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Introduction and Objective of the Workshop

Overview on Assessment of Groundfish Stocks Based on Bottom Trawl Survey Results

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Introduction

In recent years the Scientific Council has recorded an increasing importance on abundance data derived from research surveys, for the fish stock assessments. While there are serious problems with the quality of the catch statistics necessary for assessments, several important stocks assessed by the Scientific Council are under moratoria and are therefore not producing fishery data. In these cases, abundance survey data are the only available reliable source of information on stock status. Observing the urgent need to consider fishery independent methods of stock assessments, the Scientific Council called for a Workshop to review the methods, at its Special Session to be held in conjunction with the 18th Annual Meeting of NAFO.

The Workshop titled 'Assessment of Groundfish Stocks Based on Bottom Trawl Survey Results' with H. Lassen as convener was held during 4–6 September 1996, at Shuvalov Palace, St. Petersburg, Russia. The Workshop was open to the general scientific community, although participation was primarily aimed at the NAFO Scientific Council members.

Considering the hands-on nature of the Workshop, the total number of participants was limited. A total of 39 participants attended from Canada, Denmark, Germany, Greenland, Faroe Islands, Japan, Norway, Portugal, Russia, Spain, United Kingdom and the United States of America.

The Scientific Council is fortunate that there are extensive survey data available for most of the important fish stock in the Regulatory Area. With the deterioration of the catch statistics, it becomes imperative to establish survey methods that provide absolute abundance estimates. There is ongoing work in this context that have been available to the Scientific Council. They are along such lines as studies which have shown how to modify the research gear to reduce variability and to reduce size selectivity in the gear. There are also methods that combine bottom trawl and hydro-acoustic survey techniques under development. The Council was presented with two papers dealing with this aspect (NAFO SCR 96/91 and /92). These two papers were not reviewed at this Workshop but they proposed a way to estimate catches in years where significant under reporting occur. These methods are based on estimation of the catchabilities for periods when catch data are considered to be reliable together with estimates of total mortality from survey data. Such guesses of the catch therefore carry the variability inherent in the surveys that are quite considerable but the methods are useful in identifying years with problems.

New methods for the analysis of results from bottom trawl surveys have appeared in the scientific literature on fisheries in recent years. Many of these methods are build on the statistical resampling theory (bootstrapping), which has been developed in the theoretical statistical literature after 1979. These methods are very demanding on computer power and have therefore only been of practical use with the easy access to cheap powerful computers. Even the machines available to fisheries scientists today are often stretched to their limits when such methods are applied. Also, improved methods for integrated analysis of catch results and environmental data have been published recently.

Modern statistical techniques are often linked closely to a particular software. These softwares are often commercial products and a presentation of the techniques make explicit references to these software. In the present Workshop special references are made to S-PLUS and to the SURFER software. The S-PLUS is a general purpose statistical analysis software while SURFER is designed for spatial interpolation. The S-PLUS software was used for the hands-on sessions on the bootstrap method and for the Generalized Additive Models (GAM) analysis, while the SURFER software was used for the spatial interpolation of environmental observations. The Scientific Council was grateful for the support extended by the firm behind S-PLUS (StatSci, a division of MatSoft, inc., Seattle, WA, USA), to allow the use of their software free of charge for the duration of the Workshop and also making available five manuals of the S-PLUS program.

The Workshop

The Workshop was limited to bottom trawl survey data and had the following objectives:

a) To further the Scientific Council's stock assessments, by improving on analyses of fish distributions observed during abundance surveys, with special attention to the relationships between distribution of fish and the environmental conditions during the surveys.

b) To further the work on how to assess stocks under moratoria, i.e. assessment of fish stocks based on survey data only.

c) To present an overview of techniques available for these types of analyses in the form of a NAFO publication.

The structure of the Workshop was built around keynote presentations and hands-on sessions for the participants (see Program).

The first keynote address by Stephen Walsh (Canada) introduced to the Workshop a review on estimating efficiency of sampling trawls to derive survey abundance indices. The topics of the hands-on sessions of the Workshop were then introduced by two overview lectures. The first by Stephen Smith (Canada) dealt with fish abundance estimation while in the second by Manfred Stein (EU–Germany) dealt with estimation of the geographical distribution of environmental parameters. The topics then progressed with Hajo Rätz (EU–Germany) discussing the link between survey catches and environmental parameters followed by Loretta O'Brien (USA) who introduced the concept of Generalized Additive Models (GAM).

The three hands-on sessions presented:

1. estimation of over-all abundance and its variance using bootstrapping techniques,

2. estimation of the geographical distribution of environmental parameters which may be used for abundance estimation, and

3. integrating CPUE results with observations of environmental parameters to obtain a better estimate of abundance and its variance using GAM.

The potential usefulness of environmental data to improve the abundance estimate, i.e. providing estimates with less variance was stressed on several occasions.

The Workshop did not address estimation of catchability, i.e. obtaining absolute abundance estimate from surveys. The best approach to a solution of this problem seems at present to be through the linkage between total catches and survey results interpreted as abundance indices. The appropriate techniques are extended VPA techniques such as ADAPT, CAGEAN, XSA etc.

Analysis of Bottom Trawl Surveys

Standard assessment techniques, e.g. ADAPT, usually use results from bottom trawl surveys as indices of stock abundance. These methods assume that the full set of fishing mortalities and stock sizes in the cohort model can be estimated based on the matrix of catch-at-age in numbers by year together with at least a survey series providing indices of one or more age groups. This is, however, only true if the catchabilities by age or size are constant (or known) over the time series. Survey indices, which are often age disaggregated, are compared across years, while comparison across ages within a year is often difficult because catchability and availability vary with size and hence age. These catchabilities are mainly unknown or when estimates are available they are based catch levels. The absolute level of stock abundance is established through the catches, while the surveys provide information about the proportion of an age group that is removed. Similar information is also available from the age compositions in the catches under the assumption of a constant exploitation pattern.

The aim of an abundance survey is to provide knowledge on the density of fish over the area of occurrence. This objective may be addressed ambitiously to estimate the density function D(x,l) where x is the geographical co-ordinates and l is the size of the fish/shellfish. However, for standard fish stock assessment the required result is less demanding since only I D(x,l)dx, the density function integrated over the survey area, is needed.

The density function D(x,l) is estimated as:

$$D(x,l) = \text{Catch/Swept area/Availability/Efficiency}$$

Here:

- catch is the direct observation, e.g. in number of fish by size category,
- swept area is the area which was effectively sampled,
- availability is the proportion of the stock which was seen by the trawl. Fish which were too high in the water or buried too deep in the bottom are not available to the gear,
- Efficiency is the proportion of the fish seen by the gear which are actually retained.

For practical use, since only an abundance index is required, D(x,l) is replaced by CPUE under the assumptions:

- Swept area per hour trawling is constant,
- Availability and catchability are constant throughout the survey or at least vary randomly with a reasonable small variance.

Efficiency and availability depend on the gear used for the study. Knowledge of the sampling properties of trawls is a prerequisite for the usefulness of the statistical analysis and subsequent fish stock assessment. Stephen Walsh's review stresses this need for a detailed understanding of how sampling gears reflects the fish population. He notes that trawl selectivity is not only a matter of cod-end selection but particularly the design of the footrope is important. There are examples where gears used for scientific surveys showed marked size selectivity, where there was diel variation in the efficiency, and where swept area varied with fishing depth. Research has been directed to remedy these problems and some solutions are available. This raises the question whether the variability observed between trawl hauls is a reflection of the temporal and spatial variation in the population, or whether variation in gear performance could be a key factor. This standard assumption may in many cases be at least partly invalid. This variability may vary systematically or in a random fashion, noting that systematic variability will lead to biased abundance estimates.

The key objective when designing a survey is that it should provide unbiased abundance estimates of either D(x,l) or $\int$ D(x,l)dx, with minimum variance under the constraint of the number of trawl stations. This minimum variance objective may also be viewed as putting the available ship-time to the best possible use.

This problem could be addressed at several levels:

- General form of the survey – total coverage over the area of occurrence or the use of indicator stations.
- Timing of the survey – choice of ship and gear.
- Design of survey – systematic *vs* stratified random survey.
- Duration of hauls – measurements to be taken on each station. These problems were not addressed in any details by the Workshop.

Timing and choice of gear is not discussed any further here.

A basic design feature is whether the survey should cover the entire area of occurrence or whether indicator stations could serve the purpose of tracing stock development. The costs in ship-time could be quite different between these two approaches. The variability of the spatial distribution between years would be the determining factor whether indicator stations or full coverage surveys should be preferred, indicator stations only being useful if a stable spatial distribution exists between years.

In the case of not using indicator stations, the use of statistical sampling theory for abundance surveys requires that all possible sites in the survey area be considered for sampling. This is obviously not so for non-trawlable grounds when considering bottom trawl surveys. Therefore bottom trawl surveys at best only provide an abundance estimate of the population present on trawlable grounds. This may be a reasonable proxy to the entire population but non-trawlable grounds may in some cases hold a significant proportion of the population under investigation. In these cases gear other than trawls, e.g. gillnets or long lines would be more appropriate. However these gear, being highly size selective, present yet another set of problems for their proper use.

A standard question in designing bottom trawl surveys is whether a stratified random design or a systematic design possibly with some stratification should be used. This relates to the need to adequately sample the entire survey area (systematic coverage of the survey area) or the need to avoid biased estimates (random sampling). The systematic survey may produce biased estimates, but when these biases are constant over time and the survey results are only used as abundance indices this will be of no importance. In cases when the spatial distribution varies strongly between years, or when there is no marked large scale geographical structure in the population, stratification does not help in improving the abundance estimates. This is often also true for multispecies surveys where it may be difficult to find a geographical structure that applies across several species. For these reasons systematic survey design has become widespread. Investigations of cod surveys in the Northeast Atlantic (Icelandic and Northeast Arctic cod) suggest that stratification will not improve the abundance estimates significantly.

This design problem is addressed by Stephen Smith. He distinguished procedures based on models and those based on random haul selection. The model based methods include approaches such as:

- Contouring/splines
- Delauney triangles
- Spatial Autocorrelation
- Kriging/Co-kriging
- Optimal estimation

while design-based methods include approaches such as:

- Simple random sampling
- Stratified random sampling
- Stratified random transect
- Stratified-adaptive
- Two-stage random sampling

Model-based methods lead to a systematic distribution of haul sites over the survey area, while the design based methods require some form of stratified random design. Many model designs implicitly or explicitly assume that the spatial fish distribution is constant for the time period of the survey. Temporal and spatial distribution changes of the fish during the survey are also the reasons why many attempts to applied, e.g. kriging as a tool for analyzing bottom trawl surveys have failed. For surveys of populations that are fixed, e.g. mussels, scallops, whelks etc. these model based methods are more successful.

Statistical sampling theory not only establish the principle for sampling, i.e. the random sample, but also provides a framework for how to optimise the design. The optimal statistical design provides unbiased estimates with minimum variance constrained by the total number of samples. This is the allocation problem: once a stratification scheme has been defined how best to allocate the available sampling resources between strata. Another approach that has received scientific interest in recent years is the use of environmental parameters, e.g. temperature and salinity as predictors of CPUE in the survey. This would allow less sampling to obtain the same degree of precision and it would if real time environmental data are available, allow allocation which are based on up-to-date information and therefore make better use of ship-time. Temperature and salinity identify water masses and the inherent assumption in this approach is that fish distribution follows the water masses. The effects may be indirect that the survey species, e.g. cod, concentrate on the food concentrations which may again be concentrated in oceanographic structures such as fronts between two water masses. Establishing these relationships between the environmental observations and the catch results can be pursued both through model-based and through design-based approaches.

The resampling (bootstrap) methods are useful for obtaining abundance estimates, their CI and other statistical properties. The presentation given by Stephen Smith is based on the fundamental statistical design used in bottom trawl surveys – the stratified random survey. The variance of the abundance estimate depends both on how effective the stratification is – measured as the ratio of the within and between strata variance – and how the trawl hauls are allocated between the strata. According to the Neyman theorem, this should be done proportionally to the standard deviation within strata. The benefits of a good stratification i.e. a large ratio of the between and within variance could dissipate due to poor allocation.

Resampling techniques are superior to normal distribution theory when data are far from symmetrically distributed but have long tails. For trawl survey data this often takes the form of a few very large observations. There are furthermore a number of exploratory graphic techniques available that will help the researcher to identify these highly influential observations.

Although often forgotten the appropriate estimation procedure is linked to the sampling design. This is particularly important when applying bootstrap methods for parameter estimation. Resampling should respect the sampling design particularly the stratification. It has been shown that variance estimation may be biased and that modifications of the resampling design, e.g. not resampling the full number of samples (n) but rather only 1 to 3 samples short (n-1 or n-3) and introduce the appropriate raising would be a better strategy. It is also important to note that the number of replicates required for the resampling scheme can be quite high for variance estimation, and that some experimentation with the required number of pseudo samples is advisable.

The occurrence of highly influential observations, i.e. catches which contribute much more than the average catch to the mean abundance estimate is a distinct feature of any survey. At the Workshop, data for six bottom trawl surveys were analyzed: shrimp at West Greenland, yellowtail flounder on the Grand Bank, redfish in NAFO SA 2, several species investigated by the EU Flemish Cap survey, silver hake in NAFO Div. 4VWX and several species from a Japanese survey in the East China Sea. All of these showed such highly influential observations least for the West Greenland shrimp survey. The standard approach to deal with this problem is to assume that the underlying distribution is lognormal and to calculate the estimators and their CI accordingly. This, however, conflicts with occurrence of empty hauls something that should not occur under the lognormal assumption. There are other approaches – assuming a delta-lognormal distribution or a Gamma distribution. The approach presented to this Workshop by Stephen Smith is based on bootstrapping the observations. This means that the extreme observation should occur in the proportion corresponding to its occurrence in the population and therefore implies that the number of observations in each stratum are fairly large.

Estimation of the density over the survey area can be pursued by interpolation between the haul positions. This usually leads to unsatisfactory results. Better results may be achieved if observations of environmental variables at a finer grid than what is possible for the fishing stations are available and the environmental parameters can be established as predictors of catches

$$CPUE(x) = fct(E(x)) + \varepsilon$$

ε is the noise in the relationship. It should be noted that these functions fct generally have strong non-linear features. This is a key argument for introducing the GAM into analysis of survey results.

Manfred Stein in his presentation discusses how to interpolate environmental data observed in a spatial grid, i.e. estimation of the distribution function E(x). These interpolation techniques include inverse interpolation and kriging. He discusses the appropriateness of these different techniques.

Linking environmental data to catch data to obtain an approximation of the density function CPUE(x) was discussed by Loretta O'Brien, who introduced the GAM methods. These methods are based on a link function between the CPUE (or in the specific case log(CPUE)) and a linear combination of functions (possibly non-linear) of the dependent parameters, a non-parametric estimation procedure and application of a stepwise regression technique to identify the most reasonable functions, which could serve as predictors of CPUE based on environmental observations. These models allow direct integration of environmental observations with CPUE observations.

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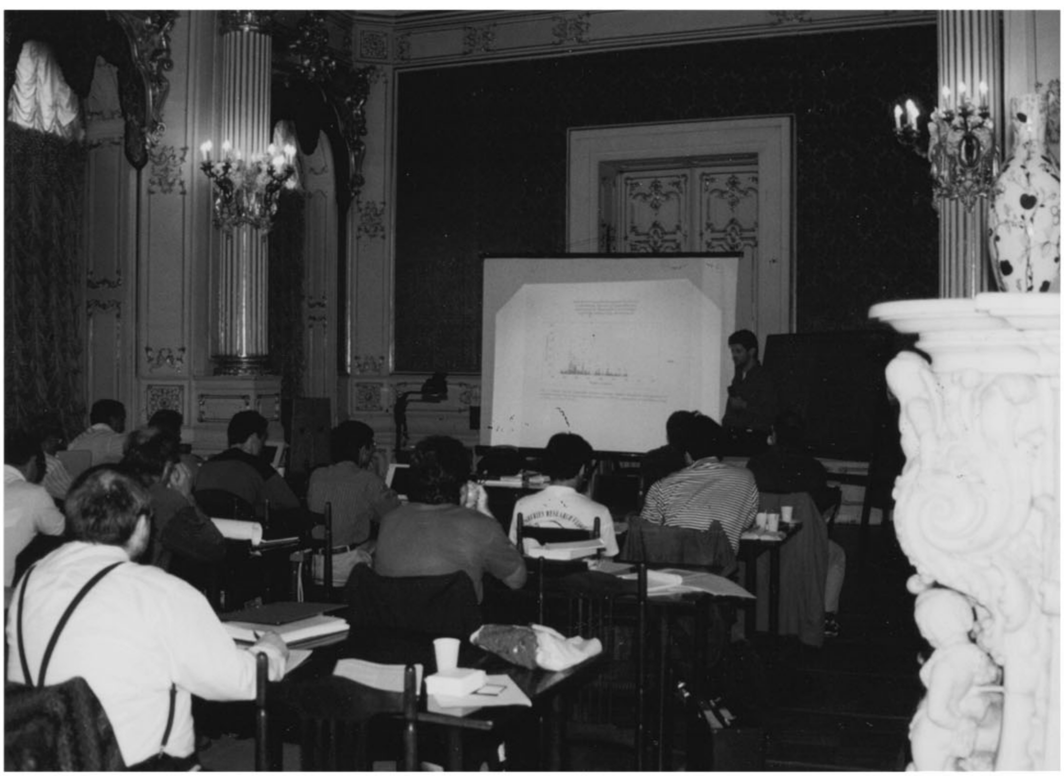

Workshop on "Assessment of Groundfish Stocks Based on Bottom Trawl Survey Results" in progress during 4–6 September 1996 held at "Shuvalov Palace", St. Petersburg, Russia.