

## **Theme Session I on Quantifying, summarizing, and integrating total uncertainty in fisheries resource surveys**

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Fisheries management requires risk assessments and methods for quantitatively evaluating changes in fish stocks or ecological systems. To evaluate risk and change, fisheries managers and scientists must be armed with a quantitative understanding of survey uncertainty that includes all the components of measurement and sampling error, both random and systematic. These errors must be incorporated into ecosystem analyses, and explicitly accounted for in stock assessment models and management advice.

Papers were invited on:

- i Methods for quantifying and summarizing the systematic and random error in survey measurements and sampling;
- ii Techniques for summarizing these components of error into estimates of total survey error;
- iii Bayesian and other techniques for incorporating systematic and random survey error in stock assessment models;
- iv Detecting changes in a measurement data series which includes systematic and random error;
- v Applications of statistical process control theory to fisheries management; and
- vi Strategies for managing fish stocks in the presence of measurement and sampling uncertainty.

There were 24 talks and 3 posters. Most of the talks addressed the quantification of one or more components of systematic or random error in survey measurements of sampling. Multiple other talks described efforts to estimate the total error in resource surveys. Two theme topics: "Applications of statistical process control theory to fisheries management," and "Bayesian and other techniques for incorporating systematic and random survey error in stock assessment models" did not receive any attention from presentations, while another unanticipated topic, "Optimal effort allocation based on the uncertainty in the measurements and sampling," received the attention of one talk and much of the discussion.

Thematic overview

- 1) Methods for quantifying and summarizing the systematic and random error in survey measurements and sampling.

An error budget for fisheries surveys begins with a listing and ranking of the potential sources of uncertainty (e.g. Gerritsen and McGrath: An overview of sources of bias and uncertainty in fisheries surveys). Principal sources of uncertainty, such as remote species identification (e.g. Massé *et al.*: An attempt to reduce species mis-identification in acoustic assessment by using school descriptors, including multi-frequency indices); target strength (Ona: Seasonal variability in cod target strength); observation volume (Scalabrin : Comparing data from hull mounted and ROV acoustics: impact on acoustic density measurements of different target to sensor distances); diel vertical migration (Godø *et al.*: Diurnal variation in frequency response of gadoids in the Barents Sea); and avoidance reactions (Hjellvik *et al.*: Correcting for

avoidance in acoustic abundance estimates for herring using a generalized linear model) were investigated.

Other papers investigating individual sources of uncertainty included: Slotte *et al.*: Size and condition of mackerel in research vessel trawl hauls versus commercial purse seine catches: implications for acoustic biomass estimation; Utne and Ona: Acoustic extinction in dense herring layers, measured from a bottom-mounted transducer; Cox *et al.*: The effect of missing acoustic observations (dropped pings) on mean area density estimates of Antarctic krill (*Euphausia superba*); Rochet *et al.*: Estimating end effect in trawl catches; and Kimura: Interpreting spatial variability found in fishery survey data. Ultimately, the effects of these individual sources of uncertainty must be combined to estimate total uncertainty.

- 2) Techniques for summarizing these components of error into estimates of total survey error.

Some methods for estimating total uncertainty assumed the components were independent and additive (Doonan: Quantifying error sources in deepwater acoustic surveys); or covariant and can be combined using Monte Carlo simulation or bootstrapping techniques (Demer: Estimates of sampling and measurement error in acoustic surveys of Antarctic krill; and Aldrin and Løland: Estimating and decomposing total uncertainty for survey-based abundance estimates of Norwegian spring-spawning herring). However, many of the papers assumed random measurement error was negligible, and estimated total sampling error using geostatistical methods (Paul Walline: Sequential geostatistical simulation methods to assess the error distribution function for biomass determined from acoustic survey data; Kasatkina and Gasyukov: Estimating uncertainty in Baltic acoustic survey results applying geostatistics techniques and simulation; and Woillez *et al.*: Evaluating the uncertainty of abundance estimates from acoustic surveys using geostatistical conditional simulations).

One paper showed how ancillary data can be used to both estimate and decrease measurement uncertainty (Smith *et al.*: Incorporating bottom type information into survey estimates of sea scallop (*Placopecten magellanicus*) abundance).

- 3) Detecting changes in a measurement data series which includes systematic and random error.

One paper reported benefits of tuning VPA with catch data and comparing the results to acoustic survey data (Pennington and Nakken: Timely evaluation of stock status based on scientific surveys, an update). Another paper provided a method for quantitatively evaluating change in a process (Nagelkerke and Tsehay: Sampling fisheries with high levels of accepted relative error may lead to overestimation of the statistical power of trend detection).

- 4) Strategies for managing fish stocks in the presence of measurement and sampling uncertainty.

One method was presented for explicitly accounting for error in fish stock management strategies (Pomarede *et al.*: Evaluating the management implications of different types of errors and biases in fisheries resources surveys using a simulation-testing framework.) This subject requires much more attention in ICES.

- 5) Optimal effort allocation based on the uncertainty in the measurements and sampling.

How much uncertainty can we accept to successfully manage fisheries and maintain natural or desirable marine biodiversity? This is the first question that must be answered, probably by stock assessment scientists and policy makers. There was one talk on this most important subject (Hjellvik and Ona: How many trawl hauls, and how many fish from each haul are needed to obtain a given precision in the age structure estimate for Norwegian spring-spawning herring? A bootstrap approach.)

## Highlights

- Estimating Total Uncertainty: “Estimates of sampling and measurement error in acoustic surveys of Antarctic krill,” by Demer, presented a number of important general ideas regarding survey uncertainty:
  - i Measurement and sampling uncertainty change with variations in the system being measured;
  - ii Systematic errors are often variable over the time- and space-scales of a survey; and thus, random error is contributed to the time-series;
  - iii Maintaining methods and instrumentation does not assure relative measures;
  - iv Characterization of total random error requires knowledge of total uncertainty; and
  - v Absolute measures must be sought.
- Reducing Uncertainty: Zeros in a measurement series are due to both sampling and the process. Methods to account for both types of zeros have been developed for the insurance industry and are applicable to resource surveys. An example of one fisheries application is Smith *et al.*, “Incorporating bottom type information into survey estimates of sea scallop (*Placopecten magellanicus*) abundance.”
- Quantitative Evaluation of Change: Only one paper provided a method for quantitatively evaluating change in a process (Nagelkerke and Tsehaye: Sampling fisheries with high levels of accepted relative error may lead to overestimation of the statistical power of trend detection). This requirement is essential to fisheries management, but gets little rigorous attention. Areas for investigation and standardization are: quantitative methods for detecting change in a time-series of serially correlated data, and correlations between serially correlated data.
- Managing Resources and Risk: A simulation-testing framework was used to evaluate resource management strategies in the presence of uncertainty and thus risk (Pomarede *et al.*: Evaluating the management implications of different types of errors and biases in fisheries resources surveys using a simulation-testing framework).
- Survey data and stock assessments: Apart from the formal presentations, there was wide-ranging discussion on the use of survey estimates in stock assessment. Diverse opinions were expressed on whether comparing survey population estimates to the converged part of the VPA populations estimates could validate assumptions such as the target strength used in acoustic surveys or catchabilities for the population model or trawl survey. In addition, it was suggested that survey data may contain more information on behaviour and population dynamics than are currently used in stock assessment models that look at the dynamics at the scale of annual catches. Most of the research discussed in the theme session dealt with surveys that were designed for a single species or a few target species. There was general agreement that using the same or similar gears to monitor more components of the ecosystem at the same time would only add increased complexity to an already complicated field of research.

## Conclusion

- Uncertainty terms should be used precisely and consistently: Total uncertainty or error is comprised of: measurement error and sampling error. Measurement error is comprised of: random error (precision) caused by the measurements being stochastic samples of the true mean density; and systematic error (bias) effects all the observations equally. Sampling error is comprised of: random error (precision), typically summarized by the C.V., and systematic error (bias), which effects all of the surveys equally
- Absolute measures must be sought. Indices or “relative measures” cannot indicate change as they are not accompanied by estimates of random error. Systematic error on one time- and space-scale may be random error on another time- and or space-scale and vice-versa.

- When conducting an error analysis, zeros must be allocated as either sampling zeros, or real zeros. Methods to do so have been developed in other fields (e.g., insurance industry) and have been recently applied to ecological problems.
- Optimal effort allocation depends on the uncertainty in the measurements and sampling. A cost benefit analysis is necessary to determine the targeted level of uncertainty in resource surveys. This area requires much more attention in both research and application. The biggest challenge in this regard will be dealing with uncertainty in the spatial-temporal characteristics of the processes to be measured.
- Methods must be further developed and used to account for total survey uncertainty when measuring change in a process, correlation between processes, and managing resources and risk.