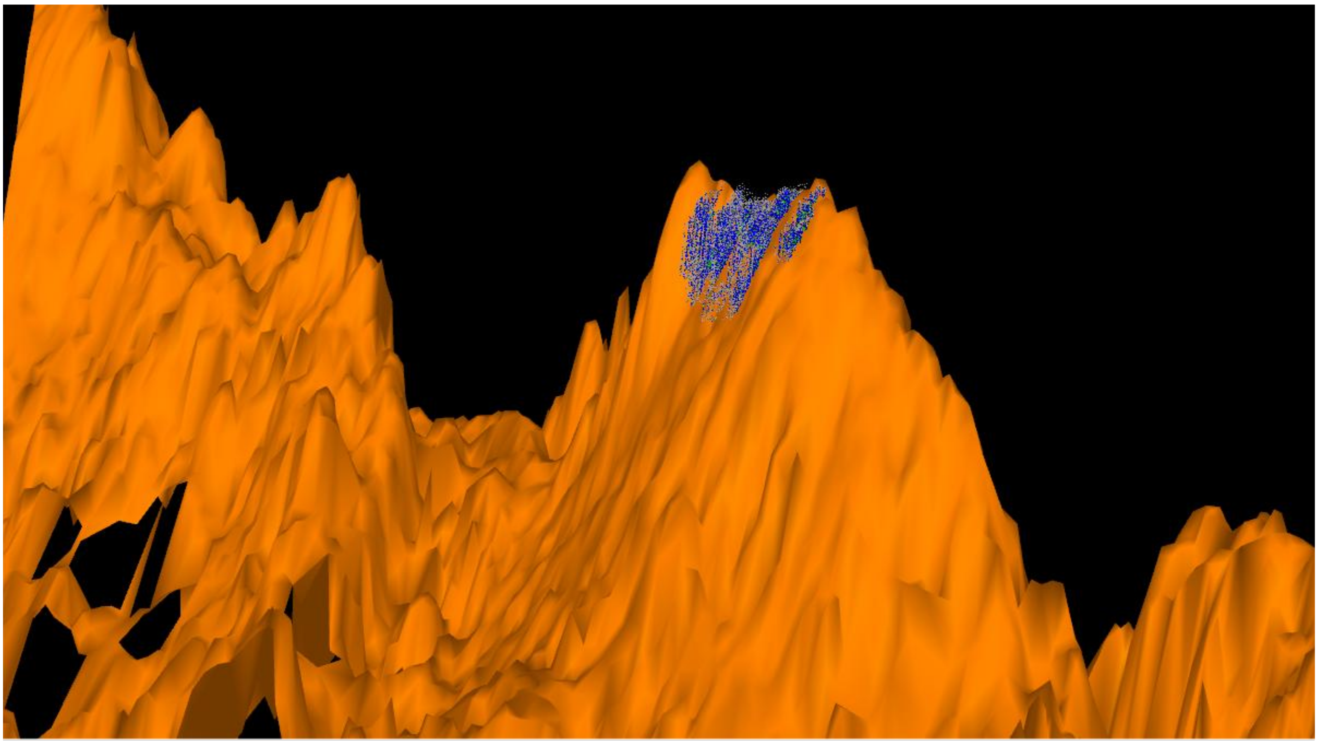
FAO Fisheries and Aquaculture Circular No.1059 FIRF/C1059 (En)
ISSN 2070-6065

FISHING VESSEL EXECUTION OF ACOUSTIC SURVEYS FOR DEEP-SEA SPECIES: MAIN ISSUES AND WAY FORWARD



Cover: Echogram of an aggregation of orange roughy on the side of a ridge along the Southwest Indian Ridge (scale 8 nm and 500–1500 m depth range); courtesy of G. Patchell, Sealord Group.

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FISHING VESSEL EXECUTION OF ACOUSTIC SURVEYS OF DEEP-SEA SPECIES: MAIN ISSUES AND WAY FORWARD

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ROME, 2012

ISBN 978-92-5-107105-2

PREPARATION OF THIS DOCUMENT

This Food and Agriculture Organization Fisheries and Aquaculture Circular is based on the Workshop on Fishing-vessel Execution of Acoustic Surveys for Deep-sea Species: Main Issues and Way Forward, held in Rome, Italy, from 9 to 11 December 2009.

The report synthesizes current knowledge and practice for engaging the fishing industry in the management of the resources they target, highlights the main challenges that arise, and discusses how analysts and decision-makers can use this experience in undertaking aggregation-based fishing-vessel executed acoustic surveys.

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The final report editing was done by Ross Shotton, Merete Tandstad and Jessica Sanders. We are grateful to Angela Towey and Françoise Labonté (FAO) for their help in preparing this circular.

FAO. 2012.
Fishing vessel execution of acoustic surveys of deep-sea species: main issues and way forward.
FAO Fisheries and Aquaculture Circular. No. 1059. Rome. 91 pp.

ABSTRACT

This circular describes the deliberations of the Workshop on Fishing-vessel Execution of Acoustic Surveys for Deep-sea Species: Main Issues and Way Forward that was held at the FAO headquarters from 9 to 11 December 2009.

The topics considered by this workshop included the conditions required at sea for successful fishing-vessel deepwater acoustics surveys, the equipment to be used and its maintenance, processing of data, the problems arising from uncertainty in the backscattering cross section–biomass relation, survey methods, the estimation of biomass abundance and the associated uncertainties, the nature of supplementary biological data that are required for interpretation of acoustic information, use of the results, funding of survey programmes and recommendations for considerations in implementation of fishing-vessel executed deepwater acoustic surveys.

The circular documents the meeting summary and the main recommendations with respect to general considerations, institutional and organization issues, applications at sea and operational challenges, vessels and equipment, survey methods, acoustic data processing and backscattering cross-section values, estimation of abundances, uncertainty of results, importance of collection of biological data, incorporating industry survey results into assessments and management process, funding of cost of acoustic surveys and discussions.

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ABBREVIATIONS AND ACRONYMS

AOS	acoustic-optical system
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
COFI	FAO Committee on Fisheries
CPUE	catch per unit effort
CSIRO	Commonwealth Scientific and Industrial Research Organization
DFO	Department of Fisheries and Oceans Canada
DNA	deoxyribonucleic acid
DSF	deep-sea fisheries
DSU	distance sampling unit
EEZ	exclusive economic zone
ESU	elementary sampling unit
F	fishing mortality
FAO	Food and Agriculture Organizations of the United Nations
F.V.	fishing vessel
GPS	Global Positioning System
GST	goods and services tax
ICES	International Council for the Exploration of the Sea
JPA	Joint Project Agreement
MLGS	maximum likelihood geostatistical approach
NIWA	National Institute of Water and Atmospheric Research Limited
QMA	quota management area
RFMO	regional fisheries management organizations
S_A	backscattering coefficient
SBW	southern blue whiting
SWIO	South Western Indian Ocean
TAC	total allowable catch
TS	target strength
USD	United States dollar
VME	vulnerable marine ecosystem
VPA	virtual population analysis

1. INTRODUCTION AND BACKGROUND

1.1 Introduction

This workshop had two origins: first, the focus by the Fisheries and Aquaculture Department of the Food and Agriculture Organization of the United Nations (FAO) on the issues relating to the management and conservation of deep-sea fisheries that in the last decade have become the focus of attention at national, regional and global levels; second, the increasing realization of the role that the fishing industry can, and should, play in the management of the fisheries resources on which their existence depends.

The fishing industry is the source of much experience and knowledge relevant to the management of the resources it targets and the challenge is for scientists and decision-makers to avail themselves of this experience. While the results of this workshop indicate how far fishing-vessel execution of acoustic survey methods have evolved, discussions at the workshop emphasized that the technique has yet much further to be developed.

Those participating (see list of participants in Appendix A) at the workshop, while doing so in a personal capacity, come from countries where these acoustic surveys methods have experienced considerable evolution and FAO has been pleased to be able to build on the previous efforts of the Expert Group working on this topic under the auspices of the International Council for the Exploration of the Sea (ICES) (ICES, 2007). The objectives of the workshop are considered consistent with the mandate of the Fisheries and Aquaculture Department of FAO as a forum for discussion and development of methods for fisheries management that are within the context of the Code of Conduct for Responsible Fisheries (FAO, 1995).

An agenda was prepared to structure the workshop's deliberations (see Appendix B), but discussions and the work plan varied considerably from that which was anticipated.

1.2 Background

The undertaking of this workshop by FAO is part of its initiatives relating to management of deep-sea fisheries, especially those undertaken on the high seas. These began with FAO's cooperation with the Government of New Zealand in the convening of the International Conference on Governance and Management of Deep-sea Fisheries and associated workshops, reported in FAO (2005) and Shotton (2005a, 2005b). Since then a series of meetings were organized leading up to the publication of the FAO International Guidelines for the Management of Deep-sea Fisheries in the High Seas (FAO, 2008d).

These DSF guidelines were prepared in response to a request by the twenty-seventh session of the FAO Committee on Fisheries (COFI) (March 2007) to elaborate technical guidelines on standards for the management of deep-sea fisheries (DSF) in the high seas and related resolutions at the United Nations General Assembly relating to conservation of deep-sea fisheries and biodiversity of related bycatch and habitats.

The FAO deep-sea guidelines note in paragraph 80:

"*States should encourage dialogue and collaboration with responsible DSF operators in the development of fishery management plans, recognising the value of industry information and experience in resource assessment and fisheries management, identification of vulnerable marine ecosystems (VMEs), responsible fishing techniques, gear development, and implementation methods to avoid or mitigate significant adverse impacts on VMEs*."

The FAO programme for the implementation of these guidelines was endorsed by the Twenty-eighth Session of COFI in 2009 and at the United Nations General Assembly in a resolution at their Sixty-third Session in 2009.[1]

The 2008 DSF guidelines were the result of several preparatory Expert Consultations organized by FAO. One of the consultations prior to the adoption of the FAO DSF guidelines, the 2007 Expert Consultation on International Guidelines for the Management of Deep-sea Fisheries in the High Seas (FAO, 2008c) concluded that (paragraph 39):

"*Biomass estimation is difficult for many, if not most, deep sea species. Given the limited resources likely to be available in offshore fisheries, and the urgent need for immediate management, fishery dependent techniques (e.g. fine-scale catch per unit of effort), and/or techniques able to be applied on commercial vessels (e.g. acoustic surveys) may need to be implemented*".

This conclusion was reached, following discussion of a number of high seas deep-sea fisheries, where key components of many of the fisheries included high spatial and temporal variability, seasonality of these fisheries and the complex topography of oceanic ridges, all of which have a major impact on the use of catch per unit effort assessments in these fisheries. A number of these fisheries involved targeting single species aggregations similar to those found within exclusive economic zones (EEZs) and typically surveyed with acoustics.

The objective of paragraph 80 has contributed to the reasons for convening the workshop, whose deliberations are reported here: it reflects the recognition, especially building on national practice in Australia and New Zealand, that deepwater commercial factory trawlers are well placed to undertake acoustic assessment of fish stocks they harvest during fishing trips interspersed with fishing operations. This practice complements, and has followed, the emergence of changes in the nature of governance of fisheries, especially in sovereign waters of countries where in many cases the rights of fishing operators to shares of the fishery, either catch or effort quotas, have been recognized. This assumption of fishing rights has in some cases accompanied the transfer to the industry of many management and assessment responsibilities.

2. INSTITUTIONAL AND ORGANIZATIONAL ISSUES

2.1 Who this report is intended for

From an institutional perspective, the workshop identified three primary groups that were to be addressed:

- *administrators* who are required to make decisions as to the permitted levels of harvest. This includes decision-makers in regional fisheries management organizations (RFMOs) and national fisheries departments;
- *vessel operators* who manage participating vessels; and
- *skippers/vessel officers* who must undertake the surveys.

[1] 41. *Welcomes* the adoption by the Technical Consultation, convened by the Food and Agriculture Organization of the United Nations, in Rome from 25 to 29 August 2008, of the International Guidelines for the Management of Deep-sea Fisheries in the High Seas, as requested in paragraph 89 of resolution 61/105, which include standards and criteria for use by States and regional fisheries management organizations or arrangements in identifying vulnerable marine ecosystems in areas beyond national jurisdiction and the impacts of fishing on such ecosystems and in establishing standards for the management of deep sea fisheries in order to facilitate the adoption and the implementation of conservation and management measures pursuant to paragraphs 83 and 86 of resolution 61/105, and calls upon States and regional fisheries management organizations or arrangements, as appropriate, to implement those Guidelines. Resolution adopted by the General Assembly [*without reference to a Main Committee (A/63/L.43 and Add.1)*] 63/112. Sustainable fisheries, including through the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and related instruments.

Administrators will be responsible for ensuring that fishing operators vessels are capable of undertaking the acoustic surveys in a manner that results in acceptably accurate estimates of stock abundance. In this regard, inherent constraints in the commercial vessel survey process should be no greater than that which would occur if the survey was undertaken by a dedicated research vessel. For example, uncertainty as to the appropriateness of the conversion factor between the sonified fish biomass and incident and echosound intensity will be the same irrespective of the nature of the vessel collecting the acoustic data – commercial fishing boat or dedicated research vessel. The administrator should also be satisfied that those undertaking the survey are capable of competently executing the procedures that are necessary and will do so.

The incentive for an administrator to adopt this approach is most likely to be financial – if there were no cost saving, then it would seem that a dedicated research vessel would be the method to use. However, such a vessel[2] may not be available, or at least, not available for the length of time that would be required to obtain a useful result. Further, in some cases, it may not be possible to address the problem at hand using a single vessel (e.g. when synoptic surveys undertaken in a short time frame are needed) and where a multiple-vessel survey is essential to obtain useful results.

The decision by the member countries of a Regional Fisheries Management Organization (RFMO) (or flag states in cases where there are no RFMOs) to embrace this method of resource assessment[3] will require (often consensual) agreement of the member countries. Some RFMO members will be less, if at all, familiar with the method than others; their flagged vessels may not be appropriately equipped to undertake such assessments, and moves to require obligatory participation of their vessels in an acoustic stock assessment programme may backfire by having the targeted countries reject this type of resource assessment. Here, consideration must be given as much to the tactics of implementing such a survey method as to the implementation strategy.

An often ignored or underrated benefit of using fishing vessels for research surveys is that this provides opportunities for interaction between scientists and fishers that encourages a cooperative approach to assessment and management. This cooperation can also lead to an increased level of trust where involving stakeholders leads to a better acceptance of the results through a sense of ownership of the research.

Vessel operators support for survey activity by their vessels is needed as it is they who provide trip/ sailing instructions to the skippers. Skippers who fail to observe their trip instructions usually are discharged. In this regard, it is essential that skippers get clear direction from their managers and will undertake what is required of them. For example, if the commitment of the vessel operators to a programme of commercial-vessel acoustic surveys is equivocal, the message to the skippers is that it will be acceptable to management whether or not they undertake the acoustic survey programme as requested by those responsible for the stock assessment. The need for unqualified support of the stock assessment programme will be less pressing when there is a requirement to undertake such surveys as a condition of their fishing licence. In this case, failure to complete the required number of surveys may result in forgoing the possibility of fishing the target stocks in the future.

It is the skippers/vessel officers who must undertake the acoustic surveys and provide the acoustic data in a satisfactory manner: they have the operational responsibility for the success of this method of stock assessment as, at sea, they alone are in the position to ensure the success of the method. Their support may be gained through a "command and control" approach where they are given the orders that they are expected to execute. Or, more constructively, their cooperation may be achieved through gaining their support for the initiative by involving them in the decision-making process and ensuring that they understand the reasons and objectives of the assessment approach. Undertaking formal consultations among skippers in some fisheries, e.g. as for the Southern Indian Ocean, has been an effective way of dealing with vessel officers' resistance to adopting new operational approaches or to

[2] In this context, a suitable research vessel could also be a chartered commercial vessel.
[3] Note that not all RFMOs do their own assessments.

any claims that their operational fishing requirements make it impossible to even contemplate such approaches.

2.2 Why there is an issue

When management of a fishery involves, as one requirement, estimates of resource abundance in the setting of catch quotas, good estimates of biomass will reduce the probability of inadvertent overfishing through the setting of excessively high quotas. Traditionally, one measure of the abundance of a fish stock is obtained through surveys by research vessels of the area in which the stock is believed to range. In the case of deepwater stocks, because of distances and weather conditions, such vessels must necessarily be large, and their daily costs can range from USD 20 000 to USD 30 000. Total costs for a resource survey using just one vessel can range up to USD 500 000 and more, depending on the length of the survey. Furthermore, there is a limit to the size of the area that one vessel can cover and using more vessels may accumulatively provide better results. In favour of the use of research vessels is that they can be equipped with the best survey equipment and be manned with highly experienced technicians.

However, many deep-sea fisheries are extensive in nature, occurring across wide oceanic areas. Where the resource is associated with sea floor features, there may be considerable inter-annual and intra-annual uncertainty as to where the fish aggregations are going to be found: there is no guarantee that fish aggregations will be found the following fishing season at the same sea floor feature. Thus, a research vessel may visit and "survey" many sea floor features, find no fish aggregations, and based on this conclude that the fishery has been depleted.

This problem is particularly acute in small fisheries (often referred to as boutique fisheries[4]), especially if they exploit many stocks across a wide area. Here, the first task is to locate the fish aggregations, then once this is done, to estimate the amount of fish in the respective concentrations. This first task is what fishing vessels do; search for fish aggregations, though to catch them rather than survey them. However, as the results of this workshop describe, in many instances, fishing vessels are now also undertaking the second of these tasks (i.e. survey) – as this may be the only way of getting a direct minimum-biomass estimate , using either a single vessel or through the use of multiple vessels..

When the fishery is small, not only may it be impossible to justify the expense of a fully committed research vessel survey, but using only a single vessel can also produce results so uncertain that the survey cannot be justified and, at the same time, at a cost that is not justified by the value of the fishery. In this case, using the commercial vessels to assess the size of the aggregations, either before or after fishing them, may be the only feasible way of obtaining a biomass estimate.

Factory trawlers prosecuting aimed-trawl fisheries characteristically encounter large fish aggregations, albeit on a sporadic basis. In these circumstances, to ensure optimal product quality, it is undesirable to have large quantities of fish on the deck if they cannot be quickly processed. Such situations are ideal for using commercial vessels to undertake the stock assessments: (i) there are large amounts of fishes present (that may be a significant fraction of the stock); and (ii) the vessel would, in any case, be laid to because of processing limitations. In these circumstances, survey work would have low or negligible opportunity costs. However, this is not to say that these are the only circumstances when a survey can be undertaken.

2.3 Strategic and tactical considerations

It is useful to explore in more detail the strategic and operational perspectives of the key stakeholders.

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[4] Though small, management of boutique fisheries will still require all of the activities associated with large fisheries – data collection, resource assessment, decisions on setting allowable catches, ensuring compliance with conservation regulations, enforcement of regulations, etc.

The relative priorities of administrators (sometimes called "decision-makers") will vary. They will be concerned with considerations such as:

- Will commercial-vessel acoustic surveys result in acceptable and/or useable estimates of stock biomass?
- Will the method be challenged/rejected because industry was responsible for the collection of the data? Is it possible for the data/results to be falsified for whatever reason?
- Has the case for using commercial vessels to collect the data been convincingly made, or made at all? Are there alternative means of providing the information that is required, e.g. using conventional methods such as "fishery-independent" surveys undertaken by dedicated (research) vessels?
- Is execution of the method acceptable/possible to all operators in the fishery? Can participation in the programme be made obligatory, e.g. through a licensing condition that makes it a requirement to undertake "specified" survey effort, and if so, would it be counter-productive to enforce such an obligation?

Administrators will deal mainly with vessel operators, i.e. usually the company owners or the flag state, but as a matter of caution they should be aware of the attitude of skippers to accepting new operational obligations. Thus, administrators may insist that there be appropriate evidence of vessel officers' competence to undertake the survey method and they may wish to ensure that there is appropriate support to ensure that skippers and vessel officers – the practitioners on the commercial vessels – are properly trained. They may also ensure that there is agreement and support among the fleet operators in a particular fishery as to their participation in the programme, and, once this agreement is obtained, that vessel skippers and officers are competent to implement the methods so that reliable and useable data are collected.

Because operators (and vessel skippers) will have the responsibility for ensuring that their bridge officers undertake the surveys as required, they must understand the reasons for supporting the method. And, as experience (reported in this report) is showing, if the incentives exist to reward industry responsibility for, and funding of, participation in such methods, they will participate with enthusiasm and diligence.

Administrators must also make the effort (and have the time) to at least understand the principles of what is involved and not merely accept as unquestionable "scientific" instructions on what should be done. This implies two responsibilities: first, that of the technical workers involved to be aware of the sources of uncertainties in their results, and second, be able to explain these uncertainties and the extent of potential error in the results they present. Such explanations should extend to describing the possible consequences to the resource of risk-prone interpretation of survey results and management advice.[5] In the case of acoustic surveys, uncertainties will arise from the model used to interpret the survey design and the quantitative relation between the incident sound, the biomass of the species that is the target of the survey and the echo intensity and hence the estimate of fish biomass derived from the acoustic results.

Administrators may have to consider the introduction of commercial-vessel acoustic stock assessment in one of two situations:

- Where no previous surveys have been undertaken and commercial vessel surveys will provide the first survey results.
- Where surveys have in the past been done by research vessels: commercial vessel surveys may be considered as a cost-saving measure or because of other considerations

[5] It is an (apocryphal?) assumption of many fishery scientists that decisions-makers will accept the most optimistic option when presented with a choice no matter the relative risks.

In the second of these cases, administrators and scientists will need to accept the reassignment of some responsibilities to the industry, though the need for monitoring the survey activity and auditing the results should remain.

The vessel operators/owners will need to ensure that their vessels are suitably equipped to undertake the acoustic surveys. This will include installation of an appropriate acoustic system in the vessel if it does not already have one. It may be that a special transducer must be fitted in the vessel's hull. This will require considerable planning as to do so is usually only possible during vessel dry docking. Needless to say, this represents a considerable capital expenditure if the vessel does not already have an appropriate acoustic system.

The vessel operator will need to ensure that the acoustic system is calibrated at regular intervals to make sure that the relation between the output of the acoustic system and the fish biomass that is sonified is stable and known – another cost and vessel activity scheduling requirement – and that the bridge officers know how to operate the system. The operator must also make effective arrangements to ensure that the raw data and survey results from all survey work are securely archived and easily accessible and that backup copies are safely stored on an indefinite basis. This archived material should include information on the system calibration and details of any changes to components of the acoustic system.

Furthermore, the vessel operator will need to budget and arrange for the analysis of the acoustic survey results. Depending on the degree of complexity that is involved in the analysis and the survey design method, this may be considered a significant cost. This work is often done by acoustic scientists or, in some cases, specialist acoustics consulting companies.

Vessel operators survive by achieving commercial advantage. Thus, especially in the absence of secure fishing rights, they will have an incentive to avoid unnecessary costs, or at least costs they believe will result in little or no benefit. There may also be an incentive to adopt a "free-rider" policy if it is possible that the required commercial-vessel acoustic surveys can, or will be done by other companies. Best results will be obtained when all vessels in a fishery participate equally in the survey responsibilities, though this does not rule out inter vessel negotiations: one vessel many contract out their survey responsibility to another operator. In either case, the responsibilities of the vessel operator must be carefully defined to avoid ambiguity and so that the survey requirements can be clearly communicated to vessels' skippers.

As the execution of commercial-vessel acoustic stock assessments will be the responsibility of the vessels' skippers and their officers'; self-evidently theirs will be the critical role in this process. Usually these vessel officers must be highly functional in using echosounders and the further step of operating an acoustic system to collect fish abundance data must not be a major difficulty for them. More important is ensuring their commitment to the process and that data are properly collected and stored. This is not a trivial matter but, as this report documents, there is now considerable experience (see Appendix F – Case Studies) as to how to ensure the success of this management method.

Vessel crews, and especially the skipper and officers, are inevitably paid on a bonus basis. If surveys cannot be conducted while the vessel is fully occupied processing fish, there will be strong incentives to find reasons why a "survey" was not possible at a time when it should be undertaken so as to instead pursue fish-catching operations – this is, after all, why the vessel is at sea. Thus, it is essential that the minimum requirements for the execution of acoustic surveys during a fishing trip be explicitly defined and communicated to the skipper during his pre-cruise briefing and that the vessel operator is clear that a skipper's tenure depends on satisfying these requirements. If the survey requirements have been defined as a licensing condition for the vessel's operations, then there will be less chance of a skipper failing to fulfil the trip surveying requirements.

There is a fourth constituency that will be important if the target fishery occurs in the high seas . These areas in almost all cases are regulated by RFMOs. Functioning and decisions within RFMOs are often the result of a complex interaction of national interventions and the interpretation of "best (available) scientific information", or indeed, any information. RFMOs will often be confronted with situations in which the use of commercial-vessel acoustic surveys would be of major benefit to their decision-making. For example in cases where the conventional means of stock assessment that rely heavily on the analysis of catch per unit effort (CPUE) and estimates of fishing mortality (F) may not reflect the anticipated relation between fishing effort and stock abundance. In some areas, e.g. the Southern Indian Ocean, deep water fisheries that target species such as orange roughy (*Hoplostethus atlanticus*) or alfonsino (*Beryx splendens*) are undertaken by aimed trawling, and local-area catch success may depend on a variety of factors not accommodated in the traditional relationship between fishing mortality and fishing effort through the catchability coefficient.

Getting agreement through an RFMO to adopt management methods that are heavily reliant on commercial-vessel stock assessment surveys may be easy if there are no alternatives. Further, it may be easy to achieve commitment to the process by the industry if there are inducements to do so, e.g. though the provision of secure fishing rights that provide an incentive to, or requirement of, the operators to assume the responsibility for the costs of providing assessment information. This developing area of international fisheries law is beyond the scope of this paper. The workshop stressed that successfully falsifying acoustic survey data was extremely difficult and was as likely to result in a losing as a winning outcome.

Perhaps the best advice that can be offered in situations where some are reluctant to accept and use information obtained in this manner is to bring to their attention examples from the many instances where the procedure works and to try to arrange direct first-hand exposure to these survey practices. Where observers are carried on the fishing vessels, and if they have the appropriate experience they may be involved in the process so as to be able to verify that procedures have been correctly followed. Further, data analysis may be undertaken by "accredited" or independent agencies in the hope that this will minimize concerns about the lack of use of objective methods in producing the results.

Where decisions by an RFMO are consensual, the agreement to use or accept commercial-vessel stock assessment procedures will depend on the agreement of the least enthusiastic member(s). Despite this, care should be taken not to minimize the complexity of the methods, their limitations and the uncertainties in the procedures. Even when these are fully acknowledged, the method may be the best, if not the only one, available that can provide the required information.

2.4 Requirements that must be met for stock assessment

Conventional fish stock assessment will attempt to obtain an estimate with the least bias and the maximum precision (i.e. smallest variance) for the survey time that is available for the assessment. Bias in estimates of deepwater fish species will, in addition to other sources, arise from:

- an unknown part of the stock occurring outside the survey area;
- target fish being unavailable for acoustic detection, e.g. through being in close contact with the sea floor so as to be masked by the bottom echo;
- uncorrected contributions to the echo intensity from non-target fish species;
- incorrect system calibration and/or system drift (rare); and
- an incorrect conversion coefficient (a function of the backscattering cross-section area – σ_b) between the measured fish echo intensity and the sonified fish biomass giving rise to the echo.

All five and certainly the last four of these sources of bias will be the same for both research-vessel and commercial-vessel surveys, and efforts directed to reducing these sources of error will benefit both types of surveys. However, the first of these sources of bias highlights a different importance in commercial-vessel surveys.

Unlike research-vessel surveys that usually attempt to survey the entire stock, or at least most of it, abundance estimates from commercial-vessel surveys will only apply to the aggregations that have been encountered. The concept of statistical bias (δ^2) in the context of its contribution to total estimate's mean square error ($\delta^2 + \sigma^2$) does not apply. The estimate will be a "minimum biomass estimate".

3. APPLICATIONS AT SEA AND OPERATIONAL CHALLENGES

3.1 Operational characteristics

There are two main methods used in undertaking acoustic surveys on commercial vessels:

- programmes controlled by RFMOs or states, where scientists join vessels and conduct surveys by directing the vessel's master[6]; and
- surveys undertaken by the vessel's master, using appropriate incentives and/or penalties.

The ICES report on the collection of acoustic data from commercial fishing vessels (ICES, 2007) is highly informative and specific on how to select suitable commercial vessels for acoustic fish resource surveys but not on how to encourage and facilitate data collection in high-seas fisheries.

The general nature of high seas fisheries requires that vessels are at sea for several months and operate long distances from ports. This generally precludes the first of the options above – using institutional fisheries scientists and, for this reason, little emphasis is given to this option. Further, methodologies for this situation are well described in the ICES report (ICES, 2007).

An important factor with most high-seas vessels is that they are large – a requirement given the distances from shore at which they operate and the often inclement weather conditions. They inevitably are equipped with a full range of high-quality electronic systems. Without these, the vessels would rapidly fail financially (unless their operations are subsidized) and leave the fishery.

To undertake acoustic fish stock assessment surveys during commercial operations in a pre-existing fishery, all prior knowledge should be evaluated first in developing a survey strategy and implementation tactics. This should involve interviews with fishermen, vessel operational managers and relevant scientists to discuss the type of survey that should be used, such as area-based surveys or aggregation-based surveys.

An essential characteristic of vessel operations in high-seas fisheries, either under the control of RFMOs where catch shares are allocated, or in those where licences are allocated (input/output control regimes), is that they are commercially competitive. There is a cost to the vessel's operation of any research activities that affects their ability to fish and thus the net returns of the fishing operations. Vessel crews and especially skippers and their officers are usually paid on a bonus basis, and a reduction in fishing effort will reduce their earnings as well as returns to the operating company. To avoid the situation of "free-riders" whereby only some of the fleets' vessels undertake survey operations, all participants in the fishery must commit to undertaking similar research programmes.

If any quota or payment is allocated by an RFMO or state in return for the research programmes carried out by commercial vessels, formal contracts must be established between the parties, i.e. the vessel owner, the vessel's management agency and the recipient of the research results (often termed the research provider).

Once protocols for the type of surveys to be undertaken have been established, the vessel operations manager, skipper and officers need operational plans to follow (e.g. FAO, 2006). These plans must be provided for each fishery and explain in detail the extent of the surveys, the anticipated sea time

[6] In such situations, the ship's captain may only be responsible for the safety of the vessel.

involved, if they are regular (annual) or "once-off" surveys, and what commitments will be involved for costs of analysis of the data and report preparation. Operators need to be aware of the commitments required of them and what the implications of the results of the survey will be. For example, whether a single survey can be used to produce a reliable biomass estimate that can be used for planning purposes for a number of years or whether surveys need to be repeated over a number of years. This may depend on the population biology of the species being surveyed, or on the nature of the habitat. For example, around a seamount the species distribution may be relatively stable or be highly mobile among the banks. Stocks may mix on the same sea floor feature for a variable part of the year – another management complication.

3.2 Role of incentives/disincentives

Under the International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (FAO, 2008A) and the FAO Code of Conduct for Responsible Fisheries (FAO, 1995), fishing vessel operators are responsible for supporting sustainable fisheries. Because of the high level of investment required for deep-sea vessels, there is an increasing incentive for operators to make the substantial investment required for deep-sea fisheries research.

One option for areas under the control of an RFMO is to specify the resource survey requirements as a licensing condition for the vessel's operations: in this case, there should be less chance of the skipper failing to fulfil the trip surveying requirements. If surveys cannot be conducted while the vessel is fully occupied processing fish, there will be strong incentives to find reasons why a "survey" was not possible at a time when it should be undertaken and instead to pursue fishing operations. In this case, one option is to define a minimum catch amount from a stock (or sea floor feature) that triggers a requirement to do a resource survey. This is an important concept and in the Indian Ocean deepwater fishery, it has been proposed that a catch of 200 tonnes of fish from a single fishing ground will trigger a requirement for an immediate resource survey. The rationale for this is that a catch of this amount implies that a significant biomass is present in the area and there is a reasonable chance of assessing them with an acoustic survey. A further (penalty) option that an RFMO might consider is that if a survey is not done on a particular ground in a fishing season by a vessel then that vessel is not allowed to fish that ground during the following year.

A potentially strong incentive for vessel operators and skippers to fulfil their survey obligations responsibly could be that if a survey is inadequately carried out it will result in a low biomass estimate, and hence correspondingly low allowable catch. Skippers and managers need to understand this may then lead to catching restrictions in the future and/or require that additional surveys are carried out in future years. Alas, the implied loss function to skippers and vessel operations of too-high estimates is not symmetrical given their shorter-term time preferences.

Participants in high-seas fisheries need to know the management rules under which fishing proceeds: this is especially important for deep-sea species because they may be highly variable in their presence over time and space. This phenomenon is well known for fisheries such as the orange roughy and alfonsino in the Indian Ocean and the Tasman Sea. With deep-sea fish stocks, one expects relative stability in the size composition/biomass between years in the absence of excessive fishing, i.e. large "real" changes in annual biomass, as can occur for species such as blue whiting, are not expected. Hence, if a survey of a particular stock is not conducted in one season because it was not fished that year, it should not result in a zero catch limit for the subsequent year. Or, if a lower estimate results from a survey, and there was no catch taken during the corresponding period, it may be caused by an inadequate survey or reduced availability of the stock. Such possible effects need careful evaluation.

The security of commercially sensitive survey information is of critical importance to vessel operators, especially in smaller high-seas fisheries where few vessels may operate. Uncontrolled or poorly controlled access to commercial-vessel survey information, i.e. acoustic logging data, can result in the free transfer of expensive-to-collect information - commonly referred to as the *intellectual property* of the operators - to other operators who have not made similar investments in the management of the fishery. This can create an important disincentive to undertake survey work, and regulatory authorities must have appropriate operational means of avoiding this in order to get reliable assessment data.

There needs to be formal means to provide constant feedback on their survey performance to keep skippers and their crews motivated: ensuring that they remain informed about the results and use of the information they collect is critical. To the surprise of some, skippers and their crews may be among the greatest proponents of such surveys and in several cases skippers have undertaken resource surveys on their own cognizance and at their own cost to their vessels' fishing success.

Pre-trip briefing and post-trip review of vessel operators, skippers and their crews can be done by scientists who provide and explain the analyses of vessel results in an understandable manner. As an indication of one aspect of this process, Figures 5.1–5.6 show the results from six years of surveys on a single stock of orange roughy in the Indian Ocean. Feedback to the skippers on the results of the 2006 survey resulted in improvement in the 2007 survey with much better coverage. In 2008, there was little catch taken from this ground and only one survey was carried out, but in 2009 several surveys were undertaken.

3.3 Integrating surveys with commercial fishing activities

Acoustic data collection from industry vessels is often carried out in conjunction with commercial fishing activities. If the vessel must suspend its fishing activities to carry out acoustic survey work, then this incurs a cost. Under certain circumstances, acoustic data collection can be carried out without compromising fishing success by using periods of fish processing time (O'Driscoll and Macaulay, 2005). This approach works well for small-scale aggregation-based acoustic surveys. The major limitation is that the boundaries of the survey area are determined by the time available during the processing "window". The length of the processing "window" depends on the size of the preceding catch (which in turn may be related to market-driven quality requirements) and also the time required to locate a suitable mark for the next commercial trawl. In surveys of New Zealand hoki, the processing window is typically 3–8 hours, which is sufficient to cover an area of about 200-300 km^2.

Other characteristics of the fishery are important for this type of survey approach. If the location of aggregations is relatively predictable, this reduces the time required to find suitable marks for commercial fishing. If aggregations are dense and catch rates are high, then tow duration can be short. The combination of these factors means that fish can be caught "on (processing) demand". In fisheries with more dispersed aggregations and/or lower catch rates, the downtime between trawls is reduced because the vessel must search for aggregations, or because the trawl is shot earlier to allow for the longer tow duration.

3.4 Echo mark identification

In high-seas fisheries on sea floor ridge systems, seamounts and banks, there is often a complex, and difficult to decipher, mix of species present because of the type of habitat. Ridges may rise from 200 to 6 000 m from the surface at the shallowest with parts of the ridge rising to 600–900 m above the surrounding sea floor. However, although there may be a complex mix of species over the ridge, the different species occupy different depth zones. Vessel officers spend much of their time at sea viewing these species' complexes on echosounders and also have access to the prior experience of other officers, who have worked on the vessel or on the same grounds. Overall, in any one region there are few fish marks that have not been targeted for fishing at some time in the past. Hence, on any echogram, vessel officers inevitably know which marks represent the target species and which do not. If the species identity of an echo mark is unknown or uncertain, typically they will fish it to determine its species composition.

This information and experience is typically unavailable to acoustic analysts unless they also have prior experience in this fishery or there is a system in place that enables them to have an effective dialogue with the vessel officers. In this context, it is essential to have a real-time logging system that would enable vessel officers to record what species they thought various marks on the echogram were. Such information must be recorded, and the only way to do this is with a written log. When a vessel is surveying, the depth zone of various species on each transect line should be noted, e.g. as described in FAO (2006). Examples of log formats that may be used are given in Appendix C.

4. VESSELS AND EQUIPMENT

4.1 Introduction

Modern echosounder technology provides the ability to collect and replay digital data needed to estimate sonified fish biomass. Unfortunately, the simplicity of use of available acoustic systems often leads to misuse and misunderstanding of the technology in collecting data for quantitative ecosystem studies or fisheries stock assessment. There are a number of basic equipment requirements for any vessel, be it a research or commercial fishing vessel, to collect quantitative acoustic data. These can be grouped into five categories: (i) the echosounder; (ii) the vessel; (iii) vessel equipment required to operate the acoustic equipment; (iv) the acoustic hardware; and (v) fish sampling gear. Specific details of these requirements are described in the ICES Report (2007), which this section borrows heavily from.

4.2 The echosounder

A high-quality acoustic system is essential if an echosounder is to be used to collect data for stock-assessment purposes. Many echosounders and depth sounders are available, but few have the quality required for scientific purposes and quantitative acoustic data collection. While there are no specified standards for acoustic survey hardware, the system must transmit a stable acoustic pulse and have stable electronic characteristics during the receive phase. Scientific acoustic systems are designed to maintain a constant transducer beam pattern and transmission power over a variety of conditions and an extended period of time. This stability allows the system, once calibrated, to collect quantitative observations that are repeatable within acceptable error bounds. Many acoustic systems can be used to locate and observe fish, but they may be unusable for quantitative purposes because they cannot detect system-related inconsistencies that, though slight, seriously affect measurements of echo intensity that are used to estimate fish biomass. Further, until recently, many commercial sounders did not provide a convenient mechanism to save the data required for editing or allow easy access for post-cruise analysis and provision of subsequent biomass estimates.

The most common commercial fishing echosounder used at present for quantitative acoustic surveying is the Simrad ES60 using either a single or split-beam transducer. Some commercial fishing vessels have even purchased EK60 scientific echosounders for fishing and data collection. However, several other manufacturers have developed both scientific and commercial fishing sounders that are capable of collecting and recording reliable quantitative acoustic data. Each system comes with its specific limitations. Simrad, BioSonics, HTI, Femto Electronics, Kaijo, Furuno and Precision Acoustic Systems are examples of some commercial manufacturers of off-the-shelf echosounders that have the capability of collecting quantified digital data.

4.3 Frequency considerations

In most scientific acoustic-system applications, there is no single transmitted sound frequency or transducer beam angle that suits all purposes. For an echosounder to be used as a quantitative tool to measure fish abundance and distribution, consideration must be given to the properties of sound transmission in seawater, the environmental conditions and the biological characteristics of the target species. Acoustically, there is an inverse relationship between the transmitted sound frequency that is used, the detection range and detectable target size. The higher the sound frequency, the greater the attenuation in seawater and thus the shorter the range capability of the system. But, the higher the frequency, the smaller the individual target that can be detected. For deep-sea fish, the workshop recommends that a frequency of 38 kHz or less is used together with a transducer with a relatively narrow beam angle. The smaller (and cheaper) the transducer, the wider the beam angle.

4.4 Choice of vessel

A major objective in using commercial fishing vessels to undertake the assessment of the stocks that they fish is to transfer the responsibility for at least some of the management activities to those who derive the direct benefits from the fishery. Thus, from an administrator's perspective, subject to obvious suitability, the issue of which vessels to use is one for the industry. If the survey activity is undertaken by a vessel active in the fishery, then self-evidently the vessel will be suitable for the weather conditions and ranges that are expected to be encountered.

It is essential that the vessel does not have noise characteristics that prevent it from obtaining useful acoustic data. Noise may be generated by, for example, a Kort nozzle if one is fitted and this may render the vessel unsuitable for undertaking acoustic surveys, or by electrical interference from vessel machinery, for example, a bilge pump that transmits a signal that is detected by the acoustic system. Such sources of noise may only be detected when the vessel is operating, which may not be the case when the calibration is being undertaken and acoustic technicians are on board. ICES (2007) discusses in detail the noise characteristics of vessels and criteria to be used in selecting survey vessels if a choice is available.

Many deepwater fishing vessels, if not all, are equipped with a complete suite of acoustics equipment, which often includes those that are necessary to undertake quantitative acoustic surveys. If this is not the case, such a vessel operator may be able to contract its survey obligations to the operator of a vessel that is appropriately equipped. However, not all vessels will be suitable to undertake acoustic surveys.

The hardware requirements to enable quantitative acoustic methods to be used are minimal and common to all deployment methods. These include a stable power supply for operation of the acoustic hardware, a general purpose transceiver and computer, and a reasonable-quality Global Positioning System (GPS) with standard NMEA 0183[7] output.

4.5 Location of transducers

An important requirement is that the vessel is equipped with a suitable transducer. This may mean that a new transducer must be fitted to the ship's hull before surveys can be undertaken, which can usually only be done during dry-docking. This implies a scheduling task for the ship's manager. If the vessel has a bulbous bow, the transducer may be fitted in here, though this part of the vessel is subject to greater pitch motion and may possibly be out of the sea in heavy weather conditions.

Additional vessel and system requirements vary depending upon whether the transducer deployment is mounted in the hull, on a pole, in a towed body, or on the fishing gear. In the first two cases, a standard transducer can be deployed near the surface; however, in using a towed body, additional requirements include a depth-rated (or calibrated) transducer, a conducting tow cable and a towed body. Most acoustic surveys using commercial fishing vessels are conducted using hull-mounted

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[7] NMEA 0183 is a combined electrical and data specification for communication between marine electronic devices such as an echosounder, sonars, anemometer, autopilot, GPS receivers and many other types of instruments. The NMEA 0183 standard uses a simple ASCII serial communications protocol to define how data are transmitted in a "sentence" from one "talker" to multiple "listeners" at a time.

systems. If a vessel is being used only occasionally to undertake surveys, experience shows that the transducer can be successfully mounted on a pole fixed to the ships side. Ideally, this pole places the transducer below the keel and may reduce possible attenuation of the sound pulse in heavy weather caused by aeration of the water from wave action.

The option of using a towed body is usually only considered for research vessels. This enables the transducer to be lowered to considerable depths depending on the length of the towing cable, the "aerodynamics" of the transducer housing, ship's speed and the weight of the towed body. A usually expensive, strengthened towing cable is required and a vessel-mounted hydraulic crane to deploy and retrieve the towed body.

4.6 Calibration

Calibration of an acoustic system is the determination of the system's output (usually in volts) to a constant and known transmitted power and the echo intensity (W/cm^2) from a target of known backscattering cross-section area. This can be done with a calibrated transducer. Equivalently, a target of known backscattering cross-section (e.g. a calibration sphere) is suspended a known distance from the ship's transducer, and the system's response undertaken to ensure that an echo intensity from an individual fish (more specifically scatterer of constant reflecting properties) under identical conditions, will result in the same system output once the physical properties, such as system gains, sound attenuation from spreading and absorption of the sound pulse, and the target's position in the acoustic beam[8] have been taken into consideration.

Calibration of an echosounder is done using a copper or tungsten-carbide sphere with a known backscattering cross-section area (Foote *et al.,* 1987). The sphere is suspended directly beneath the transducer by three adjustable lines. Positioning the ball within the acoustic beam can be time consuming when its exact location in the beam is unknown. For this reason, it is easier to calibrate a split-beam transducer.

The depth required to suspend the ball below the vessel during calibration depends upon the frequency of the sound being transmitted. The minimum distance between the transducer and the ball is also dependent upon the far field distance of the transducer. The far field is defined as the distance beyond which there is a simple relationship (proportional to $1/\text{range}^2$) of sound attenuation; this depends on the beam pattern factor, a function of beam size, shape and sound frequency. Note that this minimum distance is a theoretical calculation and range intervals greater than this are not only preferred but should be used. In practice, it is advisable to add 5 to 10 m to the minimum far-field distance to ensure the target is in the far field of the transducer, and that there is sufficient clearance above the bottom. Sea temperature and the sound absorption coefficient may have to be considered depending on the frequency of the system being calibrated. For a 38 kHz acoustic system, a minimum of 15 m below the hull is needed to undertake a calibration. However, for frequencies less than 38 kHz, it is unlikely that sufficient water depths will be available in port and the calibration must be undertaken in a sheltered bay or inlet with sufficiently deep water to accommodate the depth requirements. Calibration requirements are listed below.

[8] The further a sound scatterer is from the acoustic axis, the weaker its echo – transducer side lobes ignored.

Conditions under which acoustic system should be calibrated

Calibrations are important and technically complicated procedures are best done by skilled technicians using specialised equipment. The following specific conditions are necessary:

- vessel to be in position for at least 4 hours (for a split-beam transducer) to 8 hours (for single beam);
- vessel to be stable and not moving often anchored fore and aft;
- sea to be calm, typically in a sheltered embayment - wind, swell, tides and currents must be minimal;
- water should be clear with little biological activity or sediment load; and
- water depth should be at least 30 m, with an absolute minimum of 15 m below the transducer (for a typical 38 kHz 7º beam width transducer).

The importance of a proper pre-survey calibration cannot be stressed enough: it makes no sense to depart on a survey unless the system has been properly calibrated. This takes time and vessels' captains must understand this need for using acoustic data in a quantitative manner, i.e. for estimating fish biomass. If done incorrectly, the data collected during the surveying/fishing may be useless. Normally, calibration of acoustic systems with frequencies ≤38 kHz can be done within a day assuming all goes well. One of the problems encountered when undertaking a calibration is that fish may be attracted to the silver or copper coloured ball, thus increasing the volume scattering from the range of the calibration sphere – fish must be absent from the acoustic beam during a calibration.

A general rule for frequencies ≤38 kHz is that the minimum required time for calibration is at least eight hours. During this time, the vessel will be unavailable for operations that require movement. A vessel positioned in a bay or inlet is also subject to tides and wind that can move the vessel and/or the calibration sphere, making it difficult to accurately position the sphere on the transducer's acoustic axis, especially at the depths needed to ensure the target is positioned in the far field. In some areas, tidal movement may limit the time to only a few hours a day when calibrations are possible.

4.7 Opportunities for introduction of new technologies

New techniques continue to become available to gather information to assist with echo mark identification and the composition of species in mixed species situations. These include the deployment of underwater cameras on the headline of trawl nets. Such observation methods are now routinely being deployed in a number of fisheries around the world, and can provide visual records of fish behaviour in the net mouth, i.e. entering or avoiding the net.

5. SURVEY METHODS

5.1 Strategic considerations

The first and most important decision is to determine the study requirements. What are the management objectives and what information is it hoped that the acoustic data will provide? ICES (2007) discusses this at length, and notes the trade-offs between survey time and spatial coverage, cost and precision. For example, continuous logging of acoustic and position data from all industry vessels while they carry out their routine fishing activities would provide excellent temporal and spatial coverage of the fishery for relatively low cost, but does not provide absolute abundance estimates. Conversely, a dedicated survey (from either a research or industry platform) is expensive, restricted in space and time, but may provide highly precise, unbiased abundance estimates.

For deep-sea fisheries, the main objective of acoustic data collection is usually to provide information on stock status for single-species assessments. Because information on stock status is required, it is important that acoustic surveys provide quantitative estimates of abundance. Quantitative measures for single-species stock assessments derived from acoustic data generally fall into one of two types of estimates (ICES, 2007): relative abundance indices or absolute abundance estimates. The important difference between relative and absolute estimates of stock size is the way in which survey bias or systematic errors are incorporated. In a relative series, the annual acoustically derived indices can be biased (i.e. the ratio of the acoustic estimate to the actual stock size is greater than or less than unity) owing to systematic errors such that only a proportion of the stock is ever sampled or there are systematic errors in the estimate of backscattering cross-section of the target species. It is assumed that the bias does not change over time. This means that a time-series of relative estimates to monitor changes in stock abundance will give a true indication of changes in stock abundance. In this way, a relative acoustic series is similar to a series of trawl surveys with standardized gear. An absolute acoustic estimate is assumed to be an unbiased measure of stock size and the stock status can be determined after only one survey. However, in an absolute abundance estimate, any systematic errors must be incorporated into the overall measure of error associated with the estimate.

There are two main survey methods for providing quantitative estimates for deepwater species from industry vessels: we have termed these “aggregation-based” surveys and “area-based” surveys.

5.2 Aggregation-based surveys

5.2.1 Introduction

Aggregation-based surveys aim to cover the main target-species aggregation(s) using an adaptive design(see Section 5.2.4). There may be multiple snapshots of the same aggregation that are combined and then usually averaged, and several different aggregations may be surveyed and the resulting abundance estimates summed if it is certain that the same fish are not surveyed in different areas. The main advantage of aggregation-based surveys is that they can be carried out quickly over a small area if the fish are highly aggregated. Sometimes a survey can be run while processing fish, with no compromise to commercial fishing success (O’Driscoll and Macaulay, 2005). Aggregation-based surveys also appeal to fishermen as they concentrate on the areas of highest fish density (the same strategy as is used in most commercial fishing), the vessel can “stay in touch” with the marks, and there is little perception of ‘wasting time’ surveying areas with no (or lower density) fish. Aggregation-based surveys can work well for species like orange roughy or southern blue whiting that are highly aggregated and highly mobile.

A disadvantage of aggregation-based surveys is that they are hard to do well. The vessel crew or scientist directing the acoustic data collection needs to have a good understanding of survey design and be adaptive. Often the surveys do not adequately encompass the area of high-density fish aggregations. Even when the surveys appear to cover the main aggregation(s), there is considerable uncertainty about what proportion of fish occurs in these aggregation(s). For example, prior to spawning fish may still be moving into an area, so some may not be included in the biomass estimate. A survey of New Zealand southern blue whiting (*Micromesistius australis*) by two industry vessels in 2006 gave much lower estimates of abundance (10–15%) than that from a wide-area research survey (O’Driscoll *et al*., 2006). The two industry snapshots adequately covered the area where the highest density marks were detected during the research survey. However, there were large areas to the north and south of the industry snapshots where there were moderate densities of southern blue whiting and these contributed a much larger proportion of the total biomass.

The resulting biomass is used as an absolute estimate of fish abundance in the aggregation. Because the proportion of the stock surveyed will vary between snapshots and between survey years in relation to the amount of survey time available, it is difficult to know how to incorporate aggregation-based abundance estimates into a formal stock assessment model. One approach might be to use estimates as indices of “minimum absolute abundance”. Alternatively, it may be possible to use ancillary information to develop an informed prior probability distribution of the acoustic “survey catchability coefficient” for each industry snapshot that would allow aggregation-based surveys to be used as a relative time series. In addition to the uncertainty associated with what is the proportion of the fish in the surveyed aggregation(s), abundance estimates from aggregation-based surveys are usually treated as absolute estimates of biomass and so are sensitive to the correct choice of backscattering cross-section area (σ_b) and other survey parameters.

There are two main types of survey design for aggregation-based surveys: parallel transects and stars.

5.2.2 Spaced parallel transects

The spaced-transect method is the most suitable for aggregations over flat sea bed or bottom-ridge systems. Transects should be evenly spaced across the aggregation. The transect spacing depends on the size of the box and the number of transects. For example, if the aggregation is 10 nautical miles (nm) long, and there is time for six transects, then transects should be 10/6 = 1.6 nm apart. Transect spacing should not be less than 0.2 nm to avoid overlapping sonified volumes (i.e. the volume sonified will have a diameter of approximately 120 m at 1 000 m range for a typical transducer with a 7°beam width).

Transects should cross the shortest axis of an aggregation, and it is vital that transects are numerous enough and long enough to fully define the boundaries of the aggregation. To adequately describe the extent of the aggregation, it is important that the first and last transects are beyond the area of the marks. It is also important that transects continue while fish are still being encountered. This is illustrated in Section 5.2.4.

When there is time for multiple surveys (snapshots) of the same aggregation, the first snapshot is generally more extensive to establish the limits of the distribution. Once the boundaries of the aggregation(s) have been defined, subsequent snapshots can be more localized with closer transect spacing focusing on the areas where fish are concentrated. This will help produce a better result. A special case of this is the geostatistical design. It is important to note that for conventional, probability-based, statistical analysis, transect spacing should be regular or random across the aggregation and not purposefully related to fish density.

5.2.3 Star transects

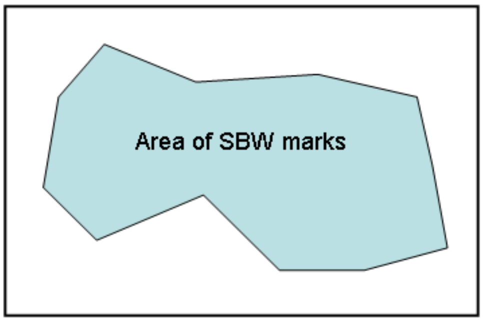
This design is most appropriate for seamounts and knolls and consists of a radial pattern of transects each passing over the centre of the feature (See Figure 8.3). The direction of the first transect should be in a random direction and subsequent transects should be spaced at regular intervals (or angles). The survey should have between four and six transects over the feature. Transects should extend far enough down the sides of the feature to define the extent of the aggregation. Because transect density usually increases towards the centre of the star, analysis must be carried out using appropriately weighted probability-based methods (e.g. Doonan, Coombs and McClatchie, 2003) or using geostatistics.

5.2.4 Protocol for aggregation-based surveys

There are three steps to designing a useful survey.

(i) Define the approximate boundaries of the aggregation.

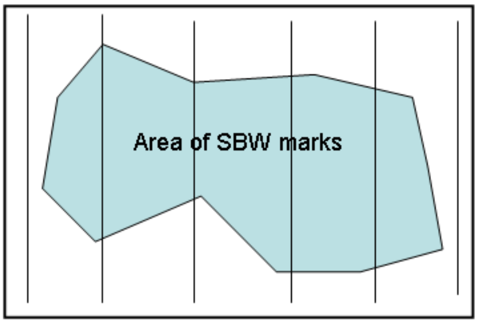
This may be best done using sonar. The idea is to define a rectangular box (with latitude and longitude boundaries) containing most of the fish. The box should be larger than the area in which the marks have been detected and it provides the basic survey area.

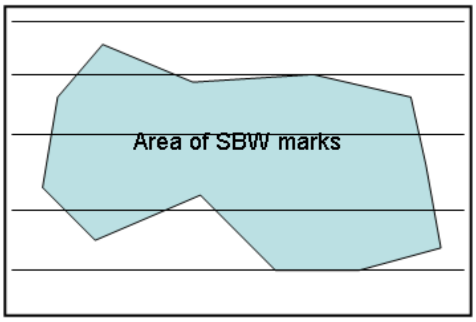


(ii) *Determine the number, orientation and spacing of acoustic transects.*

Each transect should run across the aggregation. If the box is longer in one dimension than the other, then the transects should be parallel to the shorter axis.

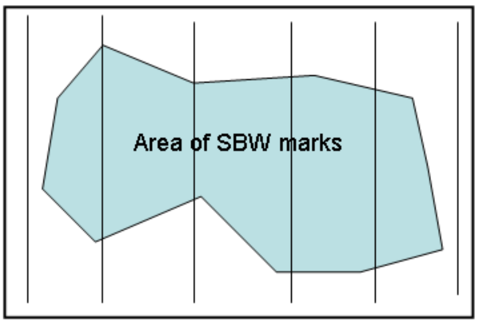
YES ✓ **NO** ✗

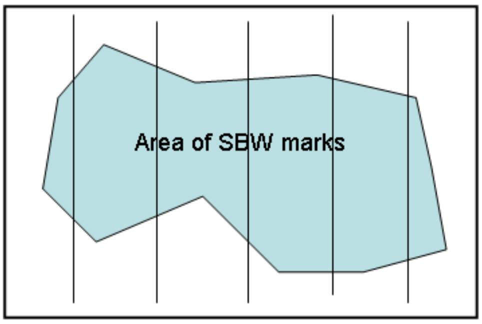




Transects should be evenly spaced across the rectangular box. The idea is to have between five and ten transects. The number of transects depends on their length and the time available to do the survey. For example, if there are four hours available for the acoustic survey, and each transect will take 30 minutes to run, then it might be possible to do six transects (allowing time for the steams between adjacent transects). The transect spacing depends on the size of the box and the number of transects. For example, if the box is 10 nm long, and there is time for six transects, then the transects should be 10/6 = 1.6 nm apart. To adequately describe the extent of the aggregation, it is important that the first and last transects are beyond the area of the marks.

YES ✓ **NO** ✗





Note that the survey area rectangle and transects do not have to run east-west or north-south as shown in the illustrations above. The example below (Figure 5.1) is the actual cruise track of the survey conducted on the bounties of southern blue whiting by the fishing vessel *F.V. Tomi Maru 87* in 2004.

There were five transects in this survey running southwest-northeast. Transects were separated by about one nautical mile and the survey took two hours to run.

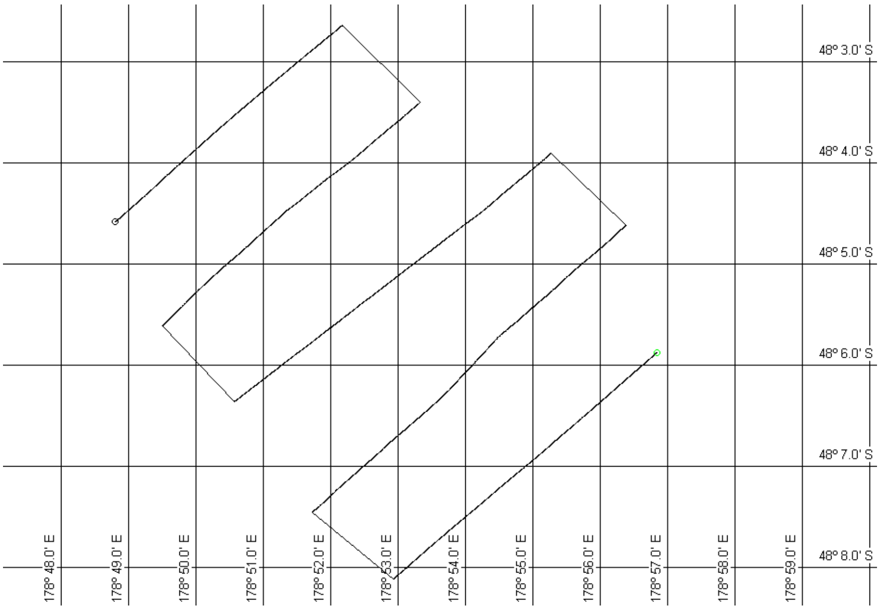
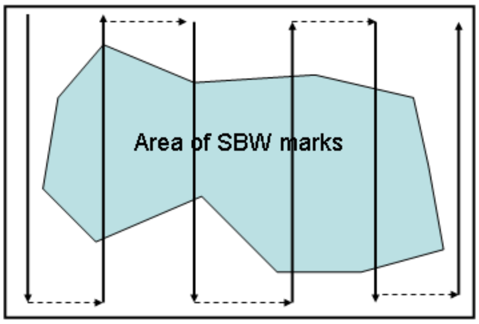


Figure 5.1: Cruise track of the survey conducted on the bounties of southern blue whiting by the *F.V. Tomi Maru 87* in 2004

(iii) *Sample the acoustic transects.*

Transects should be run at a constant speed of 6–10 knots. The speed chosen will depend on the vessel and the weather conditions. Choose the maximum speed (but no greater than 10 knots), which gives a good echosounder picture. Faster speeds are usually possible only in good weather. Acoustic data should be recorded on the transects (bold lines below), with a separate acoustic recording for each transect. Recordings should be documented. The joining legs between adjacent transects (dashed lines below) can be recorded, although this is not essential.



To avoid recording sound generated by other equipment, it is essential to turn off all other acoustic equipment while recording transects. However, other equipment may be used when steaming between adjacent transects. For example, you may wish to turn on a sonar while running along the dashed lines above to keep track of the aggregation.

It is also important that you do not stop surveying a transect while fish are still being detected. An example of an acoustic recording of a transect that was too short is shown in Figure 5.2 below. Here, fish echoes were present both at the start and the end of the transect. It is impossible to know how much further beyond the ends of the transect the fish aggregation extended, and thus it is impossible to determine the size of the aggregation. If necessary, transects can be extended beyond the survey box boundaries to ensure that the marks are fully covered.

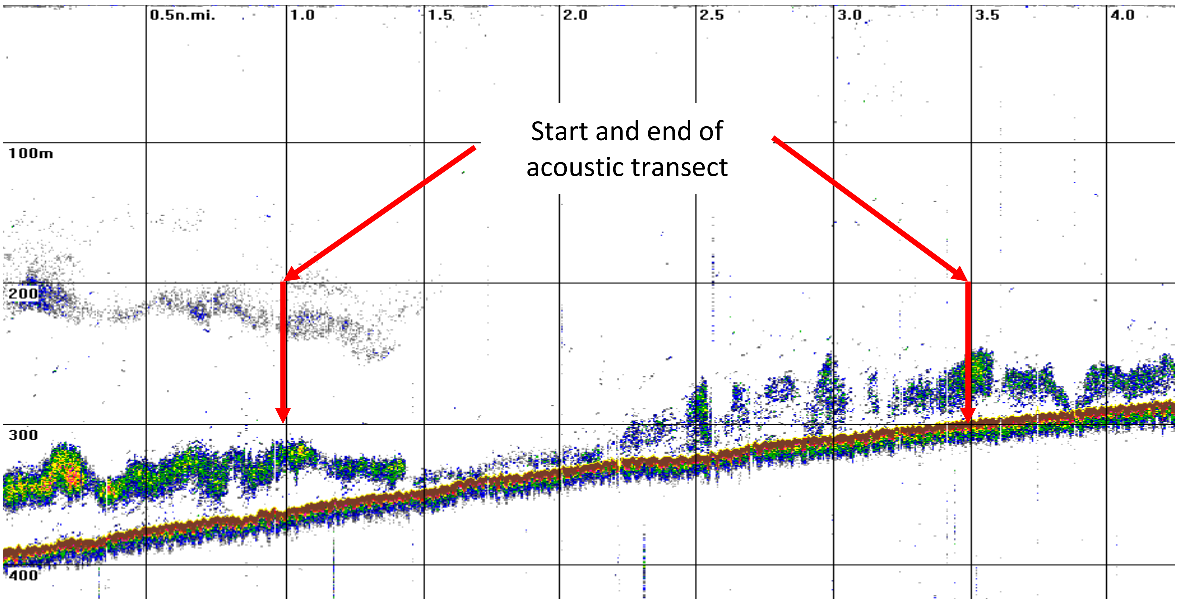
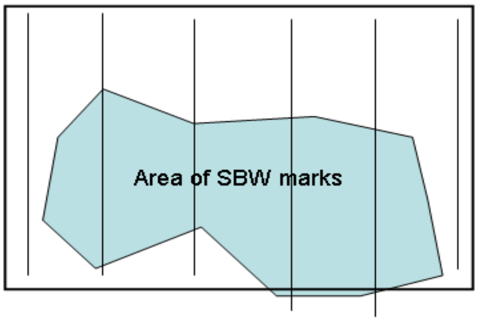


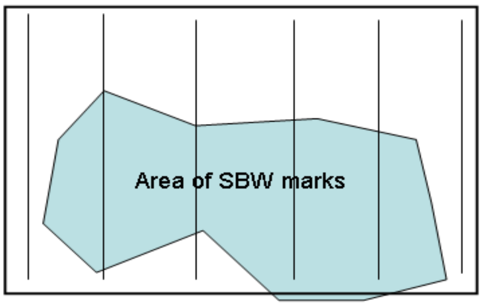
Figure 5.2: The acoustic record showing fish located both before the start and after the end of the transect

As noted**,** it is important that the first and last transects are beyond the area of the marks. If necessary additional transects can be added at the same regular interval outside the original rectangular survey box until no marks are detected on the final transect. If necessary, transects can be extended beyond the survey box boundaries to ensure that the fish aggregations are fully covered.

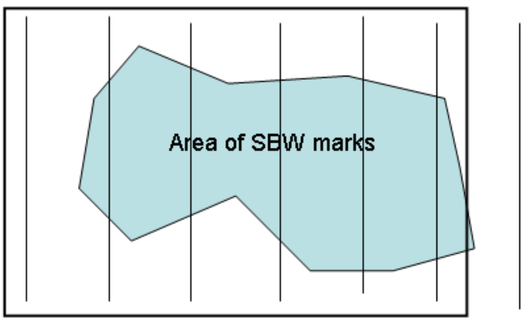
YES ✓



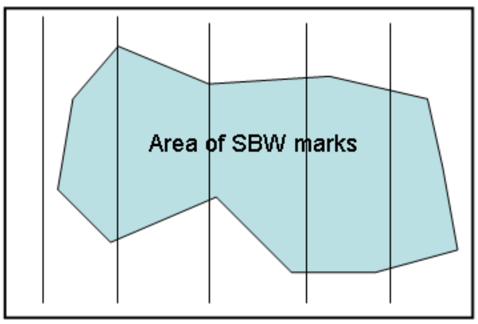
NO ✗



YES ✓



NO ✗



Figures 5.3 to 5.8 show[9] an interesting example of the development of successive survey transects of an aggregation-based survey of orange roughy in the Southern Indian Ocean.

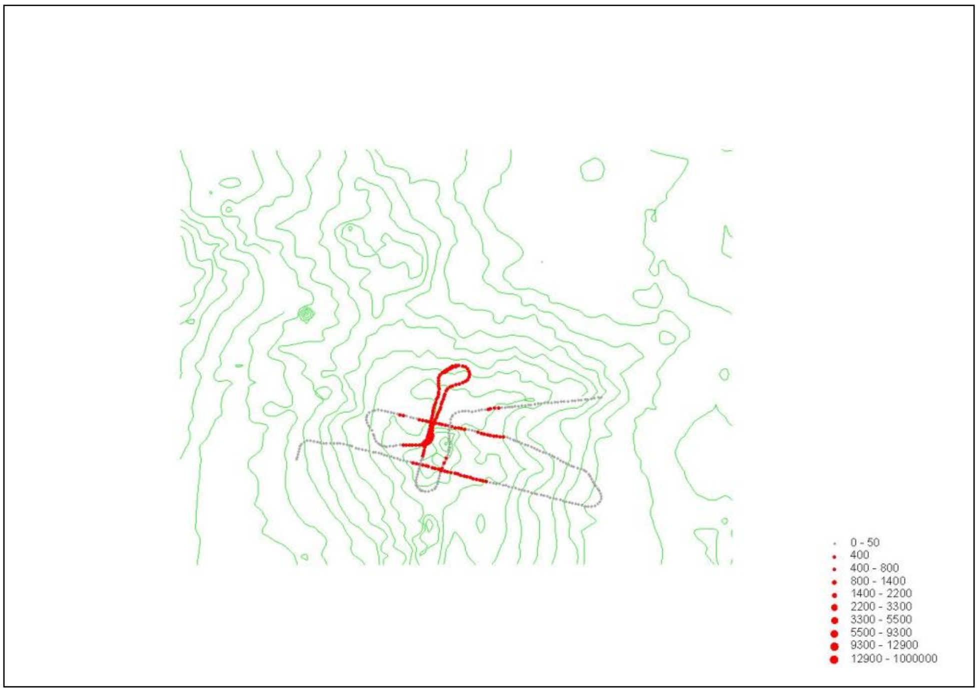


Figure 5.3: Aggregation-based survey – 2004: first discovery of ground, no survey

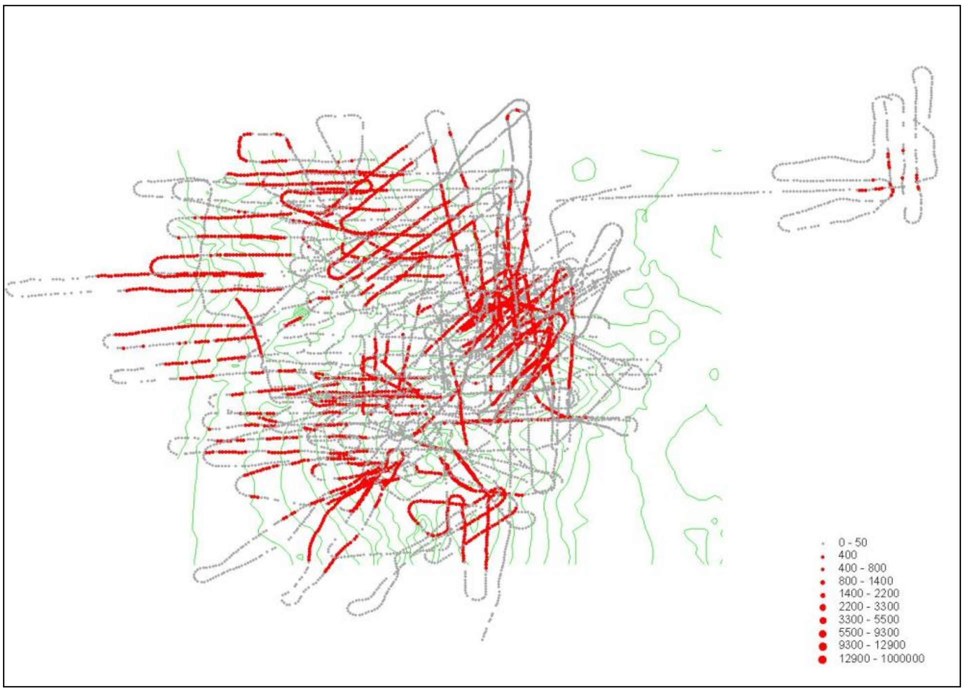


Figure 5.4: Aggregation-based survey – 2005: extensive tracking of fish movement over grounds on diurnal basis

[9] Credits for these series of plots to G. Patchell, Sealord Group, New Zealand.

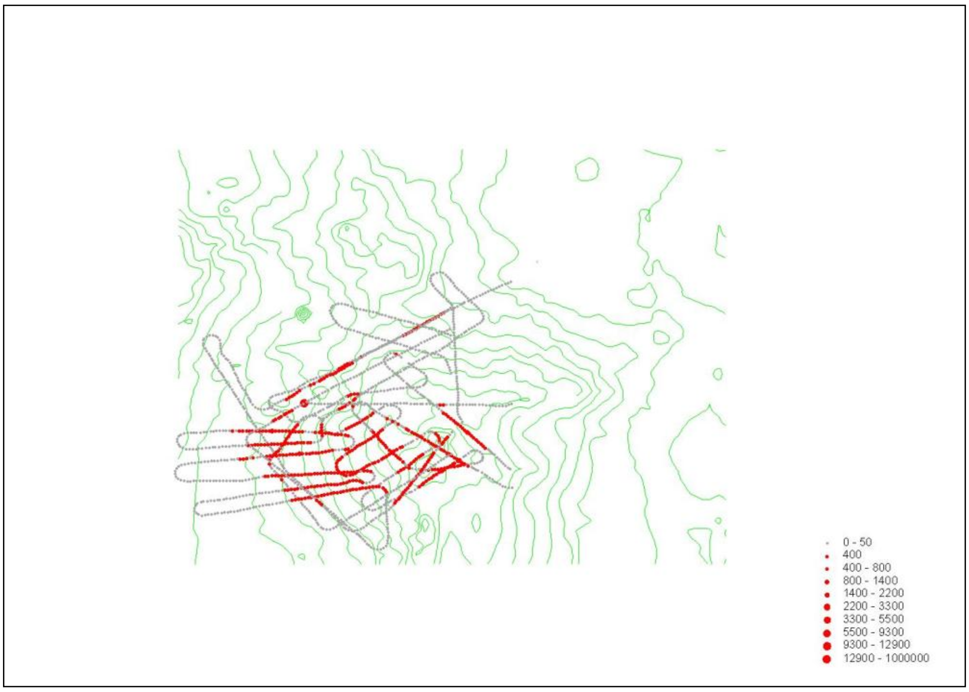


Figure 5.5: Aggregation-based survey – 2006: poor survey carried out by skipper, only a part of the fish aggregation was surveyed

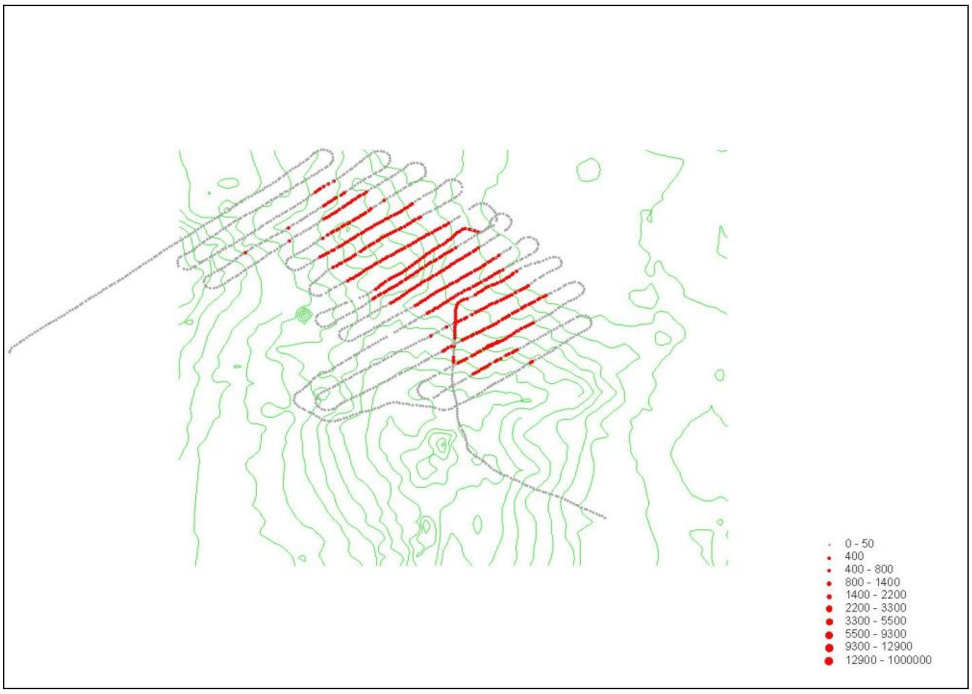


Figure 5.6: Aggregation-based survey – 2007: full-gridded survey at peak spawning time undertaken

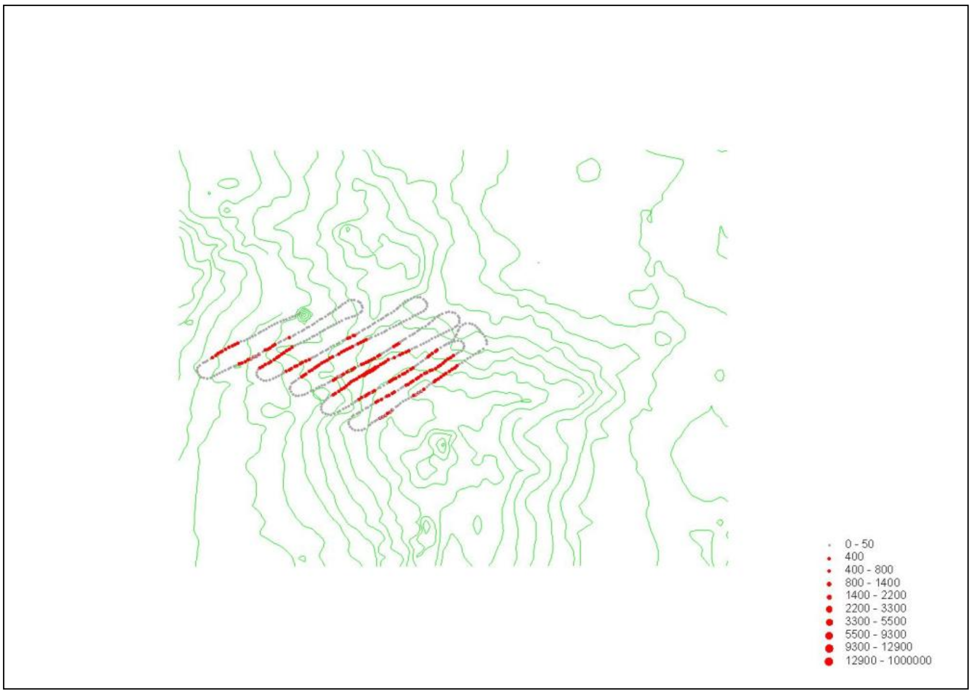


Figure 5.7: Aggregation-based survey – 2008: penultimate survey track design

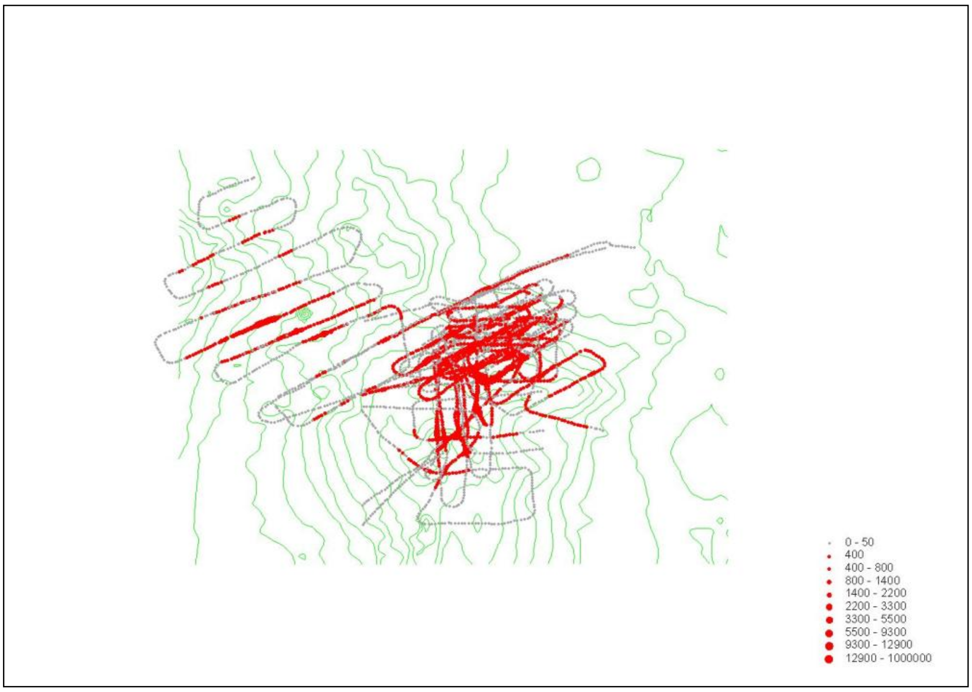


Figure 5.8: Aggregation-based survey – 2009: full survey coverage over several snapshots (survey by second calibrated vessel on the same stock)

5.3 Area-based surveys

Most research-vessel surveys (trawl and acoustic) are area-based surveys. The areas of fish occurrence are usually known and defined prior to the survey. Often the area is stratified based on bathymetry or the fish density determined from previous surveys. Transects are assigned to each area or stratum prior to the survey. This survey design is simple to implement and analyse. Vessel officers can be provided with start and finish positions of all lines, and they just have to navigate the vessel along the transect without worrying about what the fish are doing or any details of the survey design.

By standardizing the timing, area and equipment used in each survey, time series can be developed that provide relative estimates of fish abundance. Such time series provide the major input on stock status to most stock assessment models. An added advantage of relative acoustic time series is that these are not so reliant on correct choice of the backscattering cross-section value.

The major disadvantage of an area-based survey is that the areas must be defined to be sufficiently large to encompass all of the likely fish distribution. Because the locations of aggregations can be unpredictable, the time needed to carry out a survey of all the potential spawning areas may be relatively long and when integrated into commercial fishing trips may require the vessel to suspend fishing activities, demanding considerable investment and commitment. Furthermore mark identification away from the main aggregations is often less certain, so that trawling to identify the species causing fish echoes becomes important in these situations to allow correct interpretation of the acoustic data.

Area-based surveys have been carried out successfully from industry vessels, e.g. for Australian and New Zealand hoki). Hoki often spawn in canyons, where their distribution is confined by bathymetry and this makes definition of the survey area straightforward. Even so, the time needed to carry out a survey is often relatively long. For hoki, multiple surveys (snapshots) are required over an extended period of time to deal with turnover of fish on the grounds. O'Driscoll and Macaulay (2009) estimated that the six completed snapshots of hoki in Cook Strait carried out by an industry vessel represented about 140 hours of vessel time.

5.3.1 Example of a protocol for area-based surveys

Hoki has a long spawning season, from July to September, and during this time it is thought that there is a turnover of fish on the grounds. Therefore, there is no time at which all of the spawning fish are in the survey area. The survey design devised to deal with this problem consists of a number of sub-surveys or "snapshots" spread over the spawning season. Each snapshot consists of a series of random transects (following the design of Jolly and Hampton, 1990) across strata covering the known distribution of spawning hoki. Estimates of spawning biomass are calculated for each of the snapshots, and these are then averaged to obtain an estimate of the "mean plateau height" (average biomass during the main spawning season). Under various assumptions about the timing and length of the spawning season (Coombs and Cordue, 1995), estimates of mean plateau height form a valid relative abundance time series.

Start and finish positions were provided for six snapshots, each consisting of 28 random transects in six strata (e.g. Table 5.1, Figure 5.9). These six strata cover the known hoki spawning areas with depths greater than 200 m (180 m in stratum 2).

(i) Transects should be run at constant speed (6–10 knots).
(ii) Acoustic data quality needs to be good. Moderate to calm weather is important (typically winds less than 25 knots, swell less than 2 m). All other echosounders, sonars and others must be turned off to avoid acoustic interference.
(iii) A separate acoustic file should be recorded for each transect. It is not necessary to record the joining legs between transects. A log sheet should be completed (see Appendix C).
(iv) Estimates of species composition, hoki size and spawning condition in commercial catches are required, preferably from an on-board observer: this information is needed to estimate that the backscattering cross-section values).
(v) The echo-sounder needs to be calibrated and set up using scientific value settings.
(vi) To obtain a biomass index with a reasonable coefficient of variation at least, (and preferably) four "snapshots" should be completed. These should be spread over as long a period as possible between 15 July and 10 September.

(vii) An entire "snapshot" needs to be completed within 48 hours (and within 72 hours maximum) for it to be useful. All transects in the main Cook Strait Canyon (strata 2 and 5A) need to be run sequentially (i.e. without breaks) because of fish movement related to tide in this area.

Table 5.1: Stratum boundaries, areas and transect allocation in the acoustic survey of spawning hoki in Cook Strait, New Zealand. Stratum locations are shown in Figure 5.9.

Stratum	Name	Boundary	Area (km^2)	No. of transects
1	Narrows Basin	200–200 m	330	4
2	Cook Strait Canyon	180–180 m	220	9
3	Nicholson Canyon	200–200 m	55	4
5A	Cook Strait Canyon deep	Position to 200 m	90	4
5B	Deep water	Position to 200 m	215	3
6	Terawhiti Sill	200–200 m	65	4

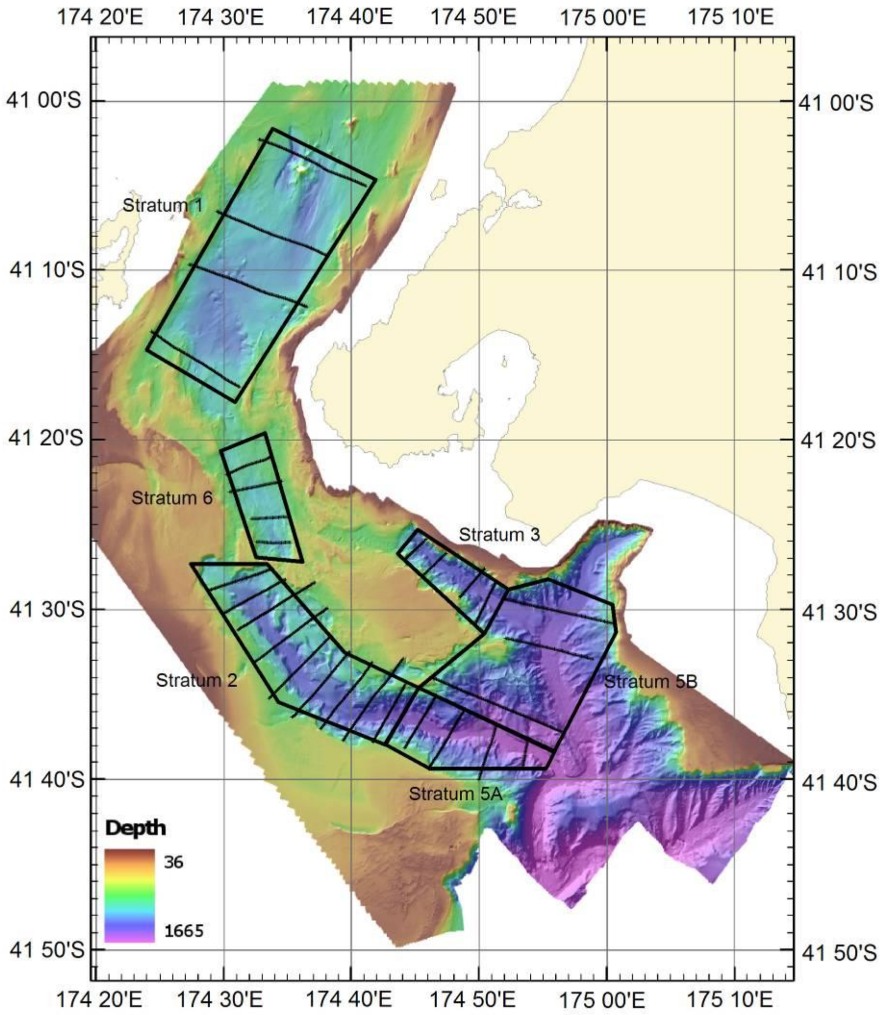


Figure 5.9: Map showing approximate stratum boundaries and example transect locations for acoustic surveys of hoki in Cook Strait, New Zealand

5.4 Multiple surveys

Regardless of whether surveys are area-based or aggregation-based, uncertainty can be reduced by carrying out repeated surveys (or snapshots) over the same area or fish aggregation. This is particularly important when surveys only cover variable (and unknown) parts of the population. Carrying out multiple snapshots maximizes the chances of surveying the population when it is most aggregated. For example, many fish aggregate for spawning, so the highest acoustically obtained abundance estimates are acquired when the fish are actively spawning. The timing of spawning may vary, so carrying out multiple surveys over the spawning period increases the chances of the survey being carried out at the optimal time. In some instances, it may be appropriate to take the maximum estimate from multiple surveys as the appropriate index of abundance. However, picking the highest of multiple snapshots increases the risk of bias caused by selecting at the extremes of the distribution of abundance estimates. Typically, sampling error is also higher for snapshots of fish aggregations with higher biomass. Where multiple snapshots all have appropriate timing and coverage, it is preferable to average snapshot estimates to produce the abundance index. If we assume that the snapshot abundance estimates are independent and identically distributed random variables, the sample variance of the snapshot means divided by the number of snapshots is then an unbiased estimator of the variance of the abundance index (the mean of the snapshot estimates).

The situation where not all the population is available to be surveyed at same time is a special instance of carrying out multiple snapshots, i.e. a transient population exists as occurs with New Zealand hoki. Estimates of spawning biomass are calculated for each of the snapshots and these are then averaged to obtain an estimate of the “mean plateau height”.

5.5 Deciding which data to use for estimation of abundance

Only acoustic data collected following the agreed operational protocols should be considered for estimating abundance. If survey protocols are not followed, then the survey results should be rejected on this basis before biomass is calculated. Once an abundance estimate is produced it is tempting to accept or reject this based on the magnitude of the estimate rather than objective criteria. It is, therefore, vital that operational protocols are clearly defined. Valid reasons for rejecting survey data after biomass has been estimated include:

- evidence that survey timing was suboptimal (e.g. gonad stage data suggests surveys of aggregations occurred outside spawning period); and
- evidence that the survey did not adequately survey the population (e.g. evidence from distribution of other fishing vessels that fish were outside the surveyed area).

Refer to Section 9.1 for the sources of uncertainty.

6. ACOUSTIC DATA PROCESSING

Post-processing of acoustic fisheries data is necessary following a successful fisheries survey to collect information for echo integration and other analyses. Data processing should be prioritized according to survey objectives. Data products may range from simple school presence/absence observations, observations of spatial and temporal dynamics through to calibrated, quality-checked distance sampling unit (DSU) outputs from echo integration. These latter data typically require the highest level of equipment capability, rigour in the processing of the data, and time to do the analyses. The following description describes the steps required for obtaining DSUs; other data products may have lesser post-processing requirements.

The first post-processing step is to identify survey data of interest. Commercial-vessel survey work may often be carried out by the ship’s officers without scientists on board, and structured acoustic surveys may be interspersed with routine fishing operations during voyages that can last for months.

Time spent locating survey data can be considerably reduced if the ship's officers have kept a log of survey activities (see examples in Appendix C).

Quality control procedures are usually applied to the selected subsets of acoustic data. A first pass review of selected survey data is beneficial to identify whether it is suitable for further analysis. Echo data quality can be affected by a number of sources including both transient and continuous noise from mechanical and electrical sources on the vessel and interference from other echosounders. Ideally, these sources of noise will have been identified and mitigated as much as possible prior to the survey commencing. Vessels that work in deep waters often experience adverse weather. Attenuation of the sound pulse owing to below-hull aeration caused by waves may affect the data quality to the point that further analysis is not worthwhile. It can be useful to have predefined criteria against which data quality are assessed. For example, the percentage of data rejected may be a criterion that if exceeded would preclude the survey from receiving further consideration.

Acoustic system settings used during a survey (transmitted pulse [power and length, data logging range) should be checked to ensure they match those specified and for which the system has been calibrated. The calibration results should be applied to the data and a check should be made to ensure that GPS data have been successfully recorded. In the case of Simrad ES60 data, the systematic triangle wave error (Ryan and Kloser, 2004) can give errors of up to +/- 0.5 dB and should be corrected for, at least for the calibration data. This error averages to zero over long data sets, and the overhead of pre-processing all field data to remove this error should be considered as in many instances the overall effect on the survey results will be negligible. Sound absorption (Doonan, Coombs and McClatchie, 2003) and sound speed (Mackenzie, 1981) estimates based on ideally continuous depth and temperature recordings or temperature-density casts (often with trawl net attached loggers) taken close in space and time to the acoustic survey should be made.

Acoustic post-processing packages provide a variety of tools to allow quality control and echogram regions to be classified. Regions of bad data can be visually identified, manually marked and excluded from echo-integration calculations. Regions of fish aggregations may be defined using manually entered polygons (defined by echo depth and pulse number) or using automatic recognition methods (e.g.Echoview[10]). The sonified volume increases as a function of the square of the range making the echo from sea floor less well defined, if not poorly defined, in deep water, particularly on sloping grounds where the acoustic bottom dead zone is large. In those situations, the definition of the sea floor can require particular attention when analysing deep-living demersal or semi-demersal species. Commonly used commercial post-processing packages include Echoview (Myriax Pty Ltd), Large Scale Survey System (LSSS)[11], Movies and Sonar5[12].

Echogram interpretation is a fundamental and often most challenging aspect of post-survey data processing. It can be straightforward in situations where fish are in well-defined discrete single species aggregations clear of the sea bottom, but in mixed-species situations it can be highly problematic. At great depths, there is an increased possibility of inclusion of non-target species in the increased range-dependent sonified volume. This can lead to significant bias if the species of interest has a low reflectance (e.g. as in the case of the orange roughy, which has a poorly reflecting wax-ester-filled swim bladder) and co-occurs with highly reflective species whose reflectivity may be 10 to 100 times greater, e.g. small fish such as myctophids that have gas-filled swim bladders (and which may resonate the incident sound) or fish with large swim bladders such as whiptails, morid cods, cardinal fish and oreos.

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[10] Echoview is a software for echosounder and data processing: www.echoview.com.
[11] LSSS is also a software for echosounder and data processing: www.marec.com.
[12] Sonar5 is a post-processing software specifically designed to identify and count fish tracks: http://tid.uio.no/~hbalk/sonar4_5/index.htm.

Echogram interpretation is typically done using several sources of information. Trawl catch data (either targeted or untargeted) are commonly used to help echogram interpretation. Net systems designed to target a particular commercial species are likely to have widely varying and unquantified selectivities that can lead to gross errors if echograms are misinterpreted from trawl catch. Lesser, but significant, errors may arise from using unrepresentative trawl catch composition to partition the echo intensities between species. When considering the utility of demersal trawls, it is necessary to keep in mind that for deepwater situations the sea volume fished by the trawl may differ from the sea volume sampled by the acoustic system. In the case of the trawl, it fishes the region up to 5–10 m from the sea floor, but this region cannot be sampled by the acoustic system as it falls within the dead zone.

Other sources of evidence include fishermen's knowledge and aggregation metrics (e.g. depth, backscatter echo intensity, fish sizes and location). A classification approach to rank confidence in the interpretation of echogram school marks according to consideration of all evidence has proved useful for both orange roughy and blue grenadier surveys (Honkalehto and Ryan, 2003; Kloser *et al*., 2006). This approach still relies to some extent on the subjective decisions of the analyst, but it does allow the sensitivity of biomass estimates used in these decisions to be quantified.

When using hull-mounted transducers for deepwater fisheries that result in a large sonified volume, the potential for sonifying mixed species leads to such large uncertainty in species identification that the results are not considered to be reliable. For example, Kloser *et al*. (2002) came to this conclusion during a combined vessel and towed body survey of orange roughy at the heavily overfished St Helens Hill seamount off Tasmania's east coast. They clearly identified a small body of orange roughy using the deep-towed multifrequency system but there was insufficient information content in the data obtained with a vessel-mounted transducer to enable the echogram to be interpreted and partitioned according to species with sufficient confidence. It was notable that if the trawl catch had been the only source of information, the interpretation of the school regions observed by the vessel acoustics may well have been classified as containing orange roughy. Similarly, there is an example of a seamount in Chatham Rise off the east coast of New Zealand where it had been suggested that the vessel-observed fish aggregations contained a large body of orange roughy. A trawl through these marks with a net-attached acoustic and optical system (Ryan, Kloser and Macaulay, 2009; Macaulay *et al.,* 2008) revealed images and trawl catch dominated by the highly reflective Johnsons Cod or Slender codling (*Halargyreus johnsonii*), but no sign of orange roughy in the video, trawl catch or by analysis of the multifrequency acoustic records. Research strategies based on vessel-mounted acoustic systems may need to consider potential uses of alterative technologies to test and prove assumptions used in analysis of the data record. For high-seas fisheries this is a challenge as vessels can be at sea for months at a time making it difficult for specialized personnel and technologies to be available for such extended periods.

7. ACOUSTIC BACKSCATTERING CROSS-SECTION VALUES

7.1 Importance of proper specification

The acoustic backscattering cross section, commonly referred to in its logarithmic transformed decibel form as target strength[13] by acoustic technicians, relates to the fraction of incident sound intensity (e.g. W/cm^2) that is reflected by the fish. Where there is a large difference in the densities of contiguous reflecting materials (e.g. gas in the swim bladder and surrounding flesh, between bone and fish flesh, or between flesh with high and low oil content), the amount of sound energy reflected is higher than when the density difference is small. Any error in the value used for the backscattering cross-section or its derivation, the volume scattering cross section, as a function of fish size will have a linear affect on biomass estimates as usually the amount of fish biomass in a survey area is taken to be a linear function of the volume-scattering cross section. A factor of two in the volume backscattering-biomass relation will result in a similar level of error in the absolute biomass estimates with a possible biomass estimate in the range of half or double the actual estimate. Errors in the

[13] Target strength, TS = 10 $\log_{10}\sigma_b$.

backscattering cross-section fish-size function are considered to be the major sources of error in acoustic fish survey estimates, are highly problematic and can arise from several causes.

7.2 Problems associated with use of σ_b and s_v values

As noted, inferences about the amount of fish biomass in a sonified volume depends on knowledge of how much of the incident sound energy is reflected back to the transducer. When a fish changes its orientation to the incident sound pulse, so it will change the backscattering cross-section area that it presents to the transducer. An analogy is hearing your echo from, for example a barn directly in front of you to the echo you would hear when the barn is positioned at an extreme angle. So it is with fish, there is a fish orientation relative to the transducer at which the echo intensity is at a maximum. Depending on the characteristics of the reflecting components of the fish (e.g. swim bladder, vertebrae, gonads, stomach contents, musculature, etc.), changes in the orientation of these components will change its effective backscattering cross-section area. If there is a diel pattern or some cause of a cyclical or short-term change in the (average) orientation of fish, then their backscattering cross-sectional area will change and thus any inference about the biomass of fish that has been sonified.

A further cause of error is the presence of non-target species of fish in the sonified volume that have a much greater backscattering cross-section area that the target fish. An important example is that of orange roughy, which has a relatively low backscattering cross-section area because its swim bladder is filled with wax and not gas. When other species of fish, such as oreos, co-occur with the roughy, a correction is needed to separate the echo intensity of the orange roughy from those of the oreos. This requires knowledge of the relative frequencies of the two species in the sonified volume, which is usually inferred from the species composition of the trawl catch. But, if the two (or more) species have different vulnerabilities to capture by the trawl such that species composition of the trawl catch does not reflect that of the sonified volume, the analysis becomes yet more problematic.

To some extent, the problem of non-target species in the sonified volume can be reduced by appropriate pre-processing of the echo data (Section 6). This may involve visual examination of the echo record and editing of the data files to remove data that are evidently not from the target species. Various proprietary and custom-written softwares are available to do this.

8. ESTIMATION OF ABUNDANCE

8.1 Introduction

The usual objective of a commercial vessel acoustic survey is to estimate the total fish stock abundance, i.e. a stand-alone, absolute estimate of the total biomass or fish numbers, or if a relative measure is being used, the addition of an annual data point to a time series or abundance indices. The estimation of a total biomass entails not only obtaining a scientifically “good” value, but also the evaluation of the statistical uncertainty (technically referred to as the “error”) associated with this value, as the real value cannot possibly be known without error. Statistical estimation is the identification of the best[14] value for an unknown quantity – the estimate – and a measure of the uncertainty of this estimate using data and a probability model[15] for the data. The uncertainty usually takes the form of an “estimation variance”, i.e. the variance of the estimate.

[14] “Best” will usually mean the value most supported by the data, with the least “statistical” error.

[15] Usually, equal probability of being sampled is assigned to each part of the survey area, i.e. any possible transect has an equal probability of being selected for survey.

The estimation of total fish abundance for an area from a fish survey may involve the use of a statistical model for the fish density data. In that case one of the parameters of this model should be the abundance estimate, or the abundance estimate should be available from parameters in the model. The nature of the model is defined by the way in which the data were generated by the survey. For example, if the survey recorded counts of fish, the model could be based on the Poisson or negative binomial distribution, whereas when the survey records a measure of continuous fish density, as in the case of acoustic surveys, the model could be based on the lognormal or Gamma distribution.

In the case of fisheries surveys done by commercial fishing vessels, a fundamental distinction occurs between surveys that are: (i) carried out by exploring a pre-established area with fixed station locations regardless of the distribution of fish that is observed inside the survey area (area-based surveys); and (ii) surveys that are done by searching for aggregations of fish within a pre-established area and then surveying these aggregations (aggregation-based surveys). In area-based surveys a probabilistic sampling design is usually established in advance. On the contrary, in the case of aggregation-based surveys, there is usually no prior probabilistic sampling design, and the observations that are obtained are in effect “purposeful”: sampling effort is intensified when an aggregation of fish is detected.

In general, data obtained through implementation of a pre-established probabilistic sampling design will be analysed to estimate abundance, with a design-based method, such as those described in classical finite population inference textbooks (e.g. Cochran, 1977; Thompson, 1992). A fully design-based method would consider the data as generated by a deterministic process so that all randomness arises only from the application of a probabilistic sampling design.

Data obtained through implementation of a probabilistic sampling design in an area-based survey can also be used to estimate abundance, using a model-based method. In contrast to design-based inference, model-based inference methods consider the data as generated by a stochastic process so that randomness arises from the data themselves, as realizations of a random variable, as well as from the observation process. However, model-based inference can be less efficient, i.e. it produces an abundance estimate with higher variance, when applied to data from an area-based survey, as compared with data obtained through an aggregation-based survey.

Alternatively, data generated by a survey that does not follow a pre-established probabilistic sampling design, i.e. an aggregation-based survey, will generally be analysed using model-based inference methods only. This is because the absence of a pre-established sampling design makes it very difficult to understand how the sampling generates randomness, so that it is more convenient to use the randomness implicit in a probability model to make inferences. A final relevant distinction in this review of approaches to estimate abundance is whether the inference method considers the spatial correlation inherent of fish density data, either for the estimation variance only or for both the abundance estimate and its estimation variance.

The main characteristics and field of application of the different choices that can be made when planning and analysing a fishery survey are described in more detail in the following sections. The specific methods covered are those categorized schematically in Table 8.1.

Table 8.1: Survey types and inference options to estimate abundance from marine surveys

Survey type	**Area-based**		**Aggregation-based**	
Inference method	Design-based	Model-based	Design-based	Model-based
Non-spatial	Classical finite population methods	Predictive approach with covariates Frequency model	Adaptive sampling	No useful method
Spatial	Transitive geostatistics	Intrinsic geostatistics Likelihood geostatistics	No known method	Intrinsic geostatistics Likelihood geostatistics

8.2 Area-based surveys

8.2.1 Application of area-based surveys

In area-based surveys, a region is sampled at prespecified station locations (such as fixed transects), often over a relatively short period of time to estimate fish a bundance over the survey region. An example of an area-based survey carried out on chartered fishing vessels is the summer trawl survey for Alaska snow crab (Figure 8.1) that has been carried out annually since 1975 (Chilton, Armistead and Foy, 2009). To ensure the usefulness of the time series created by these types of surveys, it is imperative that repetitions of the survey be done following a pre-established standard procedure. The vessel(s)[16] may not be the same in every repetition, but other relevant factors, such as the design of the fishing gear, tow duration, acoustic equipment, etc., should be kept unchanged.

The standardization of observation procedures in area-based surveys allows the elimination of nuisance parameters in the model for estimating total abundance, such as changes in survey catchability of the target species resulting from changes in vulnerability to capture from using different fishing gears. This is important since the elimination of nuisance parameters by other means usually entails a reduction in the quality of the estimate for the fish total as further assumptions, which may not hold true, must be introduced in making “corrections”.

Among the class of area-based surveys, an equally spaced-transect survey is the most suitable for ridges or large banks when carrying out acoustical transects. Figure 8.2 shows one such survey where the vessel transects were spaced 0.2 nm apart. Vessels normally undertake this method while processing fish. The time available will depend on the type of fishery in which the vessel is operating. However, the choice of when the survey is carried out is usually at the skipper’s discretion. Each of the snapshots during the surveys above were completed over a period of 2–6 hours while the vessel was processing catch. This enables survey areas of 10–40 km^2 to be covered.

[16] Using different vessels for acoustic surveys introduces a further source of uncertainty – something that may be unavoidable with commercial-vessel acoustic surveys.

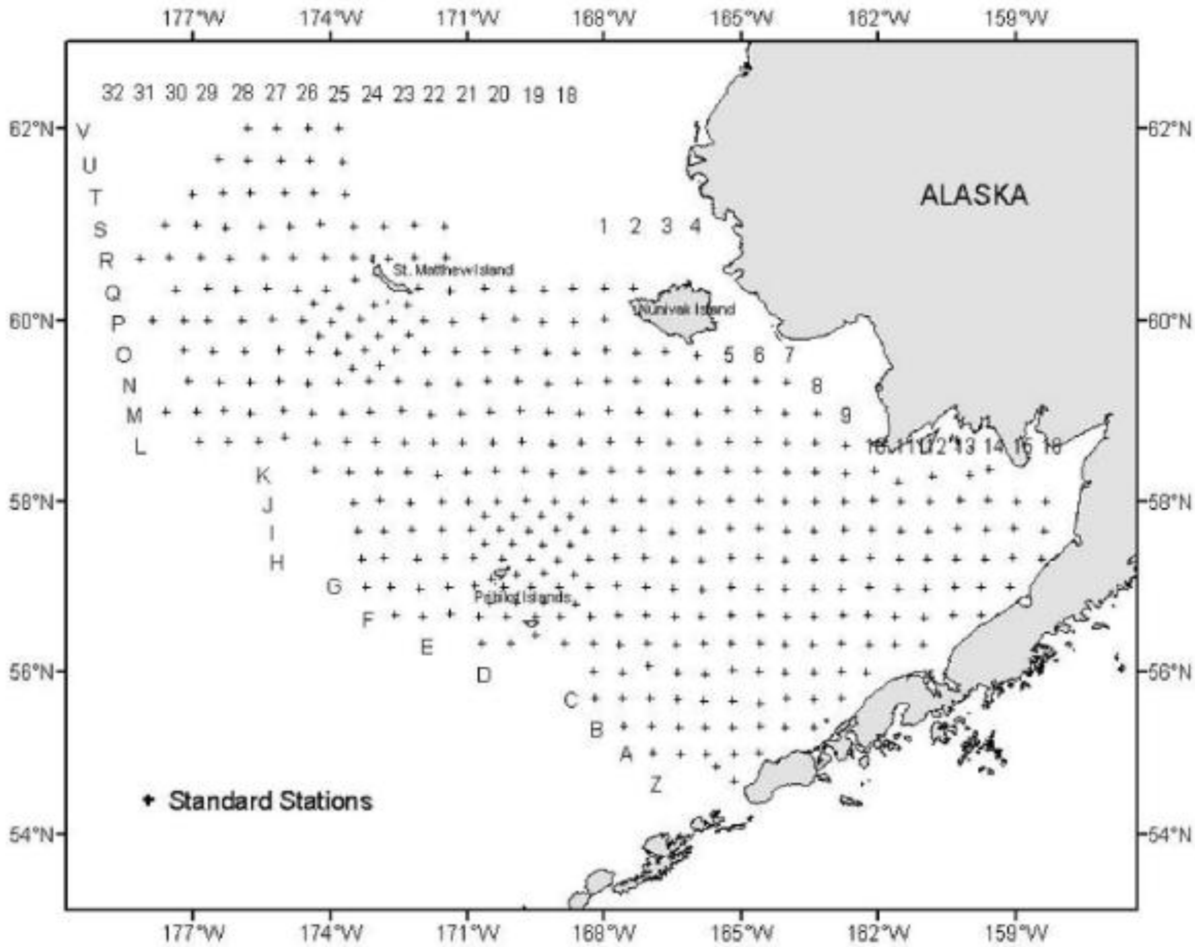

Figure 8.1: Area-based annual summer survey for Alaska snow crab and other groundfish resources in the Eastern Bering Sea carried out by fishing vessels chartered by the United States National Marine Fisheries Service

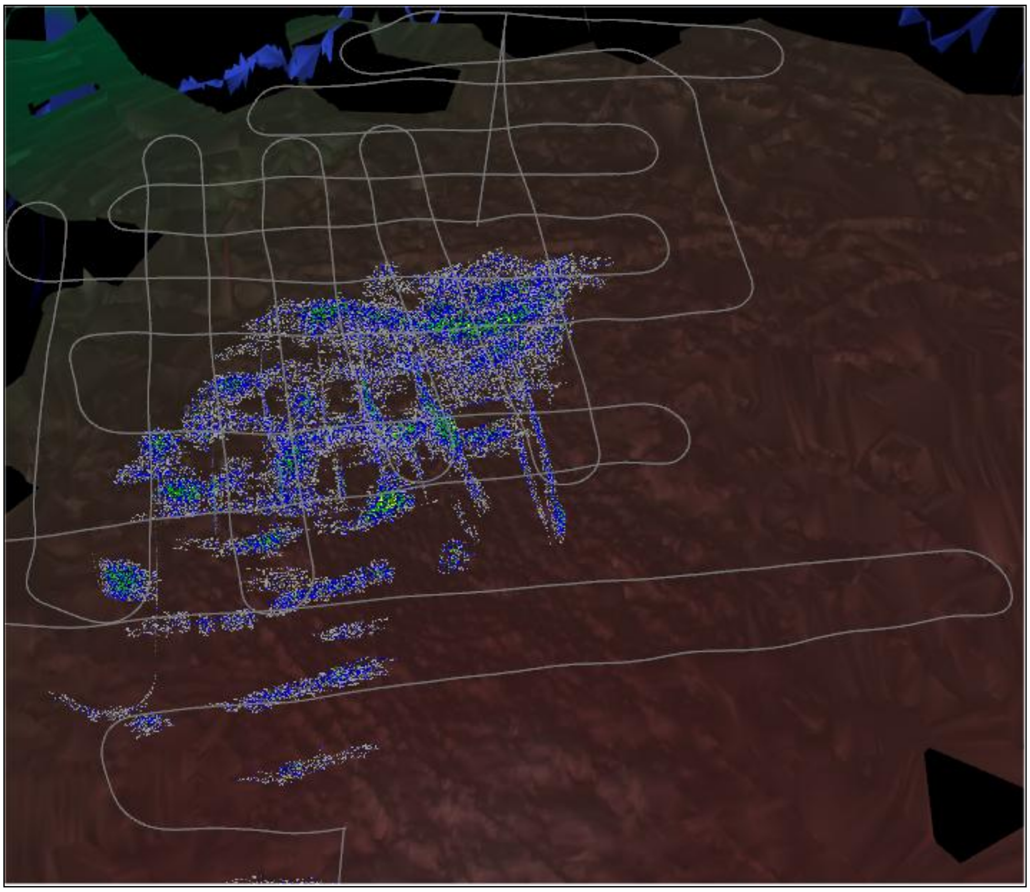

Figure 8.2: Transects for an area-based acoustic survey for orange roughy in the southern Indian Ocean

For individual seamounts and knolls, a “star” (Figure 8.3) or (“bicycle wheel” pattern may be better. Many skippers use this mapping technique during fishing operations, especially for locating alfonsino aggregations.

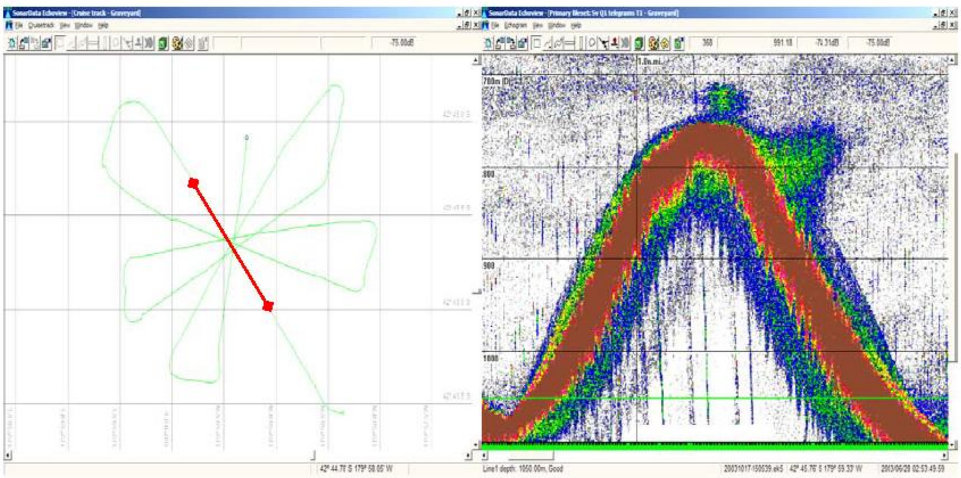

Figure 8.3: A star-shaped spatial configuration of an area-based hydroacoustic survey for alfonsino

8.2.2 Design-based estimation in area-based surveys

8.2.2.1 Characteristics of design-based estimation in area-based surveys

When using design-based statistical inference, the estimation of a parameter, such as the total abundance of fish in an area, assumes that the sampling procedure is the sole source of randomness in the estimate, i.e. it assumes that the different possible samples that can be selected in the survey area are the sole source of variability and that the observable variable (i.e. fish density) is exactly known for each sample station (i.e. a transect or part of a transect). Thus, in design-based inference, it is paramount to respect and follow the sampling design so that the probability of the samples remains known. The probability of selecting a sampling station may change over the course of the survey when using an adaptive sampling design (see below), but the probabilities of all the possible samples must remain known. Thus, design-based inference imposes strict restrictions on the observation procedure, something that is usually difficult, indeed unlikely to be accommodated by skippers of commercial fishing vessels. For this reason, a design-based survey approach may be impractical for commercial vessel resource surveys.

8.2.2.2 Non-spatial design-based methods in area-based surveys

Whereas spatial estimation methods consider the spatial correlation in fish density for the abundance estimate and/or for the estimation variance of the abundance estimate, non-spatial methods do not. Non-spatial methods may be as simple as estimating the total fish abundance from a simple random sample without replacement of sampling stations. Simple random sampling, however, is generally not used unless little or nothing is known about the spatial distribution of the fish. Usually, some form of stratified random sampling is used instead.

In the case of acoustic surveys, the observations do not form point locations as the sample record is quasi-continuous[17], even though it is discretized post hoc. For these surveys, it is natural to apply some form of transect-based stratified estimate of the total, such as the Jolly and Hampton (1990) method for parallel transects. An example is the acoustic surveys for southern blue whiting (Hanchet *et al*., 2000) and orange roughy (Clark, 2006), both in New Zealand.

8.2.2.3 Spatial design-based methods in area-based surveys

Fish density measurements from sampling stations close to each other are more similar than measurements further apart if the fish tend to be aggregated, as is overwhelmingly the case in nature. This feature of the data is ignored in non-spatial estimation methods. The transitive method of geostatistics[18] is a design-based inference method that takes advantage of the spatial similarity of fish density measurements to compute the estimation variance of the abundance estimate.

Bez (2002) demonstrated the use of this method for regular sampling designs, i.e. designs where the stations are spaced at regular intervals such as in a grid or in pre-established acoustic tracks. The estimate of abundance is obtained in the same manner as in a non-spatial sampling method (because the data are considered as generated by a deterministic process), but the estimation

[17] The nature of the sample obtained from acoustic surveys is complex and, as yet, an inadequately addressed topic. The volume sampled will depend on the transducer directivity, transmitted power used, signal-to-noise ratio, and thus, the backscattering cross-section of the target fishes and fish depth. Depending on the pulse rate and depth, volumes of the sea may be sampled repeatedly leading to considerations of autocorrelation depending on the variance model that is used. Even when the pulse rate is such that there is no overlap of the sonified volumes, calculation of the volume sampled as a function of depth is complex: it is not necessarily a uniformly increasing function of range. Estimates of abundance are usually expressed in terms of biomass/$m^{2,}$ though the sampling unit is not a simple area measurement. Any resulting variance model is problematic.

[18] "Transitive" refers to the fact that this theory accounts for transitions between the spatial process (e.g. the fish stock) and the fields where this process is located.

variance is computed using the transitive covariogram, which is where the spatial correlation is taken into account. Transitive geostatistics can also be used to estimate the area occupied by a stock within the survey area, by turning the densities data into a presence/absence representation, where a one is assigned to every positive fish density value and a zero to every zero fish density station. The implementation of these techniques can be done for certain regular sampling configurations with the free software EVA2 (Petitgas and Lafont, 1997).

8.2.3 Model-based inference in area-based surveys

8.2.3.1 Characteristics of model-based estimation

In model-based estimation, the observed variable is considered as a random variable from a distribution defined by assumed model. The probabilities of the samples come from the model's distribution function, i.e. random observations drawn from this density function, rather than, or as well as, from the sampling procedure. Conventional inference methods are model-based. Strict adherence to a pre-established sampling design is also important for model-based inference when using area-based surveys, but for different reasons than in the case of design-based inference. In this case, certain sampling designs allow a proper evaluation of the sample variance of the abundance estimate, especially in the case of intrinsic geostatistics, the most widely used technique of model-based inference of fish surveys (Petitgas, 2001).

8.2.3.2 Non-spatial model-based methods in area-based surveys

To estimate the total fish abundance from a model-based inference survey, without considering spatial correlation of successive observations, it is generally necessary to model the frequency distribution of fish density data or to model the relation of fish abundance with a covariate known for the whole survey region, the predictive approach. Formerly, the lognormal distribution (or its generalization, the Δ-distribution) was considered for some time but it was not generally adopted owing to statistical issues related to lack of robustness and bias (Smith, 1990). The predictive approach requires that the predictive covariate be known for the whole region covered by the survey, not only for the particular stations observed during the survey. A regression model between fish density and the covariates can then be used along with an exhaustive database of the covariates to estimate the total of fish in that region. These methods have been described in detail by Valliant, Dorfman and Royall (2000) in a context completely different from fisheries and sampling in the marine environment. Smith (1990) presents a fisheries application. They seem to be of limited use in the context of marine surveys, as important covariates of fish abundance are difficult to know exhaustively.

8.2.3.3 Spatial model-based methods in area-based surveys

Data generated by area-based surveys can be analysed using geostatistical models. Unlike transitive geostatistics, in model-based geostatistics both the abundance estimate and the estimation variance of the abundance estimate are derived from a model of the spatial correlation. Model-based geostatistics comes in two forms, intrinsic and likelihood geostatistics.

Intrinsic[19] geostatistics is a model-based technique to estimate total fish abundance from surveys widely used since the early 1990s (Petitgas, 1993). In this method, the spatial process (e.g. the fish stock) is considered as the single realization of a two-dimensional random function; thus, the values (fish densities) of the process at specific points are random variables. However, the probability model for the random variable is unspecified. As pointed out above, area-based surveys usually follow a regular spatial pattern pre-established in the sampling design. This is

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[19] Intrinsic refers to the fact that this theory considers only the intrinsic properties of the spatial process, not the transitions between the process (e.g. the fish stock) and the field where the process is located.

especially useful when applying intrinsic geostatistics, as in this case the variance of estimation can be computed using the free software EVA2 of Petitgas and Lafont (1997).

Like transitive geostatistics, intrinsic geostatistics is based on the spatial correlation of the sample values. However, in this case, it is necessary to estimate a model variogram, which is a mathematical model describing how the spatial correlation between points inside the spatial process decreases as the distance between point increases. The variogram and the observations are used to predict the value of the spatial process at all nodes of a grid or, equivalently, for all cells of a grid (an interpolation process called kriging), then these values are integrated over the two-dimensional field to obtain the abundance estimate. Because this technique does not consider boundary processes, it cannot be used to estimate the area occupied by a fish stock inside a survey area. Thus, in most applications, the boundaries of the stock are outlined by ad hoc means and the abundance estimate is evaluated inside these boundaries.

Because the whole set of observations from a survey is considered to be just one realization of the random function, the sample formed by all those observations together is not repeated, which creates problems in evaluating the sample variance. This problem is solved by recourse to a strong ergodicity[20] assumption - that repetitions in space of small parts of the spatial process are equivalent to repeated observations of the whole spatial process. Thus, the estimation of the variance of the total is known as “extension variance” (Journel and Huijbregts, 2004), extending from small parts to the whole.

Unlike intrinsic geostatistics, likelihood[21] geostatistics define a specific probability model for the random variable that is realized at every point of the spatial process, so that a likelihood function can be defined and then the techniques of estimation developed in mainstream statistical modelling, such as maximum likelihood, can be applied to survey data accounting for spatial correlation. The spatial model underlying likelihood geostatistics is, however, essentially the same as in intrinsic geostatistics, deepening essentially upon the estimation of parameters of a spatial correlation function.

Roa-Ureta and Niklitschek (2007) developed techniques using this theory that are especially suited to fishery surveys. These techniques include the estimation of both the area occupied by the stock inside the survey area and the total stock abundance. This convenient feature of estimating both the area occupied by the stock and the total stock abundance using the same statistical inference framework is possible because the likelihood approach allows extensions into mainstream statistical modelling techniques such as generalized linear models.

Likelihood geostatistics also permit the incorporation of additional sources of dependence in the data such as multiple surveys (multiple snapshots of the same aggregation of fish) and results of more than one vessel by extending the model through the likelihood function. This feature makes likelihood geostatistics especially valuable for survey data from several commercial vessels composing a fleet and working together to evaluate a stock in an area- or aggregation-based survey.

The analysis of survey data under the intrinsic geostatistical methodology can be carried out with one of several packages of the free statistical modelling software R[22] (R Development Core Team, 2010), and the estimation variance of an abundance estimate can be obtained with the already

[20] Ergodicity is the property of a stochastic dynamical system by which the time average of the process in the long term is the same for all initial points. In the context of this review, the analogy is in the spatial domain.

[21] Likelihood is the central concept of much statistical inference. The likelihood function is a function of parameters of a model that measures the probability of the data under various values of the parameters. Thus, when a likelihood function is available, it is possible to identify the values of parameters that maximize the probability of the data that actually occurred, i.e. that maximize the likelihood. Moreover, the curvature of the likelihood function about its maximum allows estimation of the variance of parameter estimates.

[22] www.r-project.org.

quoted EVA2 software. A likelihood geostatistical analysis can also be undertaken with R packages, specifically the geoR and geoRglm packages (Christensen and Ribeiro, 2002), to estimate the mean density inside the areas occupied by the fish stock and to estimate the area occupied by the stock, respectively (see Roa-Ureta and Niklitschek, 2007 for details).

8.3 Aggregation-based surveys

8.3.1 Application of aggregation-based surveys

When a fish aggregation is encountered using an aggregation-based survey, one or more secondary surveys are then carried out on that fish concentration. Several aggregations may be found within a fishing area, in which case the estimate of the total is given by the sum of the totals of each concentration. Unlike area-based surveys, the purpose here is not to estimate abundance over a sampled region, but rather just to estimate abundance over the observed aggregations. Thus, the estimate obtained is a "minimum biomass estimate" as it is acknowledged that other concentrations of fish will, or may, occur that were not yet encountered and so not surveyed. This method is adaptive in the sense that sampling is undertaken when fish aggregations are encountered. One example is shown as the third application in Roa-Ureta and Niklitschek (2007), where a commercial vessel passed repeatedly over a concentration of orange roughy over a seamount off central Chile.

Because this type of survey does not implement a pre-established probabilistic sampling design and the observation track implemented can be far from regular, the usual techniques of design-based inference and some model-based techniques cannot be used to estimate fish abundance and the estimation variance of the abundance estimate. However, these surveys are extremely useful from practical and logistical points of view as they allow more freedom to modify the sampling procedure as it is implemented. This is more like the usual behaviour of fishers, and this type of survey better accommodates the work regime on a commercial vessel, even when it is directed by a scientist with the skipper occupying a secondary role. In these surveys, it is still important, however, that the observation secures a wide coverage of the region where the fish stock is located, including locations of low or zero density in order to obtain a valid estimate of abundance for a region. The low or zero fish density locations can be observed much less intensively than high density locations, but still they should be part of the area covered by the survey if the survey is to have any utility from a scientific point of view.

8.3.2 Design-based estimation in aggregation-based surveys

8.3.2.1 Non-spatial design-based methods in aggregation-based surveys

The absence of a pre-established sampling design when implementing an aggregation-based survey does not mean that design-based techniques of inference are entirely inapplicable for estimating fish abundance. Adaptive sampling design inference (Thompson and Seber, 1996) can theoretically be applied to data from aggregation-based surveys. However, adaptive sampling design inference generally requires strict adherence to certain sampling rules that can be difficult to implement in an acoustic fisheries survey, especially because under adaptive sampling-design theory the final sample size is generally unknown, whereas acoustic surveys usually face limitations on the number of days at sea that are available.

8.3.3 Model-based estimation in aggregation-based surveys

8.3.3.1 Non-spatial model-based methods in aggregation-based surveys

Essentially, this is the same case as in area-based surveys. However, since the purpose here is not to estimate abundance over an area, it seems nonsensical to relate observed abundance in the aggregation with a covariate that extends to a wider region beyond the aggregation. Thus, there does not seem to be any useful method in this category.

8.3.3.2 Spatial model-based methods in aggregation-based surveys

Both intrinsic and likelihood geostatistics can be used to estimate abundance with data coming from an aggregation-based survey. It must be emphasized, however, that the estimation variance of the abundance estimate under the intrinsic theory would normally require the application of some type of regular sampling, whereas under the likelihood theory no such requirement exists as the estimation variance will come automatically from numerical maximization of the likelihood function if the maximization is successful.

It is also possible to implement an aggregation-based survey, i.e. adaptive sampling, but once aggregations are found, then apply regular sampling to each aggregation. In that case, both intrinsic and likelihood geoestatistics could be considered as equally applicable and convenient depending on the details of the data and the focus and objectives of the analysis. Software already quoted above for intrinsic and likelihood geostatistics can be used to analyse data from these surveys.

8.4 Comparison of estimators

8.4.1 Methods

The following analyses are provided to offer insight into the consequences of using different estimators. The choice of a maximum likelihood geostatistical approach (MLGS) (Roa-Ureta and Niklitschek, 2007), a model-based method, does not depend upon a particular sampling design, which is particularly suitable for data originating from surveys with a variety of sampling designs. Secondly, this method provides explicit treatment of spatial correlation, which is particularly relevant for highly aggregated resources.

To assess the effects of different estimation methods, MLGS results were compared with those obtained by two alternative methods:

(i) Random sampling design based upon transects where a simple mean area scattering coefficient (S_A) is computed from transect S_A means, weighed by transect length. Independence between transects and normally distributed errors are assumed.

(ii) Random sampling design based upon DSUs, where a conditional scattering coefficient mean is computed from all positive sampling units and then multiplied by the proportion of the survey area occupied by the stock, which is computed from all DSUs. The randomly placed transect model analysis follows Jolly and Hampton (1990)'s method for semi-random transects, and it is the most frequently used approach in dedicated orange roughy surveys elsewhere (Kloser *et al,.* 2002; Hampton and Soule, 2003; Niklitschek *et al,.* 2005; Hampton, 2004; Hampton, Soule and Nelson, 2008).

Both the MLGS and the elementary sampling units (ESUs) methods differ from the randomly placed transect model because the first two produce separate estimates: (i) for the conditional acoustic density mean (S_A), obtained from positive values only; and (ii) for the stock presence ratio. In these calculations, a binomial error distribution was assumed for the stock presence ratio for both methods and log-gamma and normal error distributions were assumed for the unconditional S_A corresponding to maximum likelihood geostatistical and ESU methods, respectively. The survey area in the randomly placed transect method is calculated as the product of transect length and mean distance between transects. In the maximum likelihood geostatistical and ESU methods this computation is not always possible (transects may not exist), and surface area is computed as the total number of 250 m^2 pixels covered by the survey.

The three methods of analysis were applied to data collected in 2008 from the Sleeping Beauty seamount. The classical randomly placed transect method produced 17 percent higher biomass estimates than the maximum likelihood geostatistical method (Table 8.2). This difference was related to a 7 percent higher estimate for the mean S_A as well as to a 10 percent larger computed survey area. The ESU method yielded biomass estimates that were close to randomly placed transect result. Here, the lower survey area computed by the randomly placed transect method was compensated for by a 7.5 percent increase in mean S_A (Table 8.3).

It is evident that computing the survey area as the product between transect length and mean distance implies a certain level of extrapolation whose importance depends on the relative dimensions of the survey area. In a design-free (i.e. irregularly covered area) context, such an approach is impractical and an objective way to define the area is by simply joining the acoustic track vertices. For the sleeping beauty feature, scaling up the maximum likelihood geostatistical method and ESU survey areas to match the randomly placed transect area reduced the differences in biomass estimates to those of the differences in the S_A estimates, i.e. the randomly placed transect biomass estimate had an estimate 7 percent higher than the maximum likelihood geostatistical method and 7 percent lower than the ESU estimate (Table 8.3).

Table 8.2: Analysis method effects upon biomass estimates in Sleeping Beauty seamount (2008)

Analysis method	**Surface area**	**Stock presence ratio**		**Unconditional acoustic density (m^2/mn^2)**		**Abundance ($\times 10^6$)**		**Biomass (tonnes)**		
		P	EE	S_A	EE	N	EE	B	EE	CV
MLGS	6.7	0.54	0.048	72.4	26.2	0.94	0.177	3 018	638	0.21
ESU	6.7	0.52	0.03	83.2	17.8	1.08	0.101	3 470	477	0.14
RTS	7.4	N/A	N/A	77.4	14.8	1.10	0.210	3 523	759	0.19

MLGS: maximum likelihood geostatistical approach (Roa-Ureta and Niklitschek, 2007); ESU: random sampling assumed from 50 m elementary sampling units; randomly placed transect method (RTS): random sampling assumed considering each transect as an individual observation; P: stock presence ratio; EE: error; S_A: unconditional acoustic density mean; N: number; B: biomass; CV: covariance. In both the MLGS and ESU method, the unconditional S_A estimate was calculated as the product of the stock presence ratio and the conditional S_A mean (from positive values); N/A: not applicable.

Table 8.3: Analysis method effects upon biomass estimates in Sleeping Beauty seamount (Survey 1, 2008)

Analysis method	**Surface area**	**Stock presence ratio**		**Unconditional acoustic density (m^2/mn^2)**		**Abundance ($\times 10^6$)**		**Biomass (tonnes)**		
		P	EE	S_A	EE	N	EE	B	EE	CV
MLGS	7.4	0.54	0.048	72.4	28.3	1.03	0.192	3 294	698	0.19
ESU	7.4	0.52	0.03	83.2	19.5	1.18	0.112	3 787	521	0.09
RTS	7.4	N/A	N/A	77.4	14.8	1.10	0.210	3 523	759	0.19

MLGS of Roa-Ureta and Niklitschek 2007; ESU random sampling assumed from 50 m elementary sampling units; randomly placed transect (RTS): random sampling assumed considering each transect as a single observation; P: stock presence ratio; EE: error; S_A: unconditional acoustic density; N: number; B: biomass; CV: covariance. Surface area values obtained using the MLGS method and with the ESUs scaled up to match the randomly placed transect method; N/A: not applicable.

8.4.2 Comparative results from applying different analysis methods to the orange roughy South Western Indian Ocean (SWIO) 2008 data

To obtain biomass estimates comparable with those given when spatial correlation is ignored, the ESU method was applied to alternative biomass estimates for ten areas surveyed in 2008 (Table 8.4). The effects of ignoring spatial correlation between samples (i.e. assuming a random sampling design) differed between estimates for the area occupied by the stock (α) and for the S_A. In the first case, there was a mean reduction of 1 percent in the estimated stock area, while there was a ~19 percent increase in the estimated mean acoustic density. Therefore, estimated biomass under the random sampling design-based approach was 18 percent higher than the one obtained by the maximum likelihood geostatistical approach. At this point, it is important to recall than the maximum likelihood geostatistical method assumes a log-gamma error distribution compared with the normal error distribution usually assumed in the two random-sampling design approaches (randomly placed transect method and random sampling elementary unit.

Table 8.4: Spatial distribution, acoustic density and relative abundance indexes estimated for orange roughy in the SWIO in 2008. Random sampling design-based analysis

Seafloor feature	Observed area (km²)	Stock presence ratio		Stock area (km²)		Acoustic density (m²/mn²)		Relative abundance index (m²)	
		E	EE	α	EE	S_A	EE	Φ	EE
BB	4.8	0.22	0.033	1.06	0.158	300	24	92	16
BO	3.7	0.64	0.040	2.37	0.148	178	32	123	23
DA	4.9	0.35	0.031	1.72	0.152	310	20	155	17
DT	1.1	0.28	0.053	0.30	0.057	321	44	28	7
MM	2.4	0.19	0.031	0.46	0.074	366	59	49	11
SA	0.7	0.14	0.063	0.10	0.044	128	19	4	2
SB	6.7	0.52	0.030	3.48	0.201	160	12	163	15
SC	2.1	0.15	0.032	0.32	0.065	245	29	23	5
SU	0.6	0.31	0.051	0.19	0.031	229	20	12	2
WR	14.8	0.19	0.012	2.77	0.173	199	17	161	17
AL	41.8	0.31	0.009	12.75	0.395	218	8	810	42

BB; BO; DA; DT; MM; SA; SB: Sleeping Beauty; SC: SU; WR; AL. E: stock presence ration; EE; α: stock area; S_A: unconditional acoustic density; Φ: relative abundance index.
Source: Hampton, Soule and Nelson (2008).

9. UNCERTAINTY OF RESULTS

9.1 Sources of uncertainty

All survey results, whether from acoustic surveys or other means of resource assessment, are subject to uncertainty[23], sometimes referred to as the survey error. Sources of uncertainty should always be reported when providing estimates of fish abundance to enable an assessment of the confidence that a decision-maker may have in the results. This is important, first, for incorporation into assessment models of the possible range an abundance estimate may have, and second, for how the results may be used in management decisions. In this way, decision-makers should gain some understanding of the level of confidence that they can place in the resource estimates.

[23] The term uncertainty is often used when it is impossible to assess the error associated with a measurement. Where the error can be estimated, use of the term following this convention would be inappropriate.

Two sources of error in the survey results are:

(i) Bias: this source of error is assumed to remain constant between surveys and is usually ignored not least because it rarely can be estimated (e.g. what fraction of the population was outside the survey area?). Hence, from the perspective of bias, the results are used in a relative sense, i.e. as indices of abundance.

(ii) Variance: (i.e. sampling error) errors that may change between surveys of the same population and need to be estimated if the results are to be compared, e.g. a transect may, by chance, pass through an area of high (or low) fish abundance.

Relative estimates are most useful when there is a time series of survey estimates, typically of several years, that are directly comparable, i.e. they have been obtained from the same areas using the same survey methodology and at the same time of year. To the extent that this is not possible, additional year-to-year error will be introduced into the survey results. The results may be biased, but this bias is assumed to remain constant between surveys. Again, this may, or may not, be true.

If results are to be used as absolute estimates, all forms of errors should be estimated, which requires use of some form of error model that describes the error processes. For this, an estimator is needed for each survey provided by an absolute biomass estimator model and likewise for the sampling errors. Conventionally, these are provided in the form of a standard deviation of the result, though measurement errors may be given as plus or minus an absolute amount. However, it is emphasized that estimates of all sources of error are rarely provided and doing so may not be feasible: and, they may provide an estimate that has such large error bounds that the result is relatively uninformative.

9.2 Sampling error

This source of random error arises from the location of the survey transects in relation to the fish aggregations. Provided that an acceptable survey design has been used, it can be estimated. This can be calculated from within survey variability between transects and between survey errors (variability between surveys) if a number of surveys have been conducted. It needs to be emphasized that as commercial vessel surveys are frequently conducted without scientists on board, the vessels must be provided with suitably detailed and descriptive instructions (instructions that must be followed!). The results from a poorly implemented survey are difficult to correct during post-processing and may not even be considered.

Many acoustic surveys are designed to be flexible, typically with the survey area and/or sampling frequency being changed as information on stock distribution is gathered during the survey – so called adaptive surveying. This serves to improve the precision of survey estimates. While intuitively this approach is attractive, if not implemented correctly (once again following clearly defined protocols), the resulting data may not be usable.

It must be emphasised that the sampling error underestimates the overall error of the survey as it excludes potential large sources of error arising from, for example, changes in fish distribution with respect to the range of the area surveyed, cyclic variation in the backscattering cross-section of the target fish, variable catchability coefficients (both between and within species) and errors in corrections for the dead zone, noise arising from, weather for instance, and in the case of deepwater surveys, the value to be used for absorption of sound by the sea water. To maximize the usefulness of the survey results, efforts should be made to minimize the errors and provide estimates of them. Some of these major sources of error are dealt with below. Here the focus is on sources of error that may be of importance to surveys conducted from commercial vessels. Table 9.1 lists some of the most important errors commonly encountered during deepwater surveys. These values are guidelines and will vary considerably depending on the species that are surveyed, the vessel used, the marine conditions and other factors.

able 9.1 : Some typical sources of systematic and random errors in deepwater acoustic surveys (adapted from Table 1.1 of ICES Report No. 287)

Source	Random error (%)	Bias (%)	Comment
Time series index error			
Random sampling	±10 to ±40		Will be minimized if a good survey design is followed.
Target strength	±5	Uncertain	Large systematic bias can occur. Diel effects may be of considerable importance.
Species identification		0 to ±80	In trawl sampling it is important to attempt to equalize catchability for all species.
Fish movement		0 to ±40	Knowledge of fish movements is important to ensure an appropriate survey design.
Diel behaviour	0 to 25		May arise from cyclical patterns of aggregation, vertical migration and changes in orientation.
Physical calibration	±2	±5	Calibrations should be made under optimal conditions.
Transducer motion		0 to –30	Can be compensated for if vessel motion is monitored.
Bubble attenuation		0 to –90	Relies on empirical corrections and depends on the sea state and vessel characteristics.
Hydrographic conditions (temperature and salinity)	±2 to ±5		Can be estimated and corrected for.
Noise interference		0 to ±20	Usually arises from vessel noise, but may also be due to other echosounders.
Absolute abundance error			
Target strength		0 to ±50	May vary in space, time and environmental condition.
Area surveyed		0 to 90	Knowledge of proportion of population surveyed crucial.
Physical calibration		±3	Higher if beam pattern of transducer unknown.
Sea state		0 to ±5	If weather too severe, surveys should not be conducted.

Sources of error of over-riding importance for deepwater acoustic surveys include:

- determination of species composition of acoustic marks;
- backscattering cross-section of sonified fish; and
- uncertainty as to the fraction of the stock surveyed (i.e. in survey area).

None of these problems are specific to acoustic surveys conducted by commercial vessels.

9.3 Determination of species composition

The species composition of marks with relevant echoes is largely determined by trawling. This sampling technique may introduce large uncertainties into acoustic survey estimates, especially when there is a high degree of species mixture in the sonified volume. This error arises from the inability to representatively sample the fishes causing the echoes because the sonified fish species may have different vulnerabilities to capture, i.e. more active fish may avoid the net while other species are preferentially caught. Or, smaller fish may pass through the trawl meshes while larger ones are retained.

In some circumstances, accurate species determination can be improved when commercial vessels are used compared with specialist research vessels, as the commercial vessels, and perhaps most importantly, their crew and gear, are chosen specifically for their ability to catch the target fish species. However, the gear on most commercial vessels is not only specifically designed to maximize the catch rate of the target species but also to minimize the catch of non-target species. For example, small fish (mesopelagic species such as myctophids), may be poorly sampled passing through the net, and hence gear and fishing techniques that avoid such species will give the appearance of such species being largely absent: in reality, they may contribute the major part of the echo intensity (their presence may be evident from their occurrence in the stomachs of predatory species while being absent from trawl catch) and thus be the dominant component of acoustic backscattering measures. Thus, changes to the gear to improve the representativeness of the catch should be considered, such as (when legally permitted) using codend liners to retain smaller fish.

In reality, the vulnerability to capture and availability of most deepwater fish species is largely unknown and hence is assumed to be one: echo marks are assigned to species according to their presence in the catch, which may result in inaccurate interpretation of the echogram. It is, therefore, important to synthesize all possible evidence to support interpretation of the echo record in terms of contributing species. Skippers and other bridge officers should be strongly requested to keep detailed notes of targets intercepted during surveys, as well as records of the performance of trawl gear.

Whenever possible, independent methods of species verification should be undertaken. Multifrequency systems deployed on towed platforms may bring the target fishes within the range of higher sound frequencies that have greater powers of size discrimination. Cameras mounted on net headropes can also provide useful information on gear avoidance by fish species. On some vessels, it may even be possible to use specialized net systems (smaller net-mesh sizes and or net designs to target different sections of deepwater communities, e.g. fine-mesh multiple opening/closing gear).

The problem of incorrect target identification is exacerbated when surveying species such as orange roughy, which does not have a gas-filled swim bladder and hence has a small backscattering cross-section area while the relative contribution to the echo intensity from non-target species arising from their gas-filled swim bladders may be large compared with their contribution in weight to the catch. Orange roughy, for example, may contribute by far the largest proportion of catch biomass but a much smaller proportion of the echo intensity. For example, in an orange roughy survey on the *Challenger Plateau* off New Zealand in 2006 the species composition by weight of one area was 99 percent orange roughy, but the proportion of acoustic backscatter from roughy was estimated to be only 72 percent, the remaining 28 percent coming from species with much higher backscattering cross sections such as ribaldo (*Mora moro*) (Clark *et al.,* 2006).

The problem of identification of the species in the sonified volume is exacerbated within the proximity of the seabed. If trawls are targeting fish that are within 5–6 m of the seabed, the fish will be within the dead zone (see below): scatterers in this region cannot be distinguished from the sea floor echo and hence cannot be detected with an echosounder. Hence, such fish when caught will not be included in the acoustic record. It is generally assumed that the species composition in the dead zone is the same as in the fish aggregations above: failure of this assumption may add to error in any estimates.

The error from combining species with vastly different backscattering cross-sections is further compounded as the backscattering cross-sections of most deepwater species are poorly known and may have to be assumed from often rather poor estimates of different-sized similar species. In deepwater, the large sonified volume (approximately 100 m in diameter at 1 000 m depth) means that it is highly likely that untargeted co-occurring species will occur within the beam, even though the aggregation of interest may be virtually monospecific. If these fish have gas-filled swim bladders, and hence large backscattering cross-sections compared with the target species, survey estimates may greatly overestimate the abundance of the target species.

All of the above emphasizes the importance of obtaining representative samples of the sonified fish. Sufficient time must be set aside for sampling, the most appropriate gear must be used and, where possible, catches should be taken from range of fish marks throughout the diel period.

9.4 Backscattering cross-section

Error in estimates of species-specific backscattering cross-sections comes in several forms:

- the uncertainty in the measurement of the backscattering cross-section (not least due to contamination of samples by non-target species);
- the error in the relation between backscattering cross-section and fish length;
- the conversion of a backscattering cross section estimate for a particular length of fish to biomass;
- errors relating to fish being sonified in different aspects compared with that used in determining the backscattering cross-section relation; and
- different physiological states, e.g. with gravid gonads, nature of stomach contents and stomach fullness, and tissue fat levels.

As noted, the backscattering cross-sections of many deepwater species have not been estimated and may be assumed to be comparable with similar, often congener, species. But even for those species where such experiments have been performed, plausible estimates can vary from half to double the estimated value. In such circumstances, any estimates are best used only in a relative sense.

Diurnal changes in backscattering cross-section, owing to changes in orientation of the fish, often as they migrate vertically through the water column, may result in large and unknown errors in their backscattering cross-section. This phenomenon is not considered further in this report.

One further source of error in estimates of backscattering cross-section that may be specific for surveys of high-seas species is that the targeted fish are often much larger than those found closer to land where backscattering cross-section–length estimates have been determined. In such cases, any length-dependent effect will increase the error in abundance estimates.

Measures to reduce the uncertainty in backscattering cross-section estimates normally require directed research often using specialized equipment that is not available on commercial vessels. Ascertaining the backscattering cross-section of a species under survey conditions is so important that time and effort should, if at all possible, be allocated for this. For example, measures to determine individual fish backscattering cross-sections with concurrent camera-based observations as a means to verifying species identification and orientation should be considered (e.g. Ryan, Kloser and Macaulay, 2009). If field data are not available, model-based estimates should be attempted.

9.5 Fish distribution and behaviour

If the range of a species is well understood, then an area-based survey may provide a relatively accurate estimate of the total population. However, if part of the stock occurs outside of the area at the time of the survey, or movement of fish into and out of the covered area during the survey is substantial, then the survey results will be compromised. This is particularly important for surveys of fish that aggregate to breed in particular places, such as orange roughy. Aggregation-based surveys may provide little information on the total stock size, but rather a minimum biomass estimate that depends on the number of aggregations that form the population that are detected and surveyed. For most high-seas species, locating all aggregations and within an acceptable time frame is, in practice, impossible.

To minimize the errors introduced by fish behaviour and distribution, it is important to obtain as much information about the stock as is possible prior to designing the survey, whether from previous surveys (no matter the methodology that was used), historical catch records, or simply from asking fishers who have worked on the grounds in the past.

9.6 Weather

Reductions in echo intensity may occur from sound attenuation caused by seawater aeration and from effects arising from excessive vessel pitch and roll, such that fish are sonified or the echoes are received in a direction of low-beam directivity, i.e. the transducer is not pointed at the scatterer. This problem is common to both commercial and research vessels. The extent to which vessel motion affects acoustic measurements depends on the sea state, swell, seagoing characteristics of the vessel and the range of the acoustic system. However, the effects can be minimized if only vessels with suitable characteristics are used, i.e. with transducers mounted in the best position. In some sea conditions, surveying may be possible steaming in one direction (with the swell) and not another.

Errors arising from aeration in the water column during bad weather can be reduced by discarding recordings when there are obvious signs of echo attenuation from this cause. Further, setting thresholds for acceptable data quality within the survey protocol, such as rejecting any surveys conducted above a specified wind speed or swell height (e.g. 25 knot and 2 m respectively) should be considered. Similarly, if a certain proportion of transmissions need to be removed during post-processing, the resulting estimates should either be downgraded (e.g. data from 10 percent of transmissions rejected) or entirely disregarded (20 percent of transmissions rejected).

Nonetheless, even for transmission data of accepted quality, a variable and negative bias will exist in poor weather, which will be dependent on vessel movement. Relatively inexpensive pitch and roll sensors that measure vessel motion have recently become available (Stanton 1982, Dunford, 2005) and should be deployed to compensate for the reduction in intensity of the transmitted pulse in the vertical direction and echo intensity from changes in the appropriate beam directivity to be used caused by vessel movement. If weather conditions deteriorate, changing vessel speed and/or direction to minimize echo intensity loss can reduce this problem. Alternatively, if feasible, a pole or towed body can be deployed to place the transducer below the surface bubble layer: when using a towed body, this will also remove errors incurred through vessel pitch and roll.

9.7 Seafloor acoustic "dead zone"

Fish closer than half the pulse width ($c\tau/2$) to the bottom will be indistinguishable from the bottom echo – the so-called acoustic dead zone. The size of the dead zone increases with depth and/or the slope of the bottom. This error is particularly severe for deepwater demersal species, and especially those that occur on rough or sloped grounds. It is common to all acoustic surveys.

For orange roughy, which are often found close to the bottom in deep water on rough ground, the proportion missed in the dead zone can be substantial. For example, Kloser (1996) estimated that in surveys of orange roughy off Tasmania with a hull-mounted transducer, roughly half the biomass is undetected in the dead zone, which can be over 30 m in extent in some places.

Corrections can be applied for loss of the signal in the acoustic dead-zone, using Barr's polynomial expression given in Doonan *et al.* (1999), to estimate the mean density of aggregations in the area immediately above the detected bottom. This method corrects the echo intensity from each aggregation on the assumption that the density of the aggregation in the dead zone is the same as that in the 1 m depth channel immediately above it. Recalculation of the biomass using the corrected aggregation backscattering intensities gives a correction factor for this phenomenon (while at the same time introducing a potential error).

As with many of the problems listed above, positioning the transducer as close as possible to the target species, either using a towed body or placing it on the trawl gear, can, at least partially, eliminate or reduce the dead-zone effect. This also moves the transducer out of the surface zone, and so eliminates the weather aspects while reducing other range-dependent issues such as acoustic absorption, noise-to-signal ratios, etc. However, such systems tend to be expensive, technically advanced and require specialized support. Space on many commercial vessels and deployment systems may not be available, as also may be the case for some research vessels.

9.8 Calibration error

Error in the accuracy of the system calibration is an issue common to all acoustic systems. Ideally, acoustic systems should be calibrated under specific conditions (see Section 4.6), but because of logistical constraints, commercial vessels are on occasion calibrated under less than non-optimal conditions and hence the calibration accuracy may be compromised. Calibrations should be carried out as frequently as possible but at least annually to minimize the chance of calibration error. This is to ensure that the system gain is set at the accepted level and also to detect system drift and/or failure of transducer elements.

9.9 Other errors

A number of other errors may also reduce the precision and/or accuracy of biomass estimates. Some of these may be specific to the use of commercial fishing vessels, such as the presence of errors from other echosounders, engines and propellers. Other sources of error may be related to the long range of the targets such that errors occurring in the standard absorption coefficient values, set in the acoustic system, become appreciable. In general, these uncertainties are considerably smaller than those described above, and, while all efforts should be made to minimize them, much greater reduction in error will be gained by improving the understanding of such factors as trawl selectivity, fish distribution and behaviour and backscattering cross-sections values.

10. IMPORTANCE OF COLLECTION OF BIOLOGICAL DATA

10.1 Data to be collected

Collection of biological data on vessels undertaking acoustic surveys is important for general fisheries management and research purposes. Such biological information can be found in Shotton (2006), for example. Sampling programmes may vary considerably, in particular for high-seas fisheries, depending on flag state requirements and those of the regional fisheries management regime in the area being fished. Management regimes and their reporting requirements, including legal constraints and potential perverse incentives[24] that might affect how reporting is done should be taken into consideration.

Biological data are also required for the interpretation of acoustic results. For this, collection of the following biological data is essential:

- determination of the species composition of the catch;
- length and weight frequency data of fish taken from each stock that is surveyed;
- if significant amounts of bycatch are caught, detailed information of their species and size composition should be collected; and
- Sex frequency composition and the status of gonads.

It is important that biological data are collected in a consistent way for a given stock and/or fishery and that a single consistent practice is applied among associated vessels. It is, therefore, critical that sample protocols are developed, agreed upon and adhered to. Several sampling protocols exist, e.g. that described for orange roughy in Appendix D of FAO Fisheries Circular 1020 (Shotton, 2006). Several national sampling guides also exist.

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[24] Subminimum sized fish may never be measured because it is “illegal” to retain them.

A possible bias may arise in the samples from different fishing vessels in a fleet if they use gear and mesh sizes that differ among vessels and from that of research vessels that use "standard" gear[25]. This should be kept in mind in the interpretation of the data. Use of "scientific" gear, i.e. trawls with small meshes, on a commercial fishing vessel may require obtaining a special permit.

10.2 Species composition of the catch

The backscattering cross-section of fish depends on their form and the composition of their body (and their behaviour as this affects their aspect in relation to the direction of the sound pulse, but knowledge of this requires direct observation). Thus, accurate information is needed about the species composition of the catch to be able to interpret the echo record. As noted in Section 9.3, care should be taken in assuming that the species composition of the catch indicate what contributed to the echo record as different species will have different vulnerabilities to capture.

10.3 Length and weight frequency data

The backscattering cross-section of a fish is a function of, among other factors, its size, more specifically the effective cross-section area it presents to the sound pulse: this, in reality, is a complicated function. Conventionally, the backscattering cross section has a general form of:

$\sigma_b = aL^b$; where: L = fish length and a and b are model coefficients.

As cross-section area is approximately proportional to the square of the length of a fish, the coefficient b is expected to be in the region of two. As it is σ_b that is measured by the acoustic system[26], knowledge of the length of the fish is required to interpret the results. Ideally, 100 measurements should be attempted. Length frequencies should be sampled in accordance with pre-agreed protocols and reported on standard reporting sheets. The length measurements should be made in accordance with agreed standards for the species in question (e.g. standard, fork or total length).

Weight information is often inferred from length frequency data. However, different populations of a species may have a different length-weight relation. Also, weight will vary depending on the condition of the gonads – when they are gravid, fish weight for a given length should be greater, as will then the relation between sonified biomass and backscattering cross section area. Weight is expected to be proportional to a function of $\sigma_b^{3/2}$.

10.4 Records of bycatch

This information is usually required for reasons other than interpretation of the acoustic record. Bycatch may be discarded, e.g. as for benthic invertebrates and sharks, or it may be retained if the species are of commercial value. When catch is discarded, best attempts at species identification should be made and samples (and in some cases tissue material) should be retained for delivery to appropriate research institutions.[27] Many organizations provide species identification guides for this purpose, such as the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR, undated) and the National Institute of Water and Atmosphere (NIWA), New Zealand (Tracey *et al.,* 2005).

10.5 Sex composition and status of gonads

Reproductive data on sex and gonad status contribute to the definition of spawning areas, spawning periods and other ecological parameters that support management of these stocks. Given that many of

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[25] Because of the need to continue using standard methods, research vessels, so as not to invalidate a time series, may continue to use an "outdated" gear design long after its use has been abandoned by commercial vessels.
[26] Strictly speaking, it is echo intensity that is measured.
[27] A particular example in the Southern Indian Ocean is the programme of the CSIRO, Australia, to investigate the status of gulper sharks (*Centrophorus* spp.*)*, which involves a programme of DNA analysis of tissue samples.

these species typically aggregate for spawning, it can provide critical information for the best timing of the survey depending on if you are planning an area-based survey (you do not want all survey effort to be in one place) or aggregation-based survey (here, the need is for the transects to be together). Gonad condition information can be essential for apportioning the echo record to different stocks, which may be required for individual stock management. Further, fish of the same species may have a different length-weight relation as a function of sex: thus, information on the sex frequency composition may assist in interpretation of the echo record.

10.6 Otoliths

Otoliths of target species, if suitable, should be collected for ageing of fish: this will depend on targeted mark identification carried out during the acoustic surveys. Age information can be used to convert the length composition into age composition for use in age-structured assessment methods. Vials or envelopes for otoliths storage must be available and those responsible for collecting the material must know how to remove the otoliths from the fish. Ageing otoliths can be a time-consuming and expensive process, so provisions for funding for this purpose will be necessary. Provisions for safe storage of the otoliths will be required.

11. INCORPORATING INDUSTRY SURVEY RESULTS INTO THE ASSESSMENT AND MANAGEMENT PROCESS

11.1 Stock assessment

The use of acoustic biomass estimates in analytical stock assessment models that originate from commercial fishing vessels will depend upon the nature of the fish stock and the survey design. Standard methods using randomly selected or systematic transects within a predefined area are well defined in the literature and provide a way to estimate biomass complete with error estimates. Unfortunately, the further data collection patterns deviate from the required standard protocols, the greater the interpretational and quantitative concerns regarding the use of the data in assessment models. This is particularly true with the potentially *ad hoc* and biased nature of acoustic data gathered during normal fishing operations. Essentially, most unstructured and opportunistically collected data are unlikely to satisfy the assumptions required for a statistically valid approach to fish stock assessment, thereby limiting their use in traditional analytical assessments. However, as this report documents, several new and creative methodologies for stock assessment and management are emerging whereby unstructured, but quantitative acoustic data, can contribute to the overall evaluation of stock status. This section discusses how acoustic data are used as an index of abundance, as well as the rigid requirements for input into an analytical assessment and a special case scenario for in-season management, followed by a short section on visualization and multibeam sonar.

11.2 Indices of abundance

In fisheries assessment, an index of abundance is defined as a relative measure of the abundance of a stock. This means that the index must be sensitive enough to track moderate changes in abundance of a stock or constant portion of the stock over time. The index can be either fishery dependent (e.g. the CPUE from catch/effort statistics) or independent (e.g. CPUE from research trawl surveys) provided there is consistency in the methodology and comparability of results between surveys throughout time. Consistency in gear and survey coverage is extremely important if the data are to be used to monitor inter-year trends. Indices that are subject to large error estimates due to inter-annual variations will be poor indicators of abundance and their influence and/or usefulness should be down weighted in an assessment model. Generally speaking, a minimum of five to seven years of survey data are required before an index of abundance is considered suitable to tune or inform an analytical assessment, unless it can be used to provide an absolute biomass estimate.

Acoustic biomass estimates from any vessel that does not follow a formal survey design does not meet the statistical assumptions and/or lacks consistency in the proportional representation of the stock will likely be rejected as a relative index of abundance in an analytical assessment. As such, there is limited scope in a formal analytical assessment forum for use of ad hoc data simply recorded during fishing operations collected by commercial fishing vessels. The data may, however, be used in an absolute sense as a minimum threshold for comparison of the assessment model outputs in spatial analysis or in a Bayesian model as a scaling factor, which the stock trajectory must run through or approach.

11.3 Fishing vessel data and stock assessments

Ten to fifteen years ago, the concept of having the fishing industry independently, cooperatively or autonomously collect quantitative acoustic information was, if not accepted, then discouraged by the scientific community. Today, many countries such as Australia, Chile, Ireland, New Zealand, Norway, Scotland and the United States of America actively use this method or are exploring possible options in this area. Chartered commercial fishing vessels either under the supervision of scientific staff, or independently of such personnel, and equipped with scientific-equivalent acoustic systems have now been used for many years. Ironically, data obtained using this approach is normally given the same consideration as if it were collected from a research vessel.

Despite this, a major obstacle in some management jurisdictions continues to be the acceptance or perceived validity of industry-collected data by the scientific community and the integration of these data into the management process. Acoustic data collected by a commercial fishing vessel without scientific supervision and specialized equipment were simply unacceptable to many. Today, it is not so much the collection of quantitative data but the survey design under which the data were collected that is at issue. The incorporation of unstructured industry collected data into the analytical assessment process still remains a difficult task. Analytical assessment models rely on indices of abundance, either relative or absolute, that are consistent in coverage and comparable from year to year or survey to survey. Acoustic data collected in an ad hoc manner that follow no structure do not fit these criteria and are extremely difficult to integrate into an analytical assessment. Unfortunately, most fishing trips follow unstructured patterns that tend to be biased toward areas of dense fish aggregations (if the skipper is competent and/or lucky), are difficult to interpret and have no statistical design for unambiguous error estimates.

The interest in employing commercial fishing vessels to undertaken scientific surveys is strong, and it is likely that the use of commercial fishing vessels to collect quantitative acoustic data will continue to increase in the future. It is, therefore, important for any project or programme using commercial fishing vessels as platforms of opportunity that all participants understand the potential limitations of the data and how the findings are to be used in the assessment and management of a fishery. Many fishers and vessel owners will volunteer to operate autonomous scientific equipment or record data using existing equipment, if they believe the extra effort is providing information useful to the assessment of stock status and the subsequent management of their fishery. In fact, many are willing to provide additional vessel time to collect supplemental data or to improve the data quality of existing practices. However, they will quickly become discouraged if the data they collect are not considered to make a contribution to the understanding of the fishery by a scientific assessment working group or steering committee or if the results of their efforts are not evident to them. This may not only result in the termination of the ongoing project, but could also have serious implications on future cooperative efforts.

Realistically, acoustic data collected during standard fishing operations are unlikely to be suitable for incorporation into an analytical assessment. Although the data may be quantitative (assuming a calibrated system has been used), they will not meet the criteria required for an index of abundance to follow trends in abundance or to tune an assessment model. This does not mean that the data are unusable. Information on the distribution and abundance of fish in a general or ecological sense is valuable, but it will not normally easily fit into an analytical assessment model. For example, acoustic data collected by multiple vessels over time are extremely useful in characterizing the sea bed and the associated fish distribution. Changes in the overall occurrence, distribution and density of fish on a spawning plume may also provide insights into a stock's status. However, unless there is a specific survey design the data are usually too variable to detect, or to reflect, significant changes in overall abundance. The observed changes may simply be an artefact of varied fishing patterns from year to year.

Hence, incorporation of acoustic data collected by one or more commercial fishing vessels equipped with a calibrated acoustic logging system into an analytical assessment requires a standardized survey design. In most cases, the design is likely to be similar or identical to one developed for a research vessel equipped with a scientific echosounder. Typically, the survey would involve a series of systematic or random transects within a predefined survey area. The most likely difference will be an increase in the survey area and/or a reduction in the time required to survey the area owing to multiple vessels. Error estimates may be slightly higher owing to variation in acoustic system calibrations and intervessel variations, or lower because of the greater survey intensity (i.e. more transects in same area). Once the transects have been completed, analysis of the data is essentially the same as if the survey had been conducted using research vessels.

The deployment of echosounder logging systems aboard commercial fishing vessels also provides an opportunity to undertake special or opportunistic surveys. It is not uncommon for fishers to report large aggregations of fish (especially for pelagic species) believed missed by a survey because the fish were just outside the survey area or observed on route to and from the fishing area. This typically occurs shortly before or after an organized survey has been conducted using either research or industry vessels. Alternatively, new aggregations of fish may be observed around previously unreported underwater features, e.g. seamounts. With good planning and an understanding of the spatial and temporal distribution of the target fish species it is possible to establish, and to provide, detailed instructions for a predefined survey protocol that one or more vessels can undertake if they deem the observation worthy of recording (Appendix D). In this way, the industry has the option to document observations that would otherwise have gone unreported, assuming a vessel with a recording system is in the vicinity. The data, if collected in accordance with the instructions, will provide a quantitative biomass estimate, complete with error parameters for the assessment. And, although the biomass estimate may not be in question, the interpretation of the results and how to incorporate them with the previous survey results will likely be a matter of serious discussion.

A point worth noting is that most vessel skippers are more than capable of following explicit survey instructions in the absence of scientific staff. Providing the start and end positions of individual transects within a predefined survey area to the vessel skipper is all that is required. Guidelines should also be in place to accommodate infrequent events such as fish aggregations extending beyond the boundaries of the survey area. However, vessel skippers must understand that transects deviating from the straight line path between the start and end positions are a waste of time and that in most cases they will be discarded from any analysis. Vessels with forward-looking sonars characteristically have a tendency to adjust their track to intersect the largest or densest portion of a fish school when running transects. This will introduce a strong positive and unwanted bias into the biomass estimate. Skippers should understand why they must resist this temptation.

12. FUNDING OF ACOUSTIC SURVEYS

12.1 Funding considerations

In general, using commercial vessels to undertake acoustic surveys involves high operational costs and this is particularly true for those participating in high-seas fisheries where fishing vessels may range between 60 and 90 m in length. Acoustic surveys may cost from USD 100 000 to USD 1 000 000.

Funding of acoustic surveys using commercial vessels has followed different strategies. Governments may finance the participation of commercial vessels by providing a fish quota to each of the vessels that participate in the survey. This fish quota is usually a fraction of the total allowable catch (TAC) for the particular species and in many countries is reserved for scientific purposes as a research quota. A related procedure, used in some countries, is to transfer the research quota to the research institution that is to carry out the research project. This institution, either private or governmental then requests tenders from fishing companies interested in undertaking the research project and selects the more suitable vessels for the required research based on predefined technical criteria. The transfer of the fish quota to the selected companies is provisional on an agreement with the responsible research institution that the chartered vessels complete the task required by the scientists satisfactorily.

The transfer of the fish quota from the research institution to the fishing companies may be done in one of several ways. One option is to directly transfer the quota to the fishing company, which is then free to harvest the quota at their convenience, retaining all the financial benefits. Alternatively, the selected fishing company may harvest the "research" quota that is owned by the research institution and receive a percentage of the total value of the landed catch. For example, the agreement between the Institute of Marine Research in Norway (IMR) and the commercial vessel members of the Norwegian Reference Fleet Program assigns 60 percent of the quota to the fishing company to cover the expenses of the vessels' operations and 40 percent to cover administration costs and pay the fishermen for the biological sampling during their normal commercial operations (IMR, 2007).

There are many cases when no research quota is available or this method is not used and the fishing industry finances all operational costs involved in the research project. Here, the industry may have approached the research institution to ask for advice on a particular problem; the institution then designs a research project to be executed. If no resources are available, the industry may also pay the expenses involving the participation of scientists.

In other countries, the government may negotiate with industry associations as to the manner in which research by fishing vessels is undertaken and funded. As these types of funding agreements mature, the industry may welcome the opportunity to undertake such research; if not because they can do it more cheaply but because they will have greater confidence in the results. An important consideration is whether the government directly recovers the cost of fisheries management, either in whole or in part. In other situations, there may be no other way of undertaking the survey work unless done by industry vessels, and in the absence of information gathered in this way government assessment scientists may adopt a risk-averse attitude in setting (lower) TACs.

12.2 Cost items

The following items will be required.

Equipment:

- Sounder – this is often already on a vessel. A split-beam transducer can cost from USD 80 000 to USD 100 000.
- Echo displays – these too may already be part of a vessel's standard equipment.
- Data storage – computerized data storage devices are essential and are not a major cost item.
- Transducers – these are expensive and must have an accurately measured beam directivity pattern from which the equivalent beam angle can be measured ($_{2\pi}\int f(\theta)\, d\theta$).
- Towed bodies and cables – if conductor cables are used, they tend to be expensive and prone to damage: this is likely to be an unusual cost item and more commonly the concern of dedicated research-vessel operators.

Calibration:

- There will be time requirements – see Section 4.6.
- Personnel – skilled technicians are usually required to undertake a calibration.
- Equipment – cables and a standard calibration sphere (or calibrated hydrophone) will be required.

- Calibrations typically cost USD 2 000-USD 5 000 depending on where the vessel is and its size.

Operational expenses:

- If the vessel does not have an appropriate transducer, installation will be a cost item.

Data analysis:

- Processing and analysis may be a considerable cost depending on the amount of data that have been collected. Data editing will probably be required prior to any data analysis. This work is usually done by specialists in this work.
- Archiving data: although this should not be a major cost item, it is important and should not be overlooked.
- Data analysis may cost from USD 10 000 to USD 50 000 a trip.

12.3 National applications

12.3.1 Australia

An annual research quota, which is a fraction of the annual quota, is reserved in most important fisheries, e.g. the (past) orange roughy and hoki fisheries. The fishermen's associations, based on technical considerations, select the commercial vessels that are to undertake the surveys. The governmental research institution – Commonwealth Scientific and Industrial Research Organization (CSIRO) or another research institution – are contracted to provide the survey design and to conduct or supervise the research project. The fish quota is harvested and sold by the fishing company: the revenues are used to cover the operational costs of the commercial vessel and the costs involved in the scientists' work. In some cases, the earnings from the research quota are insufficient to cover the expenses involved in the project, and in such cases the industry may be willing to pay for the research in recognition of their interest in the sustainability of the fishery. The annual research quotas in Australia for orange roughy and hoki are approximately 200 tonnes.

12.3.2 Canada

In 2007, a governmental decision was adopted to prohibit the use of research fish quotas to finance fisheries research. A CAD 12 million fisheries fund was created from taxes on the fishing industry. This fund is used to finance the research for all fisheries and is prioritized accordingly. In the case of the Atlantic herring stocks, CAD 250 000 is allocated for research using commercial vessels on one fishing ground through a 5-year agreement. However, in the remaining seven grounds, the industry finances the research using either governmental or non-governmental research institutions. The governmental institution retains responsibility for the review and scrutiny of the research results and undertakes its evaluation for consideration in resource assessments. The catches involved in the research come from the industry quota and the fishermen's association is responsible for the coordination of the vessels involved in the research.

12.3.3 Namibia

A general philosophy of Namibian fisheries is that fisheries management, including research, should be self-funded by the participants in the fishing industry. Several different models are used. When the Namibian orange roughy fishery was at its prime the owners of fishing licenses were jointly required to accomplish a number of research objectives largely at their own expense. In particular, they were required to undertake annual area-based acoustic and random trawl surveys and to conduct exploratory fishing surveys. They had to provide the vessel time and required acoustic equipment and allow government scientists to undertake biological sampling of the catches (Note that all species on all vessels in all fisheries are sampled in Namibia, either at sea or at port). The government was responsible for the cost involved in providing scientists and undertaking data processing, although even these costs were indirectly funded by the fishing industry, through research levies imposed on all quota-controlled landings. In the Namibian hake fishery, a research quota in the order of 1 000 tonnes is provided from the annual TAC, which is allocated to the vessel(s) that conducts an annual trawl survey. In both fisheries, there is close coordination between the responsible governmental scientific institution and the industry associations. For the sardine stock, commercial vessels are used for scouting ahead of the government research vessel, which then undertakes the acoustic survey. Once again, the survey is coordinated through the relevant industry association, but the costs are shared between all licence holders without any recompense from the government.

12.3.4 New Zealand

A research fund is provided from a levy on fish quotas to finance fisheries research. The New Zealand Ministry of Fisheries administers this fund, determining research priorities and contracting research providers. Examples of research projects include resource surveys from both research and commercial vessels. Funding of research projects directly by the different species quota-holding groups is also common.

12.3.5 Chile

A similar manner of funding is used in Chile as in New Zealand, with funds coming from the levy paid by the fishing industry. These funds are managed by a fisheries council that invites tenders for undertaking research projects. Both government and non-government research institutions bid to undertake this research. However, for most acoustic assessment surveys of the more important commercial stocks, the work is carried out by the government-owned research institution and in practice there is no option for non-governmental institutions to bid on these projects. In projects that are considered critical, research vessels and commercial vessels are used.

In most important commercial stocks, a research quota is reserved from the annual TAC. Private or governmental institutions in association with fishing companies apply to undertake research projects and request part of the reserved research quota to finance their operations and the scientific work.

13. DISCUSSION

13.1 Common views

The participants in the workshop were of general agreement regarding the problems and benefits associated with the use of commercial vessels to undertake stock assessment surveys for the purpose of resource management. However, there was no consensual agreement as to the exact extent of the benefits or the sources of uncertainty, which, given the range of situations in which this method could be used, is to be expected. But, in all cases, the view was that the method should be assessed relative to other sources of management information where there is the need for managers to decide on levels of catch and/or fishing effort.

There was agreement that multiyear surveys had benefits that go beyond simple replication of results as they at least permit data time series to be established, which diminishes dependence on single point estimates. This has implications for the institutional arrangements, no less the developing of the understanding for the need for an extended commitment to the entire concept, both by management agencies and the affected sector of the fishing industry.

The workshop noted the prevalence of strong entitlements, or fishing rights, in fisheries where the development of industry-executed and funded resource assessment surveys was most developed. 'The importance of such entitlements to ensure commitment to the process should not be underestimated, and the insistence on industry responsibility in undertaking and contributing to resource assessments should be matched by the recognition that costs incurred by the industry should be balanced e.g. by security in terms of fishing entitlements and/or concessions. Among the most important tactics available, there is the provision of exclusivity of fishing opportunities.

It was noted that in some fisheries there would be important issues of confidentiality in the provision of survey data, particularly in the case of aggregation-based surveys. Skippers may have exclusive knowledge of fishing "hotspots" that they do not wish to disclose for competitive purposes, but where at the same time assessments are needed to justify continued fishing of the resource. How such information management requirements are to be handled will continue to challenge management authorities such as those in RFMOs.

Another issue that was identified in relation to aggregation-based surveys that will need future consideration was the question of 'when to survey'. Self-evidently, if the objective is to obtain minimum-biomass estimates using an aggregation-survey method, frequent interruptions to survey small aggregations will disrupt fishing operations, endanger skipper support for the programme, and potentially result in large aggregations going undetected through lack of time to locate them. However, skippers will have an incentive to prove the existence of the highest amount of biomass possible. Still, it may be desirable that the conditions of a fishing licence require that a specified amount of survey effort is undertaken during a fishing trip. This may require agreement on a threshold level of catch, at or above which an aggregation-type survey must be undertaken.

13.2 Communication with vessel crews

Experience has shown that in at least some fisheries skippers are willing, indeed eager, to assist in stock assessment activities and ensure the sustainability of "their" fishery and will take responsible initiatives (e.g. FAO, 2006). This goodwill should be nurtured by management agencies and it was noted that for this, it is essential to keep crews informed about the programmes, i.e. relevant communications and discussions on survey strategy and tactics as often vessel officers are the best informed critics and invaluable sources of information and well-judged opinion. Ideally this process should be formalized to ensure the fishermen's knowledge and experiences are fully exploited. It can be achieved through a formal review of the sufficiency of execution of the acoustic surveys and completeness of record keeping. It was noted that often failure to provide satisfactory results by vessel operators was unintended and only a little additional effort is required to result in skippers providing satisfactory performance. Where this is not the case, appropriate incentives and/or disincentives or penalties should be applied.

The importance of formal agreements as to what is to be done during at-sea surveys was noted (Section 12 and examples in Appendixes D and E). These agreements should have the support of vessel crews in contrast to decisions taken solely at an executive level and then imposed on those who are required to undertake them. Communication with the practitioners undoubtedly results in better survey protocols and improved results.

Bridge officers will be required to ensure that satisfactory, properly annotated survey logs are maintained, which, as they do not undertake the analysis, is something whose importance they may not fully appreciate.[28] The importance of this simple and easy to do (and easy to not do) task should be well communicated to those for which it is their responsibility and/or who are responsible for its completion.

13.3 Research strategies

The difficulties of acoustic surveying of deepwater species and the associated uncertainties demand well thought-out research strategies that often require multiple lines of inquiry. Fishing vessel executed acoustic surveys will often form the core data sets used in resource management

[28] Analysts are often confronted with data collected years earlier but which have not been annotated with either a trip number or year of data collection making identification of when and where the data were collected highly problematic.

decision-making, but the assumptions should be clearly understood and the uncertainties identified. This may motivate tactical experiments targeted at a particular area of uncertainty. As an example, the largest uncertainties often relate to the backscattering cross section areas of the target species and the species composition of the fish that are sonified. Reducing these uncertainties may require deeply deployed sensors to provide detailed, higher resolution multifrequency acoustic and/or optical information. One strategy is to conduct frequent vessel-based surveys, though with higher cost and complexity with targeted experiments carried out a greater intervals. Application of targeted experiments presents particular challenges for high-seas fisheries where vessels may be at sea for months on end. New methods tailored to these situations may need to be developed.

14. WORKSHOP RECOMMENDATIONS

General and specific recommendations were made by the workshop for applications at sea and operational challenges, vessels and equipment, operational protocols, collection of biological data, acoustic data processing, estimating and estimates of acoustic backscattering values of deepwater species, estimation of abundance, uncertainty (error estimates) and, finally, of the cost involved in commercial vessel stock assessment and funding issues.

14.1 General recommendations

- Acoustic data in support of a range of research and management objectives can be collected successfully from commercial fishing vessels.
- It was concluded that the methods discussed at the workshop were valuable and:
    - in many deepwater fisheries they may be the only means of obtaining the required assessment information; thus
    - national and international fisheries managers should give serious consideration to these techniques.
- These methods were considered particularly valuable for smaller fisheries, e.g. those that support only a small number of boats that may fish an extensive ocean area, and in particular whose commercial value will not justify the use of a dedicated research vessel.
- There should be a careful, unequivocal and mutually agreed "contract" between the parties involved, e.g. between the agency with the mandate for management of the resource (usually the government) and the party that is to undertake the survey, usually by a government or industry association agreement to use one of the industry association's vessels. The agreement should define the objectives and thus requirements of the acoustic survey, how/when it will be done and assign related responsibilities.
- The workshop noted the relevance and importance of:
    - ICES Cooperative Research Report (2007) *Collection of acoustic data from fishing vessels* for the detailed operational information it offered; and
    - FAO (2008b) report of the *Technical consultation on international guidelines for the management of deep-sea fisheries in the high seas* for documentation of management requirements of deep-sea fisheries.

14.2 Applications at sea and operational challenges

- It should be confirmed that operators (will) have the skills to satisfy the survey agreement.
- Best results (commitment to the objectives of the survey and provision of resources to undertake the survey) will be obtained when there are incentives and/or disincentives to the industry to participate in the programme. This may imply provision of exclusivity in terms of fishing entitlements.
- Skippers and relevant crew should be well informed about the methods and objectives of the survey to ensure they are well motivated to undertake survey activities and mechanisms to ensure that the experience and suggestions of those responsible for implementation of the proposed methods are captured for evaluation and/or implementation.

14.3 Vessels and equipment

- The vessel(s) that undertake the surveys should be carefully selected or their suitability reviewed and assessed; they should be capable of an appropriate level of performance.
- Vessel-mounted equipment must be checked at appropriate intervals: this requires provision of adequate funds and skilled human resources.
- Valuable information can be obtained with hull-mounted and pole-mounted transducers; towed-body systems will give the best quality data but at much greater cost and operational difficulty.
- Use of split-beam transducers is preferred because of their superior ability to enable backscattering cross section area values of individually sonified fish to be calculated.
- Acoustic systems should be stable digital systems that record in detail the raw data that are collected.
- Acoustic systems should be calibrated and have their performance checked at least annually and after transducer damage or vessel dry docking.
- Selection of echosounder settings is particularly important and should follow operational protocols (particularly for the transmit power used and pulse length settings).
- Instrument settings should be recorded and checked periodically.
- GPS data should always be interfaced with the acoustic instruments.
- All other acoustic systems must be switched off during surveying to avoid this source of noise interference.
- Operators should have reliable data storage systems in place to ensure secure archiving of acoustic data, creation of backup copies of these data, and safe storage of all trip logs and relevant documents (e.g. calibration reports).
- Acoustic systems fail! Most problematically in ways that may not be noticed. Systems should be carefully monitored to ensure satisfactory performance as required.

14.4 Operational protocols

- Agreed data-collection protocols must be established and followed.
- Documentation necessary for the interpretation and efficient analysis of the acoustic data must be collected (keep logbooks).

14.5 Collection of biological data

- Biological data are critical for interpretation of acoustic data and thus derivation of abundance estimates.
- A well-defined biological data collection should be negotiated and implemented.
- Personnel for biological data collection must be available and be experienced and/or trained.

14.6 Acoustic data processing

- This should follow scientifically sound procedures.
- Data that have not been collected according to a previously-defined protocol or are of poor quality should not be used.

14.7 Estimating and estimates of acoustic backscattering values of deepwater species

- Knowledge of the backscattering cross section area values of the target species is essential for obtaining precise and unbiased estimates of abundance.
- In almost all situations, ongoing research is required to determine the functional relationship between the echo intensity that is recorded and the biomass of fish that is sonified to ensure

that biomass estimates derived from the acoustic data are correct. This inevitably involves complicated and costly research.
- Knowledge of the acoustic system settings and length and/or weight frequencies of the catch are required to determine the appropriate echo intensity biomass relation.

14.8 Estimation of abundance

- Survey methods will depend on the characteristics of target fish's habitat, distribution and behaviour.
- Random-sampling, design-based methods are well suited for area-based surveys that are undertaken independently of fishing activities.
- Geostatistical methods may be particularly applicable for aggregation-based surveys where survey activity is integrated with fishing activity.
- Selection of an area-based or aggregation-based survey method will depend on the characteristics of the fish aggregations; for example, is there:
  - a single aggregation at the survey site, or
  - several/many fish aggregations in the area of interest?
- Area-based surveys are the best choice for determining relative/absolute abundance estimates, especially when the distribution of fish is known prior to the survey and when a vessel can be dedicated to survey activity.
- Aggregation-based surveys are best for localized and mobile stocks and where the survey vessel must integrate its survey activity with fishing operations.
- Both methods can integrate additional sea time into survey effort, but particular attention is required to the statistical design and/or analysis when this is done in area-based surveys.
- Integration of surveys with commercial fishing activities, if not essential, should be encouraged. This will optimize use of vessel at-sea time and encourage support by vessel crews who must undertake the survey work.
- Those involved in designing, analysing and providing survey estimates from data collected by fishing vessels should be explicit about the sources and extent of uncertainty (i.e. possible error) in the estimates they provide. It is then the responsibility of decision-makers to incorporate this information into risk-assessing management models. Uncertainty in resource estimates provided by surveys undertaken by commercial fishing vessels will be similar to that obtained when research vessels are used to undertake similar surveys.

14.9 Uncertainty (error in estimates)

- Uncertainty will arise from:
  - system-derived uncertainty, e.g. errors in calibration, differences between values assumed for sound attenuation in seawater and the attenuation that actually occurs;
  - survey-based uncertainty, e.g. sampling error (variance) in estimates of totals derived from sample results;
  - "acoustics"-based uncertainty, i.e. irresolvable or difficult-to-resolve-errors in the backscattering cross section area – biomass function, contribution to the echo intensity by non-target species whose presence is undetected or not possible to correct for; and
  - reporting of uncertainty – failure to include all sources of error.
- All sources of error must be considered (backscattering cross section values, species identification of echoes and attribution of echoes to particular species, fish availability (i.e. what fraction of the total stock is in the survey area), acoustic dead zone effects (i.e. arising from target fish being so close to the seafloor that they are indistinguishable from the bottom echo, sampling/survey error resulting from randomized location of the survey transects).
- The nature (i.e. amenability to mitigation) and extent of sources of error should determine research priorities and be clearly communicated in management advice.

14.10 Costs involved in commercial vessel stock assessment and funding issues

- Funding is required for:
  - equipment;
  - calibration;
  - operational expenses; and
  - data analysis and report preparation.

A long-term commitment for funding is desirable as the value of the surveys will increase as the number of surveys (i.e. years) that the survey is undertaken increases.

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APPENDIX A

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APPENDIX B

Agenda

DAY 1 – 9 December 2009		
09:00	Welcome to workshop; introductions, business items.	
09:30	Review of agenda and programme of work – report structure.	
10:30	**Coffee break**	
11:00	Review of objectives of the workshop.	
12:00	**Banking, lunch**	
14:00	Identification of topic leaders and text drafting groups; discussion on report structure and contents.	
15:15	**Coffee break**	
15:35	Review of draft Chapter 1.	
17:00	Drafting as agreed.	
DAY 2 – 10 December 2009		
08: 30	Applications at sea and operational challenges.	
10:30	**Coffee break**	
11:00	Acoustic data processing.	
11:30	Acoustic equipment.	
12:00	Survey design.	
12:30	**Lunch**	
14:00	Estimating and estimates of acoustic backscattering values of deepwater species	
15:15	**Coffee break**	
15:30	Estimation of abundance	
DAY 3 – 11 December 2009		
08:30	Loose ends; discussion as required.	
09:00	Start review of sections: Sections 1, 2 and 3.	
10:30	**Coffee break**	
11:00	Continue review: Sections 4 and 5.	
12:30	**Lunch**	
14:00	Continue: More on Section 6? Then σ_b and s_v values; how much fish is there? The issues.	
15:00	**Coffee break**	
15:30	Continue; Review of where we got; what is outstanding – if anything – and in which case how to proceed. Report to ICES group?	
16:30	Meeting wrap up.	

APPENDIX C

Examples of Trip Survey Summary Report and Echo Mark Encounter Log

Part 1: Example of Trip Survey Summary Report

Name of survey vessel: Trip no.:

Name of captain:

Names and agency of observers (if none indicate none):

1. 2.

Port of departure: *Departure date: day / month / year*

Port of discharge – end of trip: *Port arrival date: day / month / year*

Names of people and their position (e.g. vessel officer, consulting company name) involved in the acoustic survey:

1. 2.

3. 4.

Calibration details:
Date: Location:

Chief technician responsible:

Method used:

Calibration report reference:

System gain required:

Comments on calibration:

Biological information:
Person responsible for preparation of biological measurements report:

Report submitted to:

Acoustic system:

Make and model type:
Pulse width used (ms):
Power used (kW):
Transducer details:
Make: Beam width:
(indicate units/dimensions)

Part 2: Example of Echo Mark Encounter Log

Name of survey vessel: Trip no.:
Departure date: dd / mm / year *Port arrival date: dd / mm / year*
Chief scientist/technical officer: Acoustic system:

Acoustic transect	Date and time observed	Depth of mark (m)	Species ID	Comments	Initials

Echo mark logs should be completed *in full* keeping in mind that they may be needed to clarify survey information several years after the actual survey and when the people who undertook the survey are long gone. Depending on operational practice, it may be desirable to complete a new log form for each day on which there were survey operations. These completed forms should be tied to the Trip Summary Report (Appendix C, part 1).

APPENDIX D

Example of a Joint Project Agreement: Support for conducting Atlantic herring spawning ground acoustic surveys in Scots Bay and other spawning areas of Southwest Nova Scotia

This Joint Project Agreement is made in duplicate.

BETWEEN: **HER MAJESTY THE QUEEN IN RIGHT OF CANADA**, as represented by the Minister of Fisheries and Oceans ('the Minister').

AND: **HERRING SCIENCE COUNCIL**, a body duly incorporated under the ***Societies Act of Nova Scotia***, with a head office located at (**address here), Nova Scotia** hereinafter called ('Council').

WHEREAS the Minister and the Council ('the Parties') wish to collect scientific data and provide support to conduct acoustic surveys in Scots Bay and other spawning areas in Southwest Nova Scotia for the assessment of Atlantic herring in NAFO Division 4X ('the Project');

NOW THEREFORE, the Parties agree as follows:

1. DEFINITIONS

1.1 'Intellectual Property' means any technical, financial and business information relating to a Party's research, development, inventions, products, production, manufacturing, finances, marketing, customers, or business plans, including without limitation, trade secrets, know-how, data, formulae, processes, other intellectual property, or confidential communications, that (a) is or has been disclosed to or otherwise received or obtained by a Receiving Party, whether or not in connection with or pursuant to this Agreement, and (b) has been marked by the Disclosing Party as Proprietary or Confidential Information or, if disclosed orally, has been stated to be confidential or has been confirmed in writing by the Disclosing Party, within thirty (30) days from the date of such disclosure, to be Proprietary or Confidential Information.

2. THE PROJECT

2.1 The project is described in Schedule A. The responsibilities of each Party with respect to this Project are described in the Project Work Plan, attached as Schedule B.

3. OBLIGATIONS OF THE MINISTER

3.1 The total financial responsibility of the Minister towards this Project shall be $XX.

3.2 In kind contributions to the Minister by the Council as specified in Part II of the Project Work Plan, together with the financial responsibilities of the Minister as specified in Part I of the Project Work Plan, shall be used by the Minister to perform the work responsibilities specified therein.

3.3 Funds received by the Minister shall be accounted for in accordance with applicable Treasury Board Regulations and expended in accordance with Government Contract Regulations. Any amount remaining from the funds paid to the Minister under the Joint Project Agreement shall be repaid to the Council in accordance with the Repayment of Receipts Regulations except if that amount is less than $100 in which case the funds will be placed in the Consolidated Revenue Fund. This clause is not applicable as the Project involves in kind contributions only.

3.4 Funds shall be forwarded to the Council at the following address:

Name of Director
Herring Science Council
Address here

4. OBLIGATIONS OF 'THE COUNCIL'

4.1 The total financial responsibility of the Council towards this Project shall be $XXX.

4.2 The Council shall pay the funds or the equivalent in-kind contributions to the Minister and shall perform the work responsibilities and fulfil the financial responsibilities specified in Part II of the Project Work Plan.

4.3 The funds payable or the equivalent in-kind contributions from the Council to the Minister shall be paid to the Minister in accordance with the payment schedule specified in the Project Work Plan. The paying instrument shall be made payable to the Receiver General for Canada.

4.4 Funds shall be forwarded to the following address: **Not Applicable**.

5. REPRESENTATIVES

5.1 For the Minister:
Scientific Authority:

____
Department of Fisheries and Oceans
St. Andrews Biological Station
(address here)

5.2 For the Council
Project Authorities:

____
Herring Science Council
(address here)

6. AUDITING AND MONITORING

6.1 The Minister and the Council agree to maintain books, records, documents, and other evidence pertaining to all costs and expenses incurred and expended and funds acquired under this Agreement to the extent and in such detail as will properly reflect all costs, direct and indirect, of labour, materials, equipment, supplies and services. Records and documentation shall be retained by each Party for a period of three (3) years after the termination of this Agreement for whatever reason. Both Parties agree that all records pertaining to this Project shall be made available, subject to the provisions of the *Access to Information* and *Privacy Acts*, to the other Party for verification and audit upon request.

7. INTELLECTUAL PROPERTY AND PUBLICATION

7.1 Subject to the *Access to Information* and *Privacy Acts*, Project Data and any other Project-related information shall be freely available to both Parties to this Agreement and may be used, disseminated or published, by either party, at any time. Any proposed publication that incorporated a significant amount of project information shall be provided to the other Party prior to public dissemination. The Minister has first option to publish this data in scientific literature.

7.2 All Intellectual Property resulting from this project shall become joint property of both Parties.

7.3 Each Party shall promptly disclose to the other Party any and all Intellectual Property arising from Project-related activities that are performed by that Party or its Agents.

8. COMING INTO FORCE AND TERM

8.1 This Agreement shall come into force on the date on which it has been executed by all Parties and shall remain in force for one (1) calendar year, unless terminated sooner in accordance with Clause 9.

9. TERMINATION

9.1 This Agreement may be terminated at any time with the consent of all Parties.

9.2 The Council may terminate this Agreement, upon written notice to the Minister if the Minister breaches the terms or conditions of this Agreement.

9.3 The Minister may terminate this Agreement, upon written notice to the Council:

a. If the Council, as a whole, breach the terms or conditions of this Agreement or fails to fulfil the responsibilities under Part II or;
b. If any Company is bankrupt, files for bankruptcy, or is involved in any bankruptcy proceeding;
c. If the Minister, in his or her opinion, is unable to fulfil the obligations under this Agreement.

10. EVENTS UPON TERMINATION

10.1 Upon termination of the Agreement, the following events shall occur:

a. The Minister shall make available to the Council any and all data, reports or analyses generated pursuant to this Agreement;
b. The Council shall make available to the Minister any and all data, reports or analyses generated pursuant to this Agreement.
c. Equipment purchased as a result of this Agreement shall remain the property of the Council.

11. NOTICE

11.1 Any notice under this Agreement shall be in writing and shall be addressed to the appropriate Party as follows:

For the Minister
Dept. of Fisheries and Oceans
Maritimes Region
Chief Contract Services Division
(address here)

For the Council

____
Herring Science Council
(address here)

12. DISPUTE RESOLUTION

12.1 Where a dispute arises as to the interpretation of this Agreement or of matters relating to its termination, or of performance hereunder, the Parties shall attempt in good faith to resolve the dispute through negotiation. Should negotiation prove unsuccessful, the Parties shall submit the matter to a mutually acceptable third party for mediation. The costs of the mediation shall be divided equally between the Parties.

13. NO AGENCY

13.1 Neither the Council nor any of their personnel or agents is an employee, servant or agent of the Minister or of Her Majesty and shall not hold themselves out to be so. The Council is alone responsible and liable for all claims, demands, losses, costs, debts, actions, damages, suits or other proceedings brought against it in any way arising out of or attributable to its obligations under this Agreement.

14. HOUSE OF COMMONS

14.1 No member of the House of Commons shall be admitted to any share of this Agreement or to any benefit arising here from.

15. PUBLIC SERVANTS

15.1 A present or former public servant or public office holder who is not in compliance with the applicable provisions of the *Conflict of Interest and Post-Employment Code for Public Office Holders* or the *Conflict of Interest and Post-Employment Code for the Public Service* shall not derive a direct benefit from this Agreement.

16. APPLICABLE LAW

16.1 The laws in effect in the Province of Nova Scotia shall apply to the interpretation and administration of this Agreement.

17. TIME

17.1 Time is of the essence of this Agreement.

18. ASSIGNMENT

18.1 This Agreement may not be assigned without the consent of all Parties.

19. ENTIRE AGREEMENT

19.1 The terms and conditions herein, together with Schedules A and B, form the entire Agreement of the Parties with respect to this Project.

IN WITNESS WHEREOF the Parties hereto have executed this Joint Project Agreement by their duly authorized representatives.

For the Minister of Fisheries and Oceans

______________________	______________________
Witness	Chief:__________________
	Contract Services
	______________________
	Date
______________________	______________________
Witness	Scientific Authority: __________
	Population Ecology Section
	Science Branch
	______________________
	Date
______________________	______________________
Witness	Responsibility Centre Manager: _______
	Population Ecology Section
	Science Branch
	______________________
	Date

______________________ Witness	______________________ Division Manager: ________________ St. Andrews Biological Station Science Branch
	______________________ Date
______________________ Witness	______________________ Director of Resource Management: ______ Maritimes Region
	______________________ Date
______________________ Witness	______________________ Director of Finance: __________________ Maritimes Region
	______________________ Date
______________________ Witness	______________________ Director of Science: ___________________ Maritimes Region
	______________________ Date
	FOR THE COUNCIL
______________________ Witness	______________________ For: Herring Science Council, Chairman
	______________________ Date
______________________ Witness	______________________ For: the Herring Science Council, Executive Officer
	______________________ Date

Schedule A

Project description

Background
Industry-based acoustic surveys of spawning grounds began in 1996 in response to the need to provide a second level of protection for spawning fish within the overall TAC. Prior to the acoustic surveys, the virtual population analysis (VPA) assessment model relied upon the larval abundance index developed from the Fisheries and Oceans Canada (DFO) annual survey. With the termination of DFO larval surveys in 1998, the industry surveys became the only index of abundance for the 4VWX herring stock. Between 1999 and 2003 the stock was assessed using acoustic data as absolute biomass estimate from several major spawning grounds in 4WX. Over the last several years the VPA-estimated (2006 analysis) Spawning Stock Biomass (SSB) has been at a historically low level fluctuating around 100 000 tonnes. In 1999, the acoustic survey area was standardized so that inter-year comparisons could be undertaken and the data collected by these industry funded and conducted surveys could, after 7–9 years, become an index of abundance for input into a VPA. Since 2005 the acoustic survey biomass index, developed from commercial fishing vessel surveys of major spawning grounds, has been the primary source of information on stock trends for the assessment model. Although the last analytical assessment (2005) for this stock used German Bank surveys (which are covered under a separate Joint Project Agreement (JPA) as a tuning index, the scientific data collected from annual multiple acoustic surveys by seiners on other major spawning grounds in Southwest Nova/Bay of Fundy area, were used in the past and will likely be used in the future. The areas include Scots Bay (annually), Trinity Ledge and Spectacle Buoy (both of which are also surveyed by the inshore fleet), and Browns Bank and Seal Island (intermittent). Surveys in these areas are essential in the assessment of the 4WX Atlantic Herring Stock and scientific advice to management.

This JPA describes the contributions and survey requirements of the purse seine fleet for Scots Bay and other spawning ground surveys in the Region.

Description of project
Scots Bay and other spawning ground surveys:
This project provides support for acoustically equipped fishing vessels to conduct multiple surveys within the predefined spawning box of Scots Bay and other spawning areas excluding German Bank which is covered under a separate JPA. The survey series using herring seiners began in 1999 when the survey areas of Scots Bay and Trinity ledge were standardized to enable year to year comparison of biomass estimates. Although the number surveys conducted annually and the number of transects run during a survey have varied, under the terms of the JPA the Council is committed to 3 surveys between July and September in Scots Bay, additional surveys in collaboration with the inshore fleet on Trinity Ledge and Spectacle Buoy and ad hoc surveys on Browns Bank and Seal Island. For Scots Bay each survey will involve a minimum of 3 vessels that undertake a minimum of 8 acoustic transects extending from the northern to southern boundary of the defined spawning box. The spawning survey areas for Scots Bay and Trinity Ledge are described in Melvin and Power (1999). Surveying of other areas will follow protocols for aggregations of fish described in the annual acoustic research document. Vessels participating in the surveys and recording the acoustic transects must be equipped with an annually calibrated acoustic logging system. For structured surveys the transects will be selected by DFO and the Council which will be responsible for coordinating the surveys. Biological samples to identify the species, maturity stage and size of acoustic targets are an essential component of these surveys. Given the nature of the fish distribution within the box and the water column the fishing locations cannot be predefined. One or more commercial fishing vessels participating in the survey will collect representative samples where and whenever possible.

Data collection, security and analyses:
This aspect of the project is to provide technical and analytical support/assistance to DFO by the Council for data collection, security/archiving and analysis of the acoustical data collected during

acoustic surveys. The Council will be responsible for downloading all acoustic data from the participating vessels, transferring the edited and unedited data to DFO, data file backups, and providing a technician to undertake the initial scrutinizing of the echograms (editing) before sending the file to DFO for final editing and analysis to produce a biomass estimate. DFO will provide training for the technician and develop quality control protocols for the analysis.

Benefits to the Minister

The support provided by the industry partner is invaluable to the objective of providing biological advice for stock assessment and management. This agreement provides for a minimum of 3 acoustic surveys in the Scots Bay spawning box, collaborative surveying of Trinity Ledge and Spectacle Buoy and ad hoc surveys following standard protocols in other areas of SWNS/BoFusing calibrated acoustic technology. Analysis of these data will provide standardized spawning biomass estimates to evaluate trends in abundance. Transect data, biological samples, edited echograms and the estimate of spawning stock biomass fare essential inputs into 4WX assessment model and are required to provide advice on the overall stock status for fishery management.

Benefits to the Council

The use of commercial fishing vessels to conduct multiple acoustic surveys on spawning ground represents an efficient and practical approach to collecting data. Industry involvement in the data collection, analysis and reporting, encourages ownership of the results and leads to collaborative and cooperative partnerships. Without this support, science would be limited in the advice available on stock status, hence the quality of fishery management.

Schedule B

Project Work Plan 2008/09

PART I – THE MINISTER

A. WORK RESPONSIBILITIES

Spawning ground surveys

1) Arrange in consultation with the Council, the timing, protocol, and transect locations for all surveys.
2) Provide a supervisory, training and/or assistance to personnel related to this agreement working on the research platform conducting the survey.
3) Edit and analyze the data collected and information provided as a result of this project to estimate herring biomass for input into stock assessment model(s).

Data collection and analyses

1) Responsible for identifying expertise to conduct technical services and data analyses.
2) Responsible for identifying protocol for data analyses and technical services.
3) Provide a supervisory, training and/or assistance to personnel involved in this agreement.
4) Undertake an analysis of the data by this project to estimate biomass and to provide input into stock assessment model(s) for evaluating of stock status.

B. PROJECT SCHEDULE

All work responsibilities to be conducted for the duration of the Agreement.

C. MONETARY AND IN-KIND RESPONSIBILITIES (Canadian Dollars)

Analyses in-kind	CAD XX
Salaries (in-kind)	CAD XX
Employee benefits (20%) (in-kind)	CAD XX
Total	CAD XX

O AL MINIS ER'S PROJEC CON RIBU ION: CAD10 000

D. PAYMENT SCHEDULE

This project has no planned expenditures of funds received from the Minister as this project involves in-kind contributions only.

E. PLANNED EXPENDITURES OF FUNDS RECEIVED FROM THE ASSOCIATIONS AND THE COUNCIL

This project has no planned expenditures of funds received from the Council as this project involves in-kind contributions only.

PART II – THE ASSOCIATIONS AND THE COUNCIL

A. WORK RESPONSIBILITIES

Spawning ground surveys

1) Provide a minimum of 3 suitable, acoustically equipped vessels as a platform to conduct 3 surveys of in the Scots Bay spawning box. Equipment involves but is not limited to, calibrated acoustic equipment, ship's crew, stores, fuel, fishing gear, etc.
2) Undertake a minimum of 3 acoustic surveys involving a minimum of 8 transects per survey between July and September in the Scots Bay spawning box. This will involve collection of acoustic data and maintaining a bridge log of observations.

3) Responsible for provision of the timing (in consultation with the Scientific Authority) and transect locations for all survey stations.
4) Provide representative length frequency and biological sample of acoustic targets (i.e. herring) observed during the survey using commercial fishing gear where and whenever possible.
5) Collaborate with the inshore fleet on surveying of Trinity Ledge and Spectacle Buoy as required.
6) Undertake ad hoc surveys and collect biological samples of herring aggregations on other spawning grounds in the SWNS/BoF area when possible, such as Browns Bank and Seal Island.

Data collection and analyses

1) Responsible for downloading and archiving (backup) the data files from all vessels participating in the spawning surveys.
2) Provide DFO with a copy of both the un-edited and edited acoustic data files and bridge logs within a reasonable period of time (1 month) upon completion of the survey.
3) Provide technical support for coordinating surveys and initial scrutinizing (i.e. data editing) of echograms.

B. PROJECT SCHEDULE

All work responsibilities to be conducted for the duration of the Agreement.

C. FINANCIAL RESPONSIBILITIES

In-kind, per year, no allowance for inflation

In kind contributions in terms of dollar value for 3 Scots Bay Surveys (app. 24 transects) and surveying in other areas	CAD XX
Technical support Data collection archiving and analysis	CAD XX
Council administration and Survey Coordination	CAD XX
Total	CAD XX

TOTAL COUNCIL PROJECT CONTRIBUTION: $XX

WORK PLAN FOR 2008/2009 APPROVED BY:

____
For the Minister

____
For the Associations and the Council

DATE WORK PLAN APPROVED: ______________________________

APPENDIX E

Example of Agreement for Fishing Vessel – Management Authority – New Zealand

<table>
<tr><td colspan="2">SHORT FORM AGREEMENT FOR CONSULTANT ENGAGEMENT (COMMERCIAL)
BETWEEN:
DEEPWATER GROUP LIMITED C/O CLEMENT AND ASSOCIATES, PO BOX 1460, NELSON (CLIENT)
AND: NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH LIMITED (CONSULTANT)</td></tr>
<tr><td>PROJECT:
Acoustic survey of southern blue whiting on Bounty Platform from industry vessels in winter 2009</td><td>LOCATION:</td></tr>
<tr><td colspan="2">SCOPE & NATURE OF THE SERVICES:

As described in the attached proposal.

The objectives are to:
1. Carry out calibration of ES60 on Tomi Maru 87 and analyse calibration data to provide calibration coefficients for 2009.
2. Brief the Fishing Master aboard Tomi Maru 87 before the survey voyage about survey protocols and set up the ES60 for surveying.
3. Provide and install data logger.
4. Debrief the Fishing Master after the voyage and secure survey data.
5. Analyse acoustic data in conjunction with supporting biological data from observer programme (SOP) towards the provision of southern blue whitening (SBW) biomass estimates and associated oefficients of variation (CVs).
6. Provide survey report to Distant Water Group (DWG).
7. Report results to Middle Depths Working Group.</td></tr>
<tr><td colspan="2">PROGRAMME FOR THE SERVICES:

The timetable for the project is as follows:

30 June 2009 — Calibration carried out and coefficients calculated.

15 August 2009 — Instructions and briefing provided to industry participants.

30 September 2009 — Survey completed and acoustic data provided to NIWA.

30 November 2009 — Acoustic analysis completed and draft report submitted to DWG.

December 2009 — Presentation of the results to the Middle Depths Fishery Assessment Working Group in Wellington as required.

31 January 2010 — Final client report submitted to DWG, incorporating reasonable changes as requested by the Working Group.</td></tr>
<tr><td colspan="2">FEES & TIMING OF PAYMENTS:

NZD plus GST.

To be invoiced on completion of work.</td></tr>
</table>

<table>
<tr><td colspan="2">INFORMATION OR SERVICES TO BE PROVIDED BY THE CLIENT:

Ensure that MFish SOP observer is onboard FV Tomi Maru 87

Provide access to vessel(s) for calibration. This includes any costs associated with getting onboard the vessel(s) from the nearest port (e.g. pilot boat).</td></tr>
<tr><td colspan="2">The Client engages the Consultant to provide the Services described above and the Consultant agrees to perform the Services for the remuneration provided above. Both Parties agree to be bound by the provision of the Short Form Model Conditions of Engagement (overleaf), including clauses 1,8 and 9, and any variations noted below. Once signed, this agreement, together with the conditions overleaf and any attachments, will replace all or any oral agreement previously reached between the Parties.</td></tr>
<tr><td colspan="2">VARIATIONS TO THE SHORT FORM MODEL CONDITIONS OF ENGAGEMENT (OVERLEAF):
The parties shall not use (except for the purposes of utilising the deliverables for their intended purpose), or disclose to any third party, any information which may reasonably be regarded as confidential provided by the other party, or obtained or produced during the course of undertaking the Services of this Agreement.</td></tr>
<tr><td>CLIENT’S AUTHORISED SIGNATORY (IES):

PRINT NAME:
DATE:</td><td>CONSULTANT’S AUTHORISED SIGNATORY (IES):

PRINT NAME: DR JOHN MCKOY
DATE:</td></tr>
</table>

SHORT FORM MODEL CONDITIONS OF ENGAGEMENT (COMMERCIAL)

1. The Consultant shall perform the Services as described in the attached documents. The Client and the Consultant agree that the Services are acquired for the purposes of a business and that the provisions of the Consumer Guarantees Act 1993 are excluded in relation to the Services.

2. In providing the Services the Consultant shall exercise the degree of skill, care and diligence normally expected of a competent professional.

3. The Client shall provide to the Consultant, free of cost, as soon as practicable following any request for information, all information in his or her power to obtain which may relate to the Services. The Consultant shall not, without the Client's prior consent, use information provided by the Client for purposes unrelated to the Services. In providing the information to the Consultant, the Client shall ensure compliance with the Copyright Act 1994 and shall identify any proprietary rights that any other person may have in any information provided.

4. The Client may order variations to the Services in writing or may request the Consultant to submit proposals for variation to the Services.

5. The Client shall pay the Consultant for the Services the fees and expenses at the times and in the manner set out in the attached documents. Where this Agreement has been entered by an Agent (or a person purporting to act as Agent) on behalf of the Client, the Agent and Client shall be jointly and severally liable for payment of all fees and expenses due to the Consultant under this Agreement.

6. All amounts payable by the Client shall be paid within twenty (20) working days of the relevant invoice being mailed to the Client. Late payment shall constitute a default, and the Client shall pay default interest on overdue amounts from the date payment falls due to the date of payment at the rate of the Consultant's overdraft rate plus 2 percent and in addition the costs of any actions taken by the Consultant to recover the debt.

7. Where Services are carried out on a time charge basis, the Consultant may purchase such incidental goods and/or Services as are reasonably required for the Consultant to perform the Services. The cost of obtaining such incidental goods and/or Services shall be payable by the Client. The Consultant shall maintain records which clearly identify time and expenses incurred.

8. The liability of the Consultant to the Client in respect of his or her Services for the project, whether in contract, tort or otherwise, shall be limited to the lesser of five times the value of the fees (exclusive GST and disbursements), or the sum of NZD100 000. The Consultant shall only be liable to the Client for direct loss or damage suffered by the Client as the result of a breach by the Consultant of his or her obligations under this Agreement and shall not be liable for any loss of profits.

9. The Consultant acknowledges that the Consultant currently holds a policy of Professional Indemnity insurance for the lesser of NZD100 000 or five times the value of the fees (exclusive of GST and disbursements). The Consultant undertakes to use all reasonable endeavours to maintain a similar policy of insurance for six years after the completion of the Services.

10. Neither the Client nor the Consultant shall be considered liable for any loss or damage resulting from any occurrence unless a claim is formally made on him or her within six years from completion of the Services.

11. If either Party is found liable to the other (whether in contract, tort or otherwise), and the claiming Party and/or a Third Party has contributed to the loss or damage, the liable Party shall only be liable to the proportional extent of its own contribution.

12. The Consultant shall retain intellectual property/copyright in all drawings, specifications and other documents prepared by the Consultant. The Client shall be entitled to use them or copy them

only for the Works and the purpose for which they are intended. The ownership of data and factual information collected by the Consultant and paid for by the Client shall, after payment by the Client, lie with the Client. The Client may reproduce drawings, specifications and other documents in which the Consultant has copyright, as reasonably required in connection with the project but not otherwise. The Client shall have no right to use any of these documents where any or all of the fees and expenses remain payable to the Consultant.

13. The Consultant has not and will not assume any obligation as the Client's Agent or otherwise which may be imposed upon the Client from time to time pursuant to the Health and Safety in Employment Act 1992 ("the Act") arising out of this engagement. The Consultant and Client agree that in terms of the Act, the Consultant will not be the person who controls the place of work.

14. The Client may suspend all or part of the Services by notice to the Consultant who shall immediately make arrangements to stop the Services and minimise further expenditure. The Client and the Consultant may (in the event the other Party is in material default) terminate the Agreement by notice to the other Party. Suspension or termination shall not prejudice or affect the accrued rights or claims and liabilities of the Parties.

15. The Parties shall attempt in good faith to settle any dispute by mediation.

16. This Agreement is governed by the New Zealand law, the New Zealand courts have jurisdiction in respect of this Agreement, and all amounts are payable in New Zealand dollars.

APPENDIX F

Case studies – Summary overview of experiences with industry-based acoustic surveys for deep-sea fisheries

New Zealand: Cook Strait hoki

Principle species	Hoki (*Macruronus novaezelandiae*)
Contractor	National Institute of Water and Atmospheric Research Limited
Contracting partner	New Zealand Deepwater Group Limited
Harvest range (and/or TAC)	New Zealand catches up to 269 000 tonnes in 1997–98. Current TAC 110 000 tonnes. Annual Cook Strait catch 20 000–40 000 tonnes.
Year commercial assessment began	2007
Number of vessels involved in the survey	1–2
Annual days of survey effort	6 survey days spread over 30–40 day fishing season.
Type of survey	Area-based survey of main spawning grounds. Multiple 'snapshots' required over the season because transient spawning population
Institutional issues on negotiating commencement of programme	Acoustic surveys of spawning hoki have been conducted regularly in New Zealand since 1984. There are 15 years of results of acoustic surveys of spawning hoki in Cook Strait. There have been regular research surveys of Cook Strait at one- or two-year intervals since 1991. There was no research survey of Cook Strait budgeted by the New Zealand Ministry of Fisheries in 2007, but the fishing industry agreed to carry out the survey from the fishing vessel *Thomas Harrison* following standard survey protocols. This was successful and results from the 2007 survey were incorporated in the relative time series used in hoki assessment. In 2008, both research vessel and industry surveys were carried out concurrently with the aim of comparing survey results. Unfortunately a transducer fault for the duration of the survey period meant that the acoustic data from the industry vessel were uncertain and were not used for assessment (O'Driscoll and Macaulay, 2009a). This emphasized the need to calibrate the echosounders of participating vessels annually prior to commencing data collection. Data were collected on two vessels in 2009 (O'Driscoll and Macaulay, 2010).
Organizational and operational issues Organizational and	The survey design is the same as that used for surveys from research vessels and so industry vessel surveys provide abundance estimates, which can be used in the same time-series of relative abundance indices. Estimation of absolute abundance is not possible in this fishery because hoki have a long spawning season, from July to September. It is thought that during the spawning season there is a turnover of fish on the grounds. Therefore, there is no time at which all of the spawning fish are available to be surveyed. The survey design devised to deal with this problem consists of a number of sub-surveys or 'snapshots' spread over the spawning season.

operational issues	Each snapshot consists of a series of random transects (following the design of Jolly and Hampton 1990) across strata covering the known distribution of spawning hoki. Estimates of spawning biomass are calculated for each of the snapshots, and these are then averaged to obtain an estimate of the 'mean plateau height' (average biomass during the main spawning season). Under various assumptions about the timing and length of the spawning season (Coombs and Cordue, 1995), estimates of mean plateau height form a valid relative abundance time series. National Institute of Water and Atmospheric Research Limited (NIWA) provided start and finish positions for 6 snapshots, each consisting of 28 random transects in six strata. It takes approximately 24 hours of constant steaming at 8 knots to complete all 28 transects within a snapshot. The stratum boundaries and areas in Cook Strait were the same as those used in previous research surveys. These six strata cover the known hoki spawning areas with depths greater than 200 m (180 m in stratum 2). The acoustic survey area in Cook Strait includes grounds, which are not commercially fished by the fleet. The Narrows Basin (stratum 1) is closed year-round by the industry agreed Code of Practice for hoki target trawling (version 8) to reduce the catch of small hoki. Nicholson Canyon (stratum 3) is closed during the spawning season, from 1 July to 1 October. There are additional constraints on survey execution designed to reduce potential bias in acoustic estimates due to fish movement. These include a requirement to complete all transects within a snapshot within a maximum of 72 hours and preferably within 48 hours. In addition, all transects in strata 2 and 5A (where fish movement is a particular concern) need to be carried out sequentially. Transects in these strata take about 7 hours. To fulfill these requirements requires considerable investment and commitment on the part of the vessel, as it is not possible to just carry out transects in the 'down-time' while processing between commercial trawls (e.g. O'Driscoll and Macaulay, 2005). Rather, fishing activities need to be suspended to collect acoustic data. In 2009, the six completed snapshots represented about 140 hours of vessel time. Acoustic data collection was supervised by vessel officers following documented protocols. Echosounders on participating vessels are now calibrated during the survey period. There is no targeted trawling for mark identification. Species composition in the dense hoki aggregations is well-known and consists of more than 95 percent hoki. However, about 30–50 percent of hoki occurs away from the main aggregations where mark identification is less certain. Mark identification of hoki in these low density areas is dependent on mark identification trawls carried out in previous research vessel surveys. Biological data collection is carried out by a scientific observer. The observer is not onboard for the entire survey period.
Current status of	Ongoing.

programme	
Evaluation of programme: - Problems - Programme strengths	The research is relatively well organised and coordinated. Results are currently used in the hoki assessment model used to inform management advice and set TAC. There is good engagement between scientists, vessel managers, and fishers. Survey protocols are usually followed. Estimates of survey uncertainty are based on a simulation method to combine uncertainties and estimate an overall value of uncertainty (c.v.) for each survey (O'Driscoll, 2004). Six sources of variance are considered: - Plateau model assumptions about timing and duration of spawning and residence time; - Sampling precision; - Detectability; - Mark identification; - Fish weight and target strength; and - Acoustic calibration. The method has two main steps. First, a probability distribution is created for each of the variables of interest. Second, random samples from each of the probability distributions are selected and combined multiplicatively in Monte Carlo simulations of the process of acoustic abundance estimation. Survey timing (including uncertainties about plateau timing and residence time) and mark identification are the major sources of uncertainty. Uncertainties due to calibration, detectability, and target strength (TS) contribute relatively little to the overall c.v. However, incorrect choice of TS and calibration coefficients do have potential to introduce bias, which is not reflected in the c.v. Industry vessel surveys have had a slightly higher overall c.v. than recent research surveys (39–46 percent for industry vessel surveys, 30–34 percent for research vessel surveys). To further reduce the overall survey uncertainty (c.v.) it would be desirable to spread the industry snapshots over a wider period (six weeks instead of four). A simulation study by O'Driscoll (2004) showed that there was little advantage in having a survey with more than six snapshots as long as those snapshots were spread over a sufficiently long survey period. The lack of targeted mark identification trawls is the major outstanding issue for industry surveys. In 2009, we relied on trawls from the research survey in 2008 (O'Driscoll, 2009) to verify mark identification. Regular sampling of all mark types is important to understand species composition, especially as this can change over time (e.g. O'Driscoll, 2007). This is particularly important for hoki fuzz marks, which typically contribute 30–50 percent of the hoki biomass in Cook Strait, but which are not usually targeted commercially because of low fish density. In future industry surveys we strongly recommend allowances be made to carry out mark identification trawls to aid interpretation of acoustic data.
Future prognosis	The programme is successful and likely to continue. It is not certain whether industry vessel surveys will eventually replace research vessel surveys in this area.

References	**Coombs, R.F. and Cordue, P.L.** 1995. Evolution of a stock assessment tool: acoustic surveys of spawning hoki (Macruronus novaezelandiae) off the west coast of South Island, New Zealand, 1985–91. *New Zealand Journal of Marine and Freshwater Research,* 29: 175–194. **Jolly, G.M. and Hampton, I.** 1990. A stratified random transect design for acoustic surveys of fish stocks. *Canadian Journal of Fisheries and Aquatic Sciences,* 47: 1282–1291. **Livingston, M.E.** 1990. Spawning hoki (Macruronus novaezelandae Hector) concentrations in Cook Strait and off the east coast off the South Island, New Zealand, August–September 1987. *New Zealand Journal of Marine and Freshwater Research*, 24: 503–517. **Macaulay, G.J.** 2006. Target strength estimates of hoki. Final research report for Ministry of Fisheries project HOK2004/03 Objective 3. 13 pp. (Unpublished report held by MFish, Wellington) **O'Driscoll, R.L.** 2004. Estimating uncertainty associated with acoustic surveys of spawning hoki (Macruronus novaezelandiae) in Cook Strait, New Zealand. *ICES Journal of Marine Science*, 61: 84–97. **O'Driscoll, R.L. and Macaulay, G.J.** 2005. Using fish processing time to carry out acoustic surveys from commercial vessels. *ICES Journal of Marine Science,* 62: 295–305. **O'Driscoll, R.L.** 2007. Acoustic survey of spawning hoki in Cook Strait and off the east coast South Island during winter 2006. *New Zealand Fisheries Assessment Report*, 2007/21, 52 pp. **O'Driscoll, R.L. and Dunford, A.J.** 2008. Acoustic survey of spawning hoki in Cook Strait during winter 2007. NIWA Client Report WLG2008-1 for The Deepwater Group Ltd. 44 pp. (Unpublished report, held by NIWA, Wellington) **O'Driscoll, R.L.** 2009. Acoustic survey of spawning hoki in Cook Strait and off the east coast South Island during winter 2008. *New Zealand Fisheries Assessment Report,* 2009/17, 52 pp. **O'Driscoll, R.L. and Macaulay, G.J.** 2009a. Industry acoustic survey of spawning hoki in Cook Strait during winter 2008. NIWA Client Report WLG2009-8 for The Deepwater Group Ltd. 40 pp. **O'Driscoll, R.L. and Macaulay, G.J.** 2009b. Acoustic surveys of spawning hoki off the South Island during winter 2008 and recommendations for future industry surveys. NIWA Client Report WLG2009-17 for The Deepwater Group Ltd. 59 pp. **O'Driscoll, R.L. and Macaulay, G.J.** 2010. Industry acoustic survey of spawning hoki in Cook Strait during winter 2009. NIWA Client Report WLG2010-xx for The Deepwater Group Ltd. 56 pp.
Other comments	Area-based surveys for spawning hoki from industry vessels have also been carried out in Pegasus Canyon and Hokitika Canyon (e.g. O'Driscoll and Macaulay, 2005). Aggregation-based surveys have also been attempted in Pegasus Canyon and on the west coast South Island, but the spatial extent of the surveys was very limited and this meant that biomass estimates were of limited usefulness for stock assessment (O'Driscoll and Macaulay, 2009b).

Australia: Tasmanian Eastern Zone orange roughy spawning grounds

Principle species	Orange Roughy (*Hoplostethus atlanticus*)
Contractor	Commonwealth Scientific and Industrial Research Organisation (CSIRO)
Contracting partner	South East Tasmania Fisheries Industry Association.
Harvest range (and/orTAC)	Closed fishery: 200 tonnes orange roughy allocated for survey quota.
Year commercial assessment began	2009
Number of vessels involved	1
Annual days of survey effort	10 days
Type of survey	Deeply towed multi-frequency acoustic-optical system (AOS) attached to trawl net.
Organizational and operational issues	Time series of vessel mounted and deep towed body surveys from research vessels from 1990 to 2006 have been used to provide echo integration biomass estimates as important criterion in a stock assessment model. Uncertainty in species composition in echos from vessel mounted acoustic systems at this location is a major issue (Kloser *et al.,* 2001). Multifrequency towed body surveys have been effective in resolving species composition at this location (Kloser *et al.,* 2002). However this approach is expensive requiring two vessels, one for the acoustic survey and another for biological sampling. Further, the acoustic towed body system is complex and requires a dedicated optic-fibre winch system and deck space to accommodate its temporary installation. The net-attached AOS approach (Ryan *et al.,* 2009) means that one vessel can complete deep-towed acoustic surveys and catch biological samples using the one net system. A dedicated winch system is not required. The trawl net is deployed and retrieved in the same manner as for commercial trawling. This method of deployment/retrieval allows the system to be used on a much greater diversity of vessels compared to those required for conventional towed body surveys. The survey operates in two modes. In the main survey mode the trawlnet/AOS is towed 200–300 m above the orange roughy aggregation to perform echo integration grid surveys. The second mode uses a conventional demersal trawl shot to obtain catch to pay for the survey. Biological samples and multi-frequency *in situ* acoustic measures of individual orange roughy target strength are taken, with concurrent visual verification of species plus estimates of length and orientation taken from the stereo digital camera system.
Current status of programme	Trials of the net attached-AOS method were successfully completed in winter 2009. A full survey programme is planned for winter 2010.
Evaluation of programme: - Problems - Programme strengths	Strengths: Species identification using multifrequency acoustics and optical images, in *situ target* strength measures, volume backscatter data at optimal range for echo integration-based biomass estimates, catch to pay for the survey and biological samples all obtained from a commercial vessel.

Evaluation of programme: - Problems - Programme strengths	Limitations: Data are not real time; the system is complex and at present requires specialised electronics technicians aboard the vessel . Towing speed is slow, also true for conventional deep towed-body surveys.
Prognosis	Next generation net-attached acoustic platforms could be simplified to enable this method of surveying to be carried out by non-specialised observers and possibly by ships officers with no technical staff onboard.
References	**Kloser, R.J., Ryan, T.E., Sakov, P., Williams, A. and Koslow, J.A.** 2002. Species identification in deep water using multiple acoustic frequencies. *Canadian Journal of Fisheries and Aquatic Sciences*, 59: 1065-1077. **Kloser, R.J., Ryan, T.E., Williams, A. and Lewis, M.E.** 2001. Development and application of a combined industry/scientific acoustic survey of orange roughy in the eastern zone. Final report to Fisheries Research and Development Corporation 99/111. Available from Fisheries Research and Development Corporation, P.O. Box 222, Deakin West, ACT 2600, Australia. ISBN 1 876996 08 0. **Ryan, T.E., Kloser, R.J. and Macaulay, G.J.** 2009. Measurement and visual verification of fish target strength using an acoustic-optical system attached to a trawlnet. *ICES Journal of Marine Science*, 66: 1238-1244.

Australia: Tasmanian west-coast blue grenadier winter spawning grounds

Principle species	Blue grenadier (*Macruronus novaezelandiae*)
Contractor	Commonwealth Scientific and Industrial Research Organisation (CSIRO)
Contracting partner	Petuna-Sealord (Industry)
Harvest range (and/or TAC)	4000 tonnes
Year commercial assessment began	2003
Number of vessels involved	1–3
Annual days of survey effort	60 days of fishing. 24–72 hours dedicated area survey, 48 hours of opportunistic aggregation surveys done during fish processing time.
Type of survey	Combination of opportunistic localised aggregations surveys and broad-scale area surveys.
Institutional issues on negotiating commencement of programme	The uncertainty in the stock assessment that was based primarily on the catch per unit effort (CPUE) and egg survey data motivated industry to collaborate with CSIRO in a program of acoustic surveys that were part of the winter fishing program.
Organizational and operational issues	The program consists of two main survey methods. The first method is the aggregation-based surveys carried out opportunistically during the 3–8 hours during which the catch is processed following a large (10–40 tonnes) trawl shot. The cost to the vessel for the aggregation surveys is relatively small, and the information gained by mapping out the aggregation can assist the subsequent trawl shot. The second survey method is a broad-scale zig-zag survey of the entire 100 nautical miles long spawning ground. For these surveys the skipper must assess the likely availability of the blue grenadier, endeavouring to survey when the fish availability is at a maximum. Fish availability varies dramatically over short periods of time (hours–days) throughout the season and the difficulty of matching the survey time to maximum fish availability is known. As a result of varying fish availability, the broad-scale surveys, despite covering a far greater survey area, will not necessarily observe the greatest biomass. A key aspect of the broad-scale surveys is that they provide a snapshot of the entire grounds providing a context to the localised aggregation surveys. This may help indicate whether there are other aggregations of fish away from the regions where fishing has been concentrated and localised aggregation surveys carried out. Broad-scale surveys are a direct cost to the vessel as they interrupt fishing and may incur an opportunity cost if trawlable aggregations cannot be quickly located after the survey. Typically 20–30 localised aggregations and 1–2 broad-scale survey(s) are done in a survey year.
Current status of programme	Industry sponsors have indicated their support for ongoing annual surveys
Evaluation of programme: - Problems - Programme strengths	The maximum assessed absolute biomass is used for input into the stock assessment. A key assumption is that despite the high level of intra-season variability in biomass estimates, the maximum biomass will not be missed. The time-series is becoming long enough (six years at present) to be useful as a relative index of abundance. Acoustic survey results have had good acceptance by the stock assessment process.

Evaluation of programme: - Problems - Programme strengths	Acoustic-based biomass estimates are now a critical input into the assessment model and have been used to rule out certain sensitivity test scenarios. Spatial dynamics of the stock are better understood and this information helped inform a contentious debate regarding the merits or otherwise of spatial closures.
Reference	**Kloser, R.J., and Fulton, E.** 2006. Model evaluation of acoustic monitoring requirements for the ecosystem approach to fisheries. *ICES FAST working group presentation*, March 2006, Hobart, Australia. **Ryan, T.E. and Kloser, R.** 2002. Analysis of industry acoustic observations of blue grenadier off the west coast of Tasmania: final report, November 2002. Copy held at CSIRO Marine and Atmospheric Research. GPO Box 1538, Hobart, Australia.

Namibia: Orange roughy fishery

Principle species	Orange roughy (*Hoplosethus atlanticus*)
Contractor	Ministry of Fisheries and Marine Resources.
Contracting partner	Namibian Deep Water Fishing Working Group.
Harvest range (and/or TAC)	1 000 to 15 000 tonnes.
Year commercial assessment began	1997
Number of vessels involved	One for acoustic data collection, often the same vessel conducted targeted trawling.[29]
Annual days of survey effort	14
Type of survey	Area-based acoustic and swept-area combined targeting spawning aggregations.
Funding	Costs borne by industry.
Institutional issues on negotiating commencement of programme	Research programme was instituted as part of licence agreement negotiated through a working group consisting of members from the fishing industry, research and compliance personnel.
Organizational and operational issues	Typically, surveys initially covered about 400 nm^2. The survey area was usually reduced to 10–30 nm^2 as the distribution of aggregations was located. For all surveys, each Quota Management Area (QMAs-there were 4 in Namibia) was surveyed at least three times using systematic or random E-W transects, which was the direction of greatest expected change in density. Survey effort being increasingly concentrated on areas of high abundance as the survey progressed, to improve precision. The initial survey areas were pre-selected on the basis of commercial catch information obtained earlier in the season and the results of surveys in previous years when available. The first one or two coverages covered the pre-selected area on transects spaced equally one or two nautical miles apart and were intended primarily to establish the general distribution of orange roughy in the area. In subsequent coverages, the area was narrowed down in both N-S and E-W directions to intensify sampling effort in the region where the highest densities had been recorded in the initial coverages. As many intensive coverages of the target area were then completed as time and circumstances allowed: transect spacing was usually then reduced to 0.5 nm. On a number of occasions, a random-transect design was used for the intensive coverages. Where a systematic coverage was repeated, the grids were usually displaced by half a transect spacing to minimize the areas left unsampled. Typically, the distribution of the aggregations could be defined adequately after at most two broad coverages, each taking about a day to complete. A number of intensive coverages could usually be completed in a day. Biomass estimates for the QMAs were calculated from each coverage of the QMAs considered valid for biomass estimation. Coverages were discarded if the weather conditions were regarded as too poor, if the

[29] Note that some years, up to two other vessels assisted the operation.

Organizational and operational issues	fish were unusually close to the seabed, or if there was considerable uncertainty concerning species of the fish that were sonified. The 'school-based' method of Kloser *et al.* (2000) was used to analyse the data. The biomass was estimated from the average echo intensity of well-defined aggregations that were characteristic orange roughy aggregations, with the assumption that no other species were present in the aggregations. All other targets were excluded, so the dispersed part of the population was ignored. The estimates of the mean and variance of the density for coverage, were raised to the size of the area surveyed to give estimates of total biomass sample variance. An overall biomass estimate for the QMA was obtained by simple averaging of the estimates for all coverages considered valid for biomass estimation. The Coefficient of Variation of this average was obtained from the sum of the sampling variances in the individual estimates.
Current status of programme	Fishery closed. Formal research surveys stopped.
Evaluation of programme: - Problems - Programme strengths	Where a second vessel was used to identify targets, every attempt was made to synchronize the vessels in time and space to maximize the chance of the catcher vessel sampling the fishes detected by the survey vessel, or fishes similar to it. However, problems often arose when the vessels became separated for operational reasons, or if the fishes were small or changed in their reflective characteristics between the time of detection and that of the attempted identification. When a single vessel was used, the usual strategy was to interrupt the survey and to make an identification haul almost immediately after detecting the target. Over the study period, the ability to identify aggregations from a second vessel deteriorated because of the decreasing number of large, easily targeted aggregations to the extent that during 1999 an acoustic estimate could only be made in only one QMA. Despite a large number (117) of targeted trawls by the catcher vessels conducted in the three QMAs, the only orange roughy targets that could be identified with any certainty were at the Frankies feature. It was largely because of this that a commercial vessel capable of trawling for orange roughy was used for the acoustic survey in 2000.
References	**Boyer, D.C. and Hampton, I.** 2001. Boyer, D., Kirchner, C., McAllister, M., Staby, A. and Staalesen, B. *In:* A Decade of Namibian Fisheries Science. Payne, A.I.L., Pillar, S.C. and Crawford, R.J.M. 2001. (Eds). *South African Journal of Maine Science*, 23: 205-222. **Kloser, R.J., Ryan, T.E., Williams, A., and Soule, M.A.** 2000. Development and implementation of an acoustic survey of orange roughy in the Chatham Rise spawning box from a commercial factory trawler, FV Amaltal Explorer. *Report 597.64*. Hobart, Tasmania, Australia.

New Zealand: Bounty Platform southern blue whiting

Principle species	Southern blue whiting *Micromesistius australis* (SBW)
Contractor	National Institute of Water and Atmospheric Research Limited.
Contracting partner	New Zealand Deepwater Group Limited.
Harvest range (TAC)	2004–2007: 3 500 tonnes. 2008: 10 000 tonnes. 2009: 15 000 tonnes. Catches are at the level of the TAC.
Year commercial assessment began	2004
Number of vessels involved	1–3
Annual days of survey effort	2–6
Type of survey	Aggregation-based survey of spawning stock biomass.
Funding	Industry funded.
Institutional issues on negotiating commencement of programme	A research programme to estimate SBW spawning stock biomass on three New Zealand fishing grounds using acoustic surveys began in 1993. The Bounty Platform, Pukaki Rise, and Campbell Island Rise were each surveyed annually between 1993 and 1995. After the first three annual surveys it was decided to survey these areas less regularly. The Bounty Platform grounds were surveyed in 1997, 1999, and most recently in 2001. The only on-going series of research surveys is on the Campbell Island Rise grounds, which have been surveyed in 1998, 2000, 2002, 2004, 2006, and 2009. The other stocks were considered too small to justify a research vessel survey time series. O'Driscoll and Hanchet (2004) carried out an acoustic survey of the Campbell Island grounds from the fishing vessel *Aoraki* in 2003 and showed that industry vessels with hull-mounted acoustic systems could be used to collect acoustic data on SBW in good weather (less than 25 knots of wind). Snapshots of the main spawning aggregations could be carried out using the processing time between commercial trawls without seriously compromising fishing success. O'Driscoll and Hanchet (2004) suggested that acoustic data collected from industry vessels might provide estimates of minimum SBW spawning biomass. Fishers suggested that the spawning stock of SBW on the Bounty Platform was much higher than estimated by the 2001 assessment. In August 2004, one of the companies, Aurora Fisheries Ltd approached NIWA asking for advice on collection of acoustic data from fishing vessel *Tomi Maru 87* on the Bounty Platform. The vessel was visited in Nelson and advice provided to vessel officers on the set-up of the Simrad ES60 echosounder and scientific data collection protocols. The scientific observer was also briefed. Acoustic data collected on the Bounty Platform in August 2004 were provided to NIWA and analysed in 2006. Results of the 2004 industry survey were consistent with the spawning stock size estimated in the 2001 assessment. Another survey was attempted in 2005, but was not suitable for abundance estimation because of interference from other acoustic equipment. Surveys were then carried out in 2006, 2007, 2008, and 2009 and analysed by NIWA.

Institutional issues on negotiating commencement of programme	Very strong SBW marks were observed during the 2007 industry survey, and the acoustic biomass estimate of about 160 000 tonnes was higher than that estimated in any of the previous research or industry surveys in this area (O'Driscoll 2007). The 2007 survey results suggested that the spawning stock size at the Bounties was much greater than that projected for 2007 by the stock assessment. When taken in conjunction with data on the size and age distribution of the fish caught in the fishery, this was indicative of very good recent recruitment. As a direct result of this survey, the TAC for Bounty Platform SBW was increased to 10 000 tonnes in 2008. The 2008 acoustic survey supported the very large recent increase in SBW spawning stock size, with an average acoustic biomass estimate from two snapshots of 148 000 tonnes (O'Driscoll and Dunford 2008). The TAC was further increased to 15 000 tonnes from 1 April 2009. At least three industry vessels collected acoustic data at the Bounties in 2009. Despite the increase in survey effort, all biomass estimates were much lower than in 2007 and 2008.
Organizational and operational issues	Protocols are provided to industry participants and officers on the F.V. *Tomi Maru 87* are briefed by NIWA scientists prior to each survey. In 2006, industry scientists were placed aboard the F.V *Tomi Maru* to supervise data collection but this was unpopular with the vessel crew and the current protocol relies on vessel officers to execute the survey. The ES60 echosounder on the F.V. *Tomi Maru 87* is calibrated annually by NIWA personnel prior to the survey and an agreed contract is in place for the analysis of data prior to commencement of data collection. Collection of data by other (Ukranian) vessels in 2009 was opportunistic and although the same acoustic data collection protocols were provided to officers on these other vessels by Sealord Ltd, there was no official briefing and NIWA was not made aware that data were being collected until after it had occurred. Consequently, calibrations of the vessels had to be arranged at short notice after the fishing season and contracts established to analyse additional data. The SBW aggregation occurs in a relatively consistent location between years, but is highly mobile. The timing of peak spawning may also vary by 10–14 days. Data collection is carried out using processing time between fishing operations. Vessels target large (60–200 tonne) catches which are then processed and the window of time available for data collection is typically 3–8 hours. Because of the behaviour of the fish, data must always be collected at night. Data collection is also severely limited by weather. To collect data of suitable quality for biomass estimation using the vessel's hull-mounted transducer requires wind of less than 25 knots and no more than a 2 m swell. Nights with suitable weather conditions occur infrequently. Consequently only 2–4 aggregation-based surveys are possible during the approximately 20 day fishing season. Data are almost always collected with recommended acoustic settings and are usually of sufficient quality to estimate biomass. However, several aspects of the survey design protocol are commonly violated.

Organizational and operational issues	Marks are often observed along one or both of the outer transects in all snapshots, indicating that the SBW aggregation extended beyond the surveyed area, and at the start and end of some transects, indicating that these transects were not long enough to cover the aggregation. Timing of surveys has also varied between years. Biological data collection is carried out by a scientific observer. There are no specific trawls for mark identification, but the spawning aggregation is known to contain almost exclusively SBW.
Current status of programme	Ongoing.
Evaluation of programme: - Problems - Programme strengths	The research is relatively well organised and coordinated. Results have led directly to TAC increases, and there is good engagement between scientists, vessel managers, and fishers. The very large decline in estimated SBW biomass at the Bounty Platform from 2008 to 2009 illustrates the major limitation on interpretation of aggregation-based acoustic abundance estimates. This decline is too great to be explained by fishing and natural mortality and was probably related mainly to the timing and extent of survey coverage. In each snapshot an unknown proportion of the spawning aggregation is surveyed, and almost certainly not the entire spawning stock. Survey coverage depends on both the amount of survey time available (which is often limited by commercial constraints) and the behaviour of the fish (e.g. the extent and density of the aggregation, and the timing of spawning). Because the proportion of the stock surveyed varies between years, it is impossible to incorporate the resulting series of abundance estimates into a formal stock assessment model as a time series. When abundance estimates from some of the snapshots are high or increasing (as in 2007 and 2008) then survey coverage is less of a concern, as we know there is ‘at least’ that biomass of SBW on the fishing grounds within the specified confidence limits (i.e. a minimum biomass approach). However, when biomass is low (as in 2009), it is impossible to determine whether there are real sustainability issues or whether the apparent decline is due to survey bias. Conservative estimates of the commercially allowable yield were made by applying the reference fishing mortality to conservative estimates of current vulnerable biomass based directly on the 2008 acoustic survey (and ignoring the low value from 2009). Various other ways of using these acoustic data are currently being investigated by the New Zealand Middle Depths Working Group.
Future prognosis	Research is likely to continue. NIWA have suggested that area-based surveys provide the best option for future acoustic data collection on SBW at the Bounty Platform from industry vessels. The goal should be to develop a time-series of relative abundance estimates for each area. These would be relatively straightforward to incorporate in the existing stock assessment model. Such estimates would be consistent with the existing research time-series. An area-based approach would require an estimated 48 hours of dedicated survey time (4 nights). This level of commitment may require a charter arrangement with one or more of the participating industry vessels.

Future prognosis	If an area-based approach is not considered feasible or cost-effective, then the goal should be to execute an aggregation-based survey as close as possible to the timing of peak spawning. The survey protocol should be strictly adhered to ensure that as much of the aggregation as possible is surveyed. The goal should be to produce maximum biomass estimates for the area.
Other comments	The same survey approach has been attempted for other New Zealand SBW stocks. An aggregation-based survey of Campbell Island SBW by two industry vessels in 2006 gave much lower estimates of abundance (10–15 percent) than that from a wide-area research survey (O'Driscoll *et al*. 2006). The two industry snapshots adequately covered the area where the highest density marks were detected during the research survey. However, there were large areas to the north and south of the industry snapshots where there were moderate densities of SBW and these contributed a much larger proportion of the total biomass. An aggregation-based approach is therefore probably not appropriate for the Campbell Island SBW stock. Aggregation based surveys of SBW at Pukaki Rise were carried out for the first time in 2009 (O'Driscoll *et al*. 2009).
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ISBN 978-92-5-107105-2 ISSN 2070-6065

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I2522E1/12.11