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Collection of acoustic data from fishing vessels

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Foreword: Synthesis of the work of the ICES Study Group on the Collection of Acoustic Data from Fishing Vessels (SGAFV)

Development and convergence of commercial and scientific acoustic systems

As acoustic techniques for detecting submarines and the seabed were developed between the two world wars, scientists and fishers began to realize the potential of these techniques for observing fish. The early applications of fishery acoustics were, of course, qualitative in nature. Nevertheless, they were of considerable scientific importance. Fishery acoustics is now recognized for its powerful quantitative capabilities, and echosounders continue to provide qualitative information to scientists and fishers alike.

Although initial development of acoustic methods for estimating fish abundance took place in the late 1950s and 1960s, quantitative methods did not become well established until the 1970s and early 1980s. As instrumentation and techniques evolved, reliable methods for calibration were developed, and suitable computer systems became available. During the past 20 years, the field of fishery acoustics has advanced substantially, and scientific acoustic systems are used throughout the world to characterize the distribution of pelagic species, estimate stock abundance, observe fish behaviour, and characterize such environmental features as substrate type, bathymetry, and aquatic vegetation distribution.

The evolution of modern scientific acoustic systems has been closely linked to the evolution of modern computer technologies. Early digital echo integrators required expensive analogue-to-digital converters (ADCs) linked to powerful minicomputers, but the emergence of microcomputers and inexpensive, high-quality ADCs allowed echosounder manufacturers to improve performance at affordable costs. Most modern scientific echosounders consist of microcomputer-controlled transceivers connected directly to transducers. The digitally controlled transmitters provide analogue signals to the transducers and signals from echoes (from fish, the seabed, etc.) received by these transducers are digitized with a high degree of accuracy and speed. These systems generally have wide dynamic ranges and high signal-to-noise ratios. High digital-to-analogue sampling rates allow fine-scale spatial resolution, and these instruments have powerful and flexible data-visualization capabilities, which may be available as real-time displays on personal computer monitors.

Modern systems are generally stable and relatively straightforward to calibrate, facilitating the collection of acoustic data in support of quantitative objectives such as abundance estimation. They can also operate at several different frequencies, enabling the detection and quantification of species with different sound-scattering properties and offering potential for species identification by interpretation of frequency-specific differences. Software controls all aspects of echosounder performance, facilitates calibration, provides for synchronization of acoustic data records with information from global positioning system (GPS) receivers and environmental sensors, and allows the automation of data collection and customization of the echosounder display. The collection of high-resolution, spatially explicit information is essential to many studies, and the availability of inexpensive, high-quality GPS receivers has greatly facilitated this type of work. Additional software, which may be provided by instrument manufacturers, third-party software manufacturers, or programmers within research institutes, is generally used to process data addressing specific research or survey goals.

While personal computers have improved scientific instrumentation and data-processing capabilities remarkably, they have also brought unprecedented changes to the bridges of fishing vessels. Microcomputer-based navigation systems can be found aboard many fishing boats today, and computer screens are replacing traditional displays of radars, engine control systems, and other devices. Fishing echosounders have become increasingly sophisticated, and

the most advanced of these are very similar in design and performance to the modern echosounders used in research.

Increasing information needs in support of abundance estimation, management, and the ecosystem approach to fisheries

Traditionally, most acoustic surveys of fish abundance have been carried out aboard dedicated research vessels. Before the advent of microcomputer-based systems, the instruments and computers required to conduct this type of work were large and expensive, and were often permanently installed aboard research vessels. Scientific-quality transducers were also expensive and either permanently installed on research vessels or in heavy towed bodies, which required winch and cable systems not generally available aboard fishing vessels. Furthermore, acoustic surveys usually require directed fishing for target identification, and the collection of ancillary biological information with specialized sampling gear. Research vessels are expensive to operate and in limited supply, however, and although successful acoustic surveys have been conducted aboard chartered fishing vessels, investigators have often faced difficult logistical and operational challenges.

The need for information to support traditional stock assessment, fishery management, and the ecosystem approach to fisheries (EAF) has increased greatly during the last decade. Fishery acoustics is unique in its ability to characterize the distribution of pelagic organisms with high spatial and temporal resolution while also recording information on bathymetry and, in some cases, substrate characteristics. Surveys can be conducted relatively quickly and, although directed (net) sampling is almost always required to support research objectives, state-of-the-art methods for collecting and interpreting multifrequency acoustic data now allow characterization of fish aggregations by species or species group in some instances. Acoustic methods are now used throughout the world to estimate biomass of commercial species, characterize the distribution of pelagic organisms in relation to environmental conditions, understand temporal and spatial variability in patterns of distribution, elucidate interactions between species and, in some cases, characterize environmental conditions (such as substrate type) directly. Fishery managers often require near real-time information on stock distribution and abundance to support in-season decisions regarding opening and closing areas for fishing; because acoustic data can be collected and interpreted rapidly, it is particularly valuable for this purpose.

Acoustics methods can be used to address a broad range of scientific and management objectives and, whereas in the recent past it was difficult to deploy scientific-quality acoustic instruments from fishing vessels, this is no longer the case. Fishery scientists throughout the world are now using fishing vessels to collect acoustic data in support of multiple objectives. This approach has been successful in many instances, and often the cooperative (industry/agency) nature of the work brings additional benefits. In fact, some types of objectives can only be addressed through the use of acoustic systems installed on fishing vessels (e.g. improved characterization of fishing effort, studies of fish/fishery interactions). Conversely, some fishing vessels are unsuitable for collecting acoustic data in support of any scientific objectives, and some fishing vessels may be suitable only for specific types of research. Radiated vessel noise and its impact on fish behaviour, and vessel design or operating conditions that constrain acoustic system performance may be of particular importance.

ICES Study Group on the Collection of Acoustic Data from Fishing Vessels (SGAFV)

In 2003, ICES established a study group (Study Group on the Collection of Acoustic Data from Fishing Vessels (SGAFV)) to evaluate the collection of acoustic data from fishing vessels and provide appropriate recommendations. Experts from 12 countries participated in the work of the study group during its three-year term. The SGAFV prepared a written report

during its three annual meetings and by correspondence between meetings. The findings and recommendations of the study group are summarized below.

Summary of the SGAFV report

Clear definition of the study aims and identification of the associated information requirements are essential precursors to any research or monitoring endeavour. This perspective is first introduced in Section 1 and is revisited throughout the document. Section 1 begins with a general overview of the work of the SGAFV and proceeds to consider the different types of research and monitoring studies that might be conducted from fishing vessels, placing particular emphasis on the importance of proper linkage between sampling strategies and research or monitoring objectives. The requirements for single-species stock assessment surveys are contrasted with the requirements for ecosystem monitoring activities; examples are drawn from the presentations made by the SGAFV participants during meetings of the study group. Different types of qualitative and quantitative goals are discussed under these two broad categories. Particular attention is paid to the concept of error analysis and the accuracy and precision trade-offs associated with different types of sampling strategies. A framework is provided to assist in formal analysis of these trade-offs. The distinctions between undirected (no structured survey design), directed (following some formal survey design), monitoring (could be directed but usually undirected), supervised (scientists are on board), and unsupervised (vessel crew collects the data) modes of data collection, and the types of objectives that can be addressed under them, are emphasized.

Research vessels may be preferred for certain types of studies, and care should always be exercised when selecting fishing vessels as platforms for acoustic data collection. The authors of Section 2 provide comprehensive background information on the behaviour of fish in relation to noise radiated by vessels and the factors (vessel design and operation) that influence the spectral characteristics and intensity of noise radiated by vessels. Much of the discussion is based on earlier work conducted under the auspices of ICES, which provides recommendations on acceptable radiated noise characteristics for research vessels. Many modern research vessels have been constructed in compliance with these recommendations, which are designed to minimize disturbance of fish during data collection. Selection of a suitable vessel should take into account the design of the propulsion system and the propeller. Specially designed, fixed-pitch propellers driven by variable speed diesel–electric propulsion systems are preferred over variable-pitch propellers driven by fixed-speed diesel engines, but these features are not available on fishing vessels. When possible, mechanical components should be mounted in a manner that isolates vibration from the hull. Radiated noise concerns should be evaluated in the context of research objectives; concerns will be greater in shallow water and for species that occur at close range to the vessel; the propensity of fish to react when they hear a vessel also varies by species, physiological condition, and other factors. Guidance is provided on all of these critical factors. The authors also provide guidance on how to characterize and document radiated noise, and on how to minimize radiated noise when fishing vessels are used (e.g. the selection of suitable propeller pitch settings, ensuring that propellers are undamaged). Recommendations on factors that should be taken into account when selecting (or installing instruments on) fishing vessels are also provided. Areas of concern include: placement of transducers to minimize aeration, design and operational factors that influence acoustic system performance in relation to weather and sea state, and elimination of electrical interference, which can greatly compromise acoustic system performance.

The information and recommendations provided in Section 2 are based, to a large extent, on the work of the ICES Study Group on Research Vessel Noise and the recommendations of that group (Mitson, 1995). As a result of these recommendations, research vessels with reduced radiated-noise characteristics have been constructed in several countries. Recent studies involving intercalibration of new noise-reduced vessels with older, non-noise-reduced vessels

(Ona *et al*., 2007; A. De Robertis, pers. comm.) indicate that fish avoidance of noise-reduced vessels does occur and that, in some situations, avoidance of noise-reduced vessels does not present the expected "linear" reduction compared with avoidance of non-noise-reduced vessels. Scientists involved in these studies concluded that vessel-avoidance behaviour is more complex than was previously thought, and that a stimulus other than one-third octave band radiated noise, as considered by Mitson (1995), must be involved. This work does not invalidate the earlier research and associated recommendations. It does suggest, however, that future research may identify additional design and operational factors to be considered when selecting fishing vessels as platforms for collecting acoustic data.

Selection of suitable echosounders and transducers is also critical to the success of any research or survey activity that involves collection of acoustic data. Geospatial information (location, speed, heading), generally provided by GPS receivers, is also of fundamental and universal importance. Ancillary instrumentation may also be important, but this will depend on research objectives. Section 3 discusses the selection, installation, and operation of acoustic instruments and equipment for measurement of operational (speed, heading, etc.), oceanographic, and meteorological parameters. For surveys carried out aboard fishing vessels, acoustic instrumentation will generally consist of conventional (vertical) echosounders connected to hull-mounted transducers, although guidance on the use of various types of sonars and alternative transducer-mounting strategies is also provided. A useful framework for evaluating the trade-offs between instrument (or data) quality and research objectives is presented. Scouting or preliminary distribution surveys, for example, may not require the use of stable, calibrated instruments, whereas a requirement for comparability over time will necessitate the use of stable systems. Calibration is also required to support abundance estimation and other quantitative objectives. Instrument synchronization is important for several reasons; time synchronization should be maintained through a common reference (GPS is recommended), and ping (acoustic transmission) synchronization should be maintained by assigning the scientific echosounder as the master and all other acoustic instruments as slaves. If a trigger delay or specific trigger pulse characteristics are required, it may be necessary to build a customized electronic interface. Researchers are advised to evaluate and address acoustic system synchronization requirements well in advance of the start of a survey. The importance of selecting appropriate echosounder parameters and settings (e.g. transmit power, pulse length, frequency) in relation to study objectives is discussed, although this requirement is common to all acoustic surveys, not only those conducted from fishing vessels.

Similarly, selection (or identification) of suitable transducers is important. Split-beam echosounders and transducers are generally recommended because they are easier to calibrate and can provide target-strength data that are required to address many research objectives. Event logging is also discussed in Section 3; researchers are strongly encouraged to keep track of all important events against the above-mentioned common time reference; electronic logging of events is preferred and often enabled by data-collection software. The author of this section does not discuss specific instrument manufacturers or compare the characteristics and performances of specific scientific and commercial echosounders. Government research institutions may be reluctant to recommend specific manufacturers or products, but the reader is encouraged to review information on specific research studies presented in Section 8 and to consider information provided by various manufacturers, which can be obtained through their URLs.

Operation of acoustic and ancillary instruments at sea, and data collection and management are discussed in Section 4. The authors begin by emphasizing the importance of clearly stated objectives and detailed, written data-collection procedures. They recognize the particular importance of clear communication when working with fishing industry personnel while, at the same time, pointing out that it is the researcher's responsibility to ensure that the quantity

and quality of data collected are sufficient to meet the agreed-upon objectives. The types of products that can be obtained through the use of acoustic instruments aboard fishing vessels are identified and discussed. Following discussions in earlier sections regarding the importance of careful calibration to support quantitative research objectives and monitor instrument performance, the authors provide a detailed discussion of this topic with recommendations for conducting successful calibrations. They then proceed to discuss the recording of research data. Written data recording is now uncommon, but is still important in some situations, such as those that require initial reporting of school characteristics to support in-season management decision-making. Most modern instruments, however, provide digital data outputs, and the output stream can be configured in a manner appropriate to support subsequent analysis. Digital data output is normally integrated with information provided by GPS receivers and, in some instances, other instruments. The authors discuss trade-offs associated with configuration of the data stream output from the echosounder. Recording at full sample resolution is generally recommended because it supports comprehensive post-processing and analysis. Although raw data files may be voluminous, high-capacity portable hard disks are now relatively inexpensive. Data volumes may be reduced by recording at a lower resolution and/or with minimum detection thresholds. It may also be advisable to record multiple data output formats in parallel. Full sample data may be recorded as a minimum requirement, but lower resolution data could also be recorded both for redundancy and to take advantage of the lesser data volume and allow quick review of the echograms. Data quality may be compromised by vessel noise, interference, and sea state; researchers are encouraged to recognize these factors (which are discussed in detail in other sections). Guidance on survey settings is provided, together with a caution regarding the importance of maintaining critical survey settings (e.g. transmit power, pulse length) during data collection. Although it may only be necessary to log data when the vessel is in the defined survey area, expensive mistakes may be avoided by logging data from the time of departure until the vessel returns to port (although the cost of data storage may be a serious consideration). Similarly, the collection of data throughout a fishing trip may be encouraged because it can provide useful ancillary research information. The value of metadata for troubleshooting and guiding subsequent processing of data is explained in detail. In all cases, data logging and recording protocols should be clearly documented, and all logging events must be recorded. Useful advice on retrieval of stored data from the fishing vessels, selection of storage media, verification of recorded data, and protocols for archiving data are also provided.

In most situations, the identification and characterization of acoustic scatterers is required to meet research objectives. This is usually achieved through direct sampling. Section 5 discusses the importance of biological sampling and recommends alternative biological sampling strategies. Key considerations include the need to minimize the selectivity of the sampling gear and to conduct sufficient sampling to characterize aggregations of interest. Commercial fishing gear is normally designed to optimize the catch of the target species and fishers are generally reluctant to set gear in locations where catch rates are expected to be low. In some cases, such as when the vessel is transiting to the fishing grounds, or when the fishing gear available is inadequate for sampling traces observed on the echosounder, acoustic data will be useful only as an indicator of the likely presence of targets of interest. Nevertheless, this type of information may prove useful as a guide for future investigations and more focused application of acoustic and direct sampling equipment. Under ideal circumstances, research fishing gear with low selectivity would be available, and protocols would allow for adequate directed sampling of aggregations of interest. This is not generally the case on fishing vessels, and guidance is provided regarding the consequences of working with selective gear and when fishing opportunities are limited. Provision of adequate biological information may be a limiting factor when fishing vessels are employed as research platforms, and care should be exercised in defining objectives that can be achieved when such sampling opportunities are limited. Guidance is also provided on sampling of catches and collection of biological information.

Methods employed for the analysis and interpretation of acoustic data collected from fishing vessels do not differ greatly from those used for data collected from research vessels. Because fishing vessels can provide much greater spatial and temporal coverage than research vessels, however, large volumes of acoustic data are often generated, particularly during undirected monitoring. The discussion of this topic in Section 6 builds on earlier discussions of data collection, metadata, and data archiving (Section 4). Types of software available for data analysis are discussed. Software packages provided by third-party vendors are generally preferred because they offer greater flexibility and the ability to input and output a range of data structures. Analytical software should be able to: (i) load and manage recorded acoustic data; (ii) view and move forwards and backwards through the recorded echograms; (iii) apply calibration corrections, define regions and layers on the echogram, and permit data quality edits; (iv) apply interpretations to the echogram (including identification, classification, and isolation of targets of interest within the echogram); (v) process the echogram to produce various outputs; (vi) support specialized analysis; and (vii) save analytical sessions to file. The basic steps involved in reviewing and preprocessing data and processing data by echo integration are described. Clearly, not all these steps will be required to analyse data from every acoustic survey, and the authors recognize that the framework they provide is general in nature. This is summarized in a flowchart that can be used to identify various products and associated analytical and data-processing steps. The importance of error analysis is also emphasized. The potential for automation of data processing, and the limitations of currently available methods are discussed, and references are provided for alternative approaches to the analysis of large, spatially explicit datasets.

A key advantage of using commercial vessels is the ability to extend the spatial and temporal coverage of acoustic data collection beyond the capacity of national research vessel fleets (Section 7). The cost of using commercial vessels is often much lower than the cost of research vessels. This is particularly true if the vessel can "pay for itself" by continuing to fish commercially during the research period. Incentives, such as allocation of fish quota to commercial vessels involved in research, can also be used to subsidize the cost to the vessel. Collaboration between scientists and fishers fosters communication and builds relationships that can be beneficial to both parties. Throughout the world, the fishing industry is becoming increasingly interested in participating in resource assessment and research; this is particularly true in areas where rights-based fishing has become established. In such situations, the fishing industry has a long-term interest in the sustainability of the resources upon which it depends. It may also have an obligation to assume some or all of the costs associated with scientific data collection and analysis. The main limitation, identified in Section 7, with using commercial vessels is the uncertain characteristics of the vessel and its instruments. Instrument characteristics can be determined by carrying out calibrations, as described in earlier sections. Radiated vessel noise and its possible impact on the behaviour of the fish aggregations of interest are also discussed in this section. Recommendations that will assist in the identification of appropriate objectives and suitable vessels are provided elsewhere in the report (Sections 1–4 and 6).

Some examples of successful projects involving collection of acoustic data from fishing vessels are described in Section 8. The authors of Section 7 refer to several of these examples and discuss four in detail to illustrate the range of possible applications, the potential benefits, and areas of particular concern. Throughout Section 7, the need for clear and unambiguous communication is emphasized. This relates to all aspects of cooperative research, including drafting of initial goals and objectives, contracting, chartering or otherwise arranging for the use of fishing vessels, establishment of protocols for calibration, acoustic and biological data collection, recording of ancillary information, etc., and dissemination of results.

Detailed instructions for the installation and calibration of instruments and the collection of acoustic and biological data are not provided in this report. SGAFV members agreed that

inclusion of a detailed instruction manual would not be appropriate because many instructions would be specific to the survey objectives and design, and choice of instrumentation. Furthermore, advances in instrumentation and methods occur frequently, and a written guide would soon become outdated. Instead, we provide a URL to the "Acoustic data logging protocols and procedures for commercial fishing vessels" document maintained by the NOAA Alaska Fisheries Science Center. This document provides guidance for those planning and carrying out several types of studies involving collection of acoustic data from fishing vessels and will be updated regularly:

http://www.afsc.noaa.gov/RACE/midwater/avo/FVA_protocols.pdf.

Principal SGAFV findings and recommendations

General

- Acoustic data in support of a range of research and monitoring objectives can be collected successfully from commercial fishing vessels. However, some objectives are better addressed through data collection from dedicated research vessels and some objectives can only be fully addressed by utilizing modern research vessels with low radiated noise characteristics. Some fishing vessels are unsuitable for collecting acoustic data in support of research and monitoring objectives, and some vessels are only suitable for supporting a limited range of objectives.
- Investigators should define research objectives and data-collection requirements carefully. This will provide a basis for determining vessel and instrumentation needs, and biological sampling requirements.
- Certain objectives can be addressed through unsupervised collection of acoustic data aboard fishing vessels, but most will require a supervised approach.

Radiated noise, fish behaviour, and selection of fishing vessels

- Some species of fish are more sensitive to radiated noise than others, and sensitivity may vary by physiological condition. Information on fish behaviour in relation to sound should be reviewed before determining the suitability of fishing vessels as platforms for supporting specific studies.
- Sound intensity attenuates with distance, therefore concerns regarding the impact of radiated noise from fishing vessels (or older research vessels) will be greatest for fish close to the vessel.
    - The design of a vessel's propulsion system and, in some cases, the choice of operating parameters, will greatly influence its radiated noise characteristics. The following considerations should be taken into account in this regard:
    - Noise-reduced vessels are preferred but generally unavailable in the fishing fleet.
    - Vessels with propulsion systems consisting of diesel generators that are isolated from the hull and supply AC current to an AC electric motor driving a fixed-pitch propeller are generally quieter than direct-drive, variable-pitch propelled vessels, but radiated tonal noise may still be problematic.
    - Vessels with propulsion systems consisting of diesel engines that are bolted to the hull and gearboxes that drive controllable-pitch propellers are generally the noisiest and may disturb sensitive fish species at distances >200 m, although careful selection of propeller pitch may mitigate radiated noise.
    - Fixed-pitch propellers (with four or more blades) are recommended, especially for assessment of sensitive species at close range. Controllable-pitch propellers should be avoided if at all possible.
    - When only controllable-pitch propellers are available, selection of optimal propeller pitch and engine rpm combinations is essential. This is difficult to accomplish without noise ranging tests, although self-noise testing will be useful.

Other vessel selection considerations

- Acoustic performance is an important criterion in any fishing-vessel-based monitoring programme. The seagoing qualities of vessels should be considered when selecting commercial vessels for scientific purposes, and transducer placement should be given particular consideration. Vessels known to force aerated bow waves under and along the hull during bad weather and at normal cruising speeds should be avoided.
- Propeller blades should be in good condition to minimize cavitation and generation of associated noise.
- Investigators should ensure that there is no electrical interference that will affect the survey echosounders, and that the electrical supply is stable in voltage and frequency.
- Vessel self-noise tests are recommended and easy to conduct through use of the noise-measurement facility built into many echosounders.
- Noise ranging is recommended.

Selection of instrumentation

- The performance of echosounders selected to support scientific objectives should be stable; digital systems that provide control over the temporal and spatial resolution of output data are preferred.
- Split-beam transducers and echosounders are generally preferred because these systems facilitate calibration and *in situ* target-strength measurement.
- Selection of appropriate echosounder settings is particularly important (e.g. transmit power, pulse length, frequency).
- Instrument settings should be checked and recorded periodically.
- GPS data should always be collected and properly interfaced with the acoustic instruments.
- The need to collect ancillary data depends on the objectives of the study.
- When appropriate, ping synchronization of acoustic systems and time synchronization of all instruments should be implemented.
- Manufacturers or products are not recommended specifically, but readers are encouraged to review information on specific research studies presented in the report and to consider information provided by various manufacturers, which can be obtained through their URLs. (See Annex 2 for contact information for hardware and software manufacturers.)

Collection of acoustic and ancillary data

- Investigators are advised to draft a survey plan that defines the survey goals and objectives and details protocols associated with all aspects of the study. This plan should also consider logistical tasks (e.g. retrieval of data, communication, and port visits).
- Collection of raw data files is generally recommended, although the storage of digital data collected during prolonged surveys can be problematic. Researchers should consider carefully the trade-offs between quantity and resolution of data collected and the ability to meet research objectives.
- Metadata requirements and recording protocols should be established and documented.
- Every effort should be made to establish good working relationships with vessel personnel and owners.
- It is useful to begin with the end in mind. Consider how data synthesis and post-voyage analysis will be done when planning fieldwork.
- Calibration of acoustic systems is required for the quantitative use of acoustic data and is recommended for all studies.
- Time synchronization of acoustic and ancillary instruments is critical. All instruments should be time-synchronized using a GPS receiver against a common standard.

- Ping synchronization is also critical to acoustic instruments. In general, the master synchronization pulse should be provided by the scientific echosounder, and all other acoustic instruments should be set up as slaves. Custom electronics may be required to address specific timing or pulse form needs. It may be necessary to turn off some vessel acoustic instruments during scientific data collection.
- Potential sources of interference by other on-board acoustic systems should be identified. In many cases, interfering sounders will need to be either synchronized with the survey sounder or turned off when collecting survey data.
- Vessel characteristics may preclude the collection of scientifically useful data under some weather and/or operating conditions. Guidelines for sea state, survey speed, etc. should be provided in the operations manual and amended as appropriate.
- Biological sampling must be consistent with survey objectives. Gear selectivity and temporal and spatial resolution will be of particular concern in this regard. It is important to ensure that sampling gear and protocols for fishing are consistent with the research/survey information needs.

Data processing and analysis

- While the requirements for processing, analysis, and interpretation of acoustic (and ancillary) data collected aboard fishing vessels may not differ markedly from the requirements for similar types of data collected aboard research vessels, some considerations are particularly important:
    - Large quantities of data may be collected, and this may require the establishment of special procedures for storage and archiving of data.
    - Metadata will be especially useful in the identification of subsets of data for detailed analysis.
    - It may be advisable to collect raw data and low-resolution data simultaneously. Low-resolution data can be reviewed rapidly to assist in identifying sequences of high-resolution data for detailed analysis.

Cooperative (industry/agency) research considerations

- Scientists should communicate clearly the objectives of the proposed research and the potential benefits to industry participants and other stakeholders.
- Scientific and industry stakeholders should strive to achieve a shared vision for the project and to identify the roles and responsibilities of the various participants. Care should be taken to ensure that terminology is understood by all participants.
- Vessel requirements should be defined and communicated as early and as clearly as possible in the process.
- Written protocols for all sampling and related operations should be drafted and agreed upon well in advance of the first sampling trip.
- A comprehensive and clear legal contract or working agreement must be developed that defines the duties and responsibilities of all partners before, during, and after a survey or specific scientific study.
- Responsibilities for drafting and publishing research results should be understood in advance. Opportunities to review draft reports and recommendations should be provided to all stakeholders. When appropriate, weekly/monthly progress reports should be provided to participants and stakeholder organizations.
- Industry participants must be assured that proprietary information they provide will not be released without consent.
- Cooperative research agreements should encourage evaluation of performance by industry and scientific participants with a focus on the development and implementation of future projects.

Note that, in order to retain consistency with recommendations provided in the individual chapters, recommendations may appear more than once in the list above.

1 Introduction

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1.1 Background

In the last half of the twentieth century, there was rapid and parallel development of acoustic instruments for scientific and fishing applications. The general requirement of both groups of users is the same: to visualize biological objects in the water column well beyond the range of human vision. Fishers use the information from their sonars and echosounders to catch fish more effectively, while fishery scientists use similar acoustic information to study fish distribution and estimate stock abundance. The major difference between fishing and scientific applications of acoustics is in the quality and level of interpretation of the acoustic data. Quantitative interpretation of acoustic returns is required for most (but not all) scientific work, but is not essential when acoustics is used by fishers as a sensing tool. Consequently, scientific acoustic instruments have historically been of higher quality, with more stable electrical components, settings that allow instruments to be calibrated to known standards, and provisions for exporting data in electronic form.

Recently, high-quality commercial echosounders have become closer in quality and capacity to scientific echosounders. This convergence is the result of several technological developments. The first key development was the adoption of a common microcomputer platform for both commercial and scientific echosounders. Software and applications developed for scientific work can now be adapted easily for commercial echosounders. A second technological advance is the ongoing development of portable data-storage devices. These devices allow reliable collection of large quantities of data in both supervised and unsupervised situations. Also of fundamental importance are the widespread availability of the global positioning system (GPS), and the integration of GPS and acoustic information, which allows the acoustic information to be evaluated in a spatial context.

As these modern instruments have been installed on commercial fishing vessels, fishery scientists in many countries have taken advantage of the opportunity to collect acoustic data from fishing vessels in support of a range of stock management and ecosystem monitoring objectives (see Table 1.2). Furthermore, many fishers and vessel owners are willing to collect acoustic data voluntarily for scientists if they believe that the information they provide will be useful for assessment and management of their fishery. The shift towards increasing use of commercial vessels as platforms for acoustic data collection has occurred as part of the evolution of fishery resource management science that recognizes the importance of exchanges of information between fishers and scientists. Cooperative research programmes benefit both fishers and researchers. Fishers can play a more active role in the science that affects their livelihoods, and researchers can access the extensive knowledge that fishers gain from years of experience.

Despite widespread and increasing use of fishing vessels for acoustic data collection, standardized methods and protocols do not exist. Concerns regarding instrument performance and calibration, fish behaviour in relation to radiated vessel noise, survey design, biological sampling, data interpretation and management, and other factors have received significant attention by the ICES Working Group on Fisheries Acoustics Science and Technology (WGFAST) and the broader scientific community. Although commercial vessels and commercial echosounders are suitable for collecting data in support of some specific research and survey objectives, use of these platforms and instruments is not always appropriate.

Representatives from several ICES member and observer countries defined a need to address the lack of methods and guidelines for appropriate collection and use of acoustic data from commercial vessels. In response, ICES established the Study Group on the Collection of Acoustic Data from Fishing Vessels (SGAFV). This group was established in 2004, for a three-year period, with the following objectives:

1) To review and evaluate recent and current research that involves the collection of scientific acoustic data from commercial vessels;
2) To develop standardized methods and protocols for collection of acoustic data to address specific ecosystem monitoring, stock assessment, and management objectives, including: acoustic system calibration and performance monitoring, characterization of radiated vessel noise, comparability of results, survey design, biological sampling, data interpretation and analysis, and data storage and management;
3) To prepare background material, guidelines, methods, and protocols for publication in the *ICES Cooperative Research Report* series.

The group met on three occasions (Gdynia, Poland, 16–17 April 2004; Rome, Italy, 17–18 April 2005; Hobart, Australia, 25–26 March 2006) and continued to work by correspondence throughout its three-year term. It was chaired by Dr William Karp (USA); information on SGAFV membership and participation is provided in Annex 1.

1.2 Collection of acoustic data from fishing vessels

Two general sets of objectives can be addressed through the collection of acoustic data from fishing vessels: (i) the provision of information in support of single-species stock assessment, and (ii) the provision of information in support of the ecosystem approach to fishery management. This information can be obtained from calibrated or uncalibrated acoustic data obtained during directed surveys or through undirected monitoring with additional biological and physical data obtained from targeted or opportunistic sampling. To maximize the utility of the information obtained from the acoustic data it is important to match the study requirements with the tools and level of direction required. Important in this process is an evaluation of the cost of the study relative to the impact the data will have in support of specific management needs or improved understanding of the functioning and dynamics of the marine ecosystem. In the following section, we describe general fishery management needs for both single-species stock assessments and broader ecosystem understanding, and the extent to which these can be addressed through the collection of acoustic data from fishing vessels.

1.2.1 Single-species stock assessment

Provision of information for single-species stock assessment is still the most common usage of acoustic data collected from both research and fishing vessels. The aim of stock assessment is to provide advice on stock status (population size). To evaluate the needs of acoustic data within a given fishery, it is desirable to evaluate the functioning of the whole fishery, considering the economic importance of the fishery, the fishers' operations, monitoring requirements, and management actions. Evaluation of all these elements can lead to the establishment of a harvest strategy for the fishery with reference points based on fishery-dependent and/or fishery-independent information, which may include information from acoustic surveys conducted on board fishing vessels. Commonly used biological reference points can be established using both limits and targets based on a range of probabilities of certainty that are set by management when evaluating the level of acceptable risk given the monitoring information available (e.g. Caddy, 2002). Evaluation of alternative harvest strategies and formalization of risk is undertaken as part of a management strategy evaluation (e.g. Smith *et al.*, 1999; Mace, 2001; Punt *et al.*, 2001). When considering alternative harvest strategies, it is important to develop a complete understanding of the monitoring requirements

to address management objectives and the associated risks fully. Acoustic observations can then be evaluated objectively within this framework to determine the requirements for a specific fishery or study.

The evaluation of monitoring strategies, including acoustic data collection, should include an evaluation of quantitative and qualitative assessment needs within known error limits, potential biases, and costs. Often, management would like to reduce the risk of fishery collapse when faced with uncertainty in data or assessment models by adopting a more precautionary approach to harvesting of the fishery (Caddy, 2002). This indicates that a detailed evaluation of the systematic and random errors inherent in the information being used is important in the assessment process.

When evaluating acoustic monitoring needs in a fishery, trade-offs between spatial and temporal coverage, precision, and cost should also be considered. Figure 1.2.1.1 illustrates the interplay between acoustic data products and spatial and temporal coverage, precision, and cost for a deep-water species, the orange roughy (*Hoplostethus atlanticus*; Kloser *et al.*, 2001). The information obtained from acoustic data ranges from general spatial and temporal dynamics of fish schools to detailed understanding of stock size at a particular location (Figure 1.2.1.1).

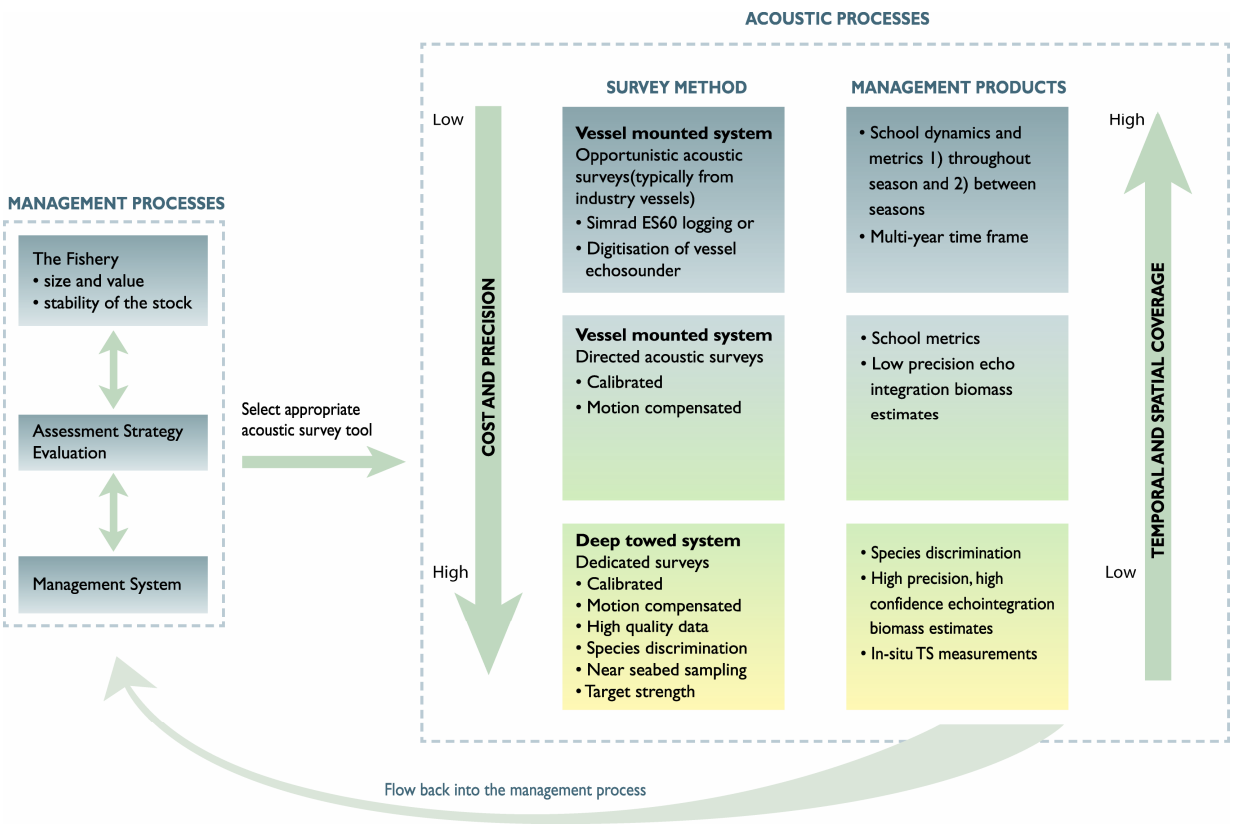

Figure 1.2.1.1. Outline of a qualitative assessment of an acoustic monitoring system for a deep-water fish, orange roughy (*Hoplostethus atlanticus*; Kloser *et al.*, 2001).

Incorporation of both quantitative and qualitative information is desirable in the stock-assessment process. Qualitative indicators that may be obtained from acoustics include: (i) location and dynamics of aggregated/non-aggregated fish; (ii) fine-scale temporal dynamics (fish behaviour); and (iii) improved definition of effort for catch per unit of effort (cpue) analyses. In general, only quantitative information can be incorporated in stock-assessment models that evaluate the stock size in relation to reference points and uncertainty levels (Mace, 2001). Progress is being made in the development of quantitative metrics from these

qualitative indicators so that they can be used in the assessment process. For example, quantitative metrics of the spatial distribution of anchovies can be derived using acoustic data (S. Bertrand *et al.*, 2004).

Quantitative metrics for single-species stock assessments derived from acoustic data generally fall into one of two estimated quantities: relative abundance (indices) or absolute abundance. The key 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 acoustic indices can be biased (i.e. the ratio, q, of the acoustic estimate to the actual stock size is greater than or less than 1) owing to systematic errors such as the proportion of stock sampled or target strength, but it is assumed that the bias does not change over time. This means a time-series of relative estimates can be used to monitor 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 (q = 1) and the stock status can be determined after only one survey. However, in an absolute abundance estimate, systematic errors must be incorporated into the overall measure of uncertainty associated with the estimate.

Evaluation of the accuracy and precision of the biomass estimate is an important aspect of a quantitative fishery assessment. When acoustic data are used in a fisheries stock assessment to provide relative or absolute estimates of stock biomass, associated estimates of accuracy and precision are also generally required. The systematic and random errors associated with acoustic surveys have been outlined and reviewed previously (e.g. Rose *et al.*, 2000; Demer, 2004; Simmonds and MacLennan, 2005). Table 1.1 provides a summary of the common systematic and random errors associated with acoustic surveys. The magnitude of these errors varies greatly depending on the species and operating environment. It is important to note that survey sampling error may only be a small component of the overall uncertainty associated with a biomass estimate (e.g. Rose *et al.*, 2000; Kloser *et al.*, 2001). When designing a monitoring programme, it is important to undertake a qualitative or quantitative assessment to reduce the potential for systematic and random errors of the types outlined in Table 1.1. Of greatest interest in the precautionary approach to fishery management are errors that tend to result in a positive bias in an estimate of absolute abundance. Positive systematic error can be the result of factors such as fish migration, diel behaviour, noise, species identification, target-strength estimation errors, and fish attraction (Table 1.1).

Often, acoustic surveys are used to provide indices of abundance to tune assessment models or as independent indicators of the status of a stock. An acoustic index used in this way relies on the assumption that a range of systematic errors, such as instrumentation performance, proportion of stock sampled, and target strength, are constant over time, but these assumptions will not always be valid. For example, when starting a time-series, consideration should be given to using similar instruments on similar vessels to improve data precision. Errors due to physical calibration, platform motion, bubble attenuation, and vessel noise may be reduced or remain constant. Potentially the greatest source of bias may be bubble attenuation, which is platform- and sea state-specific. Vessel selection based on acoustic performance is therefore an important criterion in any fishing vessel-based monitoring programme. It should be noted that selection of an appropriate vessel will not necessarily improve overall survey accuracy if errors associated with factors such as sampling design, fish migration, and species identification are substantial (Table 1.1).

Table 1.1. Sources of systematic and random errors in acoustic surveys. Values are indicative only and will vary greatly depending on the species, spatial and temporal coverage of the survey, and the operating environment (e.g. depth and sea conditions). List (a) applies to the acoustic index of relative abundance. List (b) is the additional error applied to the absolute abundance estimate. Modified from MacLennan and Simmonds (1992, p. 282).

SOURCE	RANDOM ERROR (%)	SYSTEMATIC ERROR (%) (BIAS)	COMMENT
a) Acoustic index error			
Physical calibration	±2	±5	
Transducer motion		0 to −30	Can compensate if platform motion is monitored.
Bubble attenuation		0 to −90	Relies on empirical corrections and is sea-state and platform-characteristics dependent.
Hydrographic conditions	±2 to ±5		
Target strength	±5	Uncertain	Systematic bias between years can occur. Diel effects may be of considerable importance.
Species identification		0 to ±80	
Random sampling	±10 to ±40		
Fish migration		0 to ±40	
Diel behaviour	0 to 25		May be caused by changes in patterns of aggregation, vertical migration, and changes in orientation (e.g. Simmonds *et al.*, 1992; Fréon *et al.*, 1992, 1996).
Noise interference		0 to ±20	Depends on the noise interference, usually vessel noise, but also could be caused by other echosounders.
b) Absolute abundance error			
Physical calibration		±3	Higher if beam pattern of transducer unknown.
Hydrographic conditions		0 to ±5	
Target strength		0 to ±50	May vary in space, time, and environmental condition.
Avoidance/attraction reactions		±Uncertain	

Having addressed concerns about instrument and vessel performance, investigators should concentrate on species identification, target strength, and survey design to minimize errors associated with using quantitative acoustic snapshot surveys to estimate biomass (Table 1.1). The magnitude of the effect that these parameters have on a given assessment is not specifically related to the use of fishing vessels, and each factor should be evaluated individually. The use of fishing vessels can sometimes provide useful information about species identification by fish capture and observation of school behaviour. The use of commercial and scientific net sampling, however, may not resolve uncertainties in species identification, species proportions, and species presence/absence (see Section 5). Uncertainty in species composition can introduce a significant systematic error in the assessment of deep-water fisheries (Kloser *et al.*, 2002). It may not be possible to resolve this type of uncertainty when it is associated with the interpretation of the acoustic data collected by fishing vessels. An alternative or complementary approach might involve the use of multifrequency acoustic methods currently being developed (e.g. Madureira *et al.*, 1993; Kloser *et al.*, 2002; Korneliussen and Ona, 2003a).

Another major factor impacting the use of acoustic data for the estimation of fish biomass is the estimate of mean target strength. Target strength is difficult to measure *in situ* and can vary substantially both in time and in space (e.g. Everson, 1982; Ona, 2003). Dedicated surveys with specialized instrumentation are often required for this purpose.

1.2.2 The ecosystem approach to fishery management

The ecosystem approach to fisheries is usually concerned with larger spatial and temporal scales than single-species stock assessments. It is not always possible to achieve sampling at these scales with dedicated research vessels, but increased temporal and spatial coverage can often be obtained through the use of fishing vessels. This is an evolving area of research and initial studies are being carried out worldwide (e.g. A. Bertrand *et al.*, 2003; Barbeaux *et al.*, 2005). It is important to define clear objectives in the development of acoustic monitoring for the ecosystem approach to fishery management.

Implementation of the ecosystem approach will require better governance and will greatly increase demands on our knowledge of the marine ecosystem (Browman and Stergiou, 2004). More knowledge of multispecies assemblages and their trophic interactions will be required (e.g. A. Bertrand *et al.*, 2003). These authors discuss the need for appropriate modelling of the ecosystem to implement the ecosystem approach to fisheries, supported with targeted observational data. They show that acoustic data are an essential tool, which may provide quantitative and qualitative data on various communities and allow observation of community interactions. Integrated studies based on acoustics provide new insights into ecosystem function (e.g. Croll *et al.*, 1998; A. Bertrand *et al.*, 2003). Integrated ecosystem studies including acoustics are providing large datasets, but these large datasets must be understood in terms of quality as well as quantity (Kaufman *et al.*, 2004). Simple visual qualitative descriptions of the way organisms are distributed can provide valuable information about ecosystem function that can be parameterized in ecosystem theoretical models (e.g. ICES, 2000; A. Bertrand *et al.*, 2002, 2004). The potential for acoustic data to provide both quantitative and qualitative metrics over a range of trophic levels and large spatial and temporal scales is appealing, and this potential is increasing as new methodologies and technologies are introduced (e.g. Korneliussen and Ona, 2003a; Makris *et al.*, 2006).

Sampling needs in support of the ecosystem approach to fisheries will depend on overall management strategies for the fishery, but identification of the most useful indicators can be aided by modelling. Fulton *et al.* (2005) suggest that information on gelatinous plankton, cephalopods, seagrasses, planktivores, and top predators is generally required. We suggest the addition of mesopelagic communities (micronektonic fish in particular) to this list. Furthermore, we suggest the following indicators for consideration when designing ecosystem-monitoring studies:

- Relative biomass
- Proportional cover of biogenic habitat groups
- Simple diversity indices
- Size and trophic spectra
- Size and age composition of selected commercial species
- Size at maturity of selected commercial species
- Physical properties (e.g. temperature, salinity).

Acoustic methods will not provide information on all these indicators, but can provide estimates of relative biomass, size, and trophic spectra for some species and communities. The use of ecosystem models can be extended to predict the necessary sampling precision and accuracy required of acoustic observations. In this way, the acoustic observation strategy can be matched to the ecosystem approach to fisheries more closely, and various sampling strategies can be compared for cost and management impact (e.g. Rice and Rochet, 2005).

As an example, enhanced use of acoustic data might require more emphasis on partitioning into various trophic groups (through directed sampling and/or multifrequency methods). In support of this need, use of fishing vessels can greatly increase spatial and temporal coverage with low data collection costs.

1.3 Example sampling programmes

The studies summarized in Table 1.2 address many different research objectives, including analysis of fishing behaviour and coverage (Dorn and Barbeaux, Section 8.2.4), ecosystem monitoring (Bertrand, Section 8.3.4), mapping fish distributions (Gutiérrez *et al.*, 2000), and estimating stock abundance (O'Driscoll and Macaulay, 2005). As with any sampling technique, it is important to match study objectives with appropriate tools and survey designs to achieve the level of accuracy required. Although a broad range of sampling strategies for monitoring from fishing vessels is available, approaches can be divided into two main categories: undirected monitoring and directed surveys (see Table 1.1)

Undirected monitoring occurs when acoustic data are collected while vessels are carrying out normal fishing operations. Typically, an autonomous logging system (e.g. Melvin *et al.,* 2002) is installed on the vessel, which records acoustic, spatial (GPS), and other data continuously as the vessel is fishing and steaming. There is no input from researchers about where and when data are collected. The major advantage of this type of strategy is that large amounts of data are collected, with potential for good spatial and temporal coverage of the commercial fishery. Undirected monitoring is useful for studying the behaviour of fishers and fish (e.g. Dorn and Barbeaux, Section 8.2.4), and can provide information on echo trace types from new areas (e.g. O'Driscoll and Macaulay, 2003), but it is difficult to generate abundance indices from this type of data. A notable exception is in the Canadian herring fishery, where acoustic data collected from gillnet and purse-seine vessels have been used to derive relative abundance indices suitable for stock assessment (Claytor and Allard, 2001).

Directed surveys, during which acoustic data are collected following a survey design predetermined by a scientist, are generally more suitable for abundance estimation. Data collection is usually supervised by vessel crew or scientists on board the vessel. Examples of directed acoustic surveys from fishing vessels include surveys of orange roughy in Australia (e.g. Kloser *et al.*, 2001), New Zealand (e.g. Hampton and Soule, 2003), and Chile (e.g. Niklitschek, Section 8.3.3). In these surveys, biomass estimates have been obtained for spawning orange roughy in localized spawning areas from one or more vessels. On a larger scale, the EUREKA project in Peru coordinates a large number of fishing vessels (25–50) to systematically map the distribution of anchovy over a broad area in only 2–3 days (Section 8.1.9; Gutiérrez *et al.*, 2000). Costs to the fishing companies are generally incurred with directed surveys because fishing vessels usually need to stop fishing to carry out the acoustic survey work. Participants involved in such surveys may require some incentive, such as allocation of quota, to stop fishing during the survey period. A special situation exists if there are periods of downtime during commercial fishing operations, such as the time required to process catch. Under these circumstances, directed acoustic surveys may be carried out without compromising commercial fishing success (e.g. O'Driscoll and Macaulay, 2005).

This distinction between undirected monitoring and directed surveys is somewhat arbitrary. Intermediate strategies also exist, such as the use of fishing vessels as "scouts" to locate aggregations, which are then surveyed from a research vessel (e.g. Stanley *et al.*, 2000; Peña, Section 8.2.6; Section 7). Multistage survey designs that use fishing vessels for exploratory surveys are appealing because they match strength to strength: fishing vessels to carry out large-scale qualitative surveys and research vessels for quantitative biomass estimation. Fishing vessels are also frequently used as catcher vessels to carry out biological sampling during acoustic surveys from research vessels, but this application is beyond the scope of this report.

1.4 Example management monitoring strategies

In this section, we describe some acoustic sampling strategies where fishing vessels have been used to collect the data and, once processed and reported, the results have been fed back into the management of the fishery.

In eastern Canada, a number of fishing vessels that target spawning Atlantic herring (*Clupea harengus*) have been equipped with scientific grade echosounders (Melvin and Power, 1999). This has allowed the development of a "survey, assess, then fish" management strategy. Vessels collect acoustic data along a series of pre-planned transects before a fishing ground is opened. The acoustic data are used to estimate the biomass of herring and, if sufficient biomass is present, the commercial fishery is allowed to harvest a percentage of this estimate. Vessel operators can conduct subsequent *ad hoc* surveys if they believe more herring are present than during the initial survey, and if the biomass estimate is greater than the initial survey the amount of fish available to the fleet for harvest may increase. This survey method and management model was implemented to address concerns that specific spawning grounds could be extirpated even while landings remained within the bounds of limits for the overall fishing area.

Within the Australian orange roughy fishery, the Deepwater Resources Assessment Group (consisting of managers, fishers, and scientists) is responsible for defining the requirements of a monitoring strategy that includes fishing vessel acoustic surveys. The monitoring strategy incorporates fishing vessel acoustic monitoring to provide greater spatial and temporal coverage both within and between seasons through directed surveys (Figure 1.2.1.1). This information provides details of spawning location and within – and between – season dynamics and biomass. A more comprehensive acoustic and trawling survey is carried out every 3–5 years to improve the interpretation of vessel-mounted acoustic surveys using deep-towed or lowered multifrequency transducers (Figure 1.2.1.1; Kloser *et al.*, 2001, 2002). The aim of this monitoring strategy is to maximize the strengths of the fishing vessel acoustic method while minimizing the risk of the stock being overfished.

1.5 Summary

Acoustic data from fishing vessels provide a valuable source of information for fishery management. To maximize the utility of fishing vessel acoustic data, objectives must be clearly defined in the context of the potential impact on the management of the fishery and the overall input to the ecosystem approach to fishery management. This can be achieved through a qualitative or quantitative evaluation of all monitoring needs within the fishery, through a monitoring strategy within a harvest strategy to explore the sampling needs, and necessary accuracy and precision to meet management objectives.

1.6 Recommendations

- The fishing vessel acoustic information needs should be assessed in the context of the management objectives and harvest strategy for the fishery.
- It is necessary to assess the accuracy required to meet objectives and to select appropriate tools and sampling designs to match the spatial and temporal coverage required.
- Fishing vessel acoustic data should be integrated into fisheries monitoring to maximize its benefits while minimizing known errors and limitations.
- Evaluation of acoustic monitoring strategies should include an evaluation of quantitative and qualitative assessment needs within known error limits, potential biases, and costs.
- Vessel selection based on acoustic performance is important to the success of any fishing vessel-based monitoring programme.

Table 1.2. Studies known to members of the SGAFV in which commercial vessels have been used to collect acoustic data. These studies have been divided into two basic survey strategies: (i) undirected monitoring of the vessel's acoustic instruments (echosounder or sonar) during fishing operations; and (ii) directed acoustic surveys following a predetermined survey design, using the commercial vessel as the primary research platform.

Species	Area	Survey type	Reference
Herring (*Clupea harengus*)	Eastern Canada	Monitoring	Claytor and Clay (2001); Melvin *et al.* (2001, 2002)
	Gulf of Maine	Monitoring and directed	Michaels (Section 8.2.1)
	North Sea	Monitoring	Reid (Section 8.2.9)
Rockfish (*Sebastes* spp.)	British Columbia	Monitoring and directed	Stanley *et al.* (2000, 2002); Wyeth *et al.* (2000)
	California	Directed	Demer (Section 8.2.2)
Jack mackerel (*Trachurus symmetricus murphyi*)	Chile	Monitoring and directed	Peña (Section 8.2.6); Bertrand (Section 8.3.4); Barbieri and Córdova (Section 8.1.6)
Walleye pollock (*Theragra chalcogramma*)	Alaska	Monitoring	Dorn and Barbeaux (Section 8.2.4)
Hoki (*Macruronus novaezelandiae*)	New Zealand	Directed	O'Driscoll (2003); O'Driscoll *et al.* (2004); O'Driscoll and Macaulay (2005)
	Australia	Monitoring and directed	Ryan and Kloser (2002); Kloser and Ryan (Section 8.2.3)
Orange roughy (*Hoplostethus atlanticus*)	New Zealand	Directed	Hampton and Soule (2003); Soule and Hampton (2003); Clark *et al.* (2005)
	Australia	Directed	Kloser *et al.* (2000, 2001)
	Chile	Monitoring and directed	Boyer *et al.* (2004); Niklitschek (Section 8.3.3)
Southern blue whiting (*Micromesistius australis*)	New Zealand	Directed	O'Driscoll and Hanchet (2004); O'Driscoll and Macaulay (Section 8.3.1)
Antarctic toothfish (*Dissostichus mawsoni*)	Antarctica	Monitoring	O'Driscoll and Macaulay (2003)
Capelin (*Mallotus villosus*)	Barents Sea	Directed	Peña (Section 8.3.2)
Anchovy (*Engraulis ringens*)	Peru	Directed	Gutiérrez *et al.* (2000)

2 Fishing vessels as sampling platforms

Ron Mitson and John Dalen

2.1 Introduction

In this section, we pay particular attention to fishing vessels as sampling platforms. The Study Group on the Collection of Acoustic Data from Fishing Vessels (SGAFV) was established to assist the development of new and innovative approaches to the collection of acoustic data, and to take advantage of opportunities for collecting this kind of data from fishing vessels. But commercial fishing vessels differ from research vessels in a number of important ways. These factors may impact the ability of researchers to collect scientifically useful acoustic data and may constrain the quality of data that can be collected, thus potentially restricting the extent to which inference can be drawn.

Selection of a suitable vessel and appropriate operation of that vessel may be critical to the success of a field research project that involves collection of acoustic data. Our goal is to help the reader understand the trade-offs associated with the selection of vessels and vessel operating parameters. We also wish to encourage choices that do not compromise an investigator's ability to collect data of the quality necessary to address his or her research objectives.

In the past 35 years, research has improved our understanding of the detection of sound by fish and behavioural responses of fish to sound. At the same time, our knowledge of the causes of underwater noise radiated by vessels, and the extent to which vessel design and/or operating factors can be brought to bear to reduce sound emissions that may influence fish behaviour or compromise echosounder performance, has progressed. These advances were considered by the earlier ICES Study Group on Research Vessel Noise (SGRVN) in the mid-1990s. Their findings and recommendations, published as *ICES Cooperative Research Report No. 209* (Mitson, 1995), have greatly influenced the design of modern fishery research vessels and provide the basis for much of the following discussion.

The SGRVN recommended maximum levels of noise from a free-running survey vessel at a survey speed of 11 knots. Although these recommendations can be achieved by custom-designed noise-reduced research vessels, they cannot be achieved by older research vessels or most fishing vessels. Nevertheless, they serve as a reference point for much of the following discussion (Figure 2.1.1).

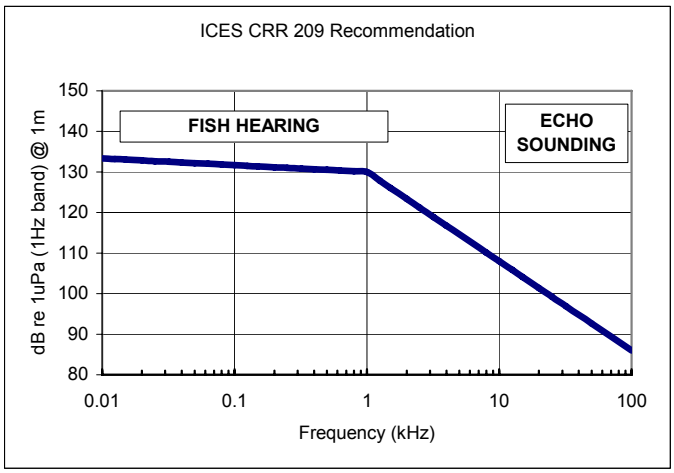

Figure 2.1.1. Maximum recommended sound pressure spectrum levels of noise from a survey vessel when free-running at any speed up to and including 11 knots with all normal ships services running.

Modern fishery research vessels, especially those constructed in compliance with the *ICES Cooperative Research Report No. 209* recommendations, provide platforms of a good standard for conducting surveys of fish abundance and associated research. These types of vessels are not, however, always available. Administrators and investigators may be asked to decide which surveys or research studies should be conducted only from *ICES Cooperative Research Report No. 209*-compliant platforms, or to determine if research and survey objectives can be met using research or commercial vessels that do not comply with *ICES Cooperative Research Report No. 209*.

In the following, we first discuss potential impacts of radiated noise on fish behaviour and the extent to which behavioural responses to radiated noise may influence availability of fish to the sampling tools (acoustic or direct fishing) employed. Next, we consider vessel design and operating factors that may constrain echosounder performance, and provide guidance for addressing these factors in reference to research objectives.

We are concerned with two different phenomena: (i) the detection of sound by fish and the potential for behavioural responses that influence availability to the sampling gear; (ii) the detection of fish with sound, and factors related to vessel design, configuration, or operations that constrain the effectiveness of acoustic sampling devices.

2.2 Detection of sound by fish

In an ideal world, sampling devices would provide unbiased information on the natural distribution of fish. However, all sampling devices are selective, and many affect fish behaviour in ways that influence availability to the gear. Furthermore, behavioural responses to sampling gear may differ according to fish size, physiological condition, and other factors, and the stimulus that elicits a given behavioural response may itself be modified by physical conditions related to weather and other aspects of the sampling environment.

2.2.1 Hearing physiology and sensitivity

Stimulation of small bony structures of the inner ear, the otoliths, is the primary mechanism for detection of sound by fish. The otoliths may be stimulated directly by transmission of sound through the soft tissue, although the rate of attenuation is high. Indirect stimulation occurs if a swimbladder is present and either in close proximity or directly connected to the inner ear. Most swimbladders contain gas that is less dense than soft tissue and, therefore, indirect otolith stimulation occurs when sound causes the walls of the bladder to vibrate. Hair cells located in the sensory epithelia of the inner ear and their associated cilia tufts detect movement of the otoliths. When a bundle of cilia is bent, microscopic calcium channels are opened, initiating a chain of events that results in the release of a neurotransmitter from the basal end of the cell, which excites the associated cranial nerve endings (Sand, 1974; Hawkins and Horner, 1981; Popper, 2003; Popper *et al*., 2005). Popper and colleagues also noted that species that hear through direct stimulation of the otoliths (hearing generalists) tend to have a narrower hearing bandwidth and poorer sensitivity than those that are capable of detecting sound through direct and indirect pathways (hearing specialists). The similar hair cells of the lateral line also play a role in sound detection (Chang *et al*., 1992). Audiograms of fish such as cod (*Gadus morhua*) and herring (*Clupea harengus*) show that these species appear to be particularly sensitive, having hearing pressure thresholds at about 75 dB re 1 µPa (Enger, 1967; Olsen, 1969; Chapman and Hawkins, 1973; Hawkins, 1981).

Measurements of hearing responses of commercial fish species were published as early as 1967 (Table 2.2.1). The table shows the calculated distance at which vessel-avoidance behaviour might occur, if the vessels exactly met the *ICES Cooperative Research Report No. 209* recommended levels, between 10 Hz and 1 kHz. Cod and herring, the most sensitive species, should not be affected beyond 20 m by such vessels. For fish with less acute hearing,

a closer approach to the vessel would be possible before any avoidance behaviour became likely, or the 20-m threshold response distance could be achieved with a noisier vessel.

Table 2.2.1. Fish audiogram characteristics and potential vessel-avoidance responses for nine species. Measurements were conducted under low ambient noise conditions.

	Approx. frequency of highest sensitivity (Hz)	≈−6 dB bandwidth (Hz)	Sensitivity (dB re 1 μPa)	Response re: cod and herring (dB)	Avoidance reaction distance re: ICES noise levels (m)	Source
Cod (*Gadus morhua*)	150	240	75	0	20	Chapman and Hawkins (1973)
Haddock (*Melanogrammus aeglefinus*)	200	220	78	−3	18	Chapman (1973)
Herring (*Clupea harengus*)	100	1170	75	0	20	Enger (1967)
Pollack (*Pollachius virens*)	180	210	78	−3	18	Chapman (1973)
Common dab (*Limanda limanda*)	100	100	90	−14	4.5	Chapman and Sand (1974)
Plaice (*Pleuronectes platessa*)	70	105	88	−13	5.5	Chapman and Sand (1974)
Perch (*Perca fluviatilis*)	100	30	88	−13	5.5	Wolff (1967)
Salmon (*Salmo salar*)	170	130	95	−20	2.5	Hawkins and Johnstone (1978)
Ling (*Molva molva*)	180	250	80	−5	15	Chapman (1973)

2.2.2 Behaviour in response to sound

Some species of fish can detect ship noise over long distances when the ambient levels are low (Buerkle, 1977) and where homogeneous propagation conditions exist, but they are unlikely to react unless the noise level is relatively high, typically when the distance is a few hundred metres or less. The reaction level is not a constant because physiological factors, ambient noise, and sound transmission anomalies may cause significant variations. Several investigators have observed that the presence of a survey vessel in the vicinity of fish can cause a change of behaviour in some species (e.g. Olsen, 1979; Olsen *et al*., 1983; Gerlotto and Fréon, 1992; Vabø *et al*., 2002; Skaret *et al*., 2005). Vessels emitting high levels of low-frequency noise, within the hearing frequency band of fish, have caused observable fish reactions. Diner and Massé (1987) documented avoidance behaviour by fish at distances of 300–400 m, as observed by scanning sonar. Some researchers have also observed directional movement in response to propeller noise at relatively short range. Ona and Godø (1990) observed that, "Downwards migration during propeller passage will reduce the available fish density for pelagic trawls but may increase the density available for bottom trawls, if the horizontal movement is moderate". Ona and Toresen (1988a) noted that, "Where pair trawling is used the propeller noise will act as a herding mechanism for the fish between the vessels". Dorchenkov (1986) described observations of fish driven down into the path of a trawl by a vessel. Handegard *et al*. (2003) documented responses of Atlantic cod to a trawling vessel at a distance of approximately 400 m. De Robertis and Wilson (2006) observed changes in backscatter of walleye pollock (*Theragra chalcogramma*) that are consistent with increased vessel avoidance while trawling. Several techniques were employed in these studies, including collection of acoustic data from stationary buoys, use of net sonars, and drifting over pelagic fish with the vessel in a "quiet" mode, with all machinery turned off, then restarting the machinery.

Abnormally high ambient noise levels in an area may effectively mask vessel noise or preclude fish from extracting directional information that might influence behavioural response. This confounding factor may be of particular concern in shallower waters. The propagation of sound waves may also be distorted when a thermocline or discontinuity is

present, and this may influence the manner and extent to which fish detect sound and respond. Factors such as the physiological condition of the fish (e.g. spawning and feeding states, migration) or physical environmental conditions (e.g. water temperature, prevailing light levels, including vessel lights at night) may also influence the type and magnitude of any reaction (e.g. Halldorsson, 1983; Ona and Toresen, 1988b). It should also be noted that fish may habituate to external stimuli and, therefore, behavioural responses may lessen or cease after prolonged exposure (Olsen, 1969).

Thus, it can be seen that behavioural responses to vessel noise may directly influence the acoustic assessment method and associated direct (e.g. trawl) sampling. The effects of these types of behaviours may be profound, such as causing target aggregations to disperse and become unavailable to acoustic assessment, or more subtle, such as changes in tilt angle affecting mean target strength, or size and/or species-specific effects on availability. These effects must be taken into account by researchers during the design and execution of field projects, and during the analysis and interpretation of data. For many types of research projects, they will have particular bearing on the selection of a research platform.

The SGRVN considered data obtained in limited experimental circumstances and recommended research vessel design criteria such that sound pressure levels should not exceed 30 dB above the fish hearing threshold at a range of 20 m from the vessel, and that these specifications should be achieved at a standard survey speed of 11 knots (see Figure 2.1.1). The recommendation was based on scientific, technical, and cost considerations. Although it was apparent that greater improvements were possible, they would be considerably more costly to achieve. The survey speed may be particularly important in the context of recommendations for selection of commercial vessels for fishery research applications. In some circumstances, it may only be possible to achieve acceptable radiated noise characteristics (for all scientific operations or when the weather is inclement) by reducing vessel speed. The investigator would then need to weigh the associated costs and benefits before finalizing vessel selection.

It is difficult to predict fish behaviour in response to vessel noise, and it may be necessary to take into account the sensitivity of the species and the characteristics of the physical environment. This supports a cautious approach to the selection of vessels as research platforms. *ICES Cooperative Research Report No. 209* recommendations are based on a likely reaction distance of 20 m for sensitive species, such as herring or cod. Using the same approach as was used to develop these recommendations, it can be demonstrated that this reaction distance would be 65 m for a 10-dB increase in noise level above the curve, and 200 m for a 20-dB increase. This information should be especially helpful in developing criteria for suitable research platforms.

2.3 Detection of fish by sound

The use of acoustics to observe fish and estimate abundance is well established and has been thoroughly described by many authors (e.g. Simmonds and MacLennan, 2005). The technique is useful for detecting fish of many different types and sizes and in water depths ranging from very shallow (<20 m) to deep (>100 m). The subject of acoustic scattering by fish is, in itself, quite complex, but modern scientific echosounders are highly sensitive and able to detect targets over a wide dynamic range of approximately 160 dB. Scientific and commercial fishery echosounders operate at frequencies above 10 kHz. A frequency of 38 kHz is commonly used, but multifrequency and broadband (12 kHz to >200 kHz) applications are becoming increasingly important. Any vessel noise generated at frequencies above 10 kHz has the potential to limit or degrade the fish-detection capability and acoustic-estimation processes. This vessel noise may obscure or distort the measurements of single fish echoes and add to the integral backscattered signal from fish aggregations, with the possibility of

biasing the overall population estimates. Potential detectability distances for six noise-limited vessels for targets of different sizes are presented in Figure 2.3.1 (Mitson and Knudsen, 2003).

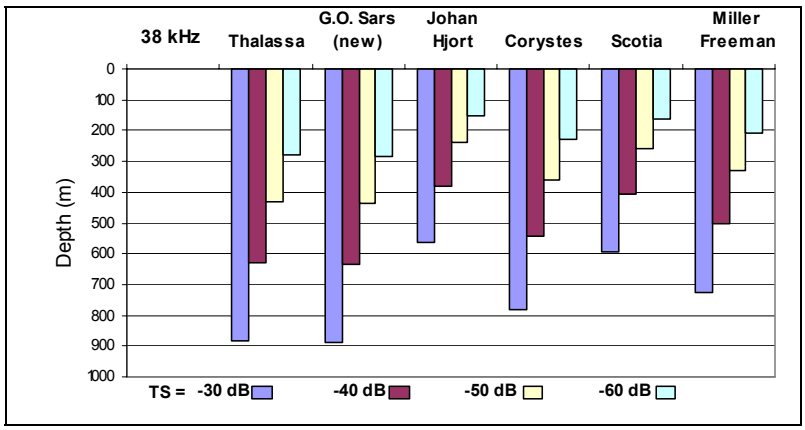

Figure 2.3.1. Potential fish-detection capability at 38 kHz of six research vessels for fish target strengths of -30, -40, -50, and -60 dB re 1 m^2 (the "new" RV "G. O. Sars" became operational in 2003).

2.4 Noise created by vessels

Fishing and research vessels radiate broadband noise over a wide range of frequencies, and we are concerned here with low-frequency emissions (up to a few kilohertz), which may directly influence fish behaviour, and higher frequencies (10 kHz and higher), which may compromise echosounder performance (see Figure 2.1.1).

2.4.1 Low-frequency noise

Evidence that fish audiograms and vessel noise have overlapping low-frequency spectra suggests that the vessel-avoidance behaviour of fish is a reaction to such noise radiated from the propeller and hull. Detailed features of the vessel noise spectrum depend on the type of machinery used, vessel speed, and propeller loading. Although propeller noise contributes to the full-frequency spectrum, the predominant variations in amplitude at low frequencies are caused by machinery. Above approximately 1 kHz, the noise is caused principally by the propeller. So, it can be stated that the significant features of the low- and high-frequency portions of a vessel's noise signature are largely independent of each other.

Broadband noise from propellers is caused by cavitation, but there may also be a significant amount of noise at the blade rate frequency and its harmonics. The principal frequency of blade rate-generated noise is:

$$f_{br} = (\text{shaft rpm} \times \text{no. of blades})/60 \text{ [Hz]}$$

Much of the machinery on a vessel produces vibration in the frequency range of a few Hertz to 1.5 kHz. This acts on the hull and causes noise to be radiated into the water. In order to minimize radiated noise in this range of frequencies, the selection, placement, and operation of these machines is particularly important. Appropriate isolation mounts should be used to reduce the levels of vibration reaching the hull.

2.4.2 High-frequency noise

Hull-mounted echosounder transducers may operate at frequencies as high as 400 kHz but, above approximately 80 kHz, the limit to fish detection is thermal noise in the sea, not vessel noise. Typical values of higher frequency noise measured on several vessels are given by Mitson and Knudsen (2003). Although noise at echosounder frequencies is mainly from

propeller cavitation and varies with vessel speed, internal salt- and freshwater pumps can also be significant sources.

Controllable-pitch propellers (CPPs) normally cavitate to some extent throughout the full set of operating conditions, with the lowest levels at maximum blade pitch. Any change of propeller shaft speed can have a significant effect on noise levels. For fixed-blade (or fixed-pitch) propellers (FPPs), cavitation may start suddenly at a critical speed or loading, typically between 9 knots and 12 knots for the type of vessel that concerns us here. Because of this, it is necessary to run at a speed below the occurrence of full cavitation. If this is not done, small changes of speed or propeller loading may cause cavitation levels to increase sharply without being recognized, resulting in a noise increase and a reduction of the fish-detection capability, which could contaminate the data.

2.4.3 Vessel design features in relation to noise

Mechanical equipment, including generators and engines, and propellers are the major sources of noise in the range of frequencies under consideration. As mentioned above, mechanical equipment is of greatest concern at frequencies below approximately 1.5 kHz and propeller noise is of greatest concern at higher frequencies. In noise-reduced vessels, considerable expense is incurred in the selection and installation of mechanical equipment to minimize low-frequency noise, and in decoupling mechanical equipment from the propeller and propeller shaft (diesel–electric propulsion). Because few research vessels and almost no commercial fishing vessels are provided with diesel–electric propulsion or vibration-reduced installation of major mechanical components, we will concentrate on propeller design and configuration in this section. From the many noise-ranging records available, it is clear that existing fishery research vessels (FRVs) built before 1988 do not meet the *ICES Cooperative Research Report No. 209* recommended levels by substantial margins. Some FRVs built more recently also fail to meet these levels, because of the unsuitable types of machinery selected for them. Some fishing vessels, therefore, may not be significantly worse than research vessels of similar size in terms of underwater noise characteristics (Figure 2.4.3.1.1). Nevertheless, when selecting a vessel for acoustic survey purposes, there are certain design features to be avoided. These are discussed below.

2.4.3.1 Propellers

Often, the most significant noise producers are variable- or controllable-pitch propellers. Changes of a few degrees in blade pitch can result in very large increases in low-frequency noise, as shown by Gjestland (1971) and also by de Haan (1992) from RV “Tridens” data. A CPP is usually driven by a diesel engine coupled to a gearbox, whose output shaft is connected to the propeller. This intermediate shaft is sometimes used to drive a generator for the ship’s electrical power supply, but such an arrangement usually results in an unstable supply owing to variable loading on the engine and reduces the flexibility of the vessel’s operation because of the need for a constant shaft speed.

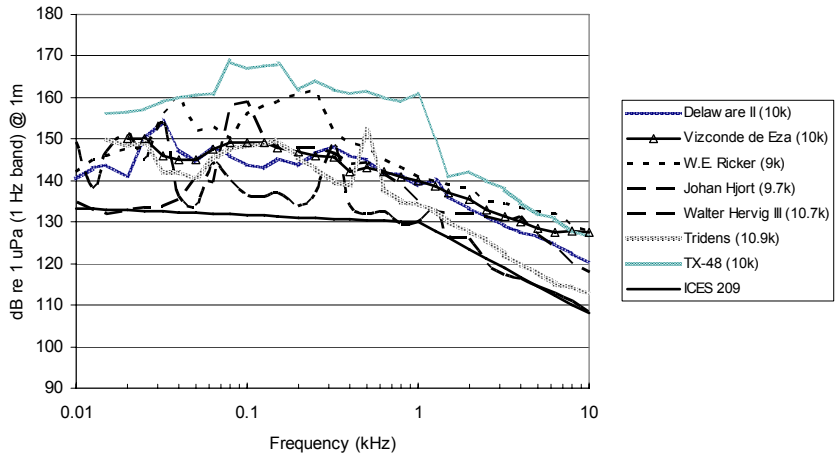

Figure 2.4.3.1.1. Noise signatures of seven vessels in comparison with the *ICES Cooperative Research Report No. 209* recommended levels. TX48 is a fishing vessel, the others are non-noise-reduced research vessels.

CPPs are therefore suboptimal for acoustic and trawl survey situations where minimization of underwater radiated noise is desirable, although they may provide a smooth speed control for the vessel. In addition, the diesel–gearbox–CPP combination requires the gearbox, which is a significant source of tonal noise, to be firmly mounted to the hull. It is also very important to understand that noise radiated from CPP vessels will not always be reduced by operating at lower speeds, although an optimal pitch/rpm setting may be possible. This can be illustrated with data from a CPP vessel, the Norwegian RV "Johan Hjort" (Figure 2.4.3.1.2). The highest radiated noise levels occur at about 20% pitch, with lowest levels being observed as the pitch approaches 100%.

It has become clear that FPPs offer the best option where low noise levels are required. As a general rule, the greater the number of blades, the lower the noise, but efficiency is also reduced, so a compromise is necessary. Most noise-reduced vessels these days have a large-diameter propeller with five highly skewed blades, while older vessels are likely to have four-bladed propellers. A vessel with a three-bladed propeller may have a fairly good propulsive efficiency but will be very noisy, because the power exerted per blade is higher, leading to greater levels of vibration and cavitation.

The six research vessels compared by Mitson and Knudsen (2003; see Figure 2.3.1) were all operating at, or close to, 11 knots. Those with the "best" propellers demonstrated the lowest high-frequency noise levels and, potentially, the best fish-detection capability. For the -30 dB target-strength class, the calculated fish-detection depths for RV "Thalassa" and the RV "G. O. Sars" are quite close to 915 m, which is the depth limit due to ambient noise caused by a 20 ms^{-1} wind. "Thalassa" has an FPP with six blades, and "G. O. Sars" has an FPP with five blades. RV "Corystes" and RV "Scotia" are also equipped with five-bladed FPPs, while RV "Johan Hjort" and RV "Miller Freeman" (both CPP vessels) are equipped with four-bladed propellers, although the "Miller Freeman" operates with a new propeller design that has highly skewed blades.

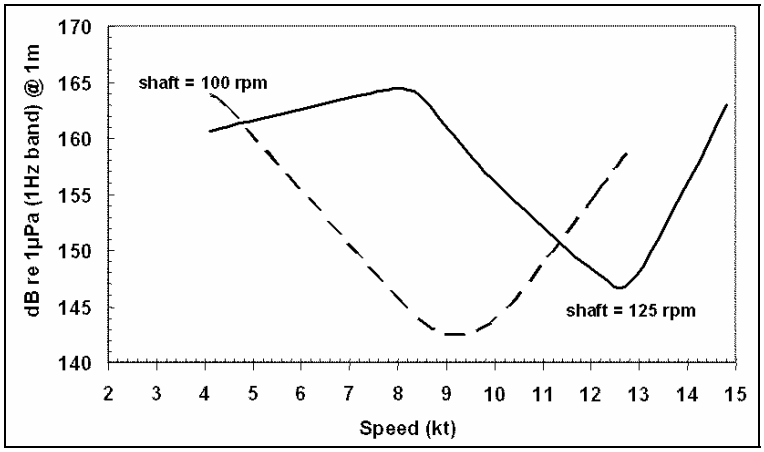

Figure 2.4.3.1.2. Noise levels (at ca. 100 Hz) at different shaft speeds and propeller pitch settings (speed) as observed for the Norwegian RV "Johan Hjort".

Propeller blades must be in good condition, because any surface, edge, or tip damage will result in increased noise being generated. Distortion of the blade shape will cause low-frequency noise and vibration. Any abrupt actions of a surveying vessel, such as a sudden change of speed, or, where CPPs are used, a sharp change in blade pitch, should be avoided wherever possible.

2.4.4 Other sources of data degradation during collection

2.4.4.1 Electrical interference

Electrical interference from on-board equipment is an additional source of high-frequency noise. This type of interference is destructive, and its source can be extremely difficult to track down, although it is often resolved by proper grounding of electrical instruments. Correct installation and screening of acoustic and other electrical equipment is extremely important (Simmonds and MacLennan, 2005).

2.4.4.2 Interference from other sounders

One of the most common problems encountered when collecting data from fishing vessels is acoustic interference from other installed echosounders and sonars. Vessels will typically have a number of acoustic systems, which normally operate independently of each other. Interference may range from being insignificant to unacceptable, depending on the characteristics of the system (e.g. frequency, bandwidth). Systems that interfere need to either be synchronized to a master echosounder or turned off when collecting survey data. This issue is discussed in more detail in Section 3.5.2.

2.4.4.3 Weather and operational considerations

Prevailing sea states resulting from wind-induced waves and swells can have significant impacts on the signals received by echosounders and sonars. Two factors combine to contribute to the degradation of the acoustic signal: vessel motion and air bubbles in the surface waters. When weather conditions are poor, hull-mounted echosounder transducers are affected by aeration and noise caused by wind-generated air bubbles and bubbles trapped beneath the hull. These bubbles pass across the active surfaces and, in so doing, decouple them from the water to a variable extent (Dalen and Løvik, 1981). Modern survey vessels are often equipped with protruding keels or keel sections. Transducers mounted in these structures can operate at depths of 2–3 m below the hull and, therefore, below the most severe bubble layer. This capability is unlikely to be available on most fishing vessels, although we are aware of one commercial vessel, the Norwegian trawler/purse-seiner FV "Libas", that is equipped with this feature (Godø, 2004; see Section 8.2.7). Hull-mounted transducer

placement may be an important factor in determining the suitability of a commercial vessel for collecting acoustic data, and the range of operating and weather conditions within which useful data can be collected.

Many scientific research vessels measure vessel motion with sensors and compensate the acoustic signal for the movement, when possible (Stanton, 1982; Dunford, 2005). The extent to which motion affects acoustic measurements depends on the sea state, swell, seagoing characteristics of the vessel, and target range. Kloser *et al*. (2000) measured vessel motion in deep water off New Zealand and found losses of up to 50% in rough conditions using Stanton's method. Relatively inexpensive pitch and roll sensors that are not affected by vessel momentum are now available, and should be used if possible when working with deep-water fish, but it should be noted that it is not possible to make reliable adjustments for large losses in signal. The solution to the problem is to avoid collecting acoustic data when there is more than a small amount of signal break-up. In general, this will occur once the wind has had a prolonged speed in excess of 10–12 ms^{-1}. Recent research has confirmed the relationship between sea state and acoustic loss (Ye and Ding, 1995; Boyer and Hampton, 2001; Hampton and Soule, 2003).

In cases where the excess sound attenuation from bubbles can be estimated (Dalen and Løvik, 1981), or when the wind force and sea state are known and recorded, correction factors can be incorporated into the biomass estimates (more accurate corrections are possible in the former case). Unfortunately, cessation of data collection in winds greater than 10–12 ms^{-1} is not always practical, given the environment and time constraints for the research. Operational limits may be increased (5–10 knots) by running transects with the wind to reduce vessel motion. However, there will come a point when even this will result is poor-quality acoustic data. It is recommended that, whenever possible, commercial fishing vessels avoid surveying in winds greater than 10 ms^{-1}.

Operating at reduced speed may be an option for surveying during poor weather conditions, but investigators are cautioned to recognize the potential for increases in radiated noise levels when propeller pitch is changed in CPP vessels to reduce speed. Nevertheless, it may be possible to adjust speed and propeller pitch to allow data collection to continue during bad weather or to allow collection of data in good weather from vessels that produce high radiated noise levels at suboptimal pitch and rpm settings.

It may be possible to deploy the transducer(s) in a towed vehicle to allow data collection during inclement weather (Kloser, 1996; Dalen *et al*., 2003). This approach is particularly attractive when attempting to assess fish aggregations at depths beyond the "normal" detection limits (see Figure 2.3.1), but costs and operational issues associated with the use of towed vehicles may be prohibitive.

2.5 Noise signatures of vessels

Almost all of the noise measurements of research vessels have been made at naval ranges, where the procedures in appendices A, B, and C of NATO STANAG 1136 (Anon., 1994) are used. The radiated noise signature of a vessel can be obtained on certain ranges within given frequency limits. These are determined at low frequencies mainly by the physical dimensions of the range and, at high frequencies, by the bandwidth of the measuring hydrophones. Third octave band measurements are normally made, then converted to a 1-Hz band. Narrowband measurements are necessary to identify any tones. Port and starboard measurements are taken separately but simultaneously and later combined to give an average result. Keel aspect measurements are needed, but are not combined with other aspects and, currently, are only used for reference purposes.

If weather and oceanographic conditions are favourable, it may be possible to use a portable noise range system such as that described by Enoch and McGowan (1997). A more recent

version is the Transportable Overside Noise Evaluation System described by Griffiths *et al.* (2001).

2.6 Summary and recommendations

2.6.1 General considerations

- Radiated vessel noise is a serious concern, and failure to recognize the consequences of fish behaviour in relation to vessel noise may compromise research results.
- Sensitivity of fish to sound is influenced by morphological and physiological factors. Less-sensitive species may be less susceptible to radiated noise than sensitive species. The prospective researcher is cautioned to review the literature relating to the species of interest.
- Sound intensity attenuates by distance (square of the distance, as a rule of thumb) and even the most sensitive species may not demonstrate behavioural responses to high levels of radiated noise at distances greater than 200 m.

2.6.2 Criteria for selecting vessels

- Noise-reduced vessels are preferred but generally unavailable in the fishing fleet. In these types of vessels, the diesel engines are double isolated from the hull, and a DC propulsion motor drives a large-diameter fixed-pitch (usually five-bladed) propeller. With such a specification, the distance for avoidance behaviour by sensitive fish species should be approximately 15–30 m.
- Vessels with propulsion systems consisting of diesel generators that are isolated from the hull and supply AC current to an AC electric motor driving a fixed-pitch propeller are generally quieter than direct-drive, variable-pitch propelled vessels, but radiated tonal noise may still be problematic. Avoidance behaviour by sensitive fish species may occur at ranges between 100 m and 200 m.
- Vessels with propulsion systems consisting of diesel engines that are bolted to the hull and gearboxes that drive controllable-pitch propellers are generally the noisiest and may disturb sensitive fish species at distances >200 m, although careful selection of propeller pitch may mitigate radiated noise to a limited extent.
- Fixed-pitch propellers (with four or more blades) are highly recommended, especially for assessment of sensitive species at close range. Controllable-pitch propellers should be avoided if at all possible owing to the high levels and variability of the radiated noise they produce, particularly transients.
- When only controllable-pitch propellers are available, selection of optimal propeller pitch and engine rpm combinations is essential. This is difficult to accomplish without noise ranging tests, although self-noise testing (see next recommendation) will be extremely useful.
- The seagoing qualities of vessels should be considered when selecting commercial vessels for scientific purposes. Vessels known to force aerated bow waves under and along the hull during bad weather and at normal cruising speeds should be avoided.

2.6.3 Other recommendations

- Vessel self-noise tests are highly recommended and easy to conduct, if the noise measurement facility built into the echosounders is used.
- Propeller blades should be in good condition to minimize cavitation and generation of associated noise.
- Noise ranging is highly recommended.
- Documentation of noise signatures would assist in the selection process of vessels suitable for acoustic surveys. A vessel whose signature is closest to the *ICES Cooperative Research Report No. 209* recommended levels and does not exceed them by more than 20 dB at frequencies up to 1 kHz would be preferred. A minimal and low-level tonal content is desirable.

- It is essential to ensure there is no electrical interference that will affect the survey echosounders and that the electrical supply is stable in voltage and frequency.
- Potential sources of interference by other on-board acoustic systems should be identified. In many cases, interfering sounders will need to be either synchronized with the survey sounder or turned off when collecting survey data.

3 Instrumentation

Gavin Macaulay

Atle Totland and Olav Rune Godø

3.1 Introduction

In this section, we discuss the types of acoustic systems that can be installed on fishing vessels, and the use to which they can be put in support of scientific surveys of fish populations. We also discuss the range of non-acoustic sensors that may be installed on fishing vessels, the types of data available from them, and the value of collecting such data. Methods of installing echosounder systems onto vessels are also discussed, as are methods for ensuring appropriate operation of the echosounder systems.

Calibrated echosounders form the basis of standard scientific acoustic surveys, and some modern commercial echosounder systems are equipped with the features required for scientific surveys.

It is important that the purpose of the survey and data-quality requirements are well defined beforehand, so as to secure a proper relationship between the technology investments and quality needed to address the research objectives.

Table 3.1.1 summarizes the factors involved in such an evaluation. When the task is to support a pilot trawl survey, the demand for quality acoustic information is low. If the focus is on correct biomass distribution and/or distribution patterns, the system must provide comparable density estimates throughout the covered area. This demands at least a stable performing system. This topic is discussed in greater detail in Section 1.

It is important to keep in mind that the simplest system may support the collection of important new information. For example, systematic evaluation of echograms for density and vertical distribution may, over time, represent an important source of information (e.g. the data can be used to compare catch rates and acoustic densities). However, even for these types of objectives, stable performance of electronic components is necessary.

In situations where a vessel's echosounders may not be suitable for collection of scientific data, the vessel's hull-mounted transducer(s) may be suitable, and it may be possible to connect them to portable electronic equipment that is capable of providing data appropriate for addressing research objectives.

Table 3.1.1. Relationship between research objectives and instrument quality (minimum requirements are indicated).

	Instrument quality		
	Unstable, uncalibrated	Stable, uncalibrated	Stable, calibrated
Scouting surveys	*X*		
Distribution estimation	*X*	*X*	
Distribution estimation with improved comparability over time		*X*	
Abundance estimation			*X*

3.2 Acoustic data

This section discusses the range of acoustic instruments that can be found (or may be installed) on commercial vessels.

3.2.1 Conventional echosounders

Conventional echosounders are used on almost all fishing vessels. Generally, they generally serve as depth sounders, as well as tools to detect fish.

Although there are no established standards for scientific acoustic hardware, amplitude stability and digitization of the received signal early in the processing are particularly important because they provide greater flexibility and overall stability of performance (Simmonds and MacLennan, 2005). Stable transducer performance is also important; this is achieved in all modern scientific-quality transducers and in many of the commercial-grade transducers available today. This stability allows the system to be calibrated or standardized so that quantitative observations are repeatable within acceptable error bounds. Stable performances of the system's transmitting and receiving components are also considerably important. Modern scientific and commercial acoustic systems generally demonstrate such stability, but it is important to bear in mind that a system that functions very well as a fishing tool to locate and observe fish or fish schools, may be completely inadequate as an analytical tool. This is because it is generally not possible to detect slight system-related inconsistencies that could have serious effects on the measurement of acoustic backscatter (i.e. signal return), which is used to estimate fish biomass. Small differences in system performance can result in large differences in biomass estimation. Nevertheless, most concerns regarding stability and performance can be addressed through careful and frequent calibration (see below). Until recently, many commercial echosounders did not provide a mechanism to extract and save the data required for subsequent analysis. The ability of commercial echosounders to log acoustic data in digital form greatly facilitates the increased use of commercial vessels for scientific purposes.

Commercial fishing transducers are available in many frequencies. The most commonly used frequency for scientific surveying is 38 kHz, but frequencies ranging from 12 kHz to 200 kHz are often used independently and in conjunction with 38 kHz. Split-beam transducers are generally found on research vessels and increasingly on commercial vessels. These are recommended for quantitative scientific work because they make it possible to position a target within the acoustic beam, which greatly facilitates calibration and estimation of the target strength of individual fish by accounting for the confounding effect of the angular variation in sensitivity of the acoustic beam (Ehrenberg, 1979).

For several years, multifrequency acoustic systems have been available for scientific purposes. Some commercial vessels are now equipped with multiple frequency systems that may provide data that can assist in species identification. The information from multifrequency systems can be very useful, particularly if the transducers are mounted with acoustic axes close enough to make pixel values comparable (Korneliussen and Ona, 2003a).

As with most scientific applications, there is no single system, frequency, or beam angle that suits all purposes. Selection of the appropriate frequency will depend upon a number of factors, including the target species, its depth range, size composition, and spatial distribution.

3.2.2 Sonars and multibeam echosounders

Sonar has been used as a major searching tool by pelagic fishing fleets since the 1960s. Over the years, the fishing skippers have acquired experience and competence in the operation of sonars and judgement of sonar recordings. The economic success of a fisher with high competence in sonar operation and interpretation is the best illustration of the importance of this equipment. However, sonar data have rarely been used quantitatively for resource evaluation. Conventional fishing vessel sonars are difficult to calibrate, and so abundance estimation is difficult; data recording can also be difficult. However, abundance can be estimated by comparing sonar recordings of schools and size of the purse-seine catches, when the whole school has been caught (e.g. the fisher's way of getting experience). Further, when

echo integration data from conventional echosounders are available, the school dimensions can be correlated with echo abundance when crossing the school. Data that can be collected during fishing vessel sonar studies include school height, school width, speed and direction of schools, and seine catch. Echo integration from conventional echosounders can supply additional support (Misund, 1997).

Fishery scientists began using multibeam echosounders (sonars) in the 1990s (Melvin *et al.,* 2003). These systems were designed to collect bathymetric data over an area wider than is possible with conventional downwards-looking echosounders; they are sometimes called "swathe" systems. Most multibeam systems are designed for mapping the seabed, but have a limited dynamic range and poor low-amplitude echo measurement accuracy. They are a poor choice for acoustic work that requires accurate measurement of relatively low-amplitude echoes (as is required for echo integration). They can, however, provide useful spatial and temporal information on aggregation size and distribution in a manner similar to sonar systems.

More recent multibeam systems do have the dynamic range and amplitude accuracy necessary for backscatter measurement, and some of these systems are available on commercial fishing vessels. Note, however, that the calibration of a multibeam system is a significant undertaking (Foote *et al.*, 2005).

3.2.3 Acoustic Doppler current profilers

Acoustic Doppler current profilers (ADCPs; Doppler logs) are often available on board modern fishing vessels. These systems measure vessel speed and/or current velocity (Section 3.3.4) and may provide important ancillary information to assist in the interpretation of information on fish distribution. For example, they can be used for the standardization of towing direction in relation to the main current (at a particular depth). Data from advanced ADCPs may be useful in the evaluation of the direction and speed of fish migration relative to water masses.

3.2.4 Calibration

The calibration of an acoustic system is a fundamental prerequisite to the quantitative use of acoustic data. Although it is possible to calibrate analogue systems and/or systems that do not provide a digital data output, procedures are complex and not applicable to acoustic systems installed on fishing vessels. Acoustic systems should be calibrated on a regular basis. In order to verify that a system is performing in a stable manner, calibrations should be conducted before and after each survey (and at intermediate stages during long surveys). At a minimum, the system should be calibrated immediately before the start of each survey. Regular calibrations also help detect problems in the system. Calibration procedures are well described in Foote *et al.* (1987), and have been updated by Simmonds and MacLennan (2005). These procedures are summarized in Section 4.2.1.

3.3 Other types of data

Commercial vessels are often equipped with non-acoustic instruments that can provide additional data during a survey. This section discusses such instruments and their uses. The relative importance of various non-echosounder sensors to the type of survey being undertaken is summarized in Table 3.3.1.

Table 3.3.1. The relative importance of collecting ancillary data under differing survey objectives.

	GEOGRAPHIC LOCATION	VESSEL MOTION	METEOROLOGICAL	OCEANOGRAPHIC	SYNCHRONIZATION (TIME, EQUIPMENT)
Scouting surveys	Required	Not necessary	Not necessary	Not necessary	Required
Distribution assessment	Required	Advantageous	Advantageous	May be necessary	Required
Quantitative abundance estimation	Required	May be necessary	Advantageous	May be necessary	Required

3.3.1 Location

To facilitate quantitative or qualitative analysis of acoustic data, observations must be spatially explicit. Although several different systems have been used over the years to provide geographic information, GPS (global positioning system) receivers now dominate the market for positioning data collection. All scientific-quality fishery acoustic systems and most commercial-quality systems are now designed to interface with GPS receivers and include spatial information in the data stream. The GPS system has the following features and advantages:

- GPS receivers are inexpensive.
- The position accuracy is very high (down to a few metres). In many areas around the world, differential correction signals are available to increase the position accuracy further, calculated from the satellite signals (this is known as DGPS).
- GPS has global coverage.
- The GPS receiver calculates and outputs vessel-log and speed-over-ground information, commonly used during echo integration. Few other positioning systems have the accuracy and reliability needed to produce such information.
- The GPS receiver outputs time telegrams with accuracy high enough for most practical applications within fishery acoustics.
- The data output format from most GPS receiver is standardized (NMEA). This makes integration with other instruments easy (e.g. echosounders).

For unmanned and remotely operated acoustic data-logging systems on board commercial vessels, GPS-derived location information may also be used to trigger the data-logging system to start/stop collecting data when the vessel moves into or out of an area.

3.3.2 Transducer motion

Transducer motion can degrade the quality of the acoustic signal, sometimes to a substantial degree. Because vessel-mounted transducers will be used in almost all applications involving fishing vessels, vessel motion and transducer motion can be considered synonymous for the purposes of this discussion. Sea state, weather, and vessel operations can all cause transducer motion. Degradation of the acoustic signal results from a decrease in received signal amplitude caused by changes in the transducer's alignment caused by angular motion. Angular motion can be determined with the use of inexpensive magnetometers or bubble units, or with more expensive and accurate accelerometre- and gyroscope-based devices (motion reference units or MRUs). In practice, these types of device are unlikely to be found on fishing vessels, and the reader is advised to exercise judgement, based on the extent of the apparent signal degradation that can be perceived from the echograms. Signal degradation can often be mitigated by slowing down or changing direction, but collection of data for quantitative purposes is precluded when motion becomes too great and/or air blocking from bubbles becomes problematic (see Sections 2 and 4). Excessive heave may also be problematic, because range to the bottom may change between successive pings. In the event that an MRU

is available, heave measurements can be delivered directly to some echosounders, and range can be corrected automatically.

3.3.3 Vessel course and heading

The importance of course over ground (COG) and heading information should be recognized. Course over ground is provided by all GPS units and heading by gyrocompass units, and in most cases, they are very similar. At low vessel speeds or in high wind or current conditions, however, they can differ significantly. In most situations, course over ground from a GPS receiver is more useful than vessel heading.

3.3.4 Vessel speed

Speed information is usually obtained from a traditional log counter (water flow, impeller), an acoustic Doppler log (working under the same principles as an ADCP), or a GPS receiver. Log counters output speed through water, while Doppler logs and GPS receivers measure speed over ground. Speed over ground information is useful for echo integration and echo counting, while speed through the water is more useful during fishing operations *per se*. In general, use of GPS-based speed information is recommended.

3.3.5 Meteorological observations

Meteorological data are often collected by "weather stations". These instruments are equipped with a range of different sensors, and data of interest include windspeed and direction, and possibly light intensity.

The windspeed and direction may affect acoustic data collection in a number of ways. The impact of greatest concern during fishery acoustics surveys is the injection of air bubbles into the near-surface water. This reduces the amplitude of received echoes and directly affects echo integration and target-strength data. Techniques to measure and correct for this extra absorption are available (Dalen and Løvik, 1981; Novarini and Bruno, 1982; Bruno and Novarini, 1983), and require estimates of the windspeed and direction. Increasing windspeed also leads to larger waves and hence increasing vessel movement, which can also affect the amplitude of the acoustic echoes (see Section 3.3.2).

Note that the vessel speed and heading have to be input to the meteorological system to obtain true windspeed and direction measurement.

For many fish species, distribution and behaviour are influenced by the light intensity. To interpret acoustic fish data correctly, it may be necessary to consider light conditions. Measuring light intensity at night can be troublesome because of the influence of deck lights and confounding consequences of light reflection from falling rain or snow. For daytime observations, light intensity can be estimated by determining the elevation of the sun, based on geographic position and time.

3.3.6 Oceanographic observations

The oceanographic properties of water masses play a vital role for all aquatic creatures. They influence the species composition, distribution, and behaviour, as well as sound propagation. Correct interpretation of acoustic data requires knowledge of relevant oceanographic processes. Common measurements include water temperature, salinity (via conductivity), oxygen, and fluorescence at a range of depths. Water temperature and conductivity are commonly collected with a CTD (conductivity, temperature, depth) probe, which can be lowered vertically to obtain a profile at a range of depths. It is also possible to use self-contained CTDs attached to the fishing gear; this is an inexpensive way of obtaining CTD data with little impact on normal fishing operations.

Commercial fishing operations often use sensors to obtain data on the performance of the gear (see section 3.3.7 below). Some of these systems record oceanographic data, such as water temperature at depth. Usually, the sensors are built to tolerate the rough treatment that can occur during fishing operations, and they tend to be less accurate compared with scientific-quality equipment. For scientific purposes, higher quality instruments can be mounted inside a protective cage, then attached to the fishing gear.

On many surveys, surface temperature is of interest, and it is often possible to obtain water-temperature measurements from recordings taken of the engine seawater intake as part of the routine engine monitoring carried out by the vessel. Alternatively, a scientific-quality water-temperature measuring device can be supplied with water from an engine-cooling-water intake.

Estimates of sound speed and acoustic absorption are important for longer range acoustic surveys, and also for correcting sonar data for the effects of water stratification. The requisite data can be derived from CTD data, or dedicated sound speed probes can be deployed. This is an important reason for taking such measurements regularly throughout the depth range over which data are being collected.

3.3.7 Direct sampling with commercial gear

Many commercial vessels have extensive equipment for measuring the performance of the fishing gear. The particulars of this equipment vary widely among vessels and fishing gear types, but in general, they can often provide useful information to support acoustic surveys. For example, trawlers often have an echosounder fixed to the headline of the net to monitor fish going into the net, and sensors to measure the distance between the trawl doors, water temperature, depth, groundrope bottom contact, and codend fullness. If considered to be useful, a procedure for recording these data should be put in place. Further discussion of fishing gear and biological sampling can be found in Section 5.

3.4 Using scientific acoustic transducers

3.4.1 Fishing vessel transducers

Transducers already installed on a vessel may be suitable for scientific data collection. Researchers should pay careful attention to the specifications and compatibility with the transceivers that will be used. Important items to consider include beam width, operating frequency, maximum allowable transmit power, and transducer impedance. As mentioned elsewhere, split-beam transducers are easier to calibrate and can be used to collect data for measurement of target-strength data and target tracking.

Transducer stability is of critical importance, and researchers are encouraged to follow system calibration recommendations to ensure that transducers and other critical components are performing consistently during surveys.

3.4.2 Towed vehicles

Towed bodies (or towed vehicles) have been used by many investigators to deploy transducers. Such systems may offer practical and efficient mobile installations, particularly when surveys are carried out routinely from various vessels. The transducer is towed behind or off the side of the vessel and is partially isolated from excessive vessel noise. Because towed vehicles must be deployed at some depth below the surface to ensure stability, it will only be possible to sample the upper layers with an upwards-oriented transducer. However, it may be advantageous to deploy a towed body at depth to improve the ability to detect deep-water species (Dalen and Bodholt, 1991; Dalen *et al.*, 2003). Towed bodies are expensive,

however, and often require expensive and difficult to install cable and winch systems, so they would not normally be deployed from fishing vessels.

3.4.3 Pole mounts

Pole-mounted transducers can be used on vessels of various sizes and generally involve a pole affixed to the side of the hull that can be rotated through 90 degrees to place the transducer either in or out of the water. The pole should extend to below the deepest part of the hull, and for large vessels this can result in poles of 10 m or more in length and correspondingly large support brackets. Owing to the heavy forces on such systems at high speed and in bad weather, this solution is most feasible for smaller craft operating under reasonable weather conditions. However, an advantage is that the system can be made portable and moved from vessel to vessel. Also, the system can be operated during other activities such as trawling and plankton sampling. The use of pole-mounted transducers may be of concern if they restrict the vessel speed, and excessive stress on the pole may be problematic in bad weather.

3.4.4 Hull and blister mounts

Hull-mounted transducers are generally preferred for most applications. However, researchers are encouraged to pay attention to their location and the potential for degradation of performance during bad weather (see earlier in this section, and Section 2). If a commercial vessel is to be used in many studies over an extensive time, it may be worthwhile considering upgrading and/or supplementing the vessel's hull-mounted transducers to support multifrequency and/or split-beam data collection.

3.4.5 Extended keel mounts

Hull mounts and pole mounts are normally susceptible to vessel- and wave-generated bubbles in the surface layers, and structures that place the transducers deeper greatly improve the quality of the acoustic data. Many research vessels now operate sensors mounted on a keel that can be lowered 2–4 m below the lowest part of the hull. Ideally, the keel can be retracted above water level within the vessel and thus facilitate access to the transducers. Keels of this type are normally not available on commercial fishing vessels.

3.4.6 Through-hull transmission

In small boats constructed of fibreglass, transmission of the acoustic signals through the hull is possible. This is not recommended in general because of the degradation of the signal. Most fishing vessels are equipped with transducers inserted into the hull, and the use of these types of installations is recommended whenever possible.

3.5 Integration of equipment

When commercial vessels are used for fishery acoustic surveys, additional equipment is often brought on board, and in many cases must be integrated with existing on-board equipment. During the planning of a survey, it is useful to map the existing equipment on board, including the input and output data formats and physical locations. Cables with correct plugs should be available during vessel mobilization, and it may be necessary to modify software to handle new data formats. In general, equipment integration benefits from careful planning and involvement of the technical staff, who normally maintain the equipment. In some situations, it may be easier to bring along separate equipment rather than try to use and integrate with existing equipment on the vessel (such as a GPS receiver).

Some important aspects of equipment integration are discussed below.

3.5.1 Log counter

Some acoustic systems require log pulses from the vessel's traditional log counter unit to perform echo integration, although most modern echo integration systems can now derive such data from a GPS receiver; this approach is generally recommended.

3.5.2 Acoustic system synchronization

The commercial vessel might have acoustic instruments (Doppler log, sonar, echosounder), which can interfere with the survey equipment, unless the systems are synchronized or the ship's equipment is turned off. External triggering, and thus synchronizing different types of equipment is often problematic owing to inconsistencies in trigger pulse specifications. Some acoustic equipment cannot be externally triggered and must be turned off if interference occurs.

In general, one of the acoustic instruments provides the master trigger, with the other instruments configured in slave mode. If a trigger delay or specific trigger pulse characteristics are required, it may be necessary to build a customized electronic interface. Researchers are advised to evaluate and address acoustic system synchronization requirements well in advance of the planned start of a survey.

3.5.3 Time synchronization

Data from a number of different sources are collected during a survey. It is critical that all data collected from the instruments aboard the survey vessel (or vessels, if multiple vessels are involved) maintain a common time reference for collection and recording of data.

It may be most practical to use universal time coordinated (UTC) time as the reference, because it is global and not influenced by local conditions (geographic location, summer time adjustments, etc.). A GPS receiver is capable of providing UTC time data with accuracy sufficiently high for most applications, and software is available that can automatically synchronize computers and other instruments to the GPS time code. Instruments that only provide manual setting of the time should be checked regularly and corrected throughout a survey. Note that the time kept by standard desktop and laptop computers is often of poor accuracy and can drift by several seconds per day. It is thus generally unsuitable for time stamping events.

It is essential that the same time reference is used for all activities aboard the vessel. This applies to vessel operation, biological sampling, and data logging from acoustic and other instruments.

3.5.4 Event logging

All events that may influence the performance of the equipment or affect data interpretation must be recorded, and a system for collecting and storing these data should be established. Events of interest include fishing operations, changes in instrument settings (including turning off and on), and vessel operation events, such as alteration of speed or propeller pitch, which can introduce noise into the acoustic data. Modern acoustic data-collection software generally includes features for logging ancillary data, which may be provided through direct connection with other instruments or computers, or by manually entering text.

3.6 Remote operations

In some countries, fishing vessels are being equipped with satellite-based broadband continuous Internet access. This capability is likely to become more widespread in the near future as communications technology improves and costs are reduced. Remote access to and operation of acoustic systems through the Internet may support advanced operations and

problem-solving, when using fishing vessels to collect acoustic data. More importantly, however, this capability will allow near real-time access to acoustic data collected during normal fish searching and catching operations by shore-based scientists.

Shipboard computer networks can now be controlled remotely from any location via the Internet. Near real-time displays of data from sonars can be displayed remotely, and data management and instrument control functions can be supported. Ancillary data such as catch information and weather conditions can also be communicated. Less sophisticated, remotely controlled systems can be facilitated through communication by cell phone or conventional radio.

3.7 Recommendations

- Calibration of acoustic systems is required for quantitative use of acoustic data and is recommended for all applications.
- Known and appropriate echosounder settings are of particular importance (e.g. transmit power, pulse length, frequency).
- A procedure should be put in place to record and check periodically that the equipment settings are as required.
- GPS (global positioning system) data should always be collected and properly interfaced with the acoustic instruments.
- The need to collect ancillary data depends to a great degree on the intended use of the acoustic data, and it is difficult to provide general recommendations in this regard.
- When appropriate, ping synchronization of acoustic systems and time synchronization of all instruments should be implemented.

Note regarding instrument and software manufacturers

Government research institutions may be reluctant to recommend manufacturer's products. The reader is encouraged to review information on specific research studies presented in Section 8 and to consider information provided by the manufacturers. See Annex 2 for contact information about hardware and software manufacturers.

4 Data collection and management

Gary Melvin and Tim Ryan

4.1 Introduction

Advances in technology have rapidly increased the possibilities for recording digitized acoustic signals from commercial fishing vessels. Stable and reliable electronics, inexpensive data storage, and the use of microcomputer platforms with commonly understood operating systems have minimized the need for at-sea electronics and computing specialists, enabling acoustic data to be collected easily and, in many cases, autonomously.

The key challenges for researchers working with commercial vessels are to:

- Ensure that the data are collected in an appropriate manner according to the survey protocols, especially when limited or no at-sea supervision is provided;
- Ensure that data quality and quantity are adequate to meet the survey objectives;
- Establish good working relationships with the vessel's officers, crew, and owners (see Section 7);
- Convert the data into useful information (see Section 6).

A range of data products can be acquired (or developed) from acoustic systems operated on board commercial vessels. These include:

- Bathymetry
- Acoustic indices of seabed roughness and hardness
- Presence/absence of schools
- Spatial and temporal distribution of schools
- School metrics (e.g. interpreted species composition, school height, intensity, length, and shape)
- Information on fish response to survey and/or fishing vessels
- Information on fish distribution and/or distribution of fishing effort
- Quantitative echo integration biomass estimates.

In this section, we discuss some of the common observations, drawbacks, and solutions associated with the collection and management of acoustic data from commercial fishing vessels. We emphasize the most exacting of the above-mentioned data products, the provision of biomass estimates based on echo integration. It is often necessary to understand the requirements for high-quality data collection in order to assess the utility of suboptimal or poor-quality datasets. Although not all datasets will be suitable for echo integration, most can still provide useful information. Many of the topics presented in this section are also discussed elsewhere in this report.

4.2 Data collection and management

Although recording of high-quality acoustic data has become more straightforward, it is important that the data collection is guided by a written survey plan that has clearly defined and well-communicated objectives. Such a plan will provide the framework in which all decisions can be made (e.g. survey settings to use, data types to record, when to record data, which vessel to assign tasks to), as well as providing the basis of discussion when engaging with industry.

The data collection carried out according to specified survey settings and protocols is essential to the success of any field programme. The subsequent management of survey data is also of fundamental importance. For programmes that involve multiple fishing vessels over extended

periods, data management may be particularly demanding. Unless clear and agreed-upon procedures are in place, there will be a tendency for data to be improperly collected, accidentally erased, or misplaced.

4.2.1 Calibration

Echosounder calibration is fundamental to the quantitative use of acoustic data from any system. It should be performed either on a regular basis or just before, during, or shortly after a survey. Regular calibration also helps to detect instrument malfunctions. The standard calibration procedure, which is well described in Foote *et al.* (1987), involves the suspension of a sphere with known acoustic properties in the acoustic beam beneath the vessel. Positioning of the reference target in the acoustic beam is easier with a split-beam system. Knowledge of the transducer's position on the hull will speed up the process, although most transducers can be located with a bit of searching. A complete calibration can be expected to take 6–8 hours, but it may take longer if multiple transducers and frequencies are involved.

Ideally, calibration is carried out at a sheltered location, and the water should be deep enough to allow the calibration sphere to be suspended in the far field of the transducer. Simmonds and MacLennan (2005) provide guidance on estimating the nearfield zone of a transducer, as well as recommendations for optimal ranges for conducting calibrations. Working close to the transducer makes it difficult to locate the calibration sphere within the beam, and typically, calibration should be carried out with at least 15 m between the transducer and the sphere. In their discussion of the TVG (time varied gain) function in the calibration section of their book, Simmonds and MacLennan (2005) point out that "as most scientific echosounders now implement the TVG by digital signal processing, the TVG error should be negligible, provided that the function has been programmed correctly"" They also note, however, that some manufacturers have not properly taken into account transmitted pulse length and receiver bandwidth when implementing the TVG function, and advise consultation with instrument manufacturers in instances where the form of the function may be in question.

To derive measures of absolute fish density from acoustic data, the equivalent beam angle of the transducer must be known (usually supplied by the transducer manufacturer) or established by measuring the return signal strength from the calibration sphere at various locations within the transducer beam, while accurately measuring the physical location of the sphere (Reynisson, 1990).

One advantage to using commercial fishing vessels as scientific platforms to collect quantitative acoustic data is the possibility of employing several boats to broaden temporal and/or spatial coverage. Ideally, an intervessel calibration (intercalibration) for all vessels involved in the survey should be performed to determine the variability among vessels. Procedures for intervessel calibration are described by several authors (Monstad *et al*., 1992; Wyeth *et al*., 2000; Mason and Schaner, 2001; Simmonds and MacLennan, 2005). Unfortunately, unless the vessels are under charter/contract and time has been allocated to perform an intervessel calibration (expensive if several vessels involved), it may be impractical to coordinate such a study. In this case, the assumption must be made that the results are comparable between vessels (and the implications of this assumption should be considered carefully). An indication of how the data differ among vessels can be seen by examining instances when the vessel tracks cross, overlap, or are in close proximity.

4.2.2 Data collection in an industry setting

The type of acoustic data collected will depend upon the purpose of the project, the survey design (*ad hoc* or structured), and how the data are to be analysed. The logging or recording of acoustic data from commercial fishing vessels can be divided into two broad categories: the physical recording of observations on written forms and the digital recording of data onto storage media.

4.2.2.1 Written recording of observations

Although written recording is now uncommon, it warrants mention because data forms continue to be used to document the occurrence and distribution of fish species from echosounder observations. Observations from acoustic equipment, such as an echosounder or sonar, may be recorded along with time, date, and location, and analysed qualitatively to provide information on the distribution and relative abundance of the target species. Fish targets were often categorized from echograms into type, subjectively scaled to a relative abundance index (e.g. light, moderate, or heavy), and their spatial distribution plotted. Examples of this approach include early surveys of Pacific herring and current surveys in Chile and Peru (Peña, Section 8.2.6; Gutiérrez *et al*., 2000).

4.2.2.2 Digital data recording

A number of commercial fishing echosounders currently on the market can collect acoustic data in several formats. Even systems that were not designed to output acoustic data can be adapted or modified to support this requirement; however, this requires specialized electronics knowledge and should only be undertaken by a qualified person. Acoustic systems are generally equipped to interface with, and possibly store, navigational (GPS) data streams, as well as capture ancillary data from other digital sensors.

4.2.2.3 Data output options and considerations

Echosounder systems that can record data will be able to output some, and possibly all, of the following data types:

- Data at full-sample resolution, recorded at a power level;
- Phase information at full-sample resolution (split-beam systems only);
- Data at full-sample resolution converted to S_v (volume backscattering strength; dB re 1 m^{-1}) or target-strength values;
- Single target detections;
- Full-sample data converted to a summary format with a limited (possibly user-defined) number of samples per ping;
- Bottom detection values.

The researcher should consider which of the possible data types should be recorded. Ideally, data should be recorded in a format that is as "raw" as possible (i.e. at full-sample resolution over the entire dynamic range of the system, with key system-setting parameters included with the record for each ping). Recording at full-sample resolution will generate a large quantity of data but, with the low cost of storage media, this is becoming less of a problem. Data volumes may be reduced by recording at a lower resolution and/or with minimum detection thresholds. It may also be advisable to record multiple data output formats in parallel. For example, full-sample data may be recorded as a minimum requirement, but lower-resolution data could also be recorded both for redundancy and to take advantage of the lower data volume, and allow quick review of the echograms.

4.2.3 Data quality

Data collected during a survey should meet or exceed the quality level demanded by the survey objectives. For example, a survey objective to observe the presence/absence of fish schools would require less exacting data quality than an objective to quantify biomass using the echo-integration method. Poor data quality can increase post-processing time greatly and may even result in failure to meet project objectives.

Factors affecting the quality of an acoustic signal during logging fall into three general categories: vessel noise, interference (electrical or acoustic), and sea state. These factors are discussed in Section 2.4.

4.2.3.1 Assessing and improving data quality

Unlike studies using research vessels, which are typically in service with one institute over a number of years, scientific programmes using commercial vessels are likely to have a far greater turnover of participating vessels. Hence, it remains necessary to evaluate the data quality and suitability of commercial vessels when they first enter into a research. A suggested evaluation cycle would be to request that the prospective vessel collect some example data, preferably in similar situations to those expected when on survey (e.g. depth, sea state). The quality of the sample data can then be assessed with regard to vessel noise, mechanical or electrical interference, and vulnerability to sea-state effects. Any problems can be communicated back to the vessel and options for elimination or improvement discussed. The cycle can be repeated to refine the data quality further. It must be noted that some vessels will have multiple factors that affect data quality, which may not be easily remedied, so they may never be suitable for scientific research (e.g. poor transducer placement, hull design, noisy electrics).

4.2.4 Survey settings

The correct setting of echosounder parameters is a basic requirement for most studies. It is essential, therefore, that the echosounder system is understood well and that the effect of any of its settings on the recorded data is known. From the researcher's perspective, echosounder settings can be grouped into two categories: (i) those that affect only the echogram display, and (ii) those that affect the data saved to the logging files (and possibly the echogram display as well). This distinction is important because the skipper will normally alter the echosounder settings to optimize the display to maximize fishing efficiency. The researcher should discuss this with the skipper, making it clear which settings affect only the display and which settings might compromise the collected data. The echosounder will have been calibrated for a particular set of transceiver settings (pulse length, power, and gain), and these same settings should be used when collecting data. In many cases, it is possible to satisfy the needs of both the skipper and the data-collection software.

Most echosounders have options for several power outputs, and standard operating procedure is to set the power level to maximum. Output settings typically range from 0.5 kW to 2.0 kW, although there are exceptions. A recent Simrad news bulletin (Simrad, 2002) reports a non-linear effect caused by harmonic distortion at certain power settings. This effect is not unique to Simrad systems. The company found that 38-kHz and 70-kHz systems can operate at powers of 2.0 and 1.0 kW, respectively, without distortion, but power levels for 120-kHz and 200-kHz systems must be reduced to 0.5 kW and 0.1 kW, respectively, to maintain stable performance. Hampton and Soule (2003) note that some Simrad ES60 systems are delivered with 4.0-kW transmitters, but operating these systems at maximum power can cause cavitation. Care must be taken, therefore, to use the optimal power setting. If in doubt, the manufacturer should be consulted.

4.2.5 When to log data

Storage of digital data can be problematic because raw data files may be quite large, especially if multifrequency information is collected. The researcher should consider carefully the trade-offs between quantity of data stored (and associated data-management, archiving, and processing issues), and the ability to meet research objectives. Logging data only during defined sampling periods will save storage space at the risk of missing off-survey observations that may be of scientific interest. Furthermore, instructions to the skipper for turning data

logging on and off may not always be followed. During the initial phase of a project, it is advised that the systems be turned on for the duration of the trip. Once the programme has been operational for some time, it may be possible to develop some simple rules specifying when data logging should occur and to work with the skipper to ensure these rules are followed. A log (paper or electronic) should be established to record these activities, to identify important observations, and to assist in the filtering of unwanted data files.

4.2.6 Logistical considerations

Ensuring that acoustic data collected on fishing vessels is retrieved and distributed to the scientists involved in the project may be problematic. Data files should be downloaded from the recording system on a regular basis to prevent losses caused by a hard disk failure or storage capacity being exceeded. It is also important that no data be erased from the recording echosounder until it is verified that data files have reached their final destination and can be read.

Viable options for data storage and retrieval include CD/DVDs, USB portable hard disk drives, and direct networking with the logging system. Retrieval of data from fishing vessels will depend on the equipment set-up and downloading hardware, and will probably vary from vessel to vessel. However, the following practical steps in the process are generally applicable:

- Retrieve acoustic data files from the echosounder;
- Transfer data to the processing site;
- Verify readability and archive;
- Delete earlier downloaded files from the vessel's computer after verification and archiving.

A generalized flowchart (Figure 4.2.6.1) illustrates the downloading steps.

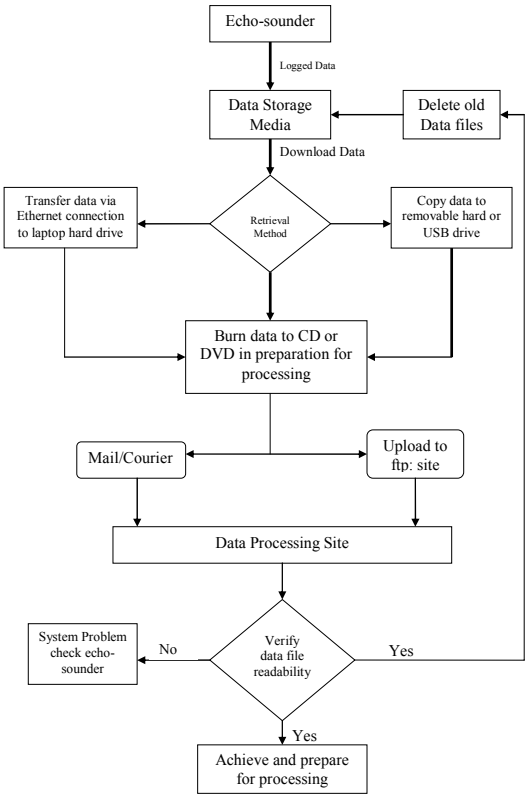

Figure 4.2.6.1. Flowchart of acoustic data-downloading options and procedures.

The logistics of echosounder calibration may also be challenging because fishing vessels are usually in port for short periods. Where the water depth alongside the wharf is sufficient, the biggest problem will be arranging access to the vessel and the availability of a qualified technician to perform the calibration. Unfortunately, wharf water depth is often insufficient to undertake a proper calibration. In this situation, the vessel must be moved to an offshore or sheltered area and remain stationary in relative calm seas for several hours. For charter vessels, this is not a concern because the time required would be included in the contract, but for volunteer programmes, getting the vessel to set aside the time can be difficult. The requirement (time and depth) for calibration must be identified at the beginning of the programme. A calibrated echosounder is a prerequisite for any quantitative analysis.

Maintenance and repair of multiple acoustic systems, dispersed geographically among a fleet, is also logistically challenging. Fortunately, most solid-state equipment is generally reliable and requires minimal maintenance. That said, commercial fishing vessels are constantly moving, and it is inevitable that cables become disconnected, computer boards unseated, and sounder settings changed. It is good practice for the individual(s) responsible for downloading data to check all cable connections and settings at the time of data retrieval. Quick scrutiny of a few files, including the first and last data files, is another way to identify many hardware or software problems. For vessels with technical support on board, it is useful for the acoustic observer to work through a daily checklist of key parameters (e.g. GPS input, transceiver power and pulse length, range settings) at the start of each shift.

4.2.7 Metadata

Comprehensive recording of metadata is an essential part of a well-executed survey programme and is particularly important when working with multiple vessels over a number of years. Recording metadata may present some difficulties in an industry setting, especially when there is limited or no at-sea presence of survey scientists. Consideration of metadata issues during the planning stage of a survey will greatly assist in ensuring that the right information is collected.

Metadata will range from macroscale information, such as trip details through to detailed information specific to particular instruments and possibly specific to each data point. Metadata information may include:

- Voyage details (location, dates, personnel, fish species being studied);
- Time convention used (UTC or local time);
- Echosounder equipment (manufacturer, model, serial number, key specifications, such as frequency or software version);
- Echosounder calibration details;
- Fishing gear specifications;
- Trawl (or other net sampling) information (start, stop, location, depth);
- Biological sampling details (measurements made and details of protocols used, such as conventions for measuring length, etc.);
- Details of other measurement systems and their deployment and sampling settings (e.g. CTD, motion sensors, temperature loggers);
- Key echosounder transceiver settings, ideally embedded in each ping record;
- Other important trip events (start, stop, interruptions, calibration events, etc.).

Metadata information will often be recorded on paper or in a computer text file in the first instance, but may be transferred to a database subsequently. A post-voyage report that summarizes the macroscale metadata (e.g. voyage details, table of voyage activities) is an essential document that will be referred to often during data analysis.

4.2.8 Data collection with analysis in mind

Unlike research vessels, which usually have computing specialists and data managers readily available, it is generally not possible to synthesize and review data while at sea on commercial vessels. Integration of various datasets during the analysis phase of a project may be time-consuming. Some simple steps can be taken during collection to reduce this overhead.

A well-planned and diligently recorded set of metadata will be of great assistance during the analysis phase. When dealing with large datasets, the metadata records, such as survey start/stop time, trawl times, etc., can help direct the analyst to the data that is of greatest value. Simple things, such as documenting which time zone was used (UTC or local) for the various datasets, can greatly reduce errors and confusion when synthesizing data.

Time is most often the key by which disparate datasets are joined. Prior to the start of the survey, it is good practice to adjust the clocks of all acquisition systems against an accurate source such as a GPS satellite time field. In some cases, it may be appropriate to adjust the clocks of networked computers continuously, using a time-synchronization utility.

4.2.9 Data exchange

Differences between data-storage formats often lead to difficulties in analysis and scientific exchange or review of acoustic data collected by different hardware systems and institutes. To address this problem, the ICES Working Group on Fisheries Acoustics Science and Technology (WGFAST) adopted the HAC standard acoustic data format in 1999 (Simard *et al*., 1997, 1999). The ICES Planning Group for the HAC Data Exchange Format (PGHAC) provides guidance on this topic (see www.ices.dk/iceswork/wgdetail.asp?wg=PGHAC). Most commercially available acoustic logging packages provide a translator to this format.

4.3 Recommendations

- Create a survey plan with clearly defined and well-communicated objectives, and use this as the reference point for all decisions.
- Calibrate acoustic systems prior to surveys whenever possible.
- Understand the opportunities and limitations when working in an industry setting, with particular attention to establishing good relationships with vessel personnel and owners. Also be mindful not to attempt to implement procedures that might affect the commercial efficiency of the vessel without consulting the appropriate industry people (e.g. skipper or vessel manager).
- Establish protocols for survey settings and when to record data.
- Establish protocols for collection of other data (e.g. biological measures).
- Plan for logistical tasks (e.g. retrieval of data, communication, and port visits).
- Establish what metadata are needed and develop means by which to record them (e.g. custom forms and databases).
- Begin with the end in mind. When planning and executing the data-collection phase of the project, consider how data synthesis and post-voyage analysis will be done.

5 Biological sampling

William Karp

Mariano Gutiérrez

5.1 Introduction

Although biological sampling is not needed to address some types of survey objectives, in most situations, the identification and characterization of backscatter is required. This is achieved generally through direct sampling, although developments in remote sensing methodology are promising. Information on biological characteristics is necessary to address two distinct but interrelated concerns. First, as previously discussed, mean target-strength estimates are required to scale absolute or relative biomass estimates. Target strength is influenced by a range of factors, including the size and species composition of the acoustically observed aggregations. Second, for many studies, it is important to partition biomass by size, age, and/or other biological characteristics. This is only possible if adequate sampling of the insonified aggregations is conducted.

During the design of a scientific acoustic survey, great care should be taken to minimize the selectivity of the sampling gear and to conduct sufficient sampling to characterize aggregations of interest. During the echo trace interpretation or scrutinizing process, trawl or other direct sampling data should be matched carefully to echo trace characteristics, and concerns regarding possible temporal and spatial gradients in biological characteristics taken into account (see Simmonds and MacLennan, 2005).

Although an important goal of direct sampling during scientific surveys is to minimize selectivity, this is not normally the case in commercial fishing. Furthermore, fishers may be reluctant to set gear in locations where catch rates will probably be low, even if this is necessary to provide scientists with information on biological characteristics at appropriate temporal and spatial scales. Under certain circumstances, it may be possible to provide fishing vessel operators with incentives (such as additional harvesting opportunities) to set gear in commercially unproductive areas, to modify gear to reduce selectivity, or to deploy ancillary scientific sampling gear.

Another area of concern is the fact that standardization of commercial fishing gear is uncommon. Although mesh-size restrictions are enforced in many fisheries, minimum mesh-size requirements are usually designed to increase selectivity. Furthermore, even nets of the same design will be fished differently and modified in various ways by vessel operators.

Sampling effectiveness does not depend only on gear selectivity. Avoidance may also be important (e.g. Ona and Godø, 1990; Handegard *et al.*, 2003). This is addressed to some extent in the preceding sections, but it is important for investigators to be mindful of potential vertical or horizontal gear avoidance that may be related to radiated vessel noise, disturbances caused by fishing operations, or other factors. Modern fishing vessels and research vessels are equipped with a range of sonars that can provide evidence of sampling gear avoidance. The vertical echosounders used for fishing and scientific operations may also be useful in this context. It is also important to bear in mind that hull-mounted vertical echosounders do not sample the epipelagic (upper 5–15 m) layers of the water column and that this zone is particularly difficult to sample with most conventional sampling gears.

Even under the best conditions, biological sampling may be insufficient. Useful size and species composition may be available from other sources, such as commercial catches and landings, but care must be taken to ensure temporal and spatial correspondence. During the past two decades, much work has been done to understand the factors influencing sampling data quality, and to develop improved sampling techniques and technologies. Some of these

developments may be applicable to commercial fishing and may improve the quality of biological data obtained during commercial fishing operations, but most are applicable only to dedicated research activities.

During the design of acoustic surveys, investigators must set aside sufficient time for direct sampling. This can be done by considering available information on distribution of fish by size and species from prior investigations, and recognizing the relationship between uncertainty (in species-specific biomass estimation or size composition estimation) and the adequacy of biological sampling (e.g. Godø *et al*., 1998; O'Driscoll, 2003; Petitgas *et al*., 2003). These authors also provide guidance in the assignment of biological characteristics to sequences of echo traces during data analysis. Similar issues arise during the design and analysis of data from dedicated acoustic surveys or surveys conducted by fishing vessels, but it may be more difficult to collect sufficient samples or deploy preferred sampling gear from fishing vessels.

5.2 Types of sampling

5.2.1 Commercial and research fishing

The extent to which biological sampling can or cannot be conducted and the sampling method employed will limit the types of objectives that can be addressed by the research project or survey. Several general cases are defined for the purposes of this discussion.

5.2.1.1 Biological sampling data cannot be collected

It may not be possible to collect biological data when the vessel is transiting to or from the fishing grounds or if the vessel's gear is unsuitable for sampling the echo traces encountered during all or part of the survey. Under these circumstances, it will generally not be possible to develop quantitative information regarding distribution, abundance, or biological characteristics of the echo traces. Inference regarding some characteristics may be possible through classification of echo-trace patterns and/or evaluation of the spatial extent of echo traces. In most cases, this will be useful only as an indicator of the likely presence of targets of interest, although it may also prove useful as a guide for future investigations and more focused application of acoustic and direct-sampling equipment.

The presence or absence (and relative abundance) of aggregations known to be composed largely of individuals that have been recruited to a fishery may be of direct interest to fishery managers. Gutiérrez *et al*. (2000) collected data during scientific surveys of anchovy off Peru between 1966 and 1982 and classified them according to area, season, and relative abundance. Later, relationships developed from this approach were used to quantify opportunistic acoustic data collected during fishing operations in the same region. This enabled the investigators to calculate biomass estimates from the fishery data, although data from direct sampling were not available.

5.2.1.2 Limited sampling with commercial gear

Sometimes, limited biological data are provided because commercial gear is directed to sample only aggregations of commercial interest. This would occur under normal fishing conditions. Under this circumstance, it will generally be possible to identify the size and species composition of backscatter within fished aggregations, although it should be noted that substantial contributions to backscatter in fished aggregations may not be well sampled by commercial gear. If it is possible to make assumptions regarding overall size and species composition (from prior surveys or historical commercial fishing information), this may provide a basis for quantitative estimation. However, the extent to which extensive areas of discrete or continuous scattering can be properly characterized will depend on the similarity (or lack thereof) between sampled and unsampled regions. Under this condition and the one

detailed below (Section 5.2.1.3), the type of gear employed during commercial fishing may be of particular importance. Some gear types are particularly selective (e.g. gillnets), while others are much less so (e.g. purse-seines).

5.2.1.3 Directed sampling with unmodified gear

In some cases, unmodified commercial gear is available, but vessel operators are willing to collect additional samples in accordance with agreed-upon protocols. Here, information on echo trace biological characteristics will be available from throughout the region covered by commercial vessels. This will enable more comprehensive matching of echo traces to catch composition during post-survey review. However, the aforementioned concerns about the selective characteristics of commercial fishing gear are also relevant under these circumstances. Under this and the following (Section 5.2.1.4) construct, incentives (such as access to additional harvesting opportunities) may be useful to encourage the fishing industry to participate more fully in collecting samples necessary to meet research objectives.

5.2.1.4 Sampling according to research protocols (gear may be modified)

In some situations, some modification of commercial gear is possible to reduce selectivity (e.g. a trawl modified with a codend liner) and/or the vessel is willing to deploy sampling gear in accordance with agreed-upon protocols. This improves on Section 5.2.1.3 by providing data on species and size ranges that would not normally be sampled during commercial fishing operations. Caveats that apply to any research sampling activity apply under this circumstance. These include adequacy of spatial coverage, the extent to which the selective characteristics of the sampling gear are understood, and the extent to which these patterns of selectivity constrain sampling of important scatterers. As in the previous cases, historical knowledge of patterns of scatterers' distribution in the region of interest will be particularly important when interpreting catch information.

5.2.1.5 Concurrent scientific sampling

If concurrently collected scientific sampling data are available (e.g. from research surveys conducted in the same location during the same period) or echo trace composition can be inferred from other research activities, this improves on Section 5.2.1.4 by increasing the temporal, spatial, and echo-trace content resolution. However, unless research vessel operations are directed in response to observations made aboard commercial vessels, or truly concurrent operations occur, assumptions regarding temporal and spatial consistency may be difficult to substantiate. In situations where echo-trace and biological characteristics are consistent within a given temporal/spatial stratum, the use of catch composition data from other sources will be more defensible.

5.2.2 Catch processing

Catch processing is a routine operation aboard research vessels. Techniques have been developed to address subsampling concerns, trained technicians are available to sort, process, and record sampling data, and vessel layout and the pace of operations are designed to optimize sampling and resultant data quality. This is generally not the case aboard commercial vessels during normal fishing operations.

5.2.3 Observers

When at-sea observers are deployed aboard commercial vessels collecting acoustic data, standardized, high-quality biological data collection is generally straightforward. Observer programmes generally have well-developed methods for sampling to provide species and size composition information, procedures for evaluating the quality of data collected by observers, and database systems which provide easy access to sample information during data analysis.

Even when observers are deployed, however, access to catch may be restricted by vessel configuration and operations. For example, selection of random or systematic subsamples from a catch may not be possible if the entire catch is dumped into a refrigerated seawater tank or hold, and observers may not be able to sample all catches if round-the-clock fishing operations are taking place. Sampling by a single observer during commercial fishing operations can never be as comprehensive as sampling by a team of scientists and technicians during research operations. Investigators should be aware of these limitations and, to the extent possible, communicate their sampling requirements to observers and programme personnel well in advance of deployment.

It may be possible to train observers to monitor a vessel's echosounders and to document important information regarding the proximity of fishing operations to echo-trace features. Also, in situations where commercial vessel operators are willing to make additional sets or deploy ancillary sampling gear, observers could be trained to identify echo traces of interest and direct sampling operations.

In situations where observers are not routinely deployed, the benefits of observer coverage could also be obtained by deploying specially trained scientific technicians aboard selected commercial vessels. Whether observers or technicians are employed to collect these types of data, it may be beneficial to hold periodic workshops for these individuals to compare notes and share knowledge.

5.2.4 Training of vessel personnel

Some investigators have reported considerable success in training vessel personnel to collect scientific information, such as size composition, sex, and structures for age determination (Nedreaas *et al*., 2006). Identification of primary species is generally straightforward, and it may be possible to freeze and/or photograph specimens that are difficult to identify. However, aforementioned concerns regarding the difficulty of following catch-sampling protocols during commercial fishing operations are important to bear in mind, and vessel personnel may not always fully understand the importance of following sampling protocols and matching sampling with temporal and spatial information on fishing activities. Use of automated sampling equipment (such as electronic fish measuring boards) may be particularly useful when vessel personnel are involved in sampling, and information systems that link information on fishing operations (i.e. electronic logbooks) will also minimize possibilities of data-recording errors.

5.2.5 Port sampling

The preferred method for obtaining catch data in many countries is to sample deliveries in port, but use of these types of data to characterize acoustic scatterers may be unwise for several reasons. First, deliveries contain only retained catch, and use of landings data to characterize catch is appropriate only in situations where discarding of undersized or unmarketable fish at sea does not occur. Second, haul-specific information is not available during delivery, so it is impossible to characterize echo traces at the necessary temporal and spatial scales. Under circumstances where sampling at sea is not possible, it may be possible to characterize echo traces based on sampled catches from other vessels in the fleet or, perhaps, vessel crew may be willing to separate samples of unsorted catches and retain them for processing when the vessel returns to port.

Participants in some Peruvian fisheries are now required to transmit messages containing information on catch quantity and composition to local authorities electronically, and electronic logbooks are now being used in many countries. Comparison of these reports with landing data may be helpful in determining the value of port sampling for characterizing echo traces.

5.3 Implications for data processing

During analysis of data collected during research involving the collection of acoustic and direct sampling data from research vessels, considerable effort is directed at interpreting echo traces to ensure that size- and species-related impacts on mean target strength are accounted for during echo integration and to support appropriate partitioning of acoustic biomass estimates (whether relative or absolute). Advances in methods for automatic school recognition, bottom-tracking correction, and identification of areas where records are contaminated with noise by weather, acoustic interference, or electrical interference, hold promise and may well be useful for preliminary review of acoustic data collected aboard commercial vessels. This is particularly important because of the potential for collecting vast quantities of acoustic data from vessels of opportunity. Although these approaches will probably be useful for initial filtering of data, an interactive process for combining acoustic and direct sampling data will continue to be necessary for many applications. Investigators should be mindful of the time and staff resources necessary to conduct this work, and of the need to develop clear protocols to ensure that matching of echo traces with direct sampling data is consistent and defensible.

5.4 Other considerations

Ancillary environmental data are often collected during research cruises, either to address specific research information needs or as part of a broader ecosystem monitoring plan. Because many of the commonly monitored environmental factors influence fish behaviour and distribution directly, they are often useful during the review process. Investigators should be encouraged to include systems for automated collection of basic environmental data aboard fishing vessels that are equipped to provide acoustic data for scientific purposes.

5.5 Recommendations

- Biological sampling must be consistent with survey objectives; investigators must ensure that sampling gear and protocols for fishing are consistent with the research and survey information needs.
- Gear selectivity and temporal and spatial resolution require careful consideration.
- Scientists and vessel personnel should develop and agree on scientific (biological) sampling protocols (see Section 7).

6 Data processing and analysis

Gary Melvin and Tim Ryan

6.1 Introduction

Data processing and analysis is the means by which collected data are converted into information. The type of information that may be extracted from the data is intrinsically linked to the method by which it was collected (see Sections 1, 3, and 4). Examples range from data collected during normal fishing operations to data collected under a formal survey design. In many cases, the latter may be treated in a manner similar to research vessel data, while the former may require novel methods and/or assumptions to be made before meaningful information can be extracted. This section provides a general overview of processing considerations, analysis procedures, and the subsequent uses of the data products and results.

Analytical software currently available falls into three categories.

- Processing software supplied as part of the echosounder system (e.g. Simrad BI60 software supplied with EK60 echosounders), which typically can only work with the proprietary storage formats used by the manufacturer's hardware.
- Software developed by research institutes, which may have been designed for a particular purpose and may not be available to the public.
- Commercial software developed by third-party companies. These packages strive to support the data formats of most commercial and scientific echosounders. See Annex 2 for information on software companies.

The various software packages typically have the ability to:

- Load and manage filesets of recorded acoustic data;
- View and move forwards and backwards through the recorded echograms;
- Apply calibration corrections;
- Define regions and layers on the echogram and enable data quality edits (e.g. define regions of bad data);
- Apply interpretations to the echogram, including identification, classification and isolation of targets of interest within the echogram;
- Process the echogram to produce various outputs (e.g. echo integration of data quality-checked echogram);
- Support specialized analysis (e.g. analysis if multifrequency data);
- Save analytical sessions to files.

6.2 Data processing and analysis

Data processing begins when the analyst receives the complete set of survey data files (both data and metadata information). Survey metadata are an essential aid to efficient data processing (see Section 4.2.7) and should inform the analyst which portions of data are of more interest (e.g. grid survey start/stop times, times and locations of observed school marks) and what survey settings were used. Metadata will aid in decision-making during the analytical process.

6.2.1 Archiving

Archiving of data is the starting point in the processing sequence. Large amounts of data may be collected from fishing vessels, and it is important that appropriate archival procedures are established.

Data files should first be validated to confirm that they are useable (e.g. ensuring that survey settings were used correctly and that GPS information is properly recorded). Data files typically fall into three broad categories: (i) files specific to the objectives of the current study; (ii) files containing information that may be useful for another purpose in the future; (iii) files that are incomplete or contain no relevant data. Files in the first two categories should be archived, beginning with those relevant to the existing project. Files in the last category (i.e. found to be incomplete, lacking sensor input, or containing useless data) should probably be deleted. For example, the continuous recording of the water column under a vessel while it is moored at the wharf, because the system was inadvertently left on, can represent a large portion of the archive storage media.

6.2.2 Filtering and data reprocessing

Once the original data are archived, attention can turn to preparing acoustic data files for analysis. The archiving process will have removed data files that are of no value, but it is usually necessary to identify the portions of data that are of interest from the remaining dataset. Often, survey metadata will be sufficient for this purpose (e.g. start/stop times of formal grid surveys). Sometimes, it will be necessary to scroll through echograms for the entire dataset, noting time periods of interest. This will allow the selection of a set of files for detailed analysis.

The large quantities of data collected during many of these types of surveys may be difficult to process efficiently. It may be appropriate to reprocess the data to reduce the data volume by (i) resampling at a lower resolution; (ii) removing or averaging data below or above a set threshold; (iii) including only data from a defined depth range; and/or (iv) excluding data types that are not required for the study (e.g. phase information, extra frequencies that are not of interest). These data reduction methods may be a compromise, and the implications for any quantitative results should be understood. In some situations, it is best to use reprocessed lower-resolution data for a rapid qualitative review, but to revert to the original data for detailed quantitative analysis. The manufacturer's echosounder software may allow output of lower-resolution data at the time of acquisition or during post-processing.

Reprocessing may be necessary to remove intrinsic errors in the data. See ICES (2004) for an example of a problem identified in the output of some versions of the Simrad ES60 echosounder and a solution that can be implemented through reprocessing.

6.2.3 Data analysis

These steps outline the analytical procedures for echo integration:

Apply corrections for sound speed and absorption.

1) Sound speed and absorption are ideally derived from direct measurements of conductivity and temperature profiles, but possibly from temperature profiles alone (with assumed conductivity values) or from oceanographic models of conductivity and temperature. Estimates of seawater sound speed and acoustic absorption can be made using the commonly accepted equations of Mackenzie (1981) and Francois and Garrison (1982), but see also Doonan *et al*. (2003) for an alternative absorption equation.

2) Apply calibration corrections for volume backscatter and/or target strength gain.

3) Apply correction values from echosounder calibration obtained prior to and/or subsequent to the survey, using the suspended sphere method as described by Foote *et al*. (1987).

4) Data quality control typically involves visual inspection of the echogram, followed by marking regions of bad data with polygon tools. Seabed bottom may be inspected and edited manually when the automatic seabed detection algorithm has failed. Pings that suffer from excessive noise spikes or aeration dropouts might be

marked as bad, either manually or using automatic algorithms. Figure 6.2.3.1 illustrates several data quality issues and possible solutions.

Apply other corrections as necessary.

5) Corrections for transducer off-axis motion (Stanton, 1982) and for acoustic dead-zone (Ona and Mitson, 1996) may be necessary, especially for deep-water situations or sloping bottoms.

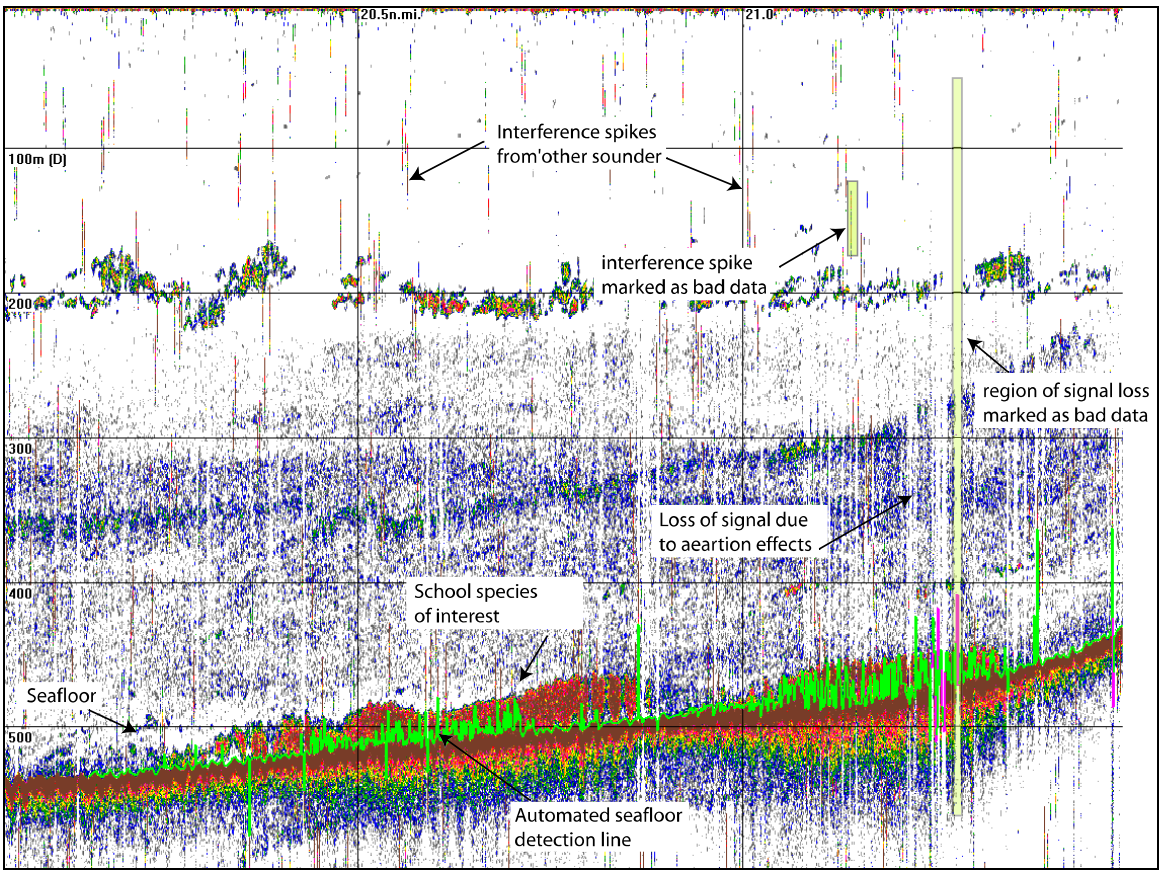

Figure 6.2.3.1. Echogram image with examples of poor data quality. Noise spikes from another sounder and signal loss caused by aeration can be marked manually as bad data or, in some cases, identified automatically. Automatic detection has failed to discriminate between the seabed and the signal from a school immediately above the seabed. The input parameters to the algorithm could be tuned to improve the detection, but in some cases manual definition of the seabed is required.

Determining species composition and relative proportions may be problematic when multiple species co-occur, and even more so if there are significant differences in target strength between species. For pelagic species that tend to aggregate into single-species groups, the main concern is school (or aggregation) identification, which is usually facilitated by direct sampling and/or use of multifrequency acoustic data. However, for species that are generally found in close association and, possibly, in varying proportions, determination of the contribution of each species may be difficult. Investigators should collect acoustic data and carry out direct sampling under a range of diel, seasonal, and environmental conditions to determine optimal times for conducting surveys and/or optimal segments of survey data for analysis.

Interpretation can be particularly difficult when acoustic data have been collected autonomously from a fishing vessel. In these situations, there has been no at-sea interpretation of the data, leaving it to the shore-based data analyst to piece together various datasets (e.g. trawl catch, vessel location) to assist in interpretation. Furthermore, sampling of echo traces may not have occurred or may have been inadequate. If ancillary data are inadequate, it may

not be possible to complete a full quantitative analysis. In such situations, it is important to identify deficiencies in the data and the underlying survey design, and use this information as a guide when designing future surveys.

The isolation or discrimination of targets or groups of targets into categories is generally accomplished by drawing (using the mouse) a box, ellipse, or polygon around the area of interest in the echogram and defining the category or species composition. The various definitions (bad data, school region, seabed detection, etc.) form a mask (or overlay), which is applied to the data by the echogram processing and export routines. Upon completion of target classification, summary statistics for the categories, school characteristics, and backscatter are exported for analysis.

1) Echo integration

Once the editing or classification of targets is complete, the integration is a simple software function. Integration data may be output from the acoustic analysis package for conversion to a biomass estimate and for detailed statistical analysis.

2) Error considerations

There are many sources of error in any acoustic analysis (e.g. Rose *et al.*, 2000; Demer, 2004; Simmonds and MacLennan, 2005). The subject of error analysis is discussed in Section 1, and the reader is advised to pay careful attention to all sources of error during collection and analysis of data (see Table 1.1). Quantitative acoustic survey results should be accompanied by estimates of error, which take these sources into account.

6.3 Automation

Processing and analysis of the vast amounts of data collected by fishing vessels could benefit from automation. Unfortunately, although the automation of acoustic-data and signal processing for fishery and environmental application is developing rapidly, it is still in its infancy. Most automated processing is related to either filtering or isolation of physical characteristics and provision of summary statistics for features within the echograms. Most algorithms are unreliable in multipurpose applications and still require a significant amount of user intervention and interpretation. Areas of application research include artificial intelligence, neural networking, image analysis, shape recognition (Barange, 1994; ICES, 2000), and frequency differences (e.g. Kloser *et al*., 2002; Korneliussen and Ona, 2003b). However, even automated bottom-detection and removal algorithms, which are commonly used by all acoustic packages, often require some user scrutinizing and manual input to ensure that unwanted signals are excluded from the integration process.

Processing procedures for individual target detection, echo counting, and target tracking are prime candidates for automation. Integration of the data from multifrequency acoustic systems is now being used to identify species and estimate fish size. Seabed classification with echosounder data is also being automated. A key component in seabed classification, as with all acoustical analysis, is ground-truthing. Data collected on the characteristics and physical properties of the seabed via direct methods are required to classify the acoustic categories with the corresponding seabed type.

6.4 Use of results

Throughout this document, attention has been paid to the importance of defining research goals and employing appropriate strategies for data collection and analysis. Standard survey designs employing random or systematic transects within an area of interest, and associated methods of providing biomass estimates and associated measures of error, are provided in the literature (Simmonds and MacLennan, 2005). However, many studies involving the collection

of acoustic data will deviate from this "standard" model and may require specialized analytical approaches. Examples are provided in Section 8 on the use of acoustic data collection from fishing vessels in support of stock assessment, in-season management, and more general objectives related to understanding the dynamics of fish behaviour in an ecosystem context, taking into account biotic and abiotic factors (see also Table 1.2).

In this section, we have provided a generalized approach that focuses on the goal of abundance estimation using echo integration methodology. Techniques for visualization of large datasets with temporal and spatial characteristics have been adopted for interpretation of acoustic data by many investigators in recent years. A discussion of this methodology is beyond the scope of this report, but the reader is encouraged to consult the literature for information on the methodology and examples of relevant applications (Gerlotto *et al*., 1999; Mayer *et al*., 2002; Melvin *et al*., 2002).

6.5 Summary

The processing and analysis of acoustic data collected by vessels of opportunity can be complex and extremely variable. In this section, we have discussed in general terms a number of generic applications, concerns, and practical solutions to the use of these data. Acceptance and inclusion of information, such as echosounder data collected by commercial fishing vessels, into the analytical assessment forum and subsequent management of a fish stock may be even more difficult. However, both technological advancements, such as near-scientific quality echosounders with logging capabilities, and the fishing industry's understanding of scientific survey requirements are paving the way for unsupervised and autonomous data collections from many types of vessels.

Finally, Figure 6.5.1 provides a generalized flowchart to aid in the development of either a scientific or industry acoustic data-collection/survey programme.

6.6 Recommendations

Although requirements for processing, analysis, and interpretation of acoustic (and ancillary) data collected on board fishing vessels may not differ markedly from requirements for similar types of data collected on board research vessels, some considerations are particularly important:

1) Large quantities of data may be collected, requiring special procedures for the storage and archiving of data.
2) Metadata will be especially useful in the identification of subsets of data for detailed analysis.
3) It may be advisable to collect raw data and low-resolution data simultaneously. Low-resolution data can be reviewed rapidly to assist in identifying sequences of high-resolution data for detailed analysis.

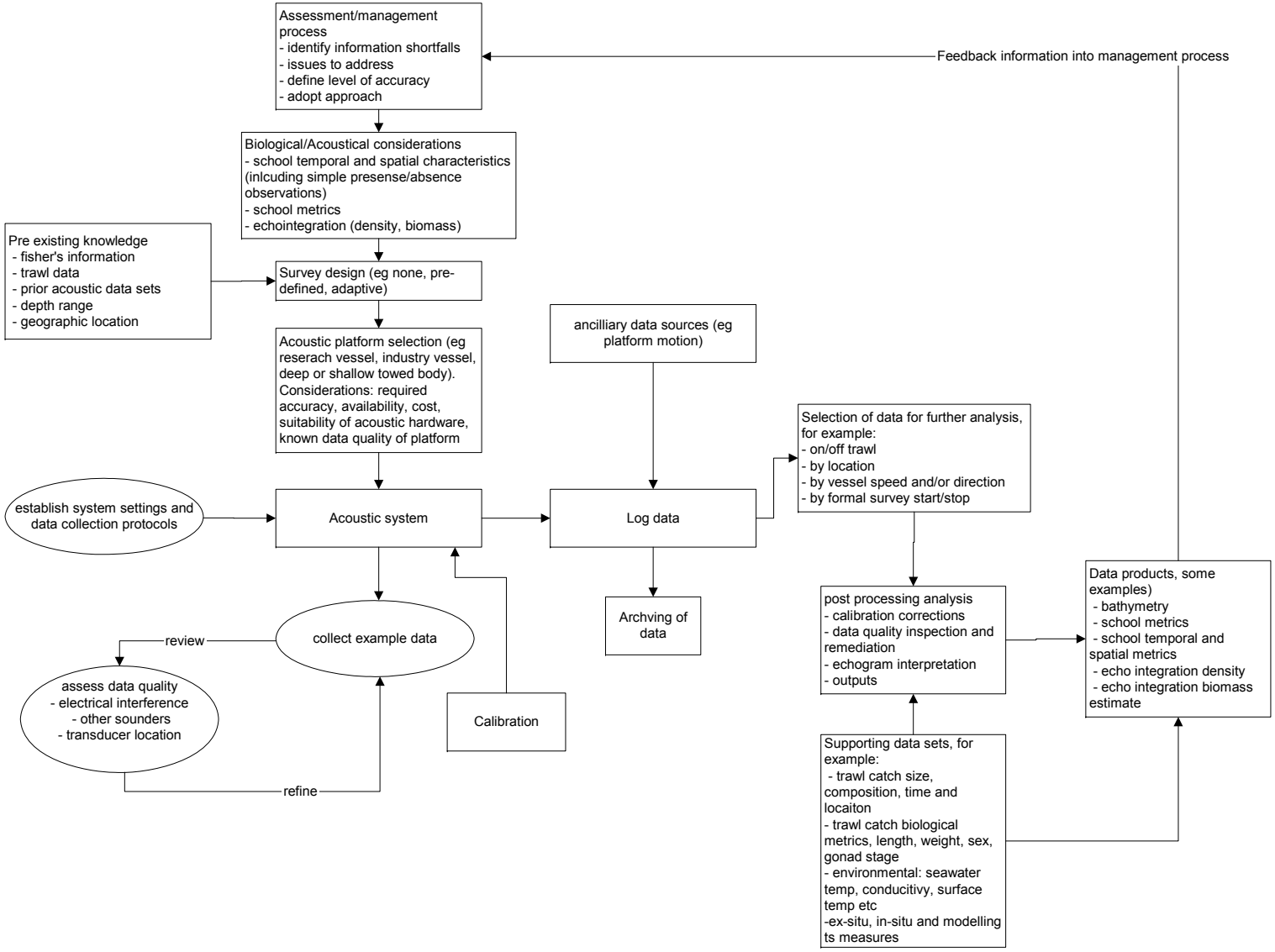

Figure 6.5.1. Key elements of an acoustic survey programme starting with assessment of the management perspective and considering sampling and data-processing details and the provision of feedback to the survey design.

7 Cooperative research considerations

Héctor Peña

Gary Melvin, François Gerlotto, Mariano Gutierrez, and Maria Angela Barbieri

7.1 Introduction

Cooperative research programmes with the fishing industry can increase our quantitative database and enhance our stock-assessment and ecosystem knowledge by providing broad spatial coverage over relatively short periods. Furthermore, commercial fishing vessels often operate for a large portion of the year and may provide seasonal information that is not otherwise available.

The concept of cooperating or partnering with the fishing industry to undertake scientific research is not new, although the degree of involvement has increased in recent years. Examples from Peru, Chile, Canada, Australia, the United States, New Zealand, Scotland, Ireland, and Norway were presented during the deliberations of the SGAFV (see Table 1.2).

7.2 Use of fishing vessels for scientific purposes

Over the years, commercial fishing vessels have been used for a variety of scientific purposes. In general, work can be carried out through dedicated scientific activities (e.g. research charters) or through collection of scientific data during fishing operations.

7.2.1 Dedicated research operations

In a dedicated research operation, the fishing vessel performs a specific scientific or management purpose. It is under the direct supervision of the scientific staff during the survey, and undertakes activities necessary to meet the scientific requirements defined by a survey design or sampling protocol. The vessel may be chartered or committed to undertake the survey as part of a co-management/cost-sharing arrangement. Fishing operations are generally non-commercial and based on scientific need, such as target identification. In some cases, however, the catch may be retained by the fishing vessel and sold, to offset costs.

7.2.2 Scientific sampling during fishing operations

In this scenario, scientific tools designed to operate in a completely autonomous way are installed aboard the vessel and set for continuous operation, at the captain's discretion or following an agreed-upon plan. There are two modes of operation: either the vessel has no commitment to scientific objectives and collects opportunistic data during trips to/from fishing grounds and during fishing operations, or the vessel has been instructed how to perform a scientific survey of an area or a fish aggregation. In the latter case, the vessel follows a strict survey design and sampling protocol developed to address specific quantitative and/or qualitative objectives.

7.3 Benefits of cooperative research

7.3.1 Scientific benefits

In most countries, insufficient research vessels are available, and the possibility of employing fishing vessels for scientific data collection often receives serious consideration. Although fishing vessels are not suitable to all research objectives that involve collection of acoustic data, they can provide effective sampling platforms in many cases. Researchers should consult other sections for examples of successful studies that have been conducted aboard fishing vessels and discussion of the concerns that should be addressed.

Fishing vessels allow sampling to be carried out on temporal and spatial scales that cannot be easily achieved by dedicated research vessels, and allow data to be collected in association with fishing operations. This may be useful to characterize fishing effort and to evaluate interactions between fish aggregations and fishing vessels during the searching and harvesting process.

7.3.2 Economic benefits

The collection of data through cooperative research is often less expensive than through the use of dedicated research vessels. Furthermore, it may be possible to allocate quotas to participating vessels to offset costs. Cooperative research also allows participants to supplement income from commercial fishing.

7.3.3 Increased understanding

Often, members of the fishing community do not understand the stringent requirements of the scientific approach. Conversely, many members of the scientific community do not understand the constraints of working at sea for a profitable operation. Employing fishing vessels to undertake scientific data collection provides a mechanism for dialogue and education of both parties.

7.3.4 Enhanced cooperation

Most fisheries would benefit from increased cooperation between government and harvesting sectors. The use of fishing vessels provides opportunities for interaction between scientists and fishers that may encourage a cooperative approach to assessment and conservation. This is particularly true when the vessel provided is part of a co-managed or rights-based fishery. In many cases, fishers can provide a practical solution to data-collection problems. These joint ventures help establish the framework for new initiatives and collaborative projects, and can also lead to increased levels of trust.

7.4 Limitations

The limitations of cooperative research are discussed in detail in the earlier sections. Of particular concern are those related to the definition of objectives, survey design, instrumentation, and vessel performance. It should also be noted that fishing vessels may not be available to conduct research work during the fishing season, and that concerns may arise when particular vessels are selected to carry out research (and, perhaps, take advantage of special fishing opportunities) and other vessels are not selected. Fair and objective criteria should be followed when selecting vessels.

7.5 Communication

Communication is critical when using fishing vessels for research purposes. The goals, objectives, responsibilities, access to data, and methods of information dissemination must be agreed upon and understood by all participants. It is particularly important that the following points be addressed:

- A clear and unambiguous description of the scientific objectives should be provided to potential industry participants and written documentation of the process for vessel selection and catch disposition be made available before soliciting industry participation. This process should be transparent and should ensure that objective criteria are employed for selecting vessels. It may also be important to minimize adverse economic impacts for other fishery participants when extra harvest opportunities are provided to commercial vessels engaged in research.
- The solicitation for participation should be widely distributed, and the contract or agreement must be clear and comprehensive.

- Operational procedures should be defined clearly and in writing, and mutual understanding of scientific and technical terminology reached.
- Understandings regarding protection of confidential information and release of scientific data should be written and unambiguous.
- Timely and useful feedback should be given to all interested parties.
- Recognition of prior performance in research studies should be made when considering specific vessels for future projects.

7.6 Incentives for industry participants

Industry may be compensated for costs associated with the collection of data through direct charter, allocation of fishing opportunities, or a mixture of the two. Proper compensation, often accompanied by increased fishing opportunities, perhaps in locations or at times outside of the normal exploitation area or period, offers significant motivation for participation. The fishing industry may also benefit greatly by contributing to overall scientific understanding of the stocks and improved management, and may be seen by the public as demonstrating a commitment to conservation and sustainability.

In some instances, broad participation by industry is an essential element of the management and/or assessment strategy for the stock. In such cases (e.g. the Chilean jack mackerel fishery and the Peruvian anchovy fishery), motivation for participation is particularly strong.

7.7 Examples of cooperative projects

Examples of cooperative projects involving the collection of acoustic data from commercial fishing vessels are provided throughout this report. Details of many of these projects can be found in Section 8, and a useful summary is provided in Section 1. Some of these examples are highlighted below to illustrate points raised in this section.

7.7.1 Chile: the Rastrillo Project

This project is of particular interest because it involves ongoing and fairly large-scale industry participation in the process of acoustic mapping of the distribution of jack mackerel off the Chilean coast. Results are used to identify areas of high abundance for management purposes, and to develop an index of abundance that is used during stock assessment. The project was initiated in the late 1990s and is ongoing. Participating vessels are directed to perform acoustic transects and collect samples for species identification and other scientific purposes. After completion of the assigned sampling, the vessels are authorized to harvest a special quota for a limited period of time.

Each year, the project is initiated through a call for proposals, which are reviewed by research scientists. The Chilean government then authorizes the vessels to participate and harvest the special quota, after completion of the specified research activities.

On board each vessel, two scientific and technical personnel hired by the research institution are responsible for collecting the acoustic and catch data. A cruise leader is responsible for coordination of all activities at sea and addressing operational problems. Twice a day, the cruise leader receives a report from each vessel, summarizing observations.

Before the start of the project, the scientists and fishers meet to discuss the objectives of the study and coordinate the activities at sea. After the cruise, the results are presented to the fishers and to the public in a workshop. The final report is released to the public through the website of the Chilean Fisheries Department. In large part, the success of this project is the result of the care that has been taken to ensure ongoing and comprehensive communication between the participants, and to the extent to which data collected during the seagoing phase is used to support management and assessment information needs. Abstracts of papers submitted

to the SGAFV on this project, and contact information for the individuals involved, can be found in Sections 8.1.6 and 8.2.6.

7.7.2 Peru: the EUREKA Programme

The EUREKA Programme consists of quick, synoptic surveys of Peruvian anchovy involving 25–50 fishing vessels contracted by the Peruvian Fisheries Agency (IMARPE). EUREKA surveys are useful for monitoring spawning and recruitment areas, establishing fishing grounds, measuring the relative abundance or availability of target species, and determining local or regional oceanographic and environmental conditions.

Each participating vessel is assigned to cover two or three parallel or triangular transects, and conduct associated oceanographic and fish sampling following a design similar to that employed during conventional acoustic surveys. With multiple vessels, the area can be completely surveyed in 2–3 days. Participating vessels are allowed to fish without restriction during the survey period. This is of particular interest to participants, because EUREKA surveys are usually conducted when the fishing season is closed.

A decision to terminate fishing is based on several factors, including achievement of the designated quota, start of the spawning season, appearance of large proportions of juvenile fish in commercial catches, and observation of major climatic perturbation (e.g. *El Niño* events). When fishing is curtailed early for one or more of these reasons, the industry may request a review of the regulations. IMARPE cannot modify regulations without adequate scientific information, but it is often possible to initiate a EUREKA survey on short notice to provide this type of information. The results of a EUREKA survey may or may not result in relaxation of fishing restrictions, but management decisions are based on joint analysis of biological, oceanographic, and acoustic information. Thus management decisions are generally supported by the industry, and political complications are avoided.

Every vessel participating in a EUREKA survey is assigned three scientific observers: an acoustician, a biologist, and an oceanographer (the acoustician uses the acoustic equipment available on board, and the biologist and oceanographer carry standard sampling equipment). It is common practice for the participating company to cover the travel expenses of the observers and purchase of the sampling equipment, thereby minimizing costs to IMARPE. For further information see Section 8.1.9.

7.7.3 Canada: Atlantic herring

Certain Canadian east coast herring stocks have been assessed and managed since 1997, based on acoustic data collected from multiple commercial fishing vessels. The programme is fully funded by the herring industry and evolved as the result of a need for information and a perceived significant decline in the overall spawning-stock biomass. This overall stock is made up of several major and minor spawning components in the Bay of Fundy and along the coast of southwestern Nova Scotia. Until recently, a significant proportion of the fishery concentrated on the spawning aggregations for the Japanese roe market. Assessment of the stock was based on a virtual population analysis (VPA), tuned with a larval abundance index.

In 1994, indications of a major decline in stock abundance appeared. As a result, the TAC was reduced from 151 000 to 80 000 t in 1995, and further reduced to 57 000 t in 1996. This prompted a cooperative research initiative to better understand the reasons for the decline and to develop harvest strategies that would improve abundance. This initiative led to the establishment of a management committee made up of government scientists and managers, as well as fishery representatives and vessel captains, with a mandate to make recommendations to address the stock issues.

A key recommendation from this group was the development and implementation of the "Survey, Assess, then Fish" protocol for individual spawning groups within the stock complex (Melvin *et al*., 2001).

The practical implementation of these guidelines would prove to be difficult, especially in the absence of a tool to estimate fish biomass. Initially, *ad hoc* multiple-vessel acoustic surveys of spawning aggregations were undertaken, using equally spaced transects within a defined area (Melvin *et al*., 2001). Echosounder observations and vessel positions were recorded by each vessel every few minutes. Upon completion of the survey, herring distribution was plotted and an educated guess of fish abundance made by scientific staff and vessel captains. It was immediately apparent, however, that although this strategy might help protect individual spawning components, estimates of biomass were subjective and not scientifically defensible.

The uncertainty in the estimate of biomass led to the development of an automated acoustic logging system (HDPS). This was developed to be adaptable to existing echosounders or to function as an independent unit. Both types of installation were calibrated. The first two systems were installed and tested in 1996, and the first organized surveys conducted in fall 1997. Currently, nine systems are deployed throughout the fleet, three systems purchased with government funds and the remainder purchased by the fishing industry. Annual calibrations are the responsibility of the system owners.

In 1999, use of a larval abundance index was abandoned and the VPA rejected. Since then, acoustic estimates of herring biomass from fishing vessels have played a key role in assessing the herring stock. Multiple surveys are undertaken annually on major spawning components by all vessels following standardized survey protocols (Melvin and Power, 1999), consisting of random transects within a predefined survey area. The data are compiled and used in the scientific assessment process. Vessel time for surveying is funded by the fishing industry as part of a joint project agreement between the fishing industry and the government. The data are considered public information, and reports on the preliminary results of a given survey are usually circulated within a week of survey completion (see Sections 8.1.4 and 8.1.5).

7.7.4 New Zealand: orange roughy, hoki, and southern blue whiting

In New Zealand, the use of commercial fishing vessels as scientific platforms for acoustic surveys is being driven by high research-vessel operating costs. Under the property-rights management system, shareholders are responsible for covering the real cost of research necessary to assess and manage a fishery. In this environment, significant cost savings to the industry may be achieved through the use of commercial vessels to undertake a survey or by conducting surveys in association with fishing operations. A key factor in the use of these vessels as survey platforms was the release of the Simrad ES60 echosounder, which can store raw acoustic data and can be calibrated to produce quantitative results

Currently, three fisheries use commercial fishing vessels to conduct acoustic surveys to estimate fish biomass: orange roughy, southern blue whiting, and hoki. Several studies have been undertaken to evaluate the potential for and optimize the use of commercial fishing vessels. The primary approach involves the combination of standard fishing operations with scientific surveys, either by allocating survey time or utilizing downtime during catch processing to survey the fishing grounds or seabed features (O'Driscoll *et al*., 2004). For orange roughy, a combination of research and commercial vessels is used to determine the biomass of spawning aggregations around seamounts and of dispersed fish in low-relief areas. Typically, the commercial vessel conducts directed fishing under the guidance of scientists aboard the research vessel. In recent years, however, fishing vessels have undertaken independent surveys of selected features using ES60 echosounders and following research survey designs. Although the approach has been validated by several studies, there is still some opposition within the scientific working groups to accepting the data, and uncertainty

regarding approaches to incorporating the results into the analytical assessments. Fortunately, the trend is towards incorporating these data into the process and the application of scientific protocols for data collection. It is likely that the current programmes will be expanded in the future (see Sections 8.1.7 and 8.3.1).

7.8 Summary

Cooperative acoustic surveys involving the collection of acoustic data from commercial fishing vessels have been successful in many instances. A range of qualitative and quantitative study objectives have been addressed by scientists and fishing industry personnel in many countries. Success is generally related to the identification of achievable objectives, mutual understanding of similarities and differences in the capabilities of fishing and research vessels, and clear and unambiguous (written) communication throughout. Some research objectives cannot be met properly using fishing vessels as sampling platforms, and vessel characteristics may be of critical importance to the success of a study. When cooperation is appropriate and carried out according to these guidelines, it can provide support for broader industry/government cooperation and the development of shared management and conservation goals, especially in rights-based fisheries. Fishers, understandably, are often anxious to resume fishing operations and concentrate on money-making activities, so it is especially important to focus on both short- and long-term benefits to industry. The importance of following scientific protocols when conducting surveys and research projects cannot be overstated, and the success of a study can be seriously compromised if protocols are not followed. Great care should be taken to develop an understanding of this requirement when working with the fishing industry.

7.9 Recommendations

- Scientists should communicate the objectives of the proposed research and the potential benefits clearly to industry participants and other stakeholders.
- Scientific and industry stakeholders should strive to achieve a shared vision for the project and to identify the roles and responsibilities of the various participants. Care should be taken to assure that terminology is understood by all participants.
- Vessel requirements should be defined and communicated as early and as clearly as possible in the process.
- Written protocols for all sampling and related operations should be drafted and agreed upon well in advance of the first sampling trip (see Sections 5.1 and 5.4).
- A comprehensive and clear legal contract or working agreement should be developed defining the duties and responsibilities of all partners before, during, and after a survey or specific scientific study.
- Responsibilities for drafting and publishing research results should be understood in advance. Opportunities to review draft reports and recommendations should be offered to all stakeholders. When appropriate, weekly/monthly progress reports should be provided to participants and stakeholder organizations.
- Industry participants must be assured that the proprietary information they provide will not be released without consent.
- Cooperative research agreements should encourage evaluation of performance by industry and scientific participants, with a focus on the development and implementation of future projects.

8 Abstracts from WGFAST 2003 and SGAFV meetings

8.1 WGFAST 2003 meeting

8.1.1 Collection of acoustic data from fishing vessels

William Karp

Stock assessment scientists often lack sufficient information to characterize the condition of commercial stocks and to recommend harvest levels. Even when reliable catch data and extensive time-series of survey results are available, questions regarding temporal and spatial distribution often remain unanswered, and historical survey results may not provide the resolution necessary to support some assessment and management information needs. Data collected during routine acoustic/trawl surveys provide important time-series of information for stock assessments in many countries. Most of these surveys are conducted with calibrated scientific acoustic systems installed on research vessels, although chartered commercial vessels are sometimes used. Acoustic data collected during normal fishing operations have also been used for stock assessment and management. Approaches have ranged from extraction of subjective relative abundance and distribution information from uncalibrated echosounder displays to absolute biomass estimation from calibrated commercial or scientific sounders connected to data-logging devices. In some cases, vessel operations have been modified to improve spatial coverage.

As information needs expand and instruments capable of collecting scientific-quality acoustic data become more widely available, the need to evaluate the success of these approaches and consider factors that may influence data quality has become apparent. This session includes presentations of several case studies involving collection of acoustic data from commercial vessels in support of stock-assessment and management goals. We also consider the objectives that might be addressed by these types of studies and the data-quality issues associated with these objectives. Radiated vessel noise, acoustic system performance and calibration, intercalibration, survey design, data storage, analysis and interpretation, and appropriate use of data are among the most important of these issues. Objectives may include improved understanding of temporal and spatial characteristics (including diel and seasonal migrations, and short-term changes in availability to the fleet), understanding of fleet "foraging behaviour", habitat characterization (for adaptive sampling or post-stratification), echo trace classification for adaptive bottom trawl sampling, and relative or absolute biomass estimation.

8.1.2 Underwater noise aspects of using fishing vessels for surveys

Ron Mitson

A survey vessel is the most important tool for fishery management purposes, providing the essential platform needed to carry equipment for sampling and assessment. That is why it is the first consideration when looking at the potential of commercial vessels, primarily designed for fishing purposes, to carry out research surveys. Vessels with a bad noise signature likely to cause fish avoidance behaviour need careful consideration before acceptance. Noise can be an advantage when fishing commercially if fish are driven into nets by vessel noise, but for sampling and collection of high-quality data, fish distributions should be undisturbed by noise.

Because of sampling problems caused by noise, ICES asked WGFAST to investigate, and it produced *ICES Cooperative Research Report No. 209*. Maximum radiated noise levels from research vessels are recommended to prevent fish being disturbed beyond 20 m from the vessel. A number of research vessels have since been built that meet that criterion. The noise signatures of most RVs currently operating exceed the *ICES Cooperative Research Report No. 209* levels, often by very significant and variable amounts. The main difference between currently operating research vessels and commercial fishing vessels is the lack of noise

ranging of the latter. By studying noise ranging reports, scientists may be able to optimize vessel operations for minimum noise by choice of propulsion conditions, but there are no immediate indications on board of radiated noise levels. Simple criteria are discussed whereby the most suitable commercial fishing vessels might be selected for research surveys, based on their likely radiated noise characteristics.

8.1.3 Industry acoustics for monitoring Australian orange roughy

Rudy Kloser

Advances in computing, post-processing software, and low-cost digital echosounders make the collection and analysis of industry acoustic data a viable prospect in many fisheries. Industry acoustics data are being collected in deep-water fisheries in many countries for a range of management objectives. The value and use of the data for management depends on the harvest and monitoring strategy in place. In some cases, simple qualitative indicators can be derived to assist in stock assessment or future monitoring. Planning a quantitative monitoring strategy involving industry acoustic data requires a realistic estimation of sources of error and bias. Most errors can be quantified or reduced based on past research, while others are difficult to quantify owing to unknown but strongly suspected biological and acoustic sampling biases. What appears to be useful in our deep-water situation is the balanced use of a number of low-cost industry surveys complemented with other multifrequency deep towed-body and biological surveys at less frequent intervals. Difficulties arise in having the overall monitoring strategy seen as a package, so that the funding is clearly identified for the whole strategy and not just funding of the low-cost portions.

8.1.4 Use of fishing vessels for surveying herring stocks in eastern Canada

G. Melvin, M. Power, and R. Stephenson

In 1995, the biomass of the 4WX herring stock appeared to be declining rapidly. Within a two-year period, the TAC was reduced to one-third its former level. However, the fishing industry remained concerned that they could systematically deplete each of the main spawning components within a global TAC. To resolve this concern, a series of industry-conducted surveys were implemented on the major spawning areas prior to fishing. These non-quantitative surveys provided a mechanism to monitor the general abundance of spawning herring before opening the area to fishing. The subjective nature of biomass estimation led to further uncertainty of stock status. Consequently, an automated and calibrated acoustic logging system was developed and deployed aboard herring-seiners for the purpose of undertaking quantitative acoustic surveys. Today, these surveys play a key role in assessing the abundance of the 4WX herring stock.

8.1.5 An industry acoustic survey design for surveying spawning herring

G. Melvin and M. Power

Prior to 2000, the 4WX herring stock complex was assessed using input from industry-based acoustic surveys and fishing excursions. Unfortunately, the data were collected in a somewhat *ad hoc* manner. The results, while providing valuable information on the abundance of herring on specific spawning grounds, were not comparable from year to year because of restricted coverage and only provide a minimum biomass estimate of the fish observed on the day surveyed. To overcome this problem, data from the fishery were used to identify potential survey areas from the distribution of catches during the spawning season. Isolating those locations, from which more than 90% of landings containing spawning fish were reported, further reduced the area of survey coverage. Thereafter, standard random transects were selected within the survey area and a protocol established for times when fish were observed beyond the survey boundaries. Standardization of the survey area provides a means to

compare observations from year to year, and forms the basis for an index of abundance in years to come.

8.1.6 Multivessel industry surveys of jack mackerel in Chile

M. A. Barbieri and J. Córdova

The jack mackerel is widespread in Chilean seas, making it difficult to perform synoptic surveys. The IFOP has been conducting multivessel surveys since 1997, using between 6 and 15 fishing vessels simultaneously and producing data on acoustic abundance values and biological data, such as egg and larvae collection. Some results from these "Rastrillo" surveys are presented, and the results are discussed.

8.1.7 Experiences with an industry vessel acoustic survey

R. L. O'Driscoll and G. J. Macaulay

An acoustic survey of spawning hoki (*Macruronus novaezelandiae*) off the east coast of South Island, New Zealand, was carried out from the 45.6-m factory/freezer stern trawler FV "Independent 1" from 2 to 11 September 2002. Acoustic data were collected using the vessel's Simrad ES60 echosounder with a hull-mounted 38-kHz split-beam transducer, which was calibrated prior to the survey. Acoustic transects were run during normal commercial fishing operations, in 4-h to 6-h windows of opportunity while the vessel processed large (10–20 t) catches. Commercial trawls provided biological data and information for mark identification. The survey confirmed fishers' perceptions that there were dense concentrations of spawning hoki in Pegasus Canyon. The acoustic biomass estimate of 49 000 t was 22% of the biomass observed in the main Cook Strait spawning grounds, indicating that Pegasus Canyon may be a significant satellite spawning area for the eastern hoki stock. This survey successfully integrated acoustic research and commercial fishing, and the Simrad ES60 acoustic system performed well. However, the approach described is only likely to be applicable to relatively small-scale surveys adjacent to areas of high catch rates. It was not possible to survey another area of interest fully (Conway Trough), because there were insufficient fish for the vessel to remain in the area and fish commercially. Future research will also be limited by the use of a hull-mounted transducer to periods of relatively good weather. Strategies to spread fishing effort through the survey area, away from the densest concentrations, are required to improve mark identification.

8.1.8 Acoustic assessment of herring from fishing vessels on the west coast of Scotland

P. G. Fernandes and D. G. Reid

Large commercial trawlers have been used to carry out acoustic surveys on the west coast of Scotland for more than ten years. The surveys are part of the International North Sea Herring Acoustic Survey (INSHAS), which takes place in July each year, involves six other research vessels, and covers the whole of the North Sea and its northwestern approaches. Chartering a commercial vessel is essential as all other appropriate research vessels are engaged in the INSHAS at the same time. In addition, the exercise allows access to a state-of-the-art fishing vessel and the cooperation of an experienced skipper and crew. The surveys are useful as a demonstration to the fishing industry of the mutual trust and respect by the scientific community. They also allow for the exchange of knowledge and ideas between the two parties. There is no doubt that such cooperation between industry and science is increasingly important, yet still quite rare. On the other hand, there may be doubts as to the quality of the acoustic data, given the stringent standards that are now expected from research vessels. This paper reviews the advantages and disadvantages of using commercial vessels for acoustic data collection, based on the experiences on the west coast of Scotland.

8.1.9 The feasibility of using fishing fleets for acoustic surveys in Peru

Mariano Gutiérrez

The EUREKA Programme was founded in 1964 by IMARPE and private fishing companies in order to collect fishery, biologic, oceanographic, and acoustic information quickly and economically, and to build synoptic maps of the abundance and distribution of pelagic fish, primarily anchovies. In recent years, it has also been used for the demersal fishery. The programme has been used to project fishing quotas and activities related to fishery management. The programme has been in existence for 39 years and has executed 65 surveys to date, although this activity was suspended between 1982 and 1991. Specifically, the EUREKA surveys are used for the following purposes:

- When a fishing quota has been reached, to analyse the possibilities of providing a new one (20%);
- To find fishing grounds, especially during winter when all the main fishing resources tend to be distributed over wider areas (20%);
- To investigate when new oceanographic conditions menace the stability of fishing operations (10%);
- To establish if spawning seasons have finished; during these periods, the fishing activities are closed (50%).

The core activity during a EUREKA survey is maintaining acoustic logbooks to describe the morphology and relative density of fish schools in sampling units of one nautical mile. This is done by scientific observers aboard 25–50 fishing vessels that usually have to survey two transects of a length between 100 and 300 nautical miles in order to cover the whole area of distribution of the target species. However, there are biases in the description of spatial structures of fish schools: too many observers inevitably increase the bias in abundance calculations (mostly relative values); there are different skill levels among observers, which sometimes makes data processing problematic; it is difficult to pay close attention to the sounder's screen during the whole survey; there are different types of sounders, gain controls, and ranges. Practically all sounders are analogue and lack a printer.

Despite these limitations, the EUREKA Programme is cost effective and useful for fishery management and scientific applications, such as the analysis of changes of gravity centre and patterns of distribution patterns of assessed species. Another important application is the cluster analysis of fish size structure to detect seasonal changes in the demography of marine populations for further corrections in VPA estimations. The programme deserves to be enhanced through the use of acoustic autonomous devices (acoustic black boxes, ABBs) to collect acoustic digital data and to overcome bias in the visual observation of echograms. This would allow more experienced acoustic staff members to concentrate on data analysis using software tools instead of taking notes aboard vessels. Some simple block diagrams are presented, showing how those ABBs would work.

In addition to EUREKA, there is a satellite-monitoring programme (SISESAT), which could be linked to the use of ABBs. The fishing activities of approximately 1000 fishing ships, equipped in Peru with satellite buoys, are monitored from IMARPE under a 1998 law that makes it obligatory to carry this kind of equipment to protect the spawning seasons, nursery areas, marine sanctuaries, etc. This makes the permanent use of ABBs possible aboard more vessels than only those used for the EUREKA surveys.

8.1.10 Use of acoustically equipped trawlers to study Barents Sea demersal fish

O. R. Godø and A. Totland

From 1991 to 1997, a number of commercial trawlers participated in a late summer survey to study the distribution and abundance of demersal fish species in the Barents Sea. Each year, one to three vessels were equipped with calibrated scientific echosounders and post-processing systems. The experiences gained during these cruises are discussed here, and some lines drawn to potential future improvements, based on new and better technology.

8.1.11 Use of commercial fleets to provide data for planning scientific surveys in Argentina

A. Madirolas

Until recently, hoki (*Macruronus magellanicus*) has been almost unexploited in Argentine waters and was known as a bottom fish, occasionally forming near-bottom schools. The decline of the hake stocks and the opening of new markets for fishing companies stimulated an interest in hoki. Knowledge of the species is still not complete and important parts of its life cycle need to be investigated further. Extensive areas need to be surveyed at different times of the year, and the availability of research vessels is very limited, representing a real challenge to researchers wanting a whole picture of hoki biology.

Agreements with fishing companies to carry out exploratory fishing experiments in lesser-known areas have been implemented to gather valuable information on the species, mainly related to the definition of possible spawning grounds in Argentine waters. Echo-recordings taken from fishing vessels during these surveys revealed the presence of large pelagic schools of hoki over the slope, possibly associated with the existence of bottom structures such as submarine canyons. This opened new possibilities for planning acoustic research surveys that targeted hoki. Tests are being carried out to explore the possibility of using Simrad ES60 echosounders to conduct preliminary, low-resolution acoustic surveys to produce gross estimates of the size of such concentrations. Bottom topography information extracted from the output files could also provide valuable data, because the exact location of bottom features believed to play a major role in relation to the presence of the species have not been described completely.

8.1.12 Designing new equipment for collection of acoustic data aboard fishing vessels

F. Gerlotto

A European Project has been submitted under the name MAREA (MARine Ecology and Acoustics) to the sixth Framework Programme, with the following five objectives:

1) To evaluate the quantity and value of the ecological information present in a "standard" acoustic survey database;
2) To conceive a methodology for an ecological analysis using "rake survey" methods;
3) To conceive an autonomous scientific echosounder (ACSES), with automatic data analysis and processing;
4) To evaluate the output and define the use of the new generation of multibeam sonar for fishery and ecology acoustics;
5) To conceive and design a special software package intended to clean up and preprocess acoustic signals from ACSES.

8.2 2004 SGAFV meeting

8.2.1 Acoustic data collection from fishing vessels in the Gulf of Maine

W. Michaels

A programme collecting acoustic data from fishing vessels targeting herring in the Gulf of Maine over the past 6–7 years was presented, with an emphasis on the objectives and design of the programme. This study was designed to measure the abundance and distribution of inshore spawning populations of herring in the Gulf of Maine, which are not part of an established acoustic survey of Georges Bank. The study evolved from unattended logging of acoustic data from vessels during routine fishing operations to a combined programme of unattended recording during normal fishing operations and a systematic survey using chartered fishing vessels, following a pre-planned cruise track. Instrumentation changed from commercial to scientific echosounders. The information collected during fishing operations was used to design the timing and spatial extent of the systematic survey. Current work focuses on the development of methods for the analysis of acoustic records made during fishing operations, because fishing vessels tend to spend most time in areas of high fish abundance.

8.2.2 Surveys with autonomous and remotely controlled echosounder systems

D. Demer

Recent developments were presented in autonomous multi-instrumented packages for use on moored buoys and modification of echosounders for use on ships of opportunity. A pole-mounted echosounder based on a scientific EK60 echosounder has been developed that can be rapidly attached and removed from the deck of small fishing vessels. The transducer can be removed from the water, which allows the vessel to move between regions of interest at high speeds.

8.2.3 Experience gained in use of ES60 and EK60 echosounders on commercial vessels

R. Kloser and T. Ryan

A combined approach to orange roughy and hoki acoustic surveys was described, based on undirected monitoring of acoustic data during commercial fishing operations and standard directed acoustic surveys using commercial vessels. The authors made the case that work must focus on how acoustic information fits into the management cycle. Even if the work is of high quality, the exercise will not be successful if it does not interface well with management. Seemingly simple questions, such as the order of magnitude of population biomass or presence at a given location, can be valuable to managers and should not be overlooked. The potential for vessel noise effects and the need for measurement of vessel noise signatures of commercial vessels were discussed.

8.2.4 Analysis and visualization of opportunistically collected echosounder data

M. Dorn and S. Barbeaux

The development was reported of methods for analysis of acoustic records collected from factory trawlers targeting pollock in the Bering Sea. The goal is to understand the dynamics of pollock aggregations over short timescales. This interest has been motivated by the possibility that fishing activity results in local depletion of prey resources for endangered Steller sea lions. The authors have designed a logging system for fishing vessels and have collected large amounts of good-quality data. They presented a comparison of records from two vessels, and have focused on areas where vessels have crossed within a few days. The backscatter recorded

by the vessels is similar. A spatial analysis of a subset of the data revealed that the backscatter is spatially correlated at scales of ~9 km, but not at 1 km. These results may reflect the scale of movement of pollock over periods of up to several days.

8.2.5 Use of operational statistics from commercial vessels for stock monitoring

S. Kasatkina and V. Ivanova

A method for estimating stock biomass based on catch and effort statistics was described. Given estimates of catch, effort, and catchability of a trawl, the biomass in a given region can be determined. This approach has been applied to the Russian 1988–1990 krill fishery in the Antarctic. The authors report that krill biomass estimates based on this method agree well with those of an annual acoustic survey.

8.2.6 Jack mackerel off central Chile using commercial vessels equipped with EK60 echosounders

H. Peña

This presentation reported on a Chilean industry-based acoustic survey of the jack mackerel stock in two distinct phases. The first phase was the mapping of the spatial distribution of jack mackerel by 17 vessels over a large area. Each vessel mapped the presence of jack mackerel, based on qualitative echosounder observations over several pre-planned transects. Vessels were allowed a subset of this time to explore higher-density areas in the same manner as they would during normal fishing operations. All transects were completed over a period of ~1 week. Based on the results of this survey, a systematic survey was designed, and fishing vessels equipped with EK60 scientific echosounders were used to conduct an acoustic survey. Incorporating the first phase results allowed an improved survey design in the second phase, which revealed for the first time that about 50% of the stock is distributed outside of the EEZ.

8.2.7 FV "Libas" – a commercial trawler/purse-seiner equipped for fishery research

A. Totland

A new vessel, designed in collaboration with the Institute of Marine Research and now under construction by the Lie Group Fishing Company in Norway, was described. The intent was to construct a vessel that scientific institutions would charter preferentially. The 94-m vessel is equipped with diesel–electric propulsion, and has additional features designed to reduce radiated noise. The vessel is also equipped with a retractable keel, dedicated scientific space, and a five-frequency scientific echosounder.

8.2.8 Automated biological sampling of fishing catches

A. Totland

A new system allowing automated processing of fishing catches is being developed through collaboration between the University of Aberdeen and the company Matcom. Scantrol will collaborate with these companies in order to bring a commercial product to market. The system is based on species recognition from optical imaging of fish and a system of conveyor belts, which move the catch past the camera. The system has been designed to achieve 98% correct species recognition and to measure volume, length, weight, and projected area of specimens. The system is also able to put aside specimens for further analysis.

8.2.9 Acoustic surveying from commercial vessels: North Sea herring as a case study

D. Reid

The aim of this project is to study the movement and fishing activities of the Scottish North Sea herring fleet in the context of the distribution of herring measured in traditional acoustic surveys conducted by a fishery research vessel. The goals of the project are to understand which schools are taken and why. The project may help managers understand the relationship between catch and effort, which will allow them to evaluate the utility of catch per unit of effort statistics for management of this fishery. Acoustic loggers have been deployed on six pelagic vessels and, in a pilot study, a vessel has been equipped with an ES60 echosounder.

8.3 2005 SGAFV meeting

8.3.1 Using fish-processing time to carry out acoustic surveys from commercial vessels

R. O'Driscoll and G. Macaulay

In some fisheries, large factory freezer trawlers have periods of downtime as the catch is processed. By utilizing this time, scientific acoustic surveys can be carried out between commercial fishing operations without compromising fishing success. Examples are presented from recent acoustic surveys for hoki (*M novaezelandiae*) and southern blue whiting (*M. australis*) in New Zealand waters conducted from commercial vessels fitted with scientifically calibrated Simrad ES60 echosounders. The approach described works well for small-scale acoustic surveys adjacent to areas of high catch rates (typically spawning aggregations) and is cost-effective because the vessel pays for itself by fishing commercially. The major limitation is that the boundaries of the survey area are determined by the time available during processing, which is related to the size of the catch and the time required to search for a suitable location for the next commercial trawl. In the New Zealand surveys, processing time was typically 3–8 h, which was sufficient to carry out about 10–70 km of acoustic transects. Acoustic research was also limited to periods of relatively good weather because of the use of a hull-mounted transducer. For further information, see the recent article by these authors (O'Driscoll and G. Macaulay, 2005).

8.3.2 Acoustic surveys of Barents Sea capelin with fishing vessels

H. Peña and O. R. Godø

This study focused on a severely depleted stock of capelin (*Mallotus villosus*) in the Barents Sea, which is co-managed by Norway and Russia. Scientific echosounders (Simrad EK60) and sonars installed on commercial vessels were used to describe the geographical distribution and abundance of the spawning stock. Three systematic surveys were conducted: no fish were detected during the first two phases, but fish were encountered during Phase 3. Phase 3 surveying was conducted during commercial catch processing. Environmental monitoring was also carried out. This survey was considered successful, because it was possible to complete the work within a relatively short (two-week) period. Survey results indicated that the capelin spawning abundance was slightly higher than expected from the stock assessment, but management advice was not adjusted. The absence of capelin during the first two survey phases could be the result of an eastern migration of capelin through the Russian EEZ, as has been observed occasionally in the past. Abnormally high surface temperatures to the west could have influenced this pattern of migration. Migration speed of the capelin is high when approaching the spawning grounds, perhaps as high as ten nautical miles per day (average swimming speed ~0.2 m/s).

8.3.3 Industry surveys of orange roughy off Chile

E. Niklitschek

The Chilean orange roughy fishery began in 1999 and covers six fishing areas (seamounts), 200–500 miles from the coast. Given the small scale of the fishery and the distance from the coast, the Chilean government has been unable to fund regular acoustic surveys. Moreover, no national research vessels have been capable of providing a stable platform with adequate fishing capabilities given the open ocean and deep distribution of this species. The only biological data available are those collected by at-sea observers from the beginning of the fishery. Consequently, orange roughy quota-holding companies in Chile recommended that a research programme based on industry acoustics be developed, and signed an agreement with the government (2002) which included:

- Logging ES/EK60 data during normal fishing operations on wetfish trawlers (delivering unprocessed catch) to obtain distribution information and, eventually, a relative abundance index alternative to cpue (2003–present);
- A collaborative 2003 survey using a chartered 58-m purse-seiner for acoustic transects; biological sampling and echo-trace identification (trawling) by industry vessels on a voluntary basis;
- A collaborative 2004 survey in which each of five fishing vessels provided 15–45 days of dedicated time to complete nine valid snapshots per seamount with a goal of <20% sampling CV. (Valid survey criteria: >25% spawning females, <25% missing pings, <25% signal attenuation caused by vessel motion);
- A collaborative 2005 survey in which a single factory vessel conducted the whole survey, including 87 days of dedicated survey time.

All vessels have been calibrated annually and operated under speed conditions that assure the lowest possible environmental noise. Results from the 2003 and 2004 surveys have been accepted as (minimum) biomass estimates, and they are used today for tuning orange roughy stock assessment models. Analysis of the routine data-logging programme is a work in progress, and relative abundance indices based upon this logging have not yet been accepted for stock assessment purposes.

Some lessons learned:

- Companies holding property rights might have higher incentives than government agencies to initiate and fund expensive research programmes in small and/or developing fisheries such as the Chilean orange roughy.
- Extensive temporal and spatial coverage of the grounds provided valuable information about distribution and school dynamic. This had been impossible to obtain by means of a traditional, single snapshot survey.
- Goals and incentives for industry managers and vessel officers/crew are clearly different in time and magnitude, especially with wetfish trawlers that have limited endurance at sea. A satisfactory process for engaging wetfish trawlers in this survey activity has not yet been developed.
- Industry protocols provide for commercial vessels to be assigned to research activities when a threshold of 25% spawning females in the catch is reached.

8.3.4 Qualitative use of echograms in support of the ecosystem approach

A. Bertrand

A brief overview of studies conducted off the coast of Chile was provided. Research included studies of jack mackerel and bigeye tuna. Acoustic data were collected during broader studies of these species and the ecosystems they inhabit. Acoustic observations revealed diel migratory behaviour of jack mackerel and information on predator–prey relationships. The author concluded that rough indices of plankton or micronekton abundance and qualitative

classification of patterns of distribution can be very valuable during ecosystem studies. He encouraged researchers to collect and archive acoustic data, and not to discard data that are considered to be “noise” during biomass estimation of target species.

9 References

Many of these references refer to unpublished reports or documents with limited circulation. This information has been included to provide a comprehensive list of references for the reader. Contact information for the authors of most of the unpublished documents can be found in Annex 1.

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Annex 1: SGAFV participants

The Study Group on the Collection of Acoustic Data from Fishing Vessels met on three occasions (Gdynia, Poland, 2004; Rome, Italy, 2005; and Hobart, Tasmania, Australia, 2006). This list of participants indicates meeting attendance and identifies principal and contributing authors of this report.

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Annex 2: Hardware and software industry contact information

Government research institutions may be reluctant to recommend manufacturer's products. The reader is encouraged to review information on specific research studies presented in Section 8 and to consider information provided by the manufacturers.

BioSonics, Inc. Scientific echosounders	http://www.biosonicsinc.com
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