stock Demographics	Age Determination	Point Estimate
1. Cumberland Sound Charr	All - trade records	All - Log Book	200/stock Plant sampling	per stock/research survey	200/stock - research survey	up to 300 otoliths plus up to 1800 otoliths (Exploratory)	none
2. Cambridge Bay Charr	All - trade records	All - Log Book	200/stock Plant sampling	per stock/research survey	200 stock - research survey	up to 1400 otoliths	occasional simple M/R
3. Hornaday River Charr	All - community records	All - Log Book	200 monitors	Research survey	inclusive in monitors	200 otoliths	occasional simple M/R
4. North Slope Dolly Varden	All - interviews	All - Monitors	200/stock monitors	Not available	inclusive in monitors	up to 800 otoliths	Rat R. 5 estimates plus Didson

Research survey - done with multimesh gillnet gangs

M/R = mark recapture using floy tags