Proceedings of the International Workshop on Acoustic Methods for Demersal Species: Recommendations for Acoustic Surveys of the Northern Cod Stock, St. John's, Newfoundland August 27-30, 1991

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Canadian Technical Report of

Fisheries and Aquatic Sciences 2083

PROCEEDINGS OF THE INTERNATIONAL WORKSHOP ON ACOUSTIC METHODS FOR DEMERSAL SPECIES: RECOMMENDATIONS FOR ACOUSTIC SURVEYS OF THE NORTHERN COD STOCK, ST. JOHN'S, NEWFOUNDLAND

AUGUST 27-30, 1991

by

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A workshop was held from 27-30 August, 1991 in St. John's, NF to recommend acoustic survey methods for demersal and semi-pelagic species in Atlantic Canada and elsewhere, with emphasis on the northern cod stock. The meeting was attended by biologists, physicists, and engineers with acoustic expertise from Canada, the U.S.A., U.K., Norway and Russia. A general conclusion from the workshop was that acoustic survey methods could contribute significantly to the assessment and management of the northern cod and other demersal and semi-pelagic fish stocks in Atlantic Canada. Generic recommendations have been made covering most aspects of the planning and conduct of surveys and analyses of acoustic data. For the northern cod, specific recommendations are made as to the development of an acoustic survey strategy. Key problem areas of equipment choice, vessel capability, target identification and strength (TS) and survey design (including combining trawl and acoustic measures) were addressed. In keeping with the general recommendation that acoustic and trawl surveys be complementary, a specific recommendation is to conduct a pilot survey in conjunction with the annual fall trawl survey (same strata, same time, different vessel). To reach these conclusions and recommendations, research contributions were made by most participants. Twenty contributed manuscripts are included in this report.

RÉSUMÉ

Rose, G. A. 1995. Proceedings for an international workshop on acoustic methods for demersal species: recommendations for acoustic surveys of the northern cod stock, St. John's, Newfoundland, August 27-31, 1991. Can. Tech. Rep. Fish. Aquat. Sci. 2083: 176 p.

Un groupe de travail s'est assemblé du 27 au 30 Septembre, 1991 à St Jean, Terre Neuve, pour recommander des méthodes de relevés de recherche pour espèces démersales et semi-pélagiques avec emphase sur les espèces de la côte Atlantique du Canada et en particulier sur le stock de morue franche du Nord (2J3KL). Le groupe, qui réunissait une expertise en échantillonage acoustique, était comprit de biologistes, physicistes et ingénieurs du Canada, des États Unis, de la Grande Bretagne, de la Norvège et de la Russie. On a conclu que l'échantillonage acoustique peut contribuer de facon marquée à la prospection et à la gestion de la morue franche du Nord ainsi qu'à celles d'autre espèce démersales et semi-pélagiques sur la côte Atlantique du Canada. Des recommandation générales concernant la plupart des aspects du plan et de la mis en oeuvre des relevés de recherche acoustiques ainsi que de leurs analyses on été formulées. Pour la morue franche du Nord, on a formulé des recommandations spécifiques sur le dévelopement d'une stratégie d'échantillonage acoustique. A ce sujet, les problèmes les plus importants on été addressés: tel le choix d'équipement, la capacités des navires, la définition et l'intensité des cibles (TS) ainsi que les plans de relevés de recherche (ce qui a inclut l'acouplement d'expertise acoustiques et de chalutage) Par rapport à une recommendation générale qui dit que les relevés de recherche acoustiques doivent être complémentaires à ceux du chalutage, une recommendation spécifique issue de la réunion est d'entreprendre un relevé de recherche pilote en combinaison avec le relevé de recherche d'automne au chalut (en même temps et aux mêmes strates mais avec différent navires). Pour arriver à ces conclusions et recommendations, des contributions de recherche on été requises de la part de la majeure partie des participants au groupe de travail. Vingt manuscrits on été contribués et sont incluent dans ce report.

INTRODUCTION

Under the mandate of the Northern Cod Science Program of the Department of Fisheries and Oceans (DFO), a workshop on acoustic methods for demersal fish species was held from 27-30, August, 1991, in St. John's, Newfoundland. The purpose of the workshop was to provide recommendations on the potential and conduct of acoustic surveys for demersal fishes, using the NAFO 2J3KL "northern" cod as the model stock. Biologists, physicists and engineers with expertise in acoustic methods from Canada, the U.S.A., U.K., Norway, and Russia participated. The workshop covered all aspects of acoustic surveying. The structure of the workshop allowed presentations and group discussions on most topics in addition to presentations of recent acoustic work on the northern cod stock (Appendix A). On the basis of these discussions, a set of recommendations was documented for acoustic surveys in general and for the northern cod stock in particular.

WORKSHOP OBJECTIVE:

To make recommendations on acoustic survey methods for fish stocks to improve current assessments of demersal fishes in general and the northern cod stock in particular. There was consensus on all key recommendations made in this report, although support was not uniform or in all cases unanimous.

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EXECUTIVE SUMMARY

PREAMBLE:

Acoustic methods can contribute significantly to assessments and management of the northern cod stock through use of recognized acoustic measurement and analysis procedures. Acoustic methods are best applied through dedicated acoustic surveys conducted under the direction of an experienced biological researcher trained in the methods of fisheries acoustics. Surveys must include directed fishing to provide the biological samples required to interpret acoustic data. Such acoustic surveys can be conducted both independently of traditional trawl surveys and in conjunction with them (coupled in space and time). For abundance estimation of demersal fishes, surveys conducted in collaboration with dedicated trawl surveys are to be preferred. Thus, in the case of the northern cod stock (NAFO 2J3KL), a late fall acoustic survey could be implemented to coincide with the annual fall groundfish trawl survey. The overall goal of acoustic biomass surveys is to obtain an estimate of the full stock biomass by age class with known bias and precision. An accurate measurement of the acoustic backscattering strength of the target species and complementary trawl information are required to achieve this goal.

The specific opinions and recommendations expressed in this report are based on available information on stock distribution and environmental conditions, and data derived from exploratory and research applications of fisheries acoustics techniques that have been conducted on this stock.

Recommendations have been made that are applicable to all acoustic surveys. Where appropriate, these generic recommendations are followed by more specific recommendations pertaining to an acoustic survey of the northern cod stock (to be conducted from the Northwest Atlantic Fisheries Centre at St. John's, Newfoundland).

This workshop has been attended by many Canadian and international scientists. Their presentations and contributions proved invaluable and made possible the options and recommendations reported here.

RECOMMENDATIONS ON THE CONDUCT OF AN ACOUSTIC SURVEY: WITH REFERENCE TO THE NAFO DIVISION 2J3KL "NORTHERN" COD.

1) PREPARATION

1.1) Ecology and Biology of the Target Stock

1.11) Generic: The geographic and depth limits of the "stock" must be defined. Within these limits, the temporal/spatial distribution patterns of the stock, and their variability, must be ascertained. Also, specific behavioral conditions, such as spawning, diel and seasonal migrations, proximity of fish to bottom (or surface), ranges of aggregation densities, fish community assemblages, feeding and related conditions factors, and their variations, all likely to affect acoustic measures, should be documented. The potential for variable vessel and trawl avoidance in relation to the most important biological and ecological factors should be assessed. Knowledge of these conditions will assist in determining the "acoustic availability" of the target species.

1.12) Specific: Documentation of the ecology and biology of the northern cod pertaining to their availability to acoustic assessment is a mandatory first step in the development of a successful survey method. For potential survey periods for which pertinent acoustic data exist (e.g. winter and spring), availability should be assessed. For a new proposed survey period (e.g. fall), historic trawl data and observations of fishermen using sounders should be summarized. These data should be supplemented with acoustic data collected during trial surveys to answer specific questions on the ecological topics, as outlined under 1.11, prior to the implementation of a full survey. Trial surveys also allow for field testing of all equipment, acoustic measurement procedures and data processing.

1.2) Personnel

1.21) Generic: A biological researcher trained in fisheries acoustic methods should be assigned the sole task of leading the acoustic survey program. An additional 2 person years of effort must be dedicated to the program. The training and skills of the "team" should cover the disciplines of fisheries acoustics, cod biology and ecology, and instrumentation and data processing. Additional personnel will be required during surveys to conduct the biological sampling. Exchanges of personnel among countries and laboratories conducting acoustic work are to be encouraged.

1.22) Specific: The required personnel must be put into place before any significant progress in the development of an acoustic survey can be expected. The leader should be the first appointment. **This is considered to be priority #1.**

1.3) Fish Capture Gear

1.31) Generic: The efficiency and size selectivity of the fish capture gear must be established before trawl based species ratios are used in the acoustic abundance estimate and prior to the comparison of net based and acoustic density or abundance estimates.

1.32) Specific: New trawls may be required to replace the presently used commercial nets on research vessels. Trawl selectivity research must be reviewed and additional work conducted as necessary prior to the implementation of new trawling methods or gear to support acoustic data.

1.4) Hardware and Software

1.41) Generic: Fundamental requirements are for an acoustic system operating at 38 kHz (120 kHz capability is also desirable for measurements on smaller fish in shallower waters and to enable frequency comparisons that may assist echo classification). The acoustic system must include scientific echosounders with 20 and 40 Log Range TVG and the capability to determine acoustic target strength (the split beam system is recognized as the current state-of-the-art). Towed body and hull mounted transducers will be required in keeping with survey conditions and vessel types. Duplicates of components subject to failure should be readily available. The system must include reliable data storage and processing. "Raw" data should be stored in a digital format. Software should display echograms in a video format with wide dynamic viewing range associated with the color spectrum of computer monitors. Processing capabilities must include echo integration, target strength analysis, single target isolation and counting. Post-processing capabilities must include geo-referenced transect and surface density maps and programs to calculate biomass estimates by species and area. The use of integrated "off the shelf" systems to the greatest extent possible will focus work on fish stock assessment rather than on systems development.

1.42) Specific:

1.421) A highly robust acoustic system is mandatory for this survey as a consequence of the severe environmental conditions that occur in Newfoundland waters. Depth can also impose problems; a survey of the "shelf" area requires measurements to >500m, and cod in the winter may be located at depths to 800-1000m. The present stern towing system on the research trawler Gadus Atlantica enables surveying to 600m through ice infested waters (in general from January to July in NAFO Division 2J). However, the rigidity of this system prevents satisfactory performance under typical open ocean conditions such as occur during the fall period (> >3 m swell). Hence, modifications to the present stern deployment system, to enable its use under all survey conditions, or, the adaptation of a rear quarter side deployment system to be used for near-surface towing during ice free periods, must be undertaken (see Appendix B). Transducer roll, pitch, and depth should be monitored. Special measure may be required to limit pitch and roll to less than half beam angles.

1.422) The present 49 kHz acoustic system at the Northwest Atlantic Fisheries Centre (NAFC) should be replaced with a 38/120 kHz system with features and capabilities as described in 1.41 and Appendix B. The new acoustic system, in addition to the specialized towing system now installed on the Gadus Atlantica, should be fitted to the new research trawler to be commissioned in 1994. The new trawler should also have a scientific sounder (split beam technology) with hull mounted transducer(s) installed as standard equipment available to the bridge and scientific staff.

1.5) Vessel and vessel noise

1.51) Generic: A suitably equipped research trawler should be used to conduct the acoustic survey. The vessel must have an acceptably low underwater noise spectrum and be able to adequately handle the acoustic system equipment. Considering the specialized nature of vessel noise measurements outside expertise is likely to be required to document noise levels and to supervise upgrading (see Appendix B).

1.52) Specific: A vessel is required for a minimum of 30 days to conduct an acoustic survey of the northern cod stock. At present the only vessel available at NAFC likely to come close to meeting the performance specifications is the Gadus Atlantica. However, noise levels from this vessel are too high for optimal acoustic use - immediate remedial steps should be taken to assess and correct the vessel/propeller noise problem (see Appendix B). Note that the Gadus Atlantica is to be replaced in 1994 with a new research vessel with a lower noise spectrum.

1.6) Survey Planning

1.61) Generic: **The goal of the survey must be clearly defined.** Once the goal is defined, the methods, time, and place of the survey should be chosen on the basis of attaining that goal. In determining a survey strategy, priority consideration must always be given to the distributional ecology of the target species and the environmental conditions under which the survey is to be undertaken. Sufficient vessel time must be available at the correct survey time to allow for comprehensive survey coverage and to attain the stated survey goal. Coverage should extend beyond the spatial range of the population to define its boundaries.

Most often, the survey goal will be to attain an unbiased estimate of the abundance of the stock with minimal variance. To accomplish this goal the initial measurement of acoustic backscatter must be converted first to relative and then absolute fish density and then to biomass. Uncertainty increases with each conversion. The following table is intended to provide relative estimates of the precision and accuracies associated with each step (accuracy is defined here as the offset between true and measured values; precision is the variation associated with repeated measures):

Measurement/Operation	Prec.	Acc. ± dB
1. Sphere calibration	0.1	0.2
2. Hydrophone based calibration	0.2	0.5
3. Backscatter measurement	0.3	0.3
4. Conversion to abs. fish density	1.0	2.0
5. Area expansion	1.0	2.0

Notes:

3. Backscatter measurement in the insonified volume includes the following sources of variance: transducer depth and temperature dependence; variations in sound speed as a function of location and depth; receiver linearity, drift, TVG, etc.; threshold and noise effects.

4. Conversion from backscatter measurement to absolute fish density estimate is primarily affected by the target strength valued used: target strength varies as a function of species, fish size, behaviour, time of day, maturity, depth and vessel avoidance. If the major error source is the target strength then precision may exceed accuracy. The short and long term stability of these factors must be considered. This error will include that associated with the classification of backscatter by species.

5. Area expansion: Extrapolation from the surface density measurements from the insonified volume of water to the entire survey area is a complex process. Various operational procedures are used that most workers agree do not adequately represent true distribution and abundance patterns attributable to environmental features and fish behaviour.

In general, surveys should attempt to estimate biomass within 2 dB of its true value (within a factor of approximately 1.5) in 95% of cases. This level of accuracy and precision will be difficult to attain in all cases. The methods and timing of a survey capable of attaining that goal can be determined only after trial surveys to determine the distributional and environmental factors likely to influence the accuracy and precision of the acoustic mensuration.

1.62) Specific:

1.621) The overall goal of the survey should be to attain an unbiased estimate of the abundance of the northern cod stock with minimal variance (in keeping with recommendations in 1.61).

1.622) Trial acoustic surveys should be conducted in conjunction with the fall trawl survey. The goal of these surveys would be to assess cod distribution patterns and the availability of cod to acoustic assessment, and the variability in these factors, during the fall migratory period. These data will determine whether or not a quantitative acoustic survey at that time is feasible and the likelihood that targets of accuracy and precision (1.61) and survey goals can be achieved. Sufficient acoustic studies on northern cod have been conducted during the winter and spring to assess the potential of these periods for acoustic surveying of this stock (for details see Appendix C).

2) DATA COLLECTION

2.1) Calibration

2.11) Generic: Only calibrated acoustic systems are to be used. Calibration includes the measurement of on-axis source level, receive sensitivities (or in the case of standard target measures their sum), and beam patterns. If noise levels are too great at proposed survey speeds, then they may be reduced by changing speed on propeller pitch (if possible). Transducer performance must be verified at all operating depths and noise characteristics should be assessed under normal operating conditions and depths. Calibration should follow the basic standard target procedures described in ICES Coop. Res. Rep. 144.

2.2) Survey Execution

2.21) Acoustic Survey Methods

2.211) Generic: No single survey methodology is best suited for all surveys. However, a few guidelines apply. The survey goal dictates the methods. The overall survey goal is most often the provision of an unbiased estimate of abundance with minimal variance. Hence, the choice of sampling and spatial averaging method will reflect the state of knowledge of the target fish stock and its distribution within the survey area. In absence of "a priori" knowledge of the distribution of the target species at the time of the survey, coverage of the survey area should be as uniform and complete as possible. If distributions are better known, then stratification and non-uniform sampling may be justified, and should be based on expected density gradients. In general, survey designs should be planned in advance and completed as planned to the greatest extent possible. Adaptive sampling is a special case to be used when distributions are understood and variable (e.g. during migration periods). A comprehensive review of these and other survey design considerations has recently been completed (Simmond et al. 1991; Simmonds (this workshop)). Survey procedures for stratified random designs were given by O'Boyle and Atkinson (1989).

2.212) Specific: The development of an optimal survey strategy and design based on known distribution and behavioral patterns of the northern cod stock should receive high priority. **This task should be considered to be an integral part of the initial research to be conducted both on historic data and through the trial surveys.** The default survey design should be a systematic parallel grid covering and extending beyond the known range of the stock, or the portion of the stock to be assessed, at the time of the survey. Research should be undertaken on the effectiveness of multi-stage sampling, especially in light of the highly contagious distributions of the northern cod evident in the most recent trawl and acoustic surveys and research. However, until research indicates that an unbiased and more precise estimate can be obtained by a different design, the default method should be employed.

2.22) Biological Sampling

2.221) Generic: Biological samples must be collected in an appropriate manner to assist in the interpretation of the species and size of acoustically identified targets. The frequency of sampling should be based on the variability in the acoustic record. Sites where no acoustic targets are evident should also be sampled. Sampling should also be conducted independent of the acoustic record (especially if the acoustic survey is not conducted in conjunction with a comprehensive trawl survey).

2.222) Specific: For northern cod, both bottom and mid-water trawling should be employed to provide biological samples as outlined in 2.221. For the recommended acoustic survey in conjunction with the bottom trawl survey, trawling from both surveys should be considered in the interpretations of the acoustic data.

2.23) Integration of Acoustic and Trawl Data

2.231) Generic: Comparisons of fundamentally different types of data on fish abundance (catch vs. acoustic backscatter) must take into account the differing availabilities of fish to these two types of sampling. Particularly for demersal species trawl and acoustic availabilities may vary independently as a function of species, age class, location, and time. Differing and variable biases may result.

2.232) Specific: Research to address the problems of comparing trawl and acoustic data on the northern cod stock should be implemented. Such comparisons must include known and anticipated variations in cod distribution, depth, and availability at diel, seasonal and other scales.

3) DATA ANALYSIS

3.1) Echo classification

3.11) Generic: The echo sounder records fish, plankton and bottom echoes as well as any other signals encountered and generates a measurement of the total backscattering strength from an insonified volume. Echo classification is used both to remove unwanted signals (e.g. bottom intrusion, noise bursts) and to include signals identified to some level of classification (e.g. species assemblages, species, sizes). Echo classification is based on acoustic information from echograms and known acoustic "signatures", "noise" characteristics, and fish density ranges, in addition to bathymetric information, physical oceanographic conditions, and fish capture data. Organization and data processing must provide all this information on a timely basis, so that classification can be done as the cruise progresses. Classification must be done only by very experienced personnel. Even though the process includes many intuitive decisions it must be well documented and tractable.

3.12) Specific: Research on echo classification should be considered an integral component of an acoustic survey of the northern cod stock (e.g. echogram video classification, acoustic "signatures" and signal discriminant classifications).

3.2) Target Strength and Density Measurements

3.21) Generic: Target strengths are required to convert measured backscattering strength to fish densities. In this conversion lies the greatest potential for error in acoustic measurements. To minimize the error, target strength studies should be conducted in support of echo integration surveys. These studies should encorporate *in situ* measures under survey conditions and experimental studies of target strength and its variability under known conditions of fish size, condition, and behaviour. In the absence of specific information on fish target strengths at the time and place of the survey, the ICES recommended equation for TS-length, or other similarly derived relationships, can be used (e.g. Foote 1987). In all cases, the target strength used and its derivation must be specified. The length-weight relationship should be attached to the density measurement.

3.22) Specific: Research on the target strength of northern cod both *in situ* and under experimental conditions should be continued and enhanced to form the basis for the scaling of integrated densities.

3.3) Abundance Estimation over Surveyed Areas

3.31) Generic: Acoustic measurements give rise to samples of fish density from within the insonified volume. In most cases the sampled volume represents only a small fraction of the full survey volume (area). Abundance estimation requires that these volumetric samples be used to estimate the biomass over the full survey area using appropriate statistical methods. The estimation methods used to interpolate densities, calculate mean densities and their precision, and then total biomass over the full area or portions of it, will be determined in part by the survey design and interpolation or averaging methods employed. Optimization of these methods will require research based on local survey conditions and fish distribution patterns. No single method can be recommended for all surveys (although the generalities expressed under 2.21 apply). A fuller account of the various methods available for abundance estimation is given in Simmonds et al. (1991) and Simmonds (this workshop). The integration of oceanographic information into the interpolation process should be investigated.

3.32) Specific: Research on statistical methods best suited to estimate abundance with minimum error (to within the target level, see 1.621) should be conducted as part of the northern cod acoustic survey program. This work must acknowledge present distribution patterns of this stock, which are highly contagious and localized.

4) DOCUMENTATION AND QUALITY CONTROL

3.51) Generic: All aspects of an acoustic survey should be well documented, tractable, and available for scrutiny. The results of acoustic surveys should be thoroughly reviewed by impartial authorities on acoustic methods prior to general acceptance.

POSTSCRIPT

Fisheries acoustics survey methods are continuously evolving, as a consequence of research on data processing, the acoustic parameters of target species, and the ecological and biological conditions under which acoustic methods are applied. It is mandatory that acoustic surveys be planned and based on a critical review of the most current state of knowledge on these factors to be undertaken by highly qualified personnel. Moreover, it is mandatory that personnel undertaking acoustic surveys pursue up to date training and an involvement in this research in order to stay abreast of the most recent developments.

CAVEAT

Rejection of any of the major recommendations made in this document will of necessity jeopardize the results of the proposed acoustic survey.

APPENDIX A: AGENDA[1]

Day 1: Tuesday, Aug. 27th

Chair - G. Rose

0900 Welcome to NAFC - S. Campbell, Director, Northern Cod Science Program

0905 Introduction to Workshop (purpose and objectives) - G. Rose

0925 An overview of fisheries acoustics at NAFC - B. Nakashima

0945 An overview of cod biology and distribution in NFLD waters - C. Bishop

1005-1030 Coffee

Topics:

1) Technology for demersal species - Chair, C. Lang/C. Stevens

1030 Hardware optimization (sounders, frequencies, transducers, deployment strategies etc.) - R. Kieser

1050 Calibration - R. Mitson

1110 Hardware and processors a) A. Clay

1130 Hardware and processors b) R. Brede

1150 Hardware and processors c) B. Johnson

1210-1300 LUNCH

2) Survey design and timing for demersal fishes - Chair, B. Warren

1300 Design principles for acoustic surveys - D. Thorne

1320 CAFSAC methods - S. Smith

1340 ICES methods - J. Simmonds

1400 Spatial statistics and methods - B. Warren

3) Signal interpretation and data analysis for demersal species - Chair, D. Miller

1420 Sources of bias and imprecision (relative & absolute estimates) - D. Thorne

1440 Effects of behaviour on acoustic measures - E. Ona

1500-1530 COFFEE

1530 Counting vs. integration - G. Thomas

1550 Bottom recognition and near bottom target discrimination - E. Ona

1610 Acoustic parameters for NE Atlantic cod - K. Foote

1630 Scales of variability in target strengths for NW Atlantic cod - G. Rose

1650 Adjourn for day

1900 Organized social event

Day 2: Wednesday, Aug. 28th

Special topics (continued):

4) Specialized signal interpretation and data presentation - Chair, G. Rose

0900 Signal classification techniques - J. Simmonds

0920 Geographic Information Systems and graphic data interpretation - R. Keiser

0940 Data management and visualization and fish production - S. Brandt

1000-1030 COFFEE

5) Comparisons/combinations of net and acoustic surveys for demersals - Chair, U. Buerkle

1030 Trawl selectivities - S. Walsh, NAFC and O. Godø

1050 Combined trawl/acoustic surveys - O. Godø

1110 Combined acoustic/trawl surveys - A. Dorchenkov

5) Lessons from past/current acoustic surveys for demersal fishes - Chair, R. Kieser

1130 Norway - O. Godø

1150 U.K. - R. Mitson

1210 USSR - W. Tesler

1230-1330 LUNCH

1330 USA - J. Traynor

1350 Canada - Redfish, B. Atkinson

1410 Canada - Cod (winter), J. Baird

1430 Canada - Cod (spring-summer), G. Rose

1450-1730 - Workshop on acoustic surveys (or combined trawl/acoustic surveys) and research on demersal species, using "northern" cod as the model stock - Chair, G. Rose

General examination of the available acoustic and distribution data on the model stock - to be made available in graphic (monitor, echogram) and numerical form (in computers or hard copy) by J. Baird (winter survey) and by G. Rose (spring survey)

1900 Organized social event

Day 3: Thursday, Aug. 29th

Workshop (continued): Specific recommendations for acoustic surveys and research on gadoid species - using northern cod as the model stock (based on theory, the available data on northern cod, and expectations and results from other surveys)

0900 Survey timing, protocol, organization - Chair, B. Nakashima

1000-1030 COFFEE

1030 Survey design - Chair, B. Warren

1130 Hardware and processors - Chair, C. Lang

1230 - 1330 LUNCH

1330 Signal interpretation and data analysis - Chair, D. Miller

1430 Other topics, including the status of fisheries acoustics in Canada, training aspects, education - Chair, J. Wheeler

1500 COFFEE

1530 Summary of recommendations - G. Rose

1700 Adjourn Workshop

Free Evening

Day 4: Friday, August 30th; Optional

Personal communications amongst workshop participants

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[1] All items on the agenda were covered although some reorganization occurred during the workshop to facilitate discussion and ensure that the stated goals were attained.

APPENDIX B:

Hardware and software requirements for northern cod acoustic survey include:

1) Towing systems on new research vessel to be upgraded to perform both in ice and under open ocean conditions (swells >>3 m),

2) Scientific echosounder (38 kHz) with 20/40 Log Range functions,

3) Multi-beam transducers (2) operating at 38 kHz, with known characteristics when deployed to 300 m depth,

4) Towed bodies (2) to fit items 1, 2, and 3,

5) Tow cable (400 m, faired) to fit items 1, 3, and 4,

6) Real-time (within 24 h) processing to include simultaneous integration and target strength analysis,

7) Digital echo data are to be stored on a PC or "Workstation" type computer. Graphic and numeric software must be available to display data over a wide range of vertical and horizontal scales (i.e. from a few pings to complete transects). Subsamples including fish schools and bottom should be readily selectable using keyboard and mouse inputs. Software to perform standard acoustic processing on the selected digital data must be available and outputs must be compatible with the analysis procedures indicated in item 7).

8) The analysis software outlined in 6) and 7) must have a flexible user interface that in addition to normal inputs from the keyboard and mouse supports full batch processing including annotated batchfiles and chaining of programs. It should be possible to run a complete analysis from a single batch file. To ease the creation of batch files the software must generate a batchfile in response to keyboard input. Full batch processing is important to record and document user inputs and to provide reliable, automatic and rapid processing or reprocessing of data sets.

9) A speed to noise (38 kHz) graph should be available for the survey vessel. The frequency of the spectrum level (SPL) should not exceed 100dB re 1 uPa in a 1 Hz at 1 metre band at the survey speed. Band level can then be obtained from SPL + 10 log bandwidth. Most noise signatures are usually displayed as equivalent mean spectrum level (e.g. 1 Hz bandwidth). Considering the specialized nature of vessel noise measurements outside expertise should be hired to document vessel noise and to supervise any required upgrading.

APPENDIX C:

The optimal timing for a full acoustic survey of the northern cod stock is not easily defined. To be considered are 2 fundamental groups of factors (optimal surveying conditions given in parentheses):

1) fish distribution,

a) depth (100-400 m total water depth),
b) horizontal (medium-high levels of aggregation),
c) vertical (fish off bottom),
d) species compositions (mono-specific better than mixed assemblages),
e) the stability of distributions, both large scale (stock) and small scale (school), both within and between surveys (stability greatly preferred).

and,

2) environmental conditions,

a) ice (no ice optimum - except as dampener for sea state),
b) the stability of sea conditions (calm weather) - stable sea conditions greatly preferred.

To produce comparable data, an annual survey should be conducted at the same period in the life cycle each year. This is especially true for a migratory stock that exhibits seasonal maturity cycles that affect distributions and could affect acoustic backscatter characteristics. However, it is unlikely that a survey could meet this goal because of the difficulty in predicting life cycle timing and also to vessel restrictions. Partial attainment of that goal requires that the survey be undertaken during a single period when survey conditions and life cycle patterns could be measured and standardized (if not made constant).

For the northern cod stock, it is unlikely that a single period exists during which all conditions for an acoustic survey would be close to optimal. The following is a brief summary of three potential survey periods, their advantages and disadvantages and research results to date:

1) During winter (January-March), mature fish on the offshore banks are likely to be found in mono-specific spawning aggregations well off bottom. This type of distribution appears to be ideal for an acoustic survey. However, there is a fundamental problem because the full stock may not be sampled (an index of spawning fish is not equivalent to a full stock index). Concerns were also expressed that the sampled portion of the population may change among surveys. Moreover, recent experiences (J. Baird, this workshop) have indicated that variable ice conditions and the deep water positioning of fish at this time of year may prohibit, or at least make very difficult, the conduct of an effective annual survey. The mandatory biological sampling to support the acoustic data interpretation has also proven to be difficult during this period, when fish can be under ice or in very deep waters (>600 m). Opinion was divided on

whether or not this approach should be pursued. However, it was agreed that a winter survey held enough promise to warrant a full evaluation of all data thus far collected (3.51). It was recognized that this evaluation will likely not commence until a project leader is appointed (1.22).

2) Spring-time weather conditions and fish distributions are in many ways ideal for acoustic work and biological sampling on the NE Nfld. Shelf (G. Rose, this workshop). Cod are well aggregated then, in shallower waters of depths <400 m and are typically distributed in layers or single fish up to 150 m off bottom. Under these conditions, only a small fraction of cod are likely to be unavailable to acoustic sampling. Biological sampling is relatively straightforward. Although some other species do cohabit with cod during the spring period (thus potentially "contaminating" a pure cod acoustic signal), catch data suggests that contamination is of the order of only 5-10%. However, the migratory nature of cod at this time could make the conduct of a full synoptic survey difficult. It would likely require several vessels. Also, in extreme years, ice may persist to July in the northern reaches of the stock area (2J) thus impeding acoustic work.

3) Compelling arguments were advanced in support of conducting an acoustic biomass survey in conjunction with a comprehensive trawl survey. The biases associated with trawl and acoustic surveys differ and may be inverse (trawl surveys can be expected to be least biased when fish are homogeneously distributed, a fixed proportion is located in the bottom few meters and abundances are relatively low - for acoustic surveys the opposite may hold). Hence, it was generally agreed that a superior analysis of the state of the stock should be possible by integrating these two types of surveys and conducting them simultaneously (see 2.23). In the case of the northern cod stock, given the present timing of the annual fall groundfish trawl survey, that would require a fall-early winter (Nov. to late Dec.) acoustic survey. However, there are disadvantages to this strategy. Fish distributions may not be stable (this condition impacts both trawl and acoustic mensurations). Sea conditions during the fall can be very rough and storms of 3-5 days duration are not uncommon. Modifications of the towing gear to sustain such conditions would likely be required (see Hardware and Appendix B). Of more fundamental importance is the fact that the distribution patterns of cod in the fall, relevant to their availability to acoustic mensuration, have not been established. Hence, trial surveys should be undertaken to establish the feasibility of conducting a full annual acoustic survey during the fall season.

Workshop participants were in agreement that acoustic research and surveys could be used to great advantage during the winter, spring and fall. However, the goals of seasonal surveys are likely to differ. Winder that spring acoustic research can provide supplementary information on stock status, even to the extent of providing measures of abundance of some portion of the stock, but their goals have not been to provide an annual measure of total stock abundance. Hence, these acoustic projects must be justified on other grounds, such as the delineation of spawning areas or migration routes, specific quantitative studies of the migrating and spawning biomass (and the development of a spawning biomass index), target strength studies and the development and application of acoustic methods for behavioral studies.

Workshop participants repeatedly stressed that research goals for any survey must be fully specified and that methods, survey strategies and assessments of projects should follow logically from those goals. In this regard, it was thought critical to define the portion of the stock which is to be surveyed (e.g. full survey vs. spawning biomass).

The workshop concluded that for stock assessment, a full stock index by age class was the most desirable goal and that at present, knowledge was too sparse to state with certainty the likelihood of achieving that objective, or to dictate precisely the optimal timing for such a survey of this stock. However, it was clear that the knowledge required to assess the potential for an acoustic survey is poorest for the period of the fall survey and the advantages attributable to conducting simultaneous fall trawl/acoustic surveys are many. Hence, to provide an annual acoustic stock index of the northern cod, **a key recommendation is to implement trial acoustic surveys in conjunction with the fall trawl survey to ascertain the feasibility of conducting a full acoustic survey at that time.**

APPENDIX D: CONTRIBUTIONS TO WORKSHOP

Atkinson, D.B. Surveying for redfish acoustically - the Newfoundland experience.

Brandt, S.B. Acoustic visualization and information retrieval.

Brede, R. Hardware and processors: the SIMRAD EK500/BI500 scientific sounder system.

Dorchenkov, A. Combined trawl - acoustic surveys: Russia.

Foote, K.G. Acoustic parameters for the northeast Arctic cod.

Godø, O.R. Combined trawl/acoustic surveys: Norway.

Godø, O.R. Experience from Norwegian Acoustic Surveys on Cod and Haddock.

Johnson, R.L. Instrumentation and software for synoptic analysis of pelagic and demersal fish populations.

Kieser, R., and G. Langford. Geographic information systems and data interpretation.

Kieser, R. Hardware optimization.

Mitson, R.B. Acoustic and trawl assessment of cod.

Mitson, R.B. Calibration: principles and practice.

Ona, E. Bottom recognition and near bottom target discrimination.

Rose, G.A. Scales of variability in target strength for NW Atlantic cod

Rose, G.A. Lessons from past acoustic surveys for demersal fishes: spring migration acoustic research on the NE Newfoundland Shelf.

Smith, S.J. Basic principles for the design of acoustic surveys for pelagic fish stocks in the CAFSAC management area.

Simmonds, J. ICES acoustic survey procedures.

Traynor, J. Acoustic surveying at the Alaska Fisheries Science Center.

Walsh, S.J., and O.R. Godø. Trawl selectivity.

Warren, W.G. Acoustic survey design and timing for demersal fishes: spatial statistics and methods.

SURVEYING FOR REDFISH ACOUSTICALLY
- THE NEWFOUNDLAND EXPERIENCE

by

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Abstract

Like many pelagic species, traditional assessment methodologies are often not applicable to redfish so the availability of a reliable alternative indicator of stock abundance is very important for management. It was recognized a considerable number of years ago that the distribution of redfish, both vertically and spatially, make it difficult to survey them utilizing more standard fishery techniques such as stratified random bottom trawl surveys. The clumped distribution of redfish spatially as well as their vertical distribution up into the water column make these fish good candidates for the application of acoustic techniques for their enumeration. Analysis of acoustic data can also provide considerable information concerning the behaviour of these fish.

The Newfoundland Region of the Department of Fisheries and Oceans first attempted to use acoustics for redfish in 1976 but with little success. Further work was initiated in 1979 and has continued on an annual basis since then. Numerous difficulties have been encountered and addressed. Redfish are distributed relatively deep, not being found in <200 m and often distributed as deep as about 750 m. For reasonable results then, it was necessary to get the transducer 'down to the fish'. Once deployed, it was necessary to have cabling of sufficient quality in order to receive a clean signal. After many years of experimentation, we are now confident that we are obtaining reasonably good data from the system.

Questions still remain however. Coincidental sampling with both mid-water and bottom gear is enabling us to evaluate our interpretation of the acoustic data. The availability of a dual beam system will enable us to collect valuable information pertaining to target strengths. Work is also on-going within the region to investigate the appropriateness of various survey designs.

It is our aim to become sufficiently confident in our results that they may be incorporated directly into the assessment process, enabling us to provide accurate and timely advice as to the status of the various redfish stocks under jurisdiction of the Newfoundland Region.

ACOUSTIC VISUALIZATION AND INFORMATION RETRIEVAL

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INTRODUCTION

Recent developments in acoustic data acquisition and signal processing techniques (e.g. multibeam transducers [Burczynski and Johnson, 1986], deconvolution theory [Stanton and Clay, 1986], multifrequency innovations [Holliday et al., 1989; Pieper et al., 1990] and Doppler applications [Flagg and Smith, 1989]) have provided robust tools to measure distributions, abundances and sizes of acoustic scatterers over large regions on a continuous basis. There is a growing interest in applying these techniques for ecologically-based fisheries science which usually requires finer detail in the data than is normally used for stock assessment programs (e.g. Brandt et al. 1991a; GLOBEC 1991). Yet, much of the high resolution spatial and temporal information inherent in acoustic signals is not being used because of the lack of suitable information processing systems. Indeed, the development of 'front-end' data gathering technology may have outpaced our ability to use and fully comprehend the vast amounts of available biological information.

The type of information that can be extracted from acoustic signals depends on the spatial and temporal resolution of the data and the level of integration of the acoustic data with other types of data and models. Below, it is argued that high-resolution, spatially-explicit (i.e. retrievable in a grid format) acoustic data are needed for stock assessment programs to accurately relate target size to target density, for survey design and data stratification, for acoustic species identification and for differentiating changes in abundance from changes in distribution. Moreover, it is suggested that high-resolution spatial data becomes critical when acoustic data are integrated with physical and biological models to examine higher-order features of the environment. Physical and biological processes are often nonlinear and simulations run at 'average' conditions may not be representative of the processes at the spatial scale at which they occur.

ACOUSTIC LEVELS OF INFORMATION

The amount of information that can be retrieved from acoustic data depends on the type of acoustic data acquisition and signal processing system and the degree to which the acoustic data are integrated with other information. Normally the integration process requires that the acoustic data be transformed with various models that require certain assumptions. We can categorize the types of information that can be derived from acoustic data into six hierarchical levels that range from raw sensor signals to regional and ecosystem features (Figure 1). Each level requires more complex signal processing and integration with other information. The terminology is, in part, borrowed from visual pattern recognition.

1) **Raw sensor signals.** At their most basic level, the raw sensor signals are the time-varying voltage signals from individual transducer array elements. The amplitude scan can be considered a raw signal. The raw sensor signals can be multivariate: a signal from each transducer element in an array and a separate set of signals for each acoustic frequency. Acoustic signals in their raw form are rarely used in fisheries applications and archiving the raw signal is data intensive.

2) **Acoustic signal primitives.** The acoustic signal primitives are the low-level features obtained from the raw sensor signals through the use of transformation and feature extraction based on a priori sensor-related information. This sensor-related information includes sensor models (array phasing, beam directivity), transmission media models, information about the transmitted pulse, transducer calibration and platform attitude, position and time. The dual-beam processor and the split-beam processor are examples of these transformations based on a priori knowledge of the transducer. The primitives include: detected target backscatter coefficient range and bearing; geographically referenced target space-time coordinates; target motion; and local mean energy in the echo signal. The A-scan can be simply mapped forward (e.g. an echogram) and considered an acoustic primitive.

3) **Bioacoustic primitives.** The bioacoustic primitives are the low-level, biologically related features determined by applying biometric-acoustic models and the like to acoustic signal primitives. The quantities are defined either for individual targets or for targets in a small neighbourhood in space X time. These data include measures of fish size derived from regression back-scatter-biometric models (Love, 1971; Foote et al., 1986] or from parameter estimation methods [Clay, 1983; Stanton and Clay, 1986], or from spectral-biometric models [Holliday and Pieper, 1980], and target volumetric densities (spatial point process intensities) from volume reverberation [Urick, 1983] (echointegration [Clay and Medwin, 1977]) models. These transformations are generally nonlinear. Also under this heading are species identifications of fish schools that use vectors of signal features extracted from A-scans [Rose and Leggett, 1988]. These quantities provide the foundation for all further processing normally done in acoustic stock assessment programs. This level of information is considered a primitive only in the sense of degree of interpretation that has occurred regarding biological processes.

4) **Bioacoustic primitive images and sample functions of marked point processes.** These images and sample functions are the "data images" obtained with acoustic multibeam, scanned or moving arrays. These data images are either functions or point process tags defined on an extended, connected, continuous region of space and time. Examples of such bioacoustic primitive images are local mean biometric size and local target volumetric density defined throughout a two-dimensional vertical plane (slice). Typically, the slices can be from tens to hundreds of meters deep and extend horizontally from a few kilometres to an entire ecosystem. Normally some level of averaging and data interpolation has been done at this stage. With a volume imaging system, the marked targets can be defined on a volume, or on an extended volume by multi-image target fusing with moving platforms. For a stationary, continuously monitoring sensor, the images or marked targets are defined on a volume x time space.

5) **Bioacoustic feature images.** Such images are obtained by computing higher level features of the environment using individual based and local-population based biological or physical models with the local values of the biological primitive functions. Models of predator growth rate and predator-prey encounter rates as functions of acoustic measures of prey density and prey size are examples [Brandt et al., 1991b].

6) **Regional/ecosystem models and features.** These are system or subsystem models and features of an entire domain over an extended time-interval. Fish production, recruitment, population abundance, area and volumetric measures of habitat classes and net migrating biomass identify either a subsystem process or the net effect of that process over some time interval. Such models and features can be linked to the use of bioacoustic images either through the use of these images for insight into model development, or through their use as boundary conditions and model validation. The selection of models on which to base estimates for quantities in the regions and time intervals between sparse samples is dependent upon the other data available (e.g. hydrographic and satellite remote sensing data) about these intervening regions and time intervals.

SPATIAL RESOLUTION OF ACOUSTIC DATA

One of the main strengths of acoustic sensors is the ability to measure densities and sizes throughout the water column at a high spatial resolution and on a continuous basis. Acoustic applications in fisheries science have largely concentrated on averaging across time and space to obtain total population abundances. The scale at which data are averaged or lumped into grids will affect data interpretation, statistics and the level of information that can be retrieved from the original acoustic data. The scale of resolution and averaging should be based on the question being addressed and on the spatial scale at which the process occurs. Obviously, acoustic studies of individual predator-prey interactions require a different sampling scale than that of system wide acoustic stock assessment programs. Examples of how high-resolution, spatially-explicit (i.e. retrieval grid data) acoustic data can be of value in both stock assessment programs and ecologically-based studies are provided below.

Acoustic Target Strength Estimations

The nonlinearity in the relationships between acoustic target strength and fish length and between fish length and fish biomass suggests that target strength conversions be done at least at the scale at which fish sizes are changing in the field so that the correct target strengths can be used to estimate fish size and to convert echo integration data into density estimates. Numerical mean target strengths taken over broad areas in a multi-size population will likely be biased because of the nonlinearity in the transformations. It is difficult to choose an appropriate scale for averaging because changes in fish sizes can occur at different vertical and horizontal spatial scales and different-sized species or different-size fishes within a species may have different scales of patchiness (e.g. Rose and Leggett 1989; Brandt et al., 1991a).

Identification of Acoustic Targets

Identification of acoustic targets is a key issue if species-specific abundance data are needed. The ability of acoustics to measure the abundance of a single species in a multispecies environment will always be limited by the level to which relative species composition of acoustic scatterers can be determined. One technique is to proportionally allocate total abundance measurements to different species on the basis of independent target identification procedures such as aimed trawling. The precision and accuracy of these biomass estimates, however, would be directly proportional to that of the 'ground truthing' technique (Brandt 1989). Acoustic identification of species at finer scales of resolution may be possible using extraction of signal features per se (Rose and Leggett 1988) or by using species-specific habitat distributions in which the biomass is allocated to different species on the basis of the type of habitat from which the measurements were taken (Brandt 1989). Fish often have specific habitat requirements and orient to specific habitat features (such as water temperatures) but fish distributions can also change dielly, seasonally or in direct response to species interactions. The above suggests that in situ identification of acoustic targets be done at least at the same or finer scale than that at which the species are segregated or at which the distributions are changing in time.

Changes in Distribution and Abundance

Fish often change their distributions in response to short term and long term changes in physical (e.g. upwelling, seasonal thermal structure) and biological conditions (e.g. availability of sufficient prey). Both of these have been documented for the Arctic Cod (Rose and Leggett 1990). If changes in distribution result in changing the proportion of the population that is available to the sampling gear, then sampling could be biased. This would occur if fish were disproportionately pushed into areas that could not be sampled by acoustics (near shore, near surface, near bottom) or the bottom trawl (more pelagic), or if some of the population moved out of the sampling region. High resolution spatial information may help to detect these potential sources of error.

Spatial Statistics

Marine biota are typically patchily distributed (Steele 1978; Bennett and Denman 1985; Nero et al. 1990) and patchiness at different scales is likely caused by the processes operating at each scale (Gower et al 1980; Carpenter 1988; Powell 1989). It has been argued that an evaluation of biological patchiness and its scale-dependent linkages to the physical system is essential if we are to understand the mechanisms regulating production processes and dynamics in the sea (Legendre and Demers 1984; Margelef 1985; Powell 1989; Hofmann 1991; GLOBEC 1991) and other aquatic systems (Carpenter 1988). Estimating true variance, patchiness and spatial statistics of a population and its relationship to the physical dynamics (e.g. water temperature, light) should help survey design and data stratification in stock assessment programs.

Ecologically-based Fishery Science

Acoustic data can be used to evaluate higher-order features of the environment such as fish production and can help fisheries scientists to understand the mechanisms causing changes in the distribution and abundance of the population. An example from ongoing research on the Chesapeake Bay will be used to illustrate this application.

APPLICATION TO ESTIMATES OF FISH PRODUCTION

AVAIR

A prototype Acoustic Visualization and Information Retrieval (AVAIR) system has been developed to provide a computer environment (SUN workstation) with a full range of tools with which to import acoustic sensor data (in real time or archived form), apply algorithms to extract biological features and to interactively analyze and visualize these quantities with high-resolution color images at each processing step. Acoustic information retrieval refers to any and all of the various data manipulations-signal transmission, signal processing, data cross correlations, statistical feature extractions, biological feature extraction and estimation, setting of model boundary conditions, model validations and the like - that is possible when moving from raw acoustic signals to acoustic images to images of biological features and finally to higher-level features of biological processes and rates. The AVAIR system is based on recent developments in applications and visualization-prototyping environments and the design concept is based on a graphical interface with all system functions in the form of processing boxes or modules.

The pairing of visualization and computational feature estimation is a guiding design for the developing AVAIR system. An important aspect of bioacoustic sensor data and the various levels of information derived from it, is the occurrence of large data arrays-data from fine-scale sampling of extended spatial regions, measured either periodically or continuously. By combining visualization capabilities with signal and data processing modules, the system provides the user the capability to visualize the large data sets of acoustics, typically images and to interactively, and adaptively operate on that data each step in the hierarchy of data reduction and feature extraction. With this technique it should be possible for the user to analyze the observed biological spatial structure by applying local and global feature estimation algorithms that exploit the inherent spatial resolution of the specific acoustic sensor system.

Fish Production Potential

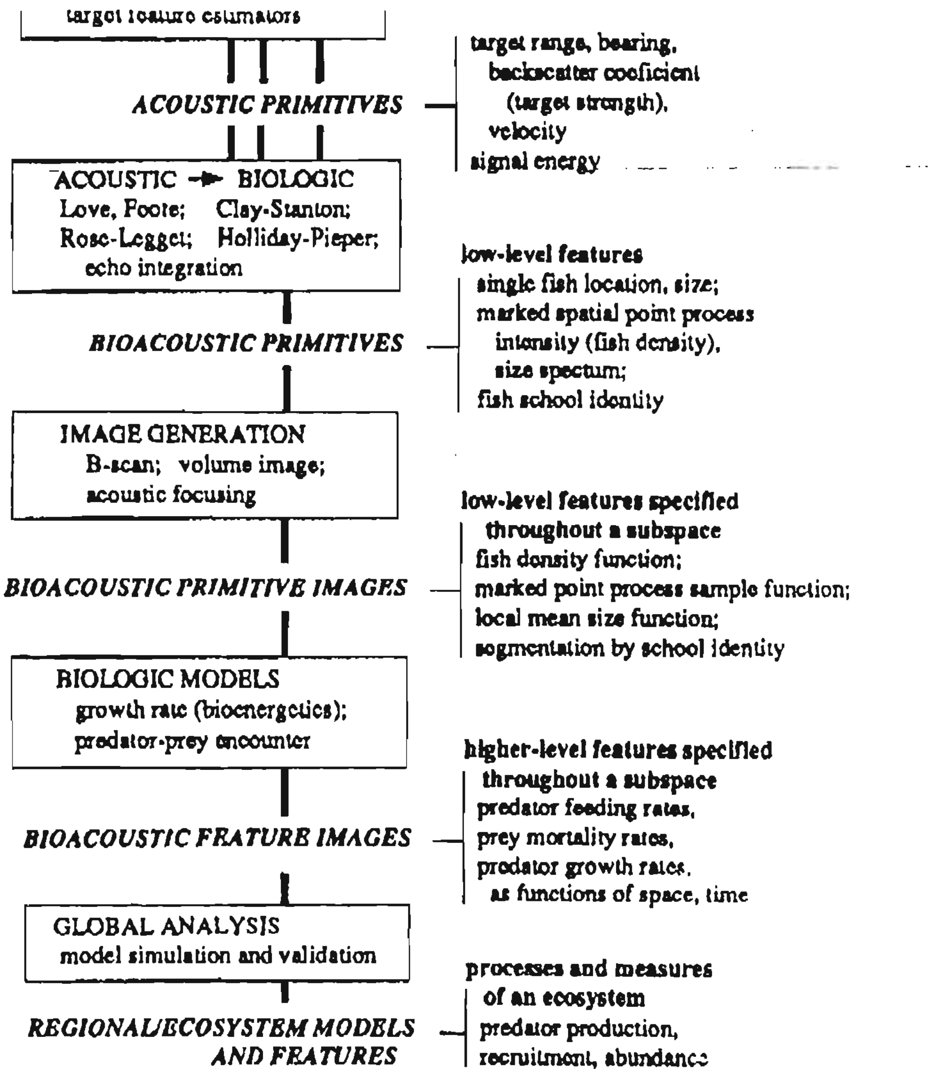
The production potential of a fish population is a function of both the mortality rates and the growth rates of individuals within the population. Fish growth rate is a function of the innate growth potential/limitations of the species and the habitat conditions (e.g. available prey sizes and densities, water temperature) at which the growth must occur. A conceptual framework for the focus on fish production is given in Figure 2. Fish production is determined by the supply of prey resources and the amount of prey that the fish requires for growth (predator demand). The functional relationship between supply and demand depends on the particular temperature-dependent physiological needs and growth rate potential of the predator and on the ability of the predator to make use of the prey supply. Prey densities and sizes are measured acoustically and incorporated into a species-specific bioenergetic models (Hewett 1989) to simulate fish growth rate potential under the observed field conditions.

Predator-prey interactions can also be strongly influenced by the spatial environment (Porter et al. 1975; Cox et al. 1982; Karieva and Anderson 1988; Possingham and Roughgarden 1990). Laskers' (1978) work, perhaps, most clearly demonstrates that average values of prey density may be meaningless to the predator and that patch spatial structure is critical to growth and survival. It would be just as meaningless to input an average water temperature and average prey density into a fish growth model to estimate average fish growth without consideration of the predator's and prey's distributional overlap across a rate-determining heterothermal environment.

Data from the Chesapeake Bay are used to illustrate that trophic supply and demand relationships cannot be entirely understood based on systemwide averages of predator and prey abundances. Spatially - explicit acoustic measurements of fish size (mm) and numerical density (#m^{-3}) across a 7.5 km section of the Chesapeake Bay are combined with temperature information and bioenergetics models of fish growth to produce a two dimensional, spatially-explicit, biophysical model of fish growth and system production. Such spatial maps of growth rate potential in effect depict the habitat suitability of the predator by integrating the predator's physiological needs with the prevailing conditions of the physical habitat and food supply. The resultant functional response has a nonlinear relationship to field conditions and spatial statistics and dynamics that differ from those of the underlying physical and biological structure of the system.

This approach goes beyond the simple (but essential) correlation of biological and physical structure to model the functional response field of fishes to their physical and biological habitats. The data can then be used as a spatially-explicit framework for assessing fish growth rates and system production at various time scales and their dependency on predator behaviour and physiology and on the spatial patterning within the environment.

FIGURE 1


target feature estimators
ACOUSTIC PRIMITIVES
target range, bearing,
backscatter coeficient
(target strength),
velocity
signal energy
ACOUSTIC → BIOLOGIC
Love, Foote; Clay-Stanton;
Rose-Legget; Holliday-Pieper;
echo integration
low-level features
single fish location, size;
marked spatial point process
intensity (fish density),
size spectum;
fish school identity
BIOACOUSTIC PRIMITIVES
IMAGE GENERATION
B-scan; volume image;
acoustic focusing
low-level features specified
throughout a subspace
fish density function;
marked point process sample function;
local mean size function;
segmentation by school identity
BIOACOUSTIC PRIMITIVE IMAGES
BIOLOGIC MODELS
growth rate (bioenergetics);
predator-prey encounter
higher-level features specified
throughout a subspace
predator feeding rates,
prey mortality rates,
predator growth rates,
as functions of space, time
BIOACOUSTIC FEATURE IMAGES
GLOBAL ANALYSIS
model simulation and validation
processes and measures
of an ecosystem
predator production,
recruitment, abundance
REGIONAL/ECOSYSTEM MODELS
AND FEATURES

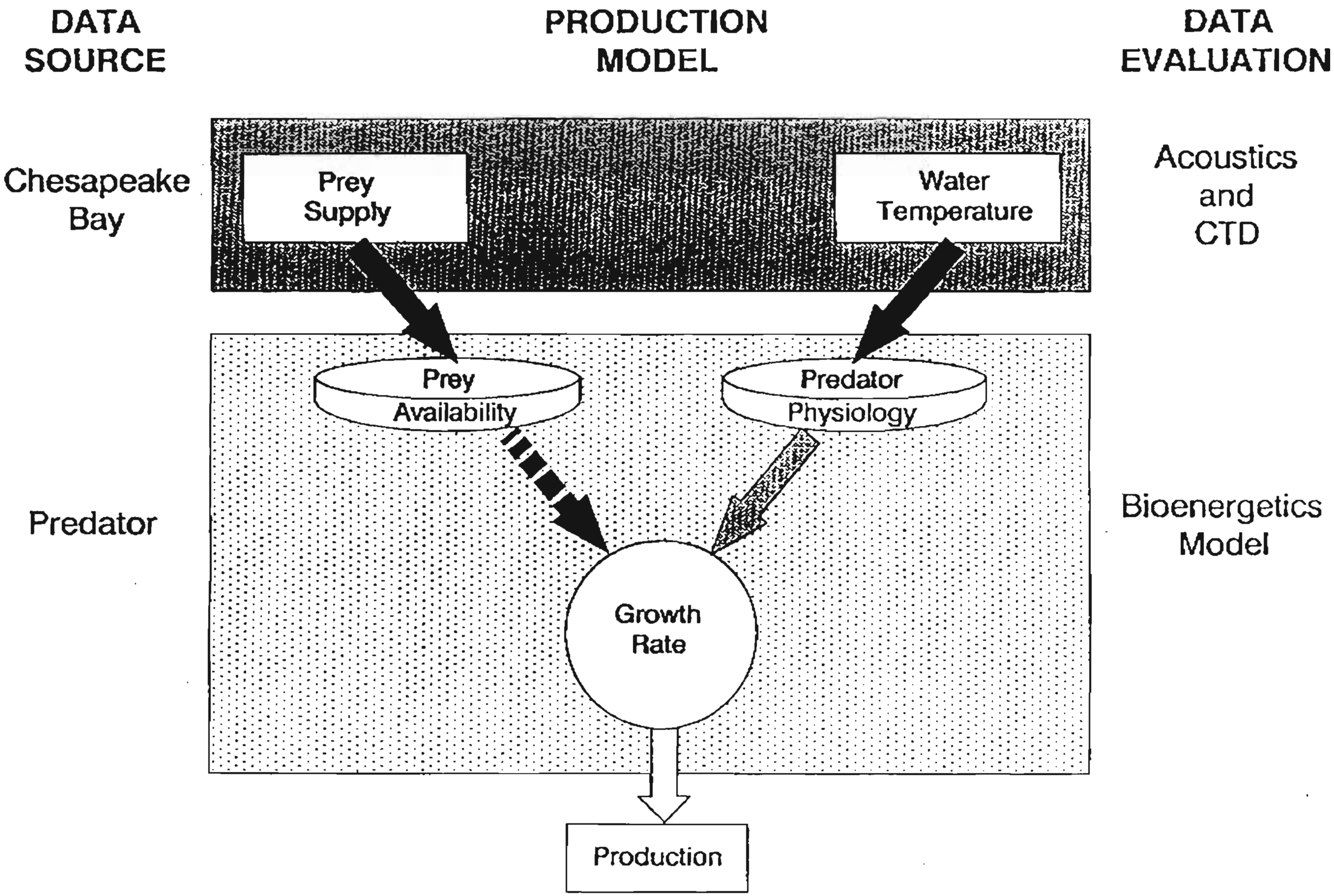

DATA SOURCE
PRODUCTION MODEL
DATA EVALUATION
Chesapeake Bay
Prey Supply
Water Temperature
Acoustics and CTD
Prey Availability
Predator Physiology
Predator
Bioenergetics Model
Growth Rate
Production

FIGURE 2

HARDWARE AND PROCESSORS:

THE SIMRAD EK500/BI500 SCIENTIFIC SOUDER SYSTEM

by

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SUMMARY:

After some general considerations on data quality, the EK500 Scientific Sounder is briefly described. The main objective with this paper is to present the various data obtained by the EK500, and how the data is processed.

The BI500 interactive post processing system for distributing the echo data on species and/or year classes is also presented.

1. INTRODUCTION

Under or over estimation of fish stocks may have severe economic consequences, and this sets high requirements on the quality of data collected by fisheries research vessels. The various sensors produce a lot of data, and the quality of these data should always be questioned and monitored to assure the best possible survey result. With today's computer technology, the data collected can be processed and presented in many ways. It is important to bear in mind, that the final result can be no better than the qualify of the raw data.

The data quality depends on many factors:

1. Sensor (Echo sounder)

2. Sensor platform (Research vessel)

3. Media (Water)

4. Target (Fish behaviour/position)

5. Instrument operator (Technician)

6. Data interpreter (Scientist)

The scientific sounders have been tremendously improved since the first type came onto the market in the early 60s', and the research vessels have also been greatly improved as instrument platforms.

There is little one can do with the media and the fish, except to try to survey when conditions are most favorable.

This paper describes a scientific sounder, and a new tool for efficient and reliable interpretation of the acoustic data.

2. THE EK500 SCIENTIFIC SOUNDER SYSTEM

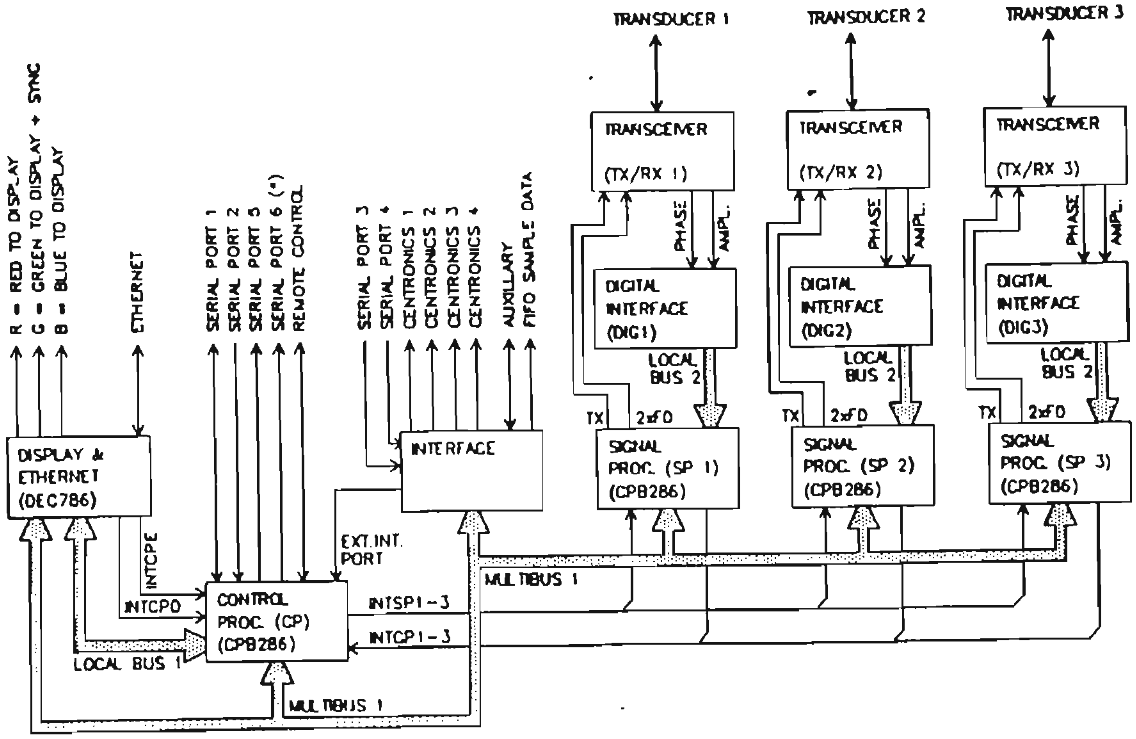
Figure 1 shows a block diagram of the complete EK500 system.

State of the art technology is implemented throughout, resulting in a compact system performing many functions. Operating three transceivers simultaneously allows comparison of echo strengths on different frequencies. The split-beam principle is available for 38 and 120 kHz.

The principle of operation is explained in 1) Bodholt et al, 1988.

Table 1, page 8, shows the detection capabilities for the sounder at various frequencies.

Figure 1. EK500 Block diagram



2.1 MAJOR INNOVATIONS

The most important advancements and new features compared to earlier scientific sounders are considered to be:

a) The new receiver concept giving an instantaneous dynamic range of 160 dB and low receiver noise level. This allows measurements of all practical target sizes over the entire depth range without changing any gain settings.

b) The receiver does not have any TVG (Time Varied Gain) function as the range compensation is done solely in software.

c) Split-beam method makes calibration easy and allows for in situ transducer beam compensation. 2) Degnbol, 1988.

d) Split-beam gives fish TS (Target Strength) and angular position. Allows tracking of fish through the sound beam and measurement of TS as function of fish position. 3) Brede et al, 1987.

e) Solid bottom detection algorithm. Gives good bottom detection even for steep bottom slopes.

f) High resolution 12-colour echogram with calibrated colours and tables for S_A (Fish backscattering area) and TS distribution.

g) Raw-data and processed data available at RS232, Centronic and Ethernet interfaces.

h) Remote control and logging of echo sounder settings. This allows easy operation and reduces the likelihood for mistakes due to incorrect use.

i) Sound velocity as a function of depth can be given as input to the sounder. This ensures correct range compensation and echogram presentation.

j) Up to four printers can be connected to the sounder for echogram and/or data presentations. All printers can be set individually with respect to echogram parameters such as frequency, range, range compensation, etc.

In addition to c) above, a program has been developed to assist beam pattern measurements and improve the EK500 beam compensation.

The program is run on an IBM AT or equivalent computer connected to the EK500 serial 1 port. To measure the beam pattern, a reference target sphere is pulled through the beam in many directions until most of the beam is covered.

The areas covered by the sphere are indicated on the pc screen to help decide when the beam is sufficiently covered. The program then calculates the parameters to be used by the EK500 software for the best possible beam compensation.

Figure 2, page 9, shows typical displays from this program.

2.2 INTERFACES

As shown in Figure 1 the sounder has six serial ports, four parallel Centronics ports, one Ethernet port and one FIFO port.

The Centronic ports are used for transferring echogram data, TS distribution and layer integration tables to the printers.

Various ping based and log based data are available on an RS232 serial port and the Ethernet port. The Ethernet transfers echogram data to the BI500 post processor.

Raw sample power data and sample angle data are available on the Ethernet and on the FIFO port for those who wish to do their own processing of the raw data.

2.3 DATA TYPES AND FORMATS

Sample data:

"Sample data" are data which are output every time sample is taken. The sample distance ranges from 2 cm at 200 kHz to 40 cm at 12kHz operating frequencies.

- Sample power data.

The sounder with its new receiver concept is basically a power meter measuring echo power levels from 10^{-16} Watt to 1 Watt at the transducer terminals.

The sample power data is the raw data of the sounder, and no form of processing is applied except calculating the power level.

The power levels are presented in logarithmic (deciBel) format as 16 bit words. The eight most significant bits correspond to the integer part relative 3.0103... dB and the eight least significant part to the fractional part.

This gives approximately 0.01 dB resolution in the sample power data.

By using the most modern instruments and automation in the final testing of the sounder, an accuracy of +/- 0.2 dB over the wide dynamic range is achieved.

- Sample angle data.

Sample angle data from the split-beam transceivers are provided for special purpose studies. The fore-and-aft and athwartships electrical angles are output as two 8-bit words: the fore-and-aft as the most important byte and the athwartships angle as the least significant byte.

- Sample S_v and sample TS data

From the measured power level, volume backscattering strength and target strength are calculated. The algorithms used are based on a physical model that accurately accounts for instrumental effects and propagation losses.

The sample S_v data provide volume backscattering strength sample data; power sample data with 20-log r range compensation and the proper instrument constant to give S_v added.

The sample TS data provide target strength sample data; power sample data with 40 log r range compensation and the proper constant to give TS added.

The sample S_v and TS data are output in the same dB format as the sample power data explained above.

Ping based data telegrams.

This is data output for every ping or sounding and the following data are ping based:

- Depth.

The depth telegram contains: Header, time tag, depth (meter) and bottom surface backscattering strength (dB).

The bottom detection algorithm is implemented solely in software, and separate algorithms are run for each transceiver channel.

The algorithm is designed with emphasis on reliability in the sense that erroneous depth detections are never output. Whenever uncertainty is associated with a detection, zero depth is output to indicate that no reliable detection was obtained.

The algorithm maintains bottom lock for a discontinuous jump in depth, and special features are included to avoid false bottom detections on fish schools.

Operational experience shows that the algorithm is indeed quite robust.

- Echo Trace.

The echo trace telegram contains single-echo detections in one ping with header, time tag, number of single echo detections (max. 30), depth (meter), beam compensation TS (dB), uncompensated TS(dB), fore-and-aft angles (degrees) and athwartships angles (degrees).

- Ping based S_v.

This telegram contains header, time tag, number of active layers, layer number, mean S_v (dB) and effective layer thickness (meter).

- Motion sensor.

If heave, roll and pitch voltages are input to the EK500 on the auxiliary interface, the motion data can be output every ping. The telegram includes header, time tag, heave (meter), voltage at roll input (times multiplier) and voltage at pitch input (times multiplier).

Log-based data:

Log-based data are data that are output for every preselected log distance sailed.

- Vessel log.

This telegram reports that a log pulse has been detected and contains header, time tag, date and updated log distance (nm).

- Layer settings.

The layer setting telegram contains the current layer settings with header, time tag, date, current log distance (nm), super layer, number of active layers, layer number, layer type, upper depth (meter), lower depth (meter), margin distance (meter), number of sub layers, and S_v threshold value (dB).

- Integrator tables.

This telegram presents the integration result with each sublayer and contains: header, time tag, date and backscattering area (m^2/nm^2) for each sublayer.

- TS distribution tables.

The telegram includes header, time tag, date, lower boundary of TS range (dB), total number of single echo detections within active layer followed by 24 fields containing detections within each TS class in percentage of total number of detections.

Asynchronous output telegrams.

Examples of asynchronous telegrams are:

- Reports on manual command operation, giving time tag, path and the parameter changed. This telegram ensures logging of any change of echo sounder settings.

- Navigation data.

When navigation data is input to the sounder, the data can also be output and contains header, time tag and position data sub-string.

- Annotation telegram, reports that a comment string has been entered (via serial port 2 or as an input annotation telegram). Contains header, time tag and annotation string.

- Status telegram.

This reports errors, warning and alarms with header, time tag and message string.

2.4 THE ECHOGRAM

The echogram is an important source of information and the EK500 echograms show most of the EK500 data. Echograms are presented on a 14" or 20" RGB monitor and may be printed on up to four printers. The monitor and printers can be individually set for different ranges, frequencies and echogram types.

Figure 3, page 10, shows the echogram layout.

The 12 echogram colours represent either target strength or volume backscattering strength depending on the range compensation chosen. There is a 3 dB step between each of the 12 colours, and the TS or S_v value corresponding to the "weakest" colour, gray, can be pre selected.

Integrator tables and TS distribution tables for up to 10 depth layers are printed out on the echogram at the selected log intervals. The echogram printout includes information on colour scale, transceiver and range in use.

3.0 The BI500 POST PROCESSING SYSTEM

Although the EK500 produces a lot of data processed to different levels, and present these in high resolution echograms, the most difficult part of the job remains. That is to interpret the data collected and distribute the integrated echo values on the various species and year classes contributing to these values.

The Institute of Marine Research, Christian Michelsens Institute and Simrad Subsea have cooperated in developing an interactive post processing system to assist the marine scientist in this difficult task.

The result of the cooperation is the Bergen Echo Integrator, 4) H.P. Knudsen, 1990, marketed by Simrad under the name BI500.

The BI500 is a software product based on worldwide accepted standards and runs on a standard graphics computer. Figure 4, page 11, shows the hardware components of the system and its connection to other sensors on board the vessel. All input data to the BI500 arrives via the Ethernet interface. This includes:

- Echo sounding data, navigation data and vessel log distance data from an EK500
- Salinity/temperature/depth profiles from an STD processing station
- Biological catch data from a trawl sample analysis station
- Weather data from a meteorological station

The BI500 user interface provides commands for EK500 remote control, EK500 data reception, survey adminstration, interactive data interpretation and output data generation. All EK500 settings can be controlled from the BI500, and the response of control commands is shown on the BI500 display. Commands for reading, loading and comparing complete EK500 parameter sets are also provided.

The following windows are typically active during interactive interpretation of survey data:

- File Selection. This window is used for selecting input data to the Scrutinize program.

- Echogram. A large window showing Ek500 echo data as a colour echogram. Layer lines separating the various fish species can be drawn inside the echogram using a mouse.

- Target strength. A bar chart shows statistical distribution of target strength based on single fish detections from the EK500.

- Interpretation. In this window, integrated echo level (within each layer drawn in the Echogram window) is associated with individual species.

- Survey Grid. A geographical map of the survey area showing vessel track plot, wind directions and various survey events.

- Salinity Temperature Depth. STD profiles from the STD processing station are shown.

- Trawl Statistics. Catch data from the trawl sample analysis station are shown.

Both processed and un-processed data is stored in the BI500 relational data base, and the SQL language provides a broad and powerful interface to the data. However, high volume EK500 echo data is stored in standard UNIX files. A few ready-to-use programs are provided for generation of output data; printed tables and data base dump to tape.

3.1 BI500 ECHOGRAM WINDOW

Figure 5, page 11, shows the echogram window with the interpretation window in the lower left corner. The window displays the colour echogram for one file set at a time. The horizontal echogram range is five nautical miles corresponding to one complete file set. The horizontal resolution is 1000 pixels, one pixel per EK500 log telegram. The vertical range is controlled by EK500 settings. The resolution is 500 + 150 pixels, one pixel per data element in the EK500 echogram telegram. The echogram window comprises four fields: the Pelagic Echogram field, the Bottom Echogram field, the Colour Scale field and the Zoom field. The Pelagic Echogram field displays a 1000x500 pixel pelagic echogram. Layer lines separating the various fish species can be drawn inside the echogram, and a school of fish is defined by positioning a rectangle around it. The Bottom Echogram field displays a 1000x150 pixel bottom echogram. A bottom detection line defines the lower boundary for echo integration. Commands for manual editing of this bottom detection line are provided. The Colour Scale field displays the relation between colours and volume backscattering strength. The colour scale can be set to cover volume backscattering strengths from -91 to -12 dB. The lower edge of the colour scale defines the threshold value for echo integration implying that echogram areas having a white colour are not integrated. The Zoom field displays a magnified view of an echogram part chosen by means of a cursor.

3.2 THE INTERPRETATION WINDOW

This includes mechanisms for assigning integrated echo level to individual fish species. One layer or school at a time, called the current region, is interpreted. The current region is selected in the Echogram window. Basically, the assignment procedure involves splitting the total integrated echo level within the current region into separate contributions from individual species. A maximum of seven species can be assigned a contribution within each region, and the assignment factor per species is set by operating the seven scroll bars.

Data is stored with a selectable horizontal resolution of 0.1, 0.5, 1.0, or 5.0 nautical mile.

4.0 CONCLUSION

The EK500/BI500 combination is a Scientific Sounder and Post Processing system based on 30 years experience in scientific sounder development and fisheries research.

The instrumentation provides high quality data processed to different levels, and these data are available at interfaces meeting today's prevailing standards.

The system based on state of the art technology opens up for continuous development and improvements. The feedback from the end users contributes substantially to this development.

Application software utilizing the data available at the system interface, and to be run on standard PCs, has already become available, and more are expected to come as the number of users increases.

TABLE 1. EK500 DETECTION CAPABILITIES

PERFORMANCE

Computed maximum range for typical operational conditions:

transd. type	freq. [kHz]	power [kW]	A [m]	B [m]	C [m]	D [m]
67CA	12	4	-	740	6000	13000
63BA	18	4	-	990	4700	8100
38-7	38	2	-	1000	2500	3400
49-26	49	2	-	780	1700	2400
120-25	120	1	-	380	700	940
200-28	200	1	-	310	530	680
ES38B	38	2	640	1000	2500	3400
ES120	120	1	250	380	700	940

GENERAL ASSUMPTIONS:

- Sound absorption according to Francois & Garrison, JASA Dec. 1982 (temperature = 10 degree Celsius, salinity = 35 parts per thousand, depth = 250 meter, pH = 8)
- Total acoustic noise spectrum level is: 142 - 20 • log(f) dB rel 1 μPa per $\sqrt{\text{Hz}}$ where f is the frequency in Hz (typical noise level for medium size vessel at 10 knots)

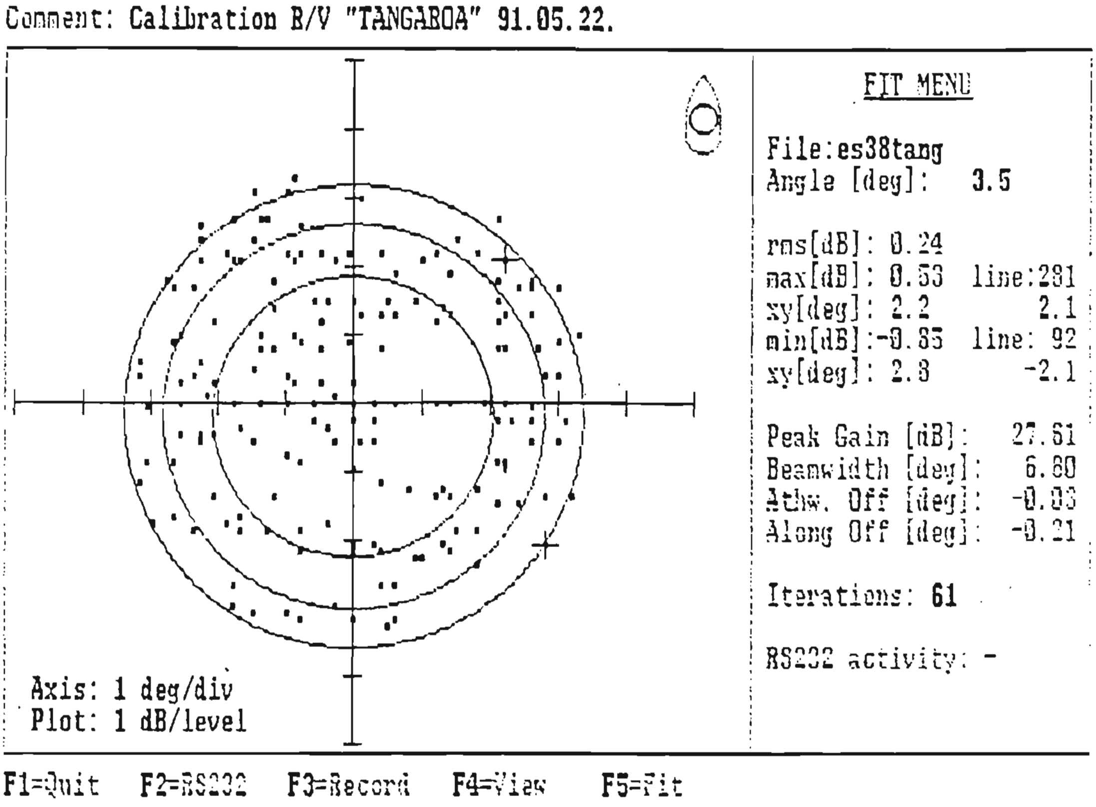
Range A (maximum range for automatic single fish detection)
TS = -30 dB (target strength)
Medium pulse length and wide receiving bandwidth
SNR = 20 dB (single-to-noise ratio)

Range B (maximum range for observation of a single fish on display or printer)
TS = -30 dB
Long pulse length and narrow receiving bandwidth
SNR = 10 dB

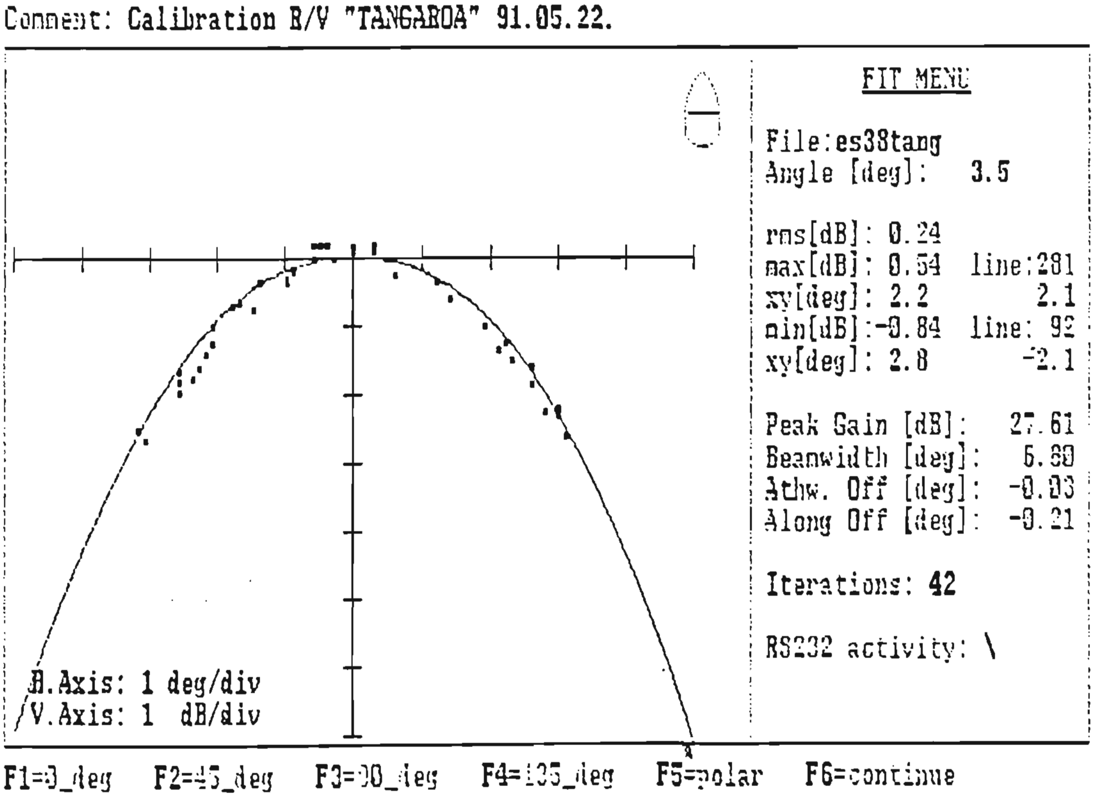
Range C (maximum range for automatic bottom detection)
S_s = -10 dB (surface backscattering strength)
Medium pulse length and wide receiving bandwidth
SNR = 20 dB

Range D (maximum range for registration of bottom contour on display or printer)
S_s = -10 dB
Long pulse length and narrow receiving bandwidth
SNR = 10 dB

FIGURE 2. BEAM COMPENSATION PLOTS



```
Comment: Calibration B/V "TANGAROA" 91.05.22.

                                   FIT MENU

                                   File:es38tang
                                   Angle [deg]:    3.5

                                   rms[dB]: 0.24
                                   max[dB]: 0.53  line:281
                                   xy[deg]: 2.2        2.1
                                   min[dB]:-0.85  line: 92
                                   xy[deg]: 2.8       -2.1

                                   Peak Gain [dB]:   27.61
                                   Beamwidth [deg]:   6.80
                                   Athw. Off [deg]:  -0.03
                                   Along Off [deg]:  -0.21

                                   Iterations: 61

 Axis: 1 deg/div                   RS232 activity: -
 Plot: 1 dB/level

F1=Quit    F2=RS232    F3=Record    F4=View     F5=Fit
```



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Comment: Calibration B/V "TANGAROA" 91.05.22.

                                   FIT MENU

                                   File:es38tang
                                   Angle [deg]:    3.5

                                   rms[dB]: 0.24
                                   max[dB]: 0.54  line:281
                                   xy[deg]: 2.2        2.1
                                   min[dB]:-0.84  line: 92
                                   xy[deg]: 2.8       -2.1

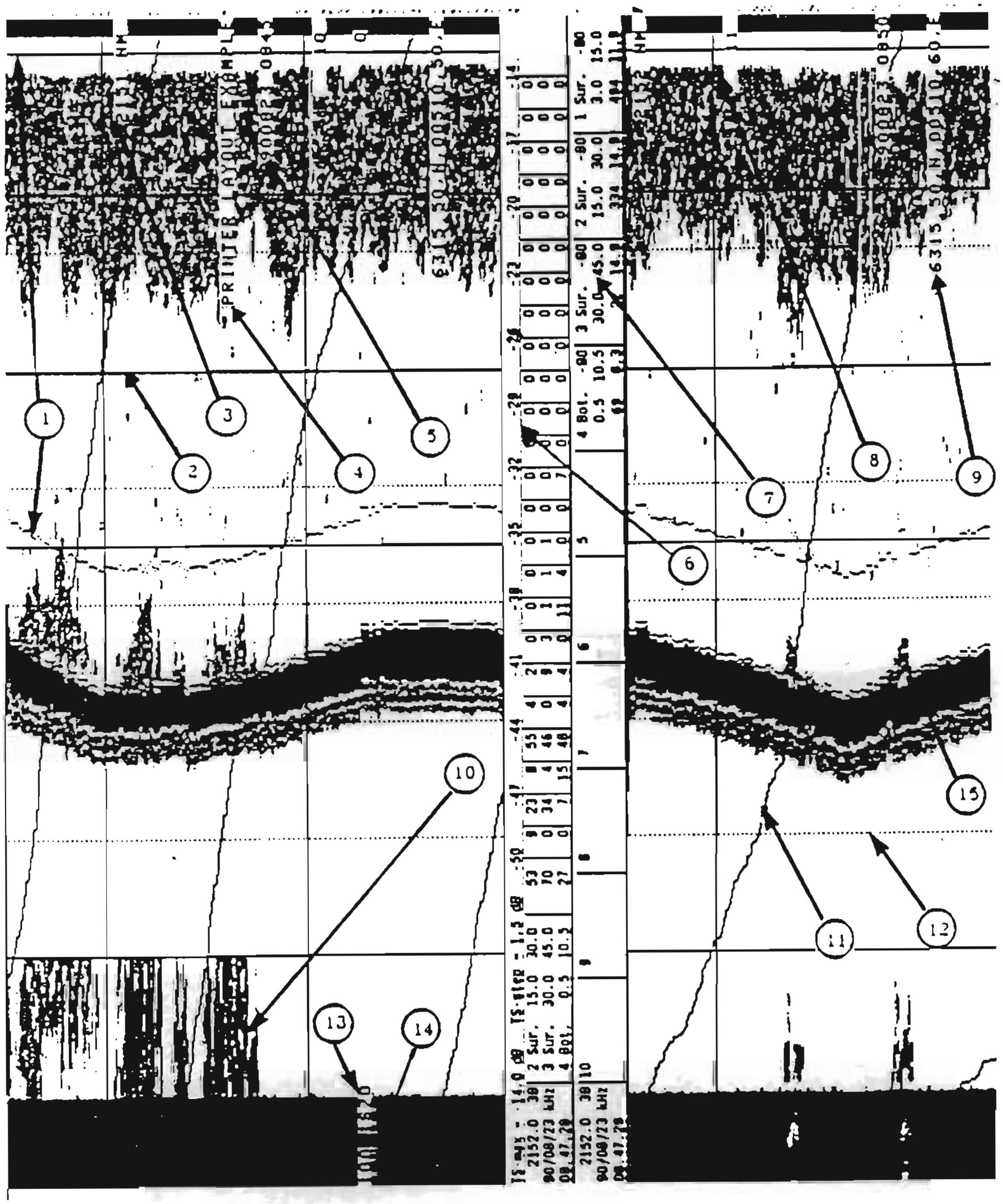
                                   Peak Gain [dB]:   27.61
                                   Beamwidth [deg]:   6.80
                                   Athw. Off [deg]:  -0.03
                                   Along Off [deg]:  -0.21

                                   Iterations: 42

                                   RS232 activity: \
 H.Axis: 1 deg/div
 V.Axis: 1  dB/div

F1=0_deg    F2=45_deg    F3=90_deg    F4=135_deg    F5=polar    F6=continue
```

FIGURE 3. EK500 ECHOGRAM LAYOUT



1 Layer lines	2 Super layer	3 Nautical mile text
4 Annotation	5 Date and time	6 TS distribution
7 Integrator table	8 Event marker	9 Navigation text
10 Bottom range	11 Integrator line	12 Scale line
13 Identification	14 Range lower	15 Bottom line

FIGURE 4. BI500 SYSTEM COMPONENTS

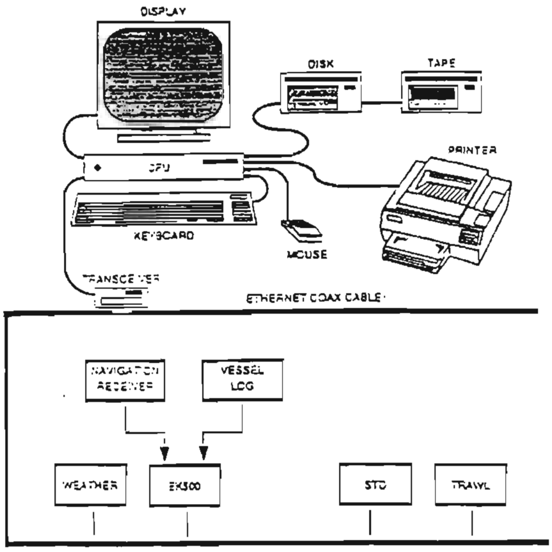
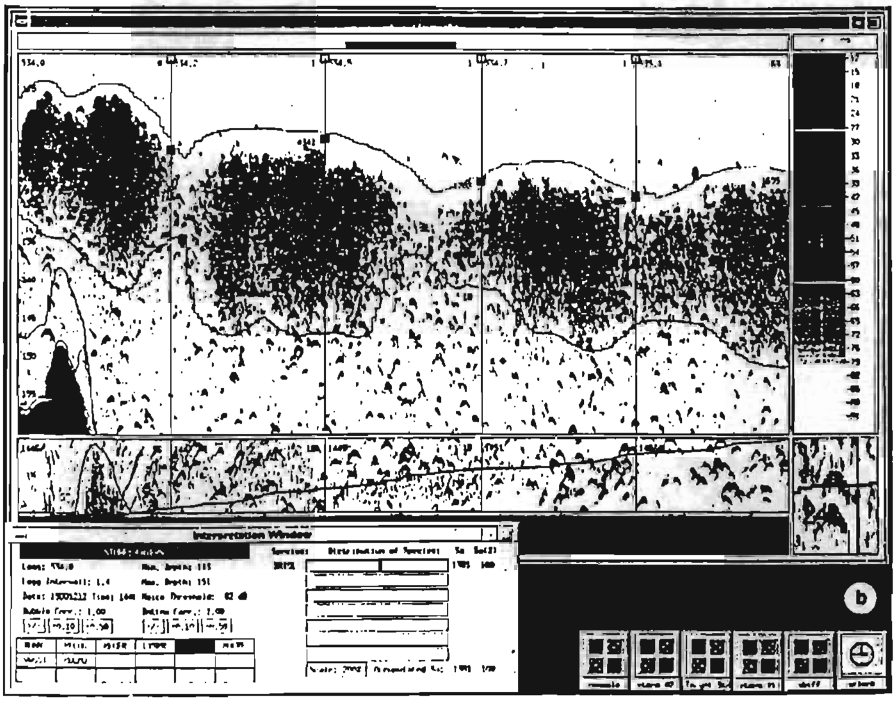


Figure 5. Echogram Window.



COMBINED TRAWL - ACOUSTIC SURVEYS

by

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ABSTRACT

The present paper presents results and methods of trawl-acoustic surveys which were carried out by PINRO research vessels in the Barents and Norwegian Seas and Canadian economic zone to study status of capelin, redfish, haddock and cod stocks. Details of assessment of cod numbers and biomass are discussed. Estimates of numbers and biomass of cod by Soviet surveys are presented.

INTRODUCTION

Some experimental methods used in trawl-acoustic surveys for cod and haddock were tested during PINRO research cruises in 1984 (October - December onboard R/V 'Persey-3') and next year (February - March, R/V 'Kokshaisk'). Extensive statistical data were first collected and processed during those cruises. The data from more than 300 bottom stations were scrutinized together with data of echointegration, which was carried out synchronically in time and depth with trawl stations (Dorchenkov, 1986). Results obtained confirmed the correctness of chosen approach. The TAS technique has been used also in surveys for capelin, cod, redfish in NAFO SA 3 since 1987 Mamylov V.S., 1988, Bakanev V.S., Mamylov V.S. 1988). Methodological aspects and accuracy of estimates from Soviet and Canadian surveys in Divs. 3LN0 were considered in detail in the paper by Mamylov V.S., Korol L.N. and Sergeeva T.M. (1990) on the basis of materials from capelin surveys. Therefore, primary attention in the present paper is given to the discussion of the methods and results from cod/haddock surveys, as these species are among most valuable for the fisheries.

METHODS

The TAS method is based on acoustic measurements of cod layer's backscattering strength (S_s), taken along the survey transects. The layers are usually registered by echosounder and echointegration system, and data from trawl sampling are used to convert the integrator readings to density and biomass. Data from trawl samples are also used in age/length/weight distribution calculations on corresponding fish aggregations. After combining trawl and acoustic estimates (this will be described later), the results are averaged: the whole area is usually divided into several subareas or geographical strata (up to 5 in capelin surveys, 100 in bottom fish surveys or 40 in joint Soviet-Norwegian surveys). Averaging of acoustic and biological data is made individually for each subarea. Numbers and biomass estimates for each subarea are summed.

In dividing the survey area into subareas, the following rule should be observed; for correct averaging, transects should be evenly distributed within a subarea, which is especially important for acoustic data. The planning of transects in cod/haddock surveys differs from procedure used for pelagic surveys, as positions of trawl stations are determined before the cruise. The problem is how to make the transects evenly distributed and the whole trip time shorter. Besides a direction of fish, seasonal migration should be made account of.

For the Barents Sea surveys, standard 40 areas are drawn on the map designed by PINRO personnel. In Canadian waters, standard NAFO strata are used as subareas (Mamylov, 1988). During the capelin survey in this region subareas are constructed after the cruise has been completed and the procedure is based chiefly on density and distribution pattern of fish with different biological properties (Bakanev et al., 1986). The acoustic measurements carried out using echointegration system are based on EK/EKS SIMRAD scientific sounders and SIORS integrators, calibrated on standard copper sphere with accuracy about 0.5 dB. The main process of calculation of acoustic component in the assessment by Soviet experts is similar to that used in joint Soviet-Norwegian TAS (Dalen and Nakken, 1983) and shown in Fig. 1.

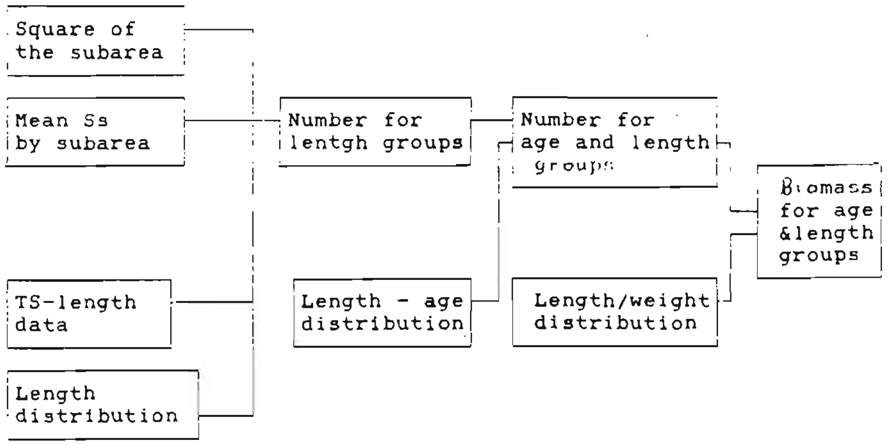


Fig. 1. The block diagram for the calculation of the acoustic component.

The calculation of the bottom component demands more elaborate approach and is based on estimation's comparison, achieved during trawl stations and simultaneous echo integration. For this purpose the bottom channel width is selected the same as the bottom trawl opening. As mentioned before, the calculation of the fish density in bottom layer was conducted using two methods: acoustical (echo integration with geometrical shadow zone coefficient).

$$Mbot = Mbot \times Ksh \qquad (1);$$

and trawl method based on the cath value and efficiency coefficient of the bottom trawl. If mean density calculated on the based of the trawl catches is 1.5 higher than obtained from the echo integration, the trawl method was selected for the density estimation and the following equation was used for the Mtr calculation:

$$Mtr = \frac{P \; x \; 4\pi \quad 10^{0.1\overline{TSkg}} \; x \; 1852}{Ltr \; x \; R} \quad m^2 \; n.m.^{-2} \qquad (2);$$

where Mtr - equivalent echointensity recalculated on the cath value;
P - catch, kg/n.m.;
TSkg - mean target strength, dB/kg;
Ltr - the trawl horizontal opening (25 m for the 2283 bottom trawl);
R - trawl efficiency coefficient (the value of 0.75 is used by Soviet personnel for cod surveys in the Barents Sea).

The Mtr (Mbot) values along transects were linearly interpolated from values on the nearest trawl stations, when no sufficient echo integration readings in the bottom channel and no recordings on the echogram were registered. This method is useful not only by cod surveys in the Barents Sea when fish aggregations are often not registered by echo sounder. The same situation also occurred during capelin surveys in the eastern part of the Great Newfoundland Bank in shallow water in div. 3LN and 3K with the bottom depth less than 300 m, where the capelin aggregations are often distributed near the bottom and so far are, in fact, not registered by echo sounder.

In the case of the mixed bottom concentrations, the same equation was used for species intensity estimation, as used during pelagic fish's surveys.

$$M1:M2:M3:.. = \frac{P1 \; x \; \overline{\alpha} \; kg1}{R1} : \quad \frac{P1 \; x \; \overline{\alpha} \; kg1}{R2} : \quad \frac{P1 \; x \; \overline{\alpha} \; kg1}{R3} : \quad ..(3);$$

where Pi - the catch of the i-th species, fish in the net included, kg;
α kg = 4 x $10^{0.1TSkg}$ - mean acoustic backscattering strength of the 1 kg of the i-th species;
Ri = the trawl efficiency coefficient for the i-th specie.

The trawl efficiency coefficient Ri depends not only on the specie but also on the length distribution of the fish. During surveys onboard r/v 'Persey 3' (March - July 1987) different values of this factor were used: R=1 for the species length L > 10 cm, R=0.3 for L=5..10 cm, R=0.1 for L=3..5 cm.

Approximate 'in situ' values of TSkg for different species and frequency 38 kHz are shown in the Table 1.

The next step is to combine the pelagic and bottom estimates into summary echo intensity.

The main algorithm of the calculation method is shown on the Fig. 2.

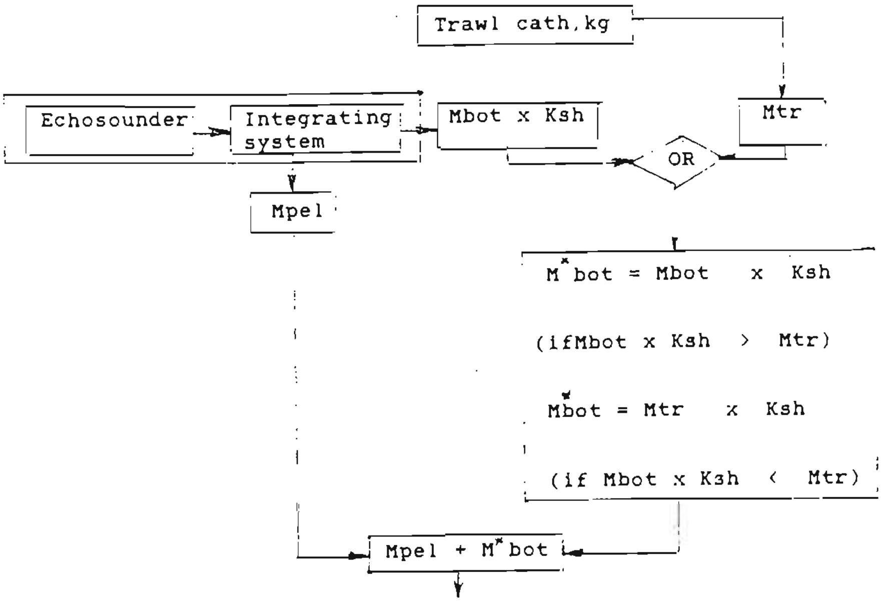


FIGURE 2. THE ALGORITHM OF THE SUMMED ECHOINTENSITY, USED FOR THE FURTHER STOCK ESTIMATION IN TAS METHOD

But simple summing of the bottom and pelagic components is not always correct because the possibility of double estimation exists connecting with fish behaviour, caused by vessel noise and corresponding fish avoidance and vertical migration. Cod and haddock at the depth 200..250 m (what covers practically all the coastal zone of Barents Sea) avoid vessel due to its propeller noise and sink down to the sea bottom, and migration speed can reach 5 m/sec. As a result, the actual fish density near the bottom may increase significantly after vessel has passed and the trawl goes on more dense concentrations as it has been registered by the sounder before, i.e. the same fish are registered first in pelagic layers and later in bottom trawl catch (see Fig. 3).

During 1988 autumn-winter cod and haddock survey in the Barents Sea onboard Soviet r/v 'PINRO', some visual observations of the cod avoidance were carried out using both echogram paper and color display of the echo sounder (Shevelev, M.S., Dorchenkov, A.E., Shvagzhdis, A.P., 1989). The observations were carried out in different depths on the dense registrations of the cod in pelagic layers. During first registration of the aggregation its upper limit could reach 150 above the bottom, so by covering this transect once again in the opposite direction, this upper limited was 50..100 m lower and simultaneously the near bottom density increased. The figure 4 shows the layers, from where the cod goes to bottom trawl with greater probability.

On the basis of these observations, the table of coefficients was suggested for Mtr recalculation (Table 2) and corresponding equation:

$$Mtr = \frac{P \; x \; 4\pi \quad 10^{0.1\overline{TS}kg} \; x \; 1852}{Ltr \; x \; R} - M \; bot^2 \qquad (4);$$

where Mbot2 - echointensity in near bottom pelagic layer, with bottom layer included.

The equation (4) is correct only if Mtr> > Mbot2 and the depth is less than 300 m, because no avoidance effects are evident on larger depths.

RESULTS

So far basic elements of the TAS methods, used at the time by PINRO personnel, are shown. The use of that method in our opinion allows to obtain more correct results, which are more close to the estimates obtained from VPA method. Table 3 contains the number and biomass estimates of the Barents Sea cod delivered by using different methods, based on the data collected onboard r/v 'PINRO' in September - October 1989. The use of acoustic methods alone and integration of pelagic and bottom layer without effects from bottom component leads to underestimation of the number and biomass. So now the discussed method is used as basic by PINRO personnel. Table 4 contains results of the number and biomass estimation for cod and haddock for 1988 - 1990, calculated through the TAS method.

CONCLUSIONS AND RECOMMENDATION

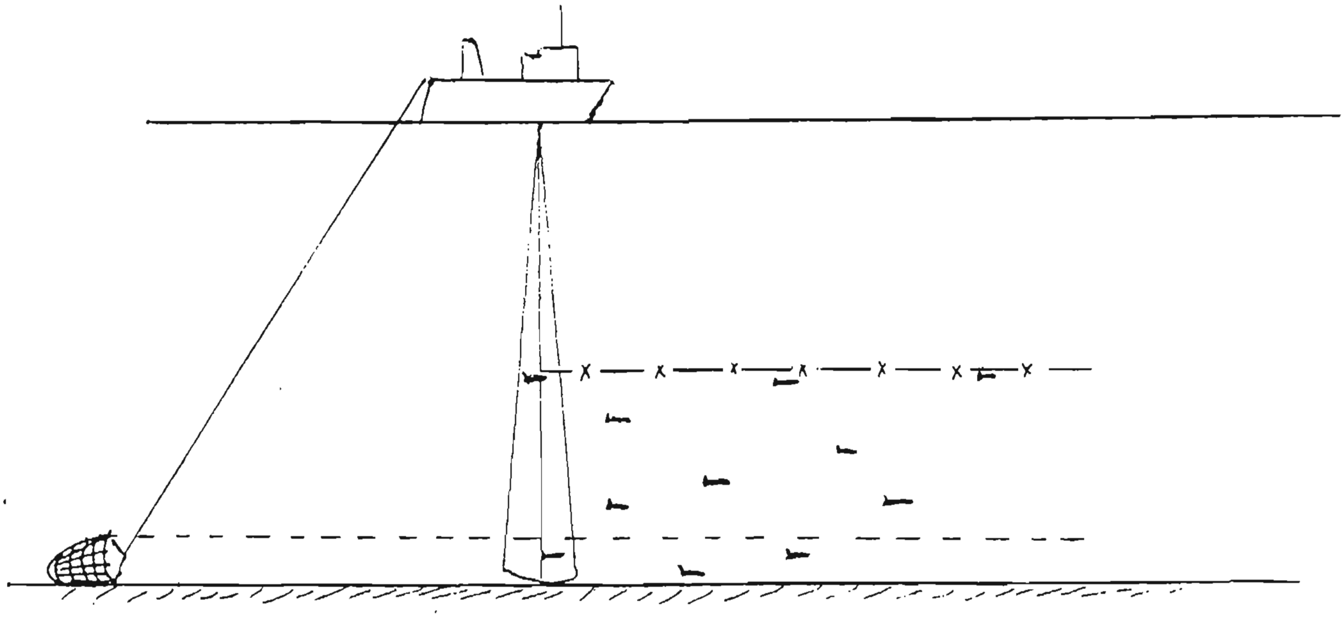
The discussed method of TAS and its data processing is acceptable for stock investigation of cod, haddock, redfish, capelin and other species in the North Atlantic region when the stock estimation is difficult or even impossible by using the pure acoustic or pure trawl methods.

This method allows to decrease the number of bottom trawl stations, what helps to save costly cruise time. Since 1988 the total number of bottom trawl stations in the Barents Sea cod surveys has decreased by about 20%.

Nowadays the time the laboratory of hydroacoustics is developing the corresponding PC AT based software for TAS data collection and processing.

However, some problems still are not solved which have influence on the accuracy of the TAS results:

FIGURE 3



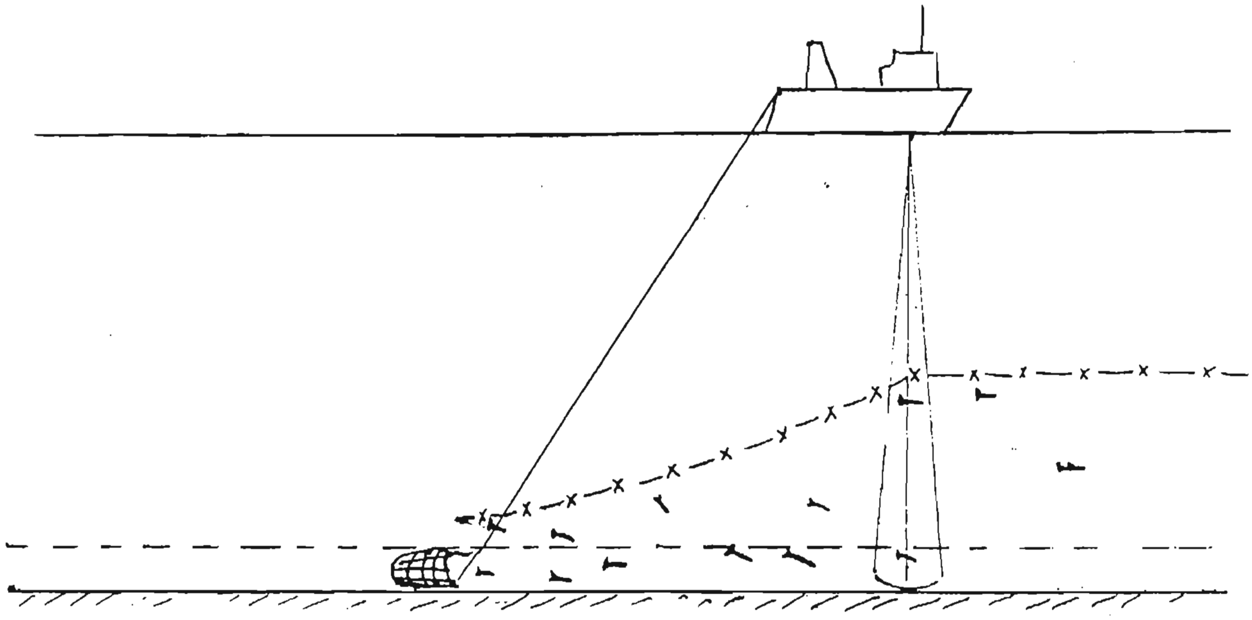
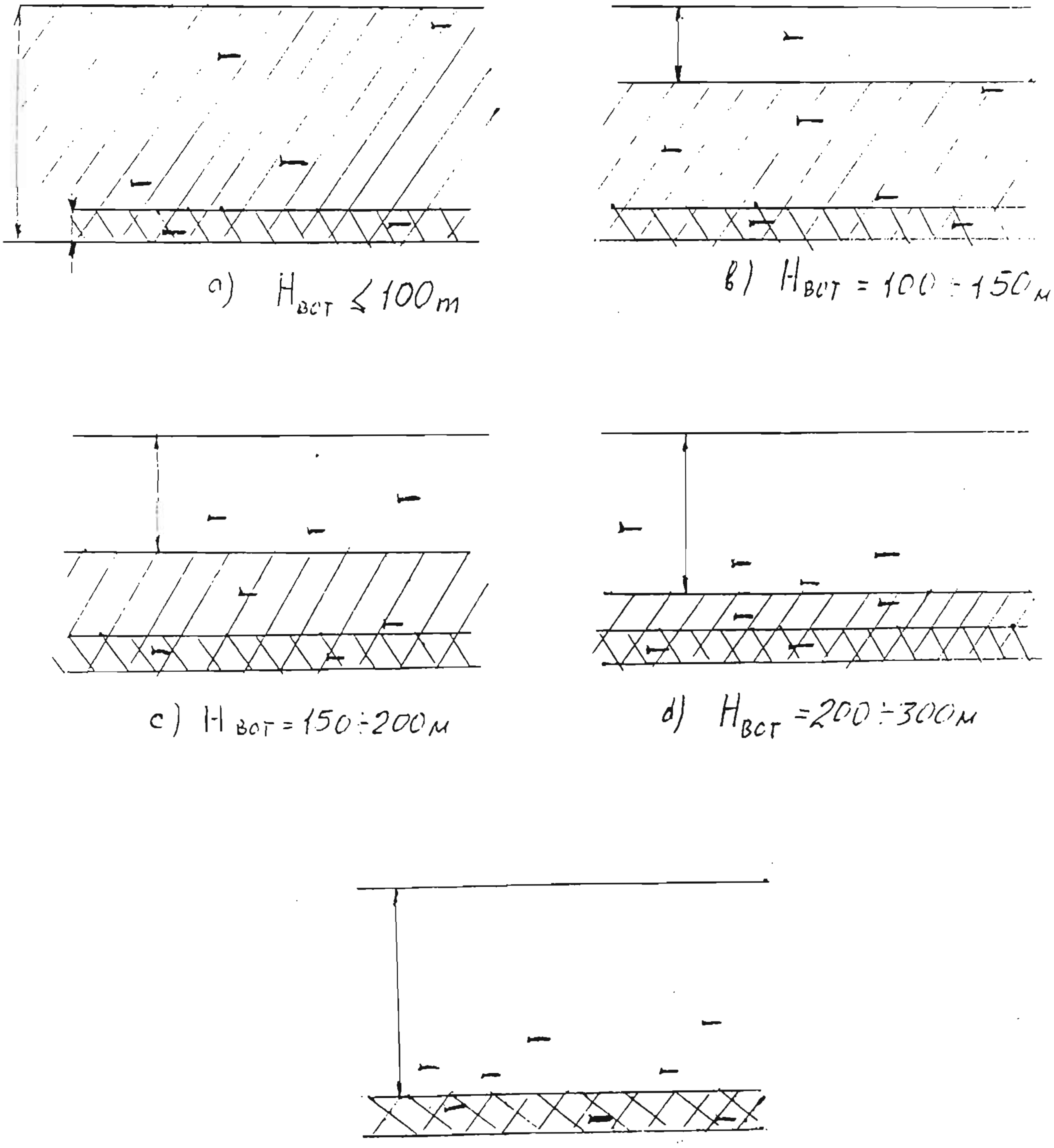


FIGURE 4



a) $H_{BCT} \leq 100m$

в) $H_{BCT} = 100 \div 150м$

c) $H_{BOT} = 150 \div 200м$

d) $H_{BCT} = 200 \div 300м$

e) $H_{BOT} > 300m$

1. For the number and biomass calculation, often the length distributions are used which are based on the bottom trawl samples. The length distribution in upper layer could have significant difference from the near bottom ones. It is clearly seen not only in the case of cod sampling but also in capelin samples from bottom trawl. Capelin in bottom trawl samples is about 10..20% larger than in pelagic trawl, as it is seen from results of Soviet-Norwegian capelin surveys.

2. The trawl efficiency coefficients for bottom trawls used during TAS are still defined to unsatisfactory accuracy.

3. Optimization in time and area during survey planning.

4. Echorecordings scrutinizing by multispecies distribution in the survey area (capelin, cod, haddock, sand eel, young fish, plankton, etc.).

Besides, the investigation of fish avoidance effects have to be continued, its reaction to the outer events.

During joint international surveys the same type of hydroacoustic equipment and trawl gear should be used, if possible, to make data comparison and combining easier.

TABLE 1. RECOMMENDED TSKG VALUES FOR USE IN ACOUSTIC SURVEYS FOR COD, HADDOCK AND REDFISH (FOR 38KHZ ECHOSOUNDER)

Species	Length cm	Weight, g	- TSkg db/kg	TS (L) "in situ"
Cod	8-12	10-27	32.5-33.3	
	12-20	27-80	33.3-33.4	TS = 21.8 x log L
	20-30	80-255	33.4-34.6	
	30-50	255-1140	34.6-36.2	-72.7
	50-70	1140-2900	36.2-37.1	
	70-100	2900-8900	37.1-38.6	
	100-130	8900-23000	38.6-40.2	
Haddock	8-12	14-30	34.0-34.4	
	12-16	30-53	34.4-34.7	
	16-20	53-95	34.7-35.7	
	20-30	95-240	35.7-36.7	TS=16.9 x log L
	30-50	240-1240	36.7-40.1	
	50-70	1240-3440	40.1-42.0	-67.9
	70-90	3440-6260	42.0-42.8	
Redfish	5-8	1,5-6	29.7-34.0	
	8-12	6-21	34.0-36.5	TS measurements
	12-16	21-57	36.5-37.8	"in situ" for
	16-20	57-113	37.8-38.3	different sizes*
	20-50	113-1430	38.3	

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* Data from PINRO surveys for 1983 - 1987.

TABLE 2. M_{BOT} AS FUNCTION OF TRAWL DEPTH

Depth, m	Integral in the bottom channel (M_{bot2})
0-100	(M- M_{bot})x 0.5*
100-150	(M- M_{bot} - M_{0-50})x 0.5
150-200	(M- M_{bot} - M_{0-100})x 0.5
200-300	(M- M_{bot} - M_{0-250})x 0.5
300	0

* Coefficient 0.5 incorporates cod avoidance reaction

TABLE 3. NUMBERS AND BIOMASS OF COD AS ESTIMATED THROUGH DIFFERENT TECHNIQUES USING MATERIALS FROM TAS FOR SEPTEMBER-OCTOBER 1989
(R/V "PINRO")

Technique acoustic		Acoustic		Acoustic+trawl**Trawl
Depth	Bot-	Pela- Total gial	Bot- tom	TotalPela-Bot-TotalPela- gialtomgialtom
Numbers mill.fish	76	99	175	76161237 76175251
Biomass thou.t	161	193	354	161317478161342503

** Pelagic component from integration above bottom channel, bottom component is calculated only from bottom trawlings with linear interpolation of equivalent echointensity between trawling stations along transects.

TABLE 4. NUMBERS AND BIOMASS OF COD AND HADDOCK IN THE BARENTS SEA AS ESTIMATED BY SOVIET TASES IN 1988-1990

Year	Cod Numbers mill.fish	 Biomass thou.t	Haddock Numbers mill.fish	 Biomass thou.t
1988***	602	617	454	426
1989***	251	503	185	105
1989	335	768	293	221
1990	376	834	1004	355

*** The survey was made in September-October, the rest in October-December.

ACOUSTIC PARAMETERS FOR NORTHEAST ARCTIC COD

by
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Eight years ago the stock of blue whiting (Micromesistius poutassou) in the Norwegian Sea was suddenly observed to be in apparent steep decline, as determined by acoustic surveying. In the course of examining the acoustic instruments on board the seven research vessels, from five nations, that participated in coordinated echo integration surveys of the stock, vast differences in performance were observed. Here is a list of ranges for single- or dispersed-fish integration beyond which the influence of threshold was deemed significant: 244, 230, 200, 133, 112, 31 and 8 m. Since blue whiting is naturally deep-water, the difficulty of making unbiased observations in the best of circumstances is obvious; in the worst cases, the task was futile. Other examples can be cited of acoustic surveys of major commercial fish stocks that demonstrate similar dangers of thresholding.

No matter what the performance of an echo sounder is, it has a threshold. For fish of a given size and noise of sufficient level, whatever its origin, the echo signal will be indistinguishable from the unwanted noise. This can be quantified through the effective opening angle of the approximate cone of detection, or equivalent beam angle. This angle decreases monotonically from its maximum near the transducer, but in the transducer farfield, until vanishing at the greatest range of detection.

A particular purpose of this talk is to call attention to the acoustic sampling volume or its differential measure, the effective equivalent beam angle. These quantities are presented together with the more familiar quantity of target strength. In addition to defining and attempting to explain these, methods for computing both the effective equivalent beam angle and target strength are illustrated for the case of northeast Arctic cod (Gadus morhua). Measurement methods are mentioned.

To supplement the presentation, reference is made to the following papers by the author: "Acoustic sampling volume", J. Acoust. Soc. Am. 90(2); "Fish target strengths for use in echo integrator surveys", J. Acoust. Soc. Am. 82(3); "Summary of methods for determining fish target strength at ultrasonic frequencies", ICES J. Mar. Sci. (in press); and "Assigning values of target strength and equivalent beam angle in acoustic surveys of fish", ICES C.M. 1991/B:34.

The present treatment is quite general and may indeed be applied to other fish stocks. It should be clear, however, that better equipment inevitably operates with a lower threshold, and can measure dispersed-fish concentrations that might be entirely missed by inferior instruments. Thus, it behooves the user confronted by marginal or difficult registration conditions to employ the best instruments, as well as the best techniques, available.

EXPERIENCE FROM NORWEGIAN ACOUSTIC SURVEYS ON COD AND HADDOCK

by

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BACKGROUND

Since the start of development of echo sounders, it has been known that the northeast Arctic cod is partly pelagically distributed. This was also a main reason for starting with routine acoustic surveys on cod and haddock (1976) before the initiating yearly bottom trawl surveys (1981). Since 1981 the two survey types have been run simultaneously with a combination of commercial trawler effort and research vessels with the acoustic equipment. These surveys mainly cover the immature part of the population in February in the Barents Sea and in September in the Svalbard area. Also, the February survey is routinely continued along the Norwegian coast towards the spawning area of Lofoten for covering the spawning population. As a curiosity it should be mentioned that fish counting cruises (counting fish traces of paper) were arranged in the Lofoten area before the standard acoustic surveys started in 1982. The results from the acoustic surveys are at present used as independent measurements of abundance in the tuning of the VPA.

The acoustic surveys on cod and haddock in Norwegian waters has played both a direct and indirect important role for the stock assessment:

1. Independent measurement of abundance, used in tuning VPA

2. Continuous horizontal and vertical distribution pattern is obtained for the whole area of distribution

3. Recruitment indices

4. Development of improved survey methods

INDEPENDENT MEASUREMENTS

Due to the lack of a trustworthy model which can combine bottom trawl and acoustic abundance estimates, the assessment working group has utilized the survey indices as independent measurements of abundance. When comparing the bottom trawl and the acoustic surveys' importance in the tuning of the VPA and in the prediction of recruitment to the commercial stock, the acoustic survey has normally been of less importance.

Better acoustic performance in the near bottom zone has therefore been aspired both through improvements of instrument, parameter estimation and data manipulation. Also, the human factor in the judging process has developed in the course of time. In other words, while the bottom trawl is relatively easily standardized through equipment, procedures and routines, the acoustic survey has been under constant development, with an inconsistency in the time series as a possible result.

DISTRIBUTION

Changes in distribution patterns, both vertical and horizontal, may very well influence both bottom trawl and acoustic surveys. Changes in distribution of the stock or a single year class in relation to bottom depth may strongly influence the assessment changes in geometry and performance of the bottom trawl at different depths. Variation in vertical distribution strongly affect the availability of fish to the bottom trawl. Changes in vertical distribution have also clearly affected the results of the acoustic survey due to a) variation in effective beam angle with depth, b) fish avoidance, c) instrument performance. The last factor is strongly affected by weather conditions, mixing with other bottom organisms and individual fish size.

RECRUITMENT

An important task for improving stock management is to estimate reliable recruitment before a year class enters the fishery. In the Norwegian Surveys, this has turned out difficult for age 1 and 2 fish both due to fish distribution, instrument performance and not to forget the highly selective properties of the sampling trawls used to identify the acoustic recordings. The uncertainty is particularly connected to the pelagic sampling due to avoidance reaction.

IMPROVEMENT OF SURVEY TECHNIQUES

The experience from Norwegian surveys has clearly showed the necessity of developing improved survey techniques to be able to apply all information from our gadoid surveys. This development work fall into three categories:

1. Improve efficiency of the sampling in the bottom trawl survey by using acoustic information about fish density and distribution,

2. Systematic recording of "survey condition" with the aim of estimating adjustment factors based on observed variation in environmental, ecological and behavioral conditions.
3. Improving one of the estimates by use of information from the others.

The goal for the future is that this strategy will in the end lead us to reliable estimates of absolute abundance.

COMBINED TRAWL/ACOUSTIC SURVEYS

by

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BACKGROUND

Combined trawl and acoustic surveys on demersal/semipelagic fish are normally carried out due to three principal reasons/purposes:

1) inability of a single method to record and quantify fish in the whole water column,

2) the need for "independent" measurements of abundance to be able to improve quality control of the individual estimates of abundance as well as the biological parameters,

3) to ameliorate estimation of absolute abundance based on a method of combination of data from the two surveys.

In the history of abundance surveys, a basic paradigm has been the idea of standardization. By using a well defined set of standardized equipment, routines and procedures, it has been assumed that the probability of biased results due to variation of the underwater reality has been minimized. The most extreme standardization is found in bottom trawl surveys, e.g. the Woods Hole Lab still use the same ship and exactly the same trawl as in the early 60's. Now it seems like problems with obtaining replacement materials for the trawls force them to changes and, also, the ship is not quite modern anymore. Even though standardized routines and procedures have been important to acoustic surveys, the obvious gain of utilising technical improvements has led to several changes of instruments in many survey time series. The major reason for the acceptance of such changes in acoustic surveys is the goal of obtaining an absolute estimate of abundance, which contrast the much more timid perspective of the bottom trawl survey, namely to produce a relative index of abundance.

METHOD COMPARISON

When the aim is to combine estimates obtained by using the two methods, a basic harmonized framework is needed. The catch equation is the basis for the bottom trawl surveys:

$$n = qfN$$

where n is the catch and N is stock size and q and f is catchability and fishing effort. In surveys f is controlled, but as q is normally unknown, n is used as an index of abundance. If the unit effort is set to the area swept by the trawl (AS), and the total distribution area of the stock is A, then we may get an estimate of density

$$\hat{d} = \frac{N}{A} = \frac{n}{qAS}$$

Similarly, the fish density can be expressed by in acoustic survey terms as

$$\epsilon = S_A \; C$$

where S_A is the acoustic backscattering coefficient (m^2/nm^2) and C is the backscattering properties by species and size.

The above equation catchability (q) is defined as the relationship between catch per area unit covered and density of fish in the area covered. However, gadoids both in the Atlantic and in the Pacific are known to be partly pelagically distributed outside the range of the bottom trawl. Hence, q should in this instance be split in an availability (q_a) and an efficiency component (q_e), i.e.

$$q = q_a \cdot q_e.$$

If true density is to be estimated by the bottom trawl method, both components of q have to be known

$$\hat{d} = \frac{n}{q_a \cdot q_e AS}$$

The efficiency is dependent on the selective properties of the trawl and is normally size and species dependent.

Similarly, the acoustic equation needs assumptions on availability of fish and efficiency of the equipment to produce absolute abundance

$$\epsilon = S_A \cdot C = S_A \; / C_a \, . \, C_e.$$

The efficiency (C_c) relates to the fish target strength (TS), and the variability involved will not be covered here. Availability problems for gadoids are mostly connected to fish distributed close to bottom and can be divided in

a) equipment limitation ("dead zone")
b) behavioral aspects (avoidance out of beam or into "dead zone")
c) biological "noise" ("hiding" of fish in other biological scatters, in most cases a problem with small fish close to bottom)

In contrast to the efficiency components of the two survey methods, which are independent features and a function of the equipment, the availability components are in most cases inversely related. Hence, conditions which are optimal for abundance estimation for one of the methods, create availability problems for the other.

UTILIZATION OF SURVEY RESULTS

At least three different ways of survey result utilization are in current use:

1. Calculate acoustic fish abundance from surface to the height of the headline of the trawl. Assume 100% trawl availability of fish from bottom to the headline height of the trawl and set q_c to an arbitrary or "reasonable" figure and calculate bottom zone abundance. Total abundance is obtained by adding the two figures. This method can be used when a very small fraction of the stock is distributed close to bottom, so that an error in q_c is of minor importance for the total abundance.

2. Same as above, but q_c is determined by species and length group from direct observations.

3. The estimates from both methods are used as independent measurements or indices of abundance.

All methods are in conflict with existing knowledge of fish behaviour and fish biology. The calculations are done under the hope that the standardized survey design and survey procedures at least justify the use of the estimates as indices. The last years use of acoustics in gadoid investigations has greatly improved our knowledge of population dynamics. Good examples are information about variation in horizontal and vertical distribution/movement and its obvious effects on the bottom trawl survey results. Further, the conversion of acoustic abundance to fish density needs fish species and length samples from trawl catches, with all errors and problems involved. The assumptions and procedure followed today in the calculation of abundance may in many instances be misleading due to uncertainty of availability (distribution and avoidance), and efficiency (trawl selectivity, acoustic bottom efficiency and variation in conversion constant). Based on the difficulties connected to solve the above problems, alternative methods of improving combination of data form the two survey methods are at the moment endeavoured:

1) Improve efficiency of the sampling in the bottom trawl survey by using acoustic information about fish density and distribution,
2) Systematic recording of "survey condition" with the aim of estimating adjustment factors based on observed variation in environmental, ecological and behavioral conditions,
3) Improving one of the estimates by use of information from the others.

We still consider the estimates as indices, but the above strategy is chosen with the ultimate goal of arriving at absolute estimates. Due to the improved possibilities of observing the underwater reality by acoustics and video techniques etc., the standardization philosophy is no longer on line with todays state of the art. The future development will to a large extent be dependent of routine utilization of a lot of information which today belong to the block of assumptions.

INSTRUMENTATION AND SOFTWARE FOR SYNOPTIC ANALYSIS OF PELAGIC AND DEMERSAL FISH POPULATIONS

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INTRODUCTION

Fisheries acoustics has become an accepted tool for fisheries assessment and management of important commercial pelagic and demersal species throughout the world. This has led to the evolution of sophisticated "state-of-the-art" instrumentation for fisheries surveys over the past two decades. At the recent "GLOBEC Workshop on Acoustical Technology and the Integration of Acoustical and Optical Sampling Methods", it was strongly recommended to move beyond the single sensor approach to a "multiple sensor" approach. It was recommended that the data should be viewed in a synoptic manner rather than serially. In order for this to be possible, it is crucial that the data be in a form that can be readily and cost effectively visualized.

It is commonly understood among fisheries acoustic researchers that large scale acoustic surveys generate an overwhelming amount of data. As a result, rarely if ever has the spatial nature of the target species or its ancillary data (both biotic and abiotic) been considered in generating abundance estimates. The lack of spatial context and ancillary data may have introduced substantial bias into the abundance estimates. The importance of the multivariate approach was pointed out by Joan Hock of the National Environmental Satellite, Data and Information Service of NOAA when she stated:

"Quantitative relationships that can be established between fisheries distribution and oceanographic variables will not only enhance future studies of fish behaviour and their responses to environmental change but ultimately improve national fisheries management practices."

We have developed the "better mouse trap" in fisheries acoustics instrumentation and now it's time to put the "mouse" into proper context; that is, to merge the information gathered by acoustics with other sensor data and place that information in a spatial context where it can be easily visualized and treated synoptically. Display and analysis of large volumes of biotic and abiotic data are not trivial when they are collected at numerous times, by numerous methods, in numerous places and, most importantly, at varying levels of spatial resolution.

It is now possible with the aid of electronic charts and sophisticated navigation aids such as GPS and TRANSIT satellite receivers to plan, log and execute multiple sensor surveys in a spatial context. This has resulted in the ongoing development of a Bio-Acoustic Mapping System (BAMS). The BAMS is comprised of several linked modules which involve all aspects of data integration from the planning stage to presentation of synoptic overlays on digital maps. The synoptic overlays may be single biotic or abiotic covariates or combinations of covariates associated with the acoustic "target" population(s).

BIO-ACOUSTIC MAPPING SYSTEM

The Bio-Acoustic Mapping System (BAMS) is comprised of fully integrated modules or subsystems operating under the Microsoft Windows environment and based on personal computer technology. The BAMS modules are:

1. **Spatial Context Interface (SCI)**
2. **Bio-Acoustic Sensor Subsystem (BASS)**
3. **Data Visualization Module (DVM)**
4. **Data Analysis Module (DAM)**

The purpose of this presentation is to present the functional instrumentation and software components of the Bio-Acoustic Mapping System. A brief description of each of the modules follows:

SPATIAL CONTEXT INTERFACE (SCI)

The purpose of the SCI is to provide a geographical reference within which the BAMS operations can be planned, executed and logged. This is accomplished by using digital charts displayed on a computer screen in conjunction with overlays related by geographical location tags or geo-codes.

Geographical reference may be obtained from any commonly used source such as:

1. GPS (Global Positioning System) receivers
2. TRANSIT satellite receivers
3. LORAN C receivers
4. Dead reckoning (vessel speed and heading)

The SCI displays the location of the vessel in relation to electronic charts by displaying a sprite on the computer screen. This allows for the layout of transect sampling design before the ship leaves port, including symbols and annotation for individual sampling stations where ancillary data (environmental, oceanographic, limnological or fish sampling) are to be collected during an acoustic survey.

Once the survey is underway, the vessel operator and survey leader may monitor the ship's current position in relation to plan. Additional symbols and annotations may be added when important observations are made. As the survey proceeds, a log may be generated automatically storing a variety of information such as time/date, ship's position, speed, bearing, cross-track error, bearing and distance to predetermined sampling locations, etc. Additional information can be manually added to the log at any time.

Depth information may be automatically acquired and displayed on the computer screen as the vessel follows the planned transects. The depths may also be written to the survey log and permanently stored with conjunctive information. The stored depth information may be accessed at a later time for import to the Data Visualization Module for creating bathymetric map overlays of the survey region.

The SCI also allows for the survey to be reviewed in the laboratory through playback of the ship's log. The survey is recreated in the same manner that it was run and the speed of review is controlled by the operator so that survey data that took several days, weeks or months to collect can be reviewed in minutes or hours. This is important in the context of quality assurance and for future survey planning.

BIO-ACOUSTIC SENSOR SUBSYSTEM (BASS)

The purpose of the Bio-Acoustic Sensor Subsystem (BASS) is to provide the platform for fish acoustic data acquisition, processing and analysis. The software components of the SCI and BASS are fully integrated allowing them to share information over the personal computer I/O bus.

The hardware components have been built in a modular format to allow flexibility of configuration for particular survey needs. Raw echo data storage is accomplished by using "off the shelf" hardware such as digital audio tape (DAT) recorders.

The system echo signal processor is comprised of one or two cards installed in a personal computer and software to control the processing function. The processor permits the user to display raw echo returns, create color echograms and analyze data for biomass and target strength. These features allow the survey leader to exercise quality control and assurance during the survey. The processed data may also be stored to a digital medium appropriate to the task (floppy disk, hard disk, tape or optical disk).

Other biotic and abiotic sensors can be coupled with the Bio-Acoustic Sensor to complete the multiple sensor array and provide opportunity for synoptic analysis of covariates. These other sensors may be operating independently as long as the geo-coding comes from a single source.

DATA VISUALIZATION MODULE

The visualization of the survey data is perhaps the most important new aspect of the BAMS. This function permits the survey leader to generate a synoptic "picture" of the survey data as the survey progresses. The geo-coded data can be rapidly processed in the field immediately following acquisition using digital terrain models such as triangulated irregular network (TIN) to produce contour maps. The contour map is then overlayed on the navigation display. This additional information will permit changes in survey design to accommodate interesting phenomena observed during the survey and to assure data integrity and continuity. The synoptic display may be viewed on the computer monitor or output to a color printer for hard copy records.

After the survey is completed, the data collected and logged during the survey may be transferred as thematic overlays to a Geographic Information System (GIS) for further detailed display and analysis. GIS is now available on systems ranging from PC's to work stations.

DATA ANALYSIS MODULE

The purpose of the data analysis module is to summarize and tabulate survey results for presentation and reporting. This is currently accomplished with the use of proprietary data analysis programs and macros developed for off-the-shelf software packages. Three forms of these packages are available to answer the three common questions involving acoustic data: (1) fish distribution and abundance estimation; (2) fish target strength estimation; and (3) routines to correlate environmental parameters.

The format of the geo-coded data is such that it is relatively straight forward to transfer the data into other analysis packages linked with other geo-coded data for more detailed analysis or display. An example would be uploading to a GIS system or to a statistical analysis package. GIS systems currently provide the best platform available for synoptic viewing of large amounts of data collected during a large scale acoustic survey of demersal fish.

HARDWARE OPTIMIZATION

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INTRODUCTION

High quality fisheries acoustic instrumentation such as echosounders and sonars have been greatly improved over the last decade. Stable transmitters, receivers and time varied gain circuits are now common and calibration has become a routine procedure. What are the next steps to optimize fisheries acoustic hardware and measurement procedures?

Experimental multi-frequency, swept-frequency, pulse coding, broad band, Doppler and resonance measurements have been made and have shown considerable promise (Holliday 1972, 1973, 1974, 1977a, 1977b, 1977c, 1980; Holliday and Pieper 1980). However, the widespread use of any of these measurement techniques depends on major advances in several areas including transducer design, electronic hardware and software. The following discussion will focus on improvements in transducer design and deployment, an area that by itself will bring significant advances and will act as a stepping stone towards the complex measurements listed above.

THE TRANSDUCER AS ACOUSTIC ANTENNA

Transducer performance and transducer development are important since the transducer is the antenna or sensor. Consequently, information that is lost at this stage will be difficult or impossible to reconstruct.

This point is illustrated by considering a series of echogram artifacts:
Single fish trace;
Minimum observed school width;
Resolution of fish near bottom;
Critical bottom slope;
Bottom step and trench;
Bottom depth.

These transducer effects are inherent in any acoustic system but careful transducer design and deployment will minimize their impact.

EXISTING SOLUTIONS

Existing solutions include dual and split beam techniques that allow us to remove the beam pattern effect from single fish echoes and to measure the acoustic fish size. These techniques, however, do little to optimize the spatial resolution of fish targets, or fish targets and bottom and to minimize signal averaging of distributed targets or side lobe effects. In general, dual beam measurements may reduce spatial resolution, a consequence of the large beam width that is required for the 'wide beam'.

IMPROVED BEAM PATTERN

Typical echo sounders use a uniform piston transducer that generates the familiar beam pattern that is characterized by a rounded beam centre and a series of relatively high side lobes. Transducer shading can be used to generate a beam that has a nearly flat beam centre with steep flanks and that is virtually free of side lobes. Figure 1 compares a calculated beam pattern for a uniform piston transducer with the measured beam pattern from shaded transducer (Furuno FQ70, 70 kHz).

A shaded or flat beam transducer will provide improved spatial resolution and generate a smaller proportion of near and sub threshold echoes. The improvement in echo amplitude is illustrated in an echo histogram, Figure 2. The effectiveness of the uniform piston and shaded beam patterns shown in Figure 1 are compared. The flat beam clearly generates more large echoes than the uniform piston, however, it falls very short of the unattainable ideal flat beam. Further shading is required to obtain a significant increase in large echoes.

An effective flat beam pattern will also reduce adverse threshold effects that can bias echo integration and echo counting measurements and will stabilize deconvolution based target strength estimation procedures. Observations over rough bottom will be much clearer without side lobe interference. Transducers with improved beam patterns, therefore, clearly deserve more attention than they have had to date.

FAN BEAM SYSTEMS

Hydrographic observations now use acoustic bottom mapping systems that survey a swath below and on either side of the survey vessel to produce a detailed map of bottom topography.

These acoustic bottom mapping systems use a fan shaped beam that covers approximately 25 on either side of the vessel. They use omnidirectional signal processing that scans the full width of the beam after each transmission to avoid the slow image build-up of the traditional scanning sonar. The orientation of the beam below and to either side of the vessel is important. Scanning between either side of the vessel provides much better near-bottom resolution and near-dorsal aspect insonification than the traditional forward scanning sonar. Existing systems, however, analyze the echo for bottom information only and, therefore, cannot be used to study fish.

A fan beam system, modified to detect fish, will provide much greater coverage than a single vertical beam. In particular, it will yield true three dimensional mapping of fish schools and give some indication of fish-vessel interactions. Density measurements at non vertical angles would provide additional information on school structure and possible species clues.

The system also can produce a bottom map that will give valuable information on fish habitat and an indication of the amount of near-bottom habitat that cannot be resolved by the acoustic beam. Optimal near-bottom detection of course is only obtained when the beam is vertical to the bottom.

TRANSDUCER DEPLOYMENT

The list of transducer artifacts indicates that the spatial resolution of an acoustic system can be increased by reducing its beam width and the range to the target. Better spatial resolution will allow us to observe fish that are normally too close to each other or the bottom. Some fish aggregations will be seen as single fish rather than schools and additional measurements will be possible that may assist in their classification.

Even if transducer size and cost is of little concern, transducer beam width is limited by vessel or towed body speed, roll and pitch. For deep targets, the typical transducer beam widths cannot be reduced significantly without risking echo signal loss due to transducer motion, unless the range between the transducer and the target is reduced.

The transducer may be mounted in a towed vehicle that can be steered towards the bottom or even track the bottom. Depending on bottom topography, fish behaviour and type of intended measurement, the range can be selected to optimize spatial resolution, near-bottom resolution, coverage and signal-to-noise ratio.

A similar but upward looking system was employed at our laboratory to observe salmon schools near the surface. To obtain adequate coverage and to avoid the wake of the vessel, the body was flown at a depth of approximately 30 m and offset from the vessel's track. Similar techniques will be useful to study plankton and fish near the surface, especially at night.

CONCLUSION

The options discussed above are intended to stimulate the search for better fisheries acoustic measurements and their interpretation. In addition to new transducers and their innovative deployment, a large number of promising improvements are possible but will require considerable development effort. This is particularly true for multi-frequency and other advanced measurement techniques. Modern split beam echosounders and sonars provide a taste of these exciting new capabilities.

GEOGRAPHIC INFORMATION SYSTEMS AND DATA INTERPRETATION

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INTRODUCTION

Geographic Information Systems (GIS) have become a standard tool in forestry, mining, resource development and urban planning. They are used to display and analyze a wide range of geographically referenced data. A typical application would be the mapping of wood lot boundaries and timber quality and the calculation of expected yield.

This paper describes the use of a GIS to display and analyze echointegration survey data. It highlights the exciting new possibilities that emerge when acoustic, trawl sampling, bathymetric and oceanographic data are analyzed jointly. The image processing capabilities of the same GIS are used to display and analyze digital echo data in unprecedented detail.

BASIC GIS REQUIREMENTS

With few exceptions, present GIS use either vector or raster based data sets to represent the information that is to be displayed. When have chosen a raster based GIS to take advantage of the superior analytic capabilities of this approach.

Each point in a typical GIS data set consists of three numbers: latitude, longitude and 'attribute'. The first two serve to locate the sample, the last to describe it. Echointegration data, for example, are presented by the geographic location of the echo sounding and a surface density value.

In a raster based GIS, points are stored as matrix elements. Our Compugrid system (Langford 1991) uses matrices of 2048x2048 or fewer cells and attributes are presented by integer values in the range from 0-32000. Resolution in latitude, longitude (y,x) and attribute (z) are intentionally limited to reduce computer memory requirements and to maximize processing speed. In practice, this combination of matrix dimensions and attribute range provide a good compromise for fisheries acoustic data.

ANALYSIS OF FISHERIES ACOUSTIC SURVEY DATA

Data from an echointegration survey for Pacific hake off Vancouver Island are used to illustrate the GIS based analysis. Data for the shoreline and bathymetry were obtained form the Canadian Hydrographic Services. GIS procedures were used to design a set of transects before the cruise commenced.

During the cruise, echo sounding was conducted along these transects and echointegration data and geographic coordinates were recorded on a PC. The data were processed on a daily basis to display and analyze actual transects, surface density measurements and biomass. Initial surface density and biomass plots show all species (Figure 1). Latitude, longitude grid and shoreline are included. Isobaths were excluded from the figure to avoid overcrowding. The local fish density is indicated by surface density uprights which are placed at one minute intervals along the transect. A logarithmic scale from 0.01 to 1.0 kg/m^2 is used and a target strength of -35.0 dB/kg is assumed.

At this stage, echograms, surface density versus distance plots, trawl locations, catch statistics and surface density plots were carefully examined to eliminate any remaining bottom interference and noise, and to determine the fish distribution by species. The GIS based maps, including surface density along transects, catch locations and bathymetry, are important to obtain an overall spatial picture that encompasses all available data sources.

AREA EXPANSION OF SURFACE DENSITY AND MULTIDIMENSIONAL DATA SETS

GIS offers new and exciting possibilities for the conversion of surface density measurements to biomass estimates and for the concurrent analysis of acoustic, hydrographic and oceanographic data (Kieser et al. 1992).

Proximal analysis provides a simple example of an objective, repeatable and fast process to convert surface density measurements to biomass estimates. Given a set of isolated measurements, such as surface density along transects, proximal analysis will assign a value to every matrix element between transects. The new value is determined by the closest measured neighbour. A mask can be used to exclude points outside the survey area. The biomass estimate will be given by the sum over all eligible points multiplied by the area represented by each matrix element. It is interesting to note that this method is identical to the standard fisheries acoustic practice of expanding the surface density measurements to the area between transects.

The process of analyzing hydroacoustic data is time consuming. Echograms, catches and charts must be examined. Updating the event file (batch file) that controls the analysis of the acoustic data may require hours. However, when this is done, standard and GIS based processing of an entire cruise including simple biomass estimation will require only minutes. Thus, turn-around time is short enough to correct errors and to explore what-if scenarios.

A raster GIS is ideally suited to simultaneously analyze hydroacoustic density data, fish habitat information, bathymetric and oceanographic parameters. Hake, for example, typically concentrate at the shelf edge and avoid shallow banks and deep areas past the continental shelf break. These areas can be mapped and excluded from the survey area that is analyzed.

We have developed a more complex experimental model that expands measured surface densities along depth contours and oceanographic features rather than along the shortest distance. This approach is based on the assumption that fish prefer certain oceanographic conditions. The validity of such models, of course, has to be established before they are used to predict biomass.

It is evident that hydroacoustic and other fisheries survey data have an essential geographic component and that GIS will provide an important tool for the visual presentation and analysis of these data. What may be less apparent, is that the same tools can also be used to analyze digital echo data in unprecedented detail. As an example, we will briefly discuss the analysis of a rockfish echogram (Kieser and Langford, 1991).

A special routine is required to enter the digital echo data. Standard GIS routines are then used to condition the echogram for bottom detection. Once detected, the bottom is removed and only fish echoes remain. At this stage, we can automatically and objectively define fish schools. Figure 2 shows towering rockfish schools at the edge of the continental shelf off Vancouver Island. The bottom has been removed from the echo data. Several fish schools have been automatically recognized and numbered. It is interesting to note that school number 5 encompasses most of the data and appears too large. Initially, several school definitions may be used on the same echogram to find an optimum process which may include several distinct school definitions. School specific properties such as mean density, depth centroid, area, periphery and echo statistics now are measured and logged in a database which will be used to characterize schools and hopefully extract species clues.

CONCLUSION

It is evident that GIS will have a significant impact on fisheries acoustic data acquisition and analysis. Its major contributions will be:

1. to display and analyze fisheries data in their essential geographic context;
2. to assist in the analysis of multi-layer data sets including fish density, net samples, habitat information and other parameters;
3. to assist in developing new concepts for the analysis of digital echo data including definition of ocean bottom, fish schools and single fish.

GIS based procedures will provide an effective and economical tool for fisheries and fisheries acoustics, if hard decisions are made of what it can do and cannot do before systems and software are purchased.

ACOUSTIC AND TRAWL ASSESSMENT OF COD

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INTRODUCTION

Acoustic methods for fish stock assessment have been extensively used for pelagic surveys but much less for demersal species. Consequently, there has been less emphasis on the development of equipment and techniques to overcome the specific problems of fish demersal surveys. The most significant of these problems is discrimination/detection of fish near the seabed [1], which is limited by the bandwidth of the echosounder and its transducer. It is now technologically feasible to produce systems with adequate bandwidth but they are not yet available.

This paper discusses work which attempted to correlate echo signals and trawl catches on the Bellsund and Hornsund banks off West Spitzbergen using a 30 kHz echosounder and a 3-amplitude pulse-height analyzer [2]. Catches of cod varied between 4180 kg per tow with very small amounts of haddock.

When this work was carried out, little was known of the characteristics of the echosounder, nor of the target strength of the fish being surveyed. It had previously been shown that visual observations of signals from demersal fish often correlated well with the quantities of fish caught by the trawl [3] so the use of the analyzer to process the signals was intended to improve the precision of data collection and recording.

METHOD

The 30 kHz signals were taken from the echosounder into three identical electronic units which carried out a number of functions. Firstly, a gating circuit of about 12 m effective opening could be placed by the operator in the approximate region of the seabed signal. All signals arriving through this gate were then rectified and used for triggering two circuits, one concerned with fish signals and the other, the seabed signal. Each circuit produced square waves, the most sensitive responded to fish signals but the other recognized only the seabed signal from which it generated a pulse of 4.4 m to 6.7 m, set by the seabed clearance control. From the "fish" circuit a fixed duration pulse equivalent to 5.5 m was fed to an AND gate, together with the seabed generated pulse. This design made an effective "seabed locked" reference in addition to counting the fish echoes.

When the system was operational and, during a time when no fish echoes were being received, the seabed clearance control was adjusted until counts were registered, then turned back by 0.9 m. Noise level was measured and the sensitivity of the 3 fish channels set respectively to 6, 12 and 18 dB above this. During the period of this work the mean noise level, when trawling, was 10 μV so the "fish" circuits were set to 20, 40 and 80 μV.

When a fish signal of 20 μV, or above, occurred, a single count was registered by C_3, if a signal was 40 μV or more, a count was recorded by both C_3 and C_2 and all channels produced a count for signals above 80 μV. For each period of 1000 counts of the seabed echo, the fish counts for C_2 were deducted from C_3 to give the true C_3 count and C_1 from C_2 to give the correct C_2 count, the true counts were then raised by their respective μV settings. The total calculated signal for the period was then multiplied by the mean depth squared and the values for each period summed to give the total for each haul. It should be pointed out that this system did not only count single fish echoes, the term count is a misnomer in this respect because the purpose was to count signals of different amplitude, from one fish, or many.

MEASUREMENTS

The system briefly described above was used during 15 trawl 'hauls' over a period of 3 consecutive days with rough weather on the first and third day. Data are given in table 1, displayed in figure 1 and summarized in table 2.

Although these data are listed in numerical order of the stations, they are grouped as A, B or C. This is because of different conditions prevailing, e.g. during the rough weather it was necessary to use a transducer projecting 0.6m below the hull to reduce the effects of severe aeration. Even so, noise pulses of high amplitude occurred when the ship rolled heavily and it was necessary to adjust the counts based on "no fish counts", i.e. periods of 1000 transmissions (approx. 10 minutes) when no fish signals of countable amplitude were observed and, therefore, all counts were due to noise. These noise counts were deducted from the total counts during other periods of the same haul.

TABLE 1

Station	Mean depth	Tow	Catch baskets			√ bskts	Signal μV.d^2
	metres	mins	Cod	Haddock	Total		X 10^{-6}
A.							
54	91.4	108	2.5	5.75	8.25	2.9	38.8
57	104.2	90	73.5	1.5	75.0	8.7	79.9
58	95.1	92	3.75	0.5	4.25	2.1	6.0
59	102.4	96	24.25	1.5	26.0	5.1	48.8
60	102.4	86	14.0	0.5	14.5	3.8	20.8
61	96.9	91	6.0	1.0	7.0	2.6	7.1
B.							
63	106	44	9.5	0.5	10.0	3.2	40.3
64	100	41	28.5	1.5	30.0	5.5	61.8
65	98.7	32	78.0	2.0	80.0	8.9	81.8
66	106	58	25.0	1.0	26.0	5.1	51.0
67*	97	59	31.0	1.0	32.0	5.7	32.5
68	100.6	27	22.5	1.0	23.5	4.8	53.3
C.							
70	104.2	45	16.25	2.0	18.25	4.3	42.3
74	98.7	56	107.5	2.5	110.0	10.5	71.1
75	100.6	31	94.5	0	94.5	9.7	61.4

For stations 63 to 68, when the sea was relatively calm, no noise pulses of this type were seen so no deductions were made. It was noted in the log that at the end of St. 67 the trawl was hauled through an extensive trace off the bottom after the counters had been stopped. This is included in data analyzed as B*.

As might be expected, the best correlation between echo signals and catch was when the signal to noise ratio was high - in good weather conditions. The square root of the number of baskets was used because pressure is proportional to √ intensity, hence fish density.

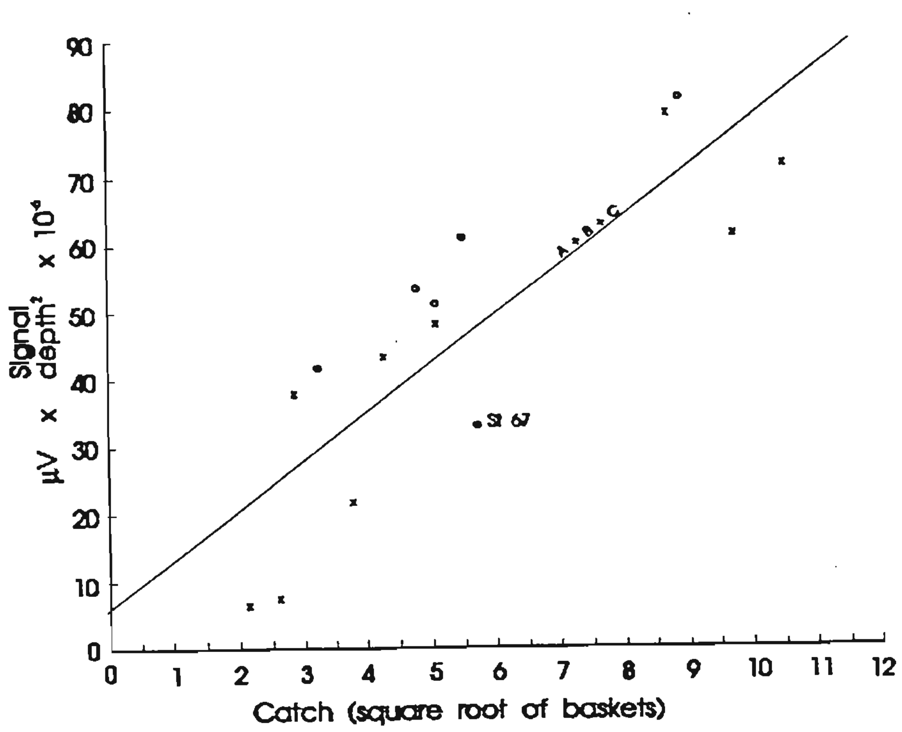

FIGURE 1. RECORDED SIGNALS PLOTTED AGAINST THE CATCH FOR ALL 15 STATIONS

Regression equations are given in table 2 for

A + B + C all 15 stations

A + C 9 stations (rough weather and the projecting transducer)

B* 6 stations in calm weather but one "rogue" result (St. 67)

B 5 stations in calm weather excluding St. 67

Data in table 1 and figure 1 are summarized below.

TABLE 2

Stations		y	r^2Sy.x
A+B+C	6.287 + 7.264x	0.7	13.3
A + C	1.420 + 7.3x	0.79	13.06

B*	14.470 + 7.04x	0.5812.45
B	17.500 + 7.3x	0.9663.29

COMPARISON OF ACOUSTIC AND TRAWL SAMPLING

A reasonable degree of correlation is shown in these data, but it is necessary to consider the correspondence of the acoustic and trawl sampling volumes to ascertain if such results should be expected. Detection of fish near the seabed is limited by the bandwidth of the echosounder which is related to the reciprocal of the pulse duration; hence, the physical pulse length. The system being discussed had a bandwidth of 2 kHz with a matched pulse duration of 0.5 ms. Assuming $c = 1500\ ms^{-1}$ the pulse length would be 0.75 m, so detection would be limited to fish higher than 0.375 m above the seabed. How important this is depends on the vertical distribution of the fish but it is evident from many acoustic surveys that some small pelagic species, even when densely schooled, can 'disappear' in the dead zone (below $c\tau/2$).

Calculation of the volume of the beam between given ranges for a rectangular transducer can be made from

$$V = 2\ \pi/3[1 - \cos(\Theta_\alpha\ \Theta_\beta)^{1/2}](R_1^3 - R_2^3)\ m^3$$

where $\Theta\alpha$ and O_β are ½ angles of the transducer planes
R_1 is the depth to the front of the pulse (nearest to the seabed)
R_2 " " " to the rear of the pulse

For this system an "electronic gate" was used, set 0.9 m above the seabed echo and extending a further 4.6 m. This effectively means that the acoustic volume being sampled by each pulse from the rectangular transducer is roughly in the shape of the frustum of a pyramid, the volume of which is given by

$$V = 0.33h\ (A + B + \sqrt{AB})\ \text{metres}$$

where
h = height of the frustum
A = area of the base
B = area of the top surface

Because of the curved wavefront, fish off the axis of the beam appear to be closer to the seabed than is actually the case so a true vertical distribution cannot be measured. For the purpose of population estimation *per se* this does not matter, but when comparing the fish population sampled by trawl and acoustics respectively, it has to be considered.

Maximum detection height above the seabed is given by

$h = d(1 - \cos O/2) + c\tau/2$ metres

where h = height above the seabed
d = depth from transducer to seabed
Θ = transducer full beam angle
τ = duration of pulse in seconds
c = speed of acoustic wave propagation

In the 30° plane of the transducer beam, fish at a height above the seabed of between 3.5 and 4 m will be detected as if they were immediately above the 0.9 m lower opening of the "gate" but the amplitude of their echoes will be reduced by about 3 dB. The narrower the beam, the smaller the fish height anomaly. With a maximum opening of 2.5 m for the trawl in the centre of the headline, there is a potential discrepancy in the fish population actually sampled by the two methods.

THE TRAWL

A standard "Granton" trawl was used with a mouth area of about 25 m^2. Towed at a speed of 4 knots, it covers a distance of 7356 m per hour or 122 m s^{-1}, therefore, the volume swept is 7356 x 25 = 184 x 10^3 m^3 or 3050 m^3 per minute. As for the volume of water sampled, table 3 compares the trawl and the acoustic beam.

TABLE 3

Station	Tow	Tx's	Volume				
	mins	x 10^3	Ac. pulse m^3	Ac. (tow) 10^6 m^3	÷29 10^6 m^3	Trawl 10^6 m^3	Acoustic ÷ trawl
54	108	10.8	6757	73.1	2.5	0.329	7.6
57	90	9.0	8863	79.8	2.75	0.274	10.0
58	92	9.2	7337	67.5	2.32	0.280	8.3
59	96	9.6	8565	82.2	2.83	0.292	9.69
60	86	8.6	8565	73.6	2.53	0.262	9.65
61	91	9.1	7628	69.4	2.39	0.277	8.63
63	44	4.4	9173	40.4	1.39	0.134	10.3
64	41	4.1	8133	33.3	1.15	0.125	9.2
65	32	3.2	7926	25.4	0.875	0.097	9.0
66	58	5.8	9175	53.2	1.83	0.177	10.3
67	59	5.9	7647	45.1	1.55	0.180	8.6
68	27	2.7	8244	22.2	0.765	0.082	9.3
70	45	4.5	8864	39.9	1.37	0.137	10.0
74	56	5.6	7926	44.4	1.53	0.170	9.0
75	31	3.1	8244	25.5	0.88	0.094	9.4

Because of the large volume sampled by the acoustic beam, there is a significant overlap between pulses, leading to over sampling by an approximate factor of 29 at the mean depth and the given speed of the vessel.

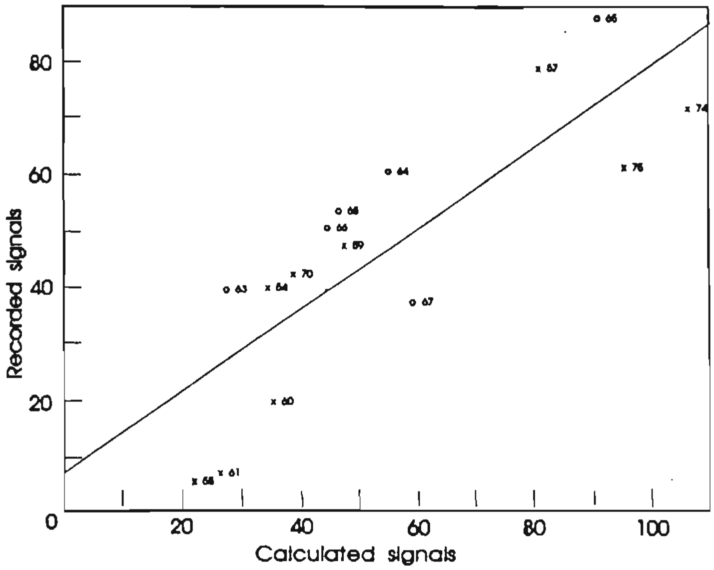

FIGURE 2. SIGNALS HAVE BEEN CALCULATED FROM THE ECHOSOUNDER AND TARGET STRENGTH PARAMETERS AND ARE PLOTTED AGAINST THE ACTUAL CATCHES FOR THE 15 HAULS

THE ECHOSOUNDER

From later measurements, the echosounder was found to have an input power of 700 W; a typical transducer had a face area of 10.8 x 10^{-3} m^2 and efficiency ≈ 30%. From these figures, the source level was calculated to be 212 dB re 1 μPa at 1 m. As a receiver, the transducer sensitivity was measured as 26 x 10^{-5} μV per 1 μPa (-191 dB re 1 V per 1 μPa). A transmission rate of 1.67 pulses per second was used.

In figure 2, signal levels have been calculated from the above using a target strength of -32.6 dB [4] for cod of 0.7 m length. The fish size is based on the average number of such fish to fill one of the baskets (a mean weight of 38kg).

There is a remarkable degree of correlation between the signals calculated from the system parameters and the fish caught. This seems to indicate that under good conditions of fish distribution relative to the echosounder sampling volume the system could have given quite precise results, particularly if a time-varied-gain amplifier had been available and a more reliable method for taking noise into account.

COMMENTS

The work described illustrates a number of the problems inherent in a demersal fish survey when a wide beam echosounder (without TVG) and a crude signal processor are employed.

A narrower beam angle of say 5° such as in common use today would have allowed a more equal volume of water to be sampled by trawl and acoustics. The unknown factor is the vertical distribution of the fish, but again, the errors due to the anomalous height of fish would be greatly reduced by use of a narrow beam.

Nevertheless there is adequate evidence to show that the survey and assessment of demersal fish could be carried out even with such a simple system. Using a calibrated, highly stable, modern echosounder - echointegrator system for demersal surveys should produce an accuracy within the most stringent limits quoted as a management goal in [5].

CALIBRATION: PRINCIPLES AND PRACTICE

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1. SURVEY REQUIREMENTS

Fisheries acoustics, when used for stock assessment purposes, requires a higher order of accuracy than any other underwater acoustics activity because of the stringent limits to which fishery managers must work. Although fisheries do not all have identical characteristics, Pope [1] proposed a framework for different levels of survey. In summary, he concluded that the overall accuracy of an acoustic survey should attain the following levels:

a) as an exploratory survey (no *a priori* knowledge of the stock) ± 3 dB (± 50%)

b) for a time series calibrated against VPA ± 2 dB (± 35%)

c) as the sole basis for setting a TAC ± 1 dB (± 20%)

These figures include all errors attributable to the survey as a whole: whether due to variations in fish target strength; random sampling; survey equipment; acoustic propagation or noise of any description. The criteria of (b) and (c) above place severe constraints on the allowable error due to electronic and acoustic parameters of the survey system. In the case of (c) the latter must be calibrated to ± 0.5 dB at the worst but preferably to ± 0.25 dB.

2. SYSTEM REQUIREMENTS

To calibrate: a dictionary definition states, 'to check, adjust or standardize systematically the graduations of a quantitative measuring instrument'. The total acoustic survey system, including the ship, is the quantitative measuring instrument which must provide an accurate relationship between the output from the signal processor and the fish being ensonified. However, a good calibration, whilst being essential, cannot guarantee the precision of the biomass estimate, there are other factors involved in a survey.

A comprehensive guide to calibration has been published in the ICES Co-operative Research Series (No. 144) [2]. This covers all aspects of the available methods for equipment calibration, giving valuable practical guidance and examples but it does not cover what is referred to later in this paper as "dynamic" calibration. Since the publication appeared in 1987 some equipment's now have in-built calibration facilities which make the process easier.

Echointegration is almost universal as the method of signal processing. It relies on the received echo energy being proportional to the density of ensonified fish but in order to make a conversion in terms of biomass it is necessary to have details of the fish target strength distribution. For this purpose, the dual-beam and split-beam methods of obtaining individual target strengths are used. Because of their mode of operation, the transducers for these systems require rather more detailed calibration than those of a single-beam echosounder.

Ship-generated noise of an electrical or acoustic nature/origin picked up or received by the acoustic equipment will bias the results, but up to the present time, ships have been largely excluded from the calibration process. It should be possible to exclude electrical noise by strict attention to detail in the installation of systems, or by filtration of the supplies feeding them. But there is increasing evidence that the survey ship's acoustic noise signature should be known [3] and taken into account both at the echosounder frequency and lower frequencies where the fish may be cared by its approach.

In recent years, improvements to the electronic units forming the echosounder and the echointegrator have greatly improved stability and reliability. Some signal processing functions have changed from hardware to software implementation (e.g. TVG) with a consequent gain in precision. Important parameters which must be included in the calibration process are:

i) transducer source level (SL) and receiving sensitivity (SRT)
(SL + VR is commonly used, this includes SRT and the receiving amplifier)

ii) transducer equivalent beam (Ψ)

As a result of the software and hardware improvements, the factors below are less critical but must not be ignored.

iii) time varied gain

iv) transmitted pulse duration and repetition rate

v) accuracy of the echointegrator.

It must be stressed that the overall calibration accuracy of the acoustic equipment is dependent on the sum of the errors resulting from item (i) to (v) above. Looking at these items in detail;

Source level (SL) and receiving sensitivity (SRT) can only be obtained as separate parameters by the use of a hydrophone (for SL) and a projector (for SRT) placed successively on the acoustic axis of the transducer under test. Knowledge of SL and SRT can be useful for diagnostic purposes if malfunction of the transducer is suspected, but it is not strictly necessary for calibration. The lumped parameters SL + VR or, SL + SRT will suffice.

Measurement of split-beam transducers must include beam pattern mapping for the derivation of Ψ.

Time-varied gain must be checked for precision and linearity.

Pulse duration (τ) and the rate of transmission is proportional to the amount of energy transmitted and to the acoustic sampling volume.

Most of the functions of echointegrators are performed by digital circuits, or in software, nevertheless the overall function must be calibrated for a range of inputs.

3. ACOUSTIC PROPAGATION

Acoustic wave propagation in echosounding is not affected by thermoclines for any practical purpose.

The frequency dependent factor a, which is due to chemical absorption constitutes the most significant fundamental limitation to accurate calibration. Alpha is dependent on temperature and salinity so it is essential to be able to measure these factors before calibration.

The most recent work in the study of absorption in the oceans is by Francois and Garrison [4] who have derived an equation based on measurements around the world. From this equation, a can be calculated between the frequencies of 0.4 kHz and 1 MHz; the range of temperature from -1.8°C to 30°C and salinity of 30 to 35 ppt. Depth and pH can also be taken into account. These authors predict the values from their equation to be accurate to within 5%, on improvement on previously reported estimates of absorption. At the most widely used frequencies of 38 and 120 kHz, the degree of error due to absorption can be assessed if a is assumed to be approximately 10 dB/km and 35 dB/km, respectively.

± 5% of 10 dB = ± dB/km (38 kHz)

± 5% of 35 dB = ± 1.75 dB/km (120 kHz)

Taking these figures and using 30 m as an extreme range for calibration, the errors would be:

± 0.03 dB at 38 kHz

± 0,3 dB at 120 kHz

Clearly, the result for 120 kHz is not acceptable and a shorter range would normally be used.

The speed of propagation (c) is the other factor to be determined because the exact range between the components of the calibration must be known. For this purpose, c is calculated from the nine-term, eight-variable equation of Mackenzie [5] which has a standard error of estimate of 0.07 ms^{-1}.

4. PRACTICE

Calibration of equipment was reviewed by Robinson [6]. The full range of techniques from caged fish to standard targets was included in this review but for the present purpose only standard target and reciprocity methods will be considered. This is because other methods have disadvantages which deter application in many circumstances, or, simply that they lack the necessary precision.

Circumstances and the available equipment may dictate the actual details of the method used for calibration. Experiment and experience in fisheries acoustics circles have determined the most suitable methods. Direct use of hydrophones is not recommended because of their long-term lack of stability and variability of beam pattern but they can be employed in some forms of reciprocity calibration where they are used for comparative purposes only.

We need to consider two situations: Static and Dynamic.

Static calibration takes place with the ship firmly secured in calm, stable conditions and this calibration determines the precision to which the acoustic system can perform.

Dynamic calibration must take into account other factors affecting the acoustic system when the ship is underway at survey speed. These include several aspects of noise generated or produced by the vessel with the potential to bias results. The survey condition is a dynamic one which must be continuously borne in mind for it can vary due to weather or water depth.

5. STATIC CALIBRATION

Calibration of the acoustic system may be required with:

i) a towed transducer

ii) a hull-mounted transducer

The preferred method of calibration is by means of spherical metal targets: full details the characteristics of these spheres can be found in [7]. Both hull-mounted and towed transducers can be calibrated in this way. Much effort has gone into the investigation of suitable spheres and those now used are made from electrical grade copper, or tungsten carbide.

Calibration needs to take place in sheltered conditions even though the water may be quite shallow. It is normal to aim a place the target at 15 to 20 m depth, well clear of the near-field distance. The deeper it goes, the greater is the difficulty in controlling its position in the beam and the higher the variability of the signals is likely to be. Conditions must be such that the wind is $<$ 15 knots and there is little or no tide running. Very detailed information and guidance is given in [2] so only a brief mention of the general practice follows. Scrupulous attention to detail is necessary throughout calibration.

Measure temperature and salinity; calculate or look up the value for a(absorption coeff.) at the frequency being used. Also, calculate c (speed of propagation).

Clean the target sphere carefully in detergent. Attach the sphere (held within a monofilament netting bag) to a short line which is securely fastened to the junction of three lines form the control winches on deck. Use the three winches to position the target in the acoustic beam. One of the practical difficulties is the alignment of the target sphere on the acoustic axis of the beam. This has to be done by movement of the sphere until the maximum echo is received. With the advent of the split-beam transducer, plus appropriate processing and display of the echo, it is now possible to see its position (hence that of the target) against a graticule. This permits easy adjustment to the axis, but is also important when the beam pattern is being measured.

Where there is no target display available, the technique described in [8] for split-beam systems can be used. Thirty measurements in the beam will determine the mean sensitivity to ± 0.5 dB or better.

To calibrate (i) above requires the use of a fairly large framework to which the transducer and other components can be attached, or alternatively, projecting arms from which a target can be suspended and controlled. Towed transducers can be calibrated by a reciprocity technique [9] which requires only a projector and a hydrophone, either of whose characteristics need to be known. Three ranges, between the transducer-hydrophone, hydrophone-projector and projector-transducer are measured. Also to be measured are three voltages, V_h at the hydrophone when the transducer is transmitting, V_b at the hydrophone when the projector is transmitting and V_c at the transducer when the projector is transmitting. Such a calibration is time-consuming because of the need to pull the rig from the water to realign the components so that the voltages can be obtained. It will give the SL + SRT parameter to an accuracy of ± 0.2 dB.

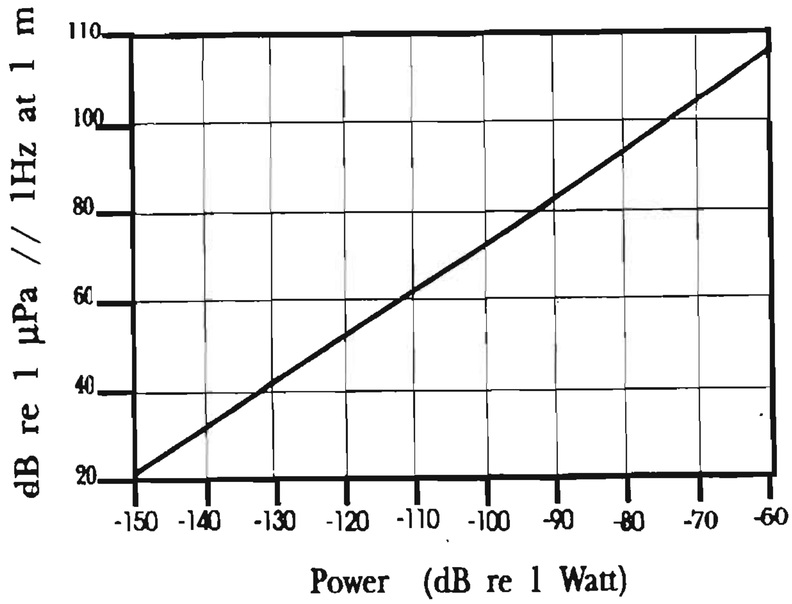
6. DYNAMIC CALIBRATION

There are two reasons for suggesting that ships be included within the overall calibration process.

a) If the noise signature, or practical experience, indicates characteristics that may cause the vessel to scare certain species of fish at particular times. The signature changes with the speed of the vessel and the 'work' it is doing, e.g. trawling.

b) Of more direct consequence is the generation of high-frequency noise. This is mainly as a result of propeller cavitation and the level of the noise is related to the speed of the vessel. It is of particular importance when working in relatively shallow waters because the radiated noise is reflected from the seabed and received by the hull-mounted, or towed transducer.

The EK500 echosounder has a built-in facility to measure noise at the transducer. This is a very useful feature, although the normal function of the echosounder has to stop during the process. The output is in terms of power (Watts) so a conversion is needed to turn it into the normal terms of spectrum level reference to 1 μPa used for underwater acoustics. Such a conversion is shown below for 38 kHz.



Once a noise figure is obtained, it must be converted to band level by using the bandwidth of the echosounder.

Band level = SPL + 10 log bandwidth (Hz)

If noise is seen to interfere with the levels of signal being integrated, it is usually possible to alleviate the situation by reducing speed. If a controllable pitch propeller is used, adjustment of the pitch may be critical.

7. COMMENTS

Calibration of an acoustic survey system is not a task to be undertaken lightly, but with care and patience, it is possible to achieve the required accuracy and to leave a margin for errors which will occur in the target strength distributions and the sampling method.

BOTTOM RECOGNITION AND NEAR BOTTOM TARGET DISCRIMINATION

by

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SUMMARY OF PRESENTATION

A brief historic perspective on acoustic detection of the sea bottom, with visual and signal discrimination of fish close to the bottom will be presented, covering a time span 60 years, from 1930 - 1991.

A detailed presentation on the ideas and developments on close bottom echointegration at IMR, Bergen are given, including the algorithms used in present systems.

The following topics of the problem will be given attention:

BOTTOM ECHO
WHITE LINE
EXPANDED DISPLAY
EFFECT OF VESSEL MOVEMENT
SLOPING BOTTOM
BOTTOM ECHO ON STABILIZED TRANSDUCERS
BOTTOM ECHO ON TOWED TRANSDUCERS

RESOLUTION VOLUME
ECHOSOUNDER DEADZONE
    THE EFFECT OF BEAM WIDTH
    THE EFFECT OF PULSE LENGTH
INTEGRATOR DEADZONE
TOTAL DEADZONE
CORRECTING FOR FISH IN THE DEADZONE

REAL TIME ALGORITHMS FOR CLOSE BOTTOM INTEGRATION
INTERPRETATION AND POST PROCESSING OF BOTTOM ECHO

FUTURE DEVELOPMENTS

Future developments in bottom recognition and near bottom target discrimination will be discussed. The need for work in this area, especially for demersally oriented fishes, will be highlighted. Prospects for new algorithms to define the location of the first bottom echo will be discussed.

Additional collaborations with geophysicists and ocean physicists would prove helpful in the development of bottom recognition and near bottom target discrimination techniques.

LESSONS FROM PAST ACOUSTIC SURVEYS FOR DEMERSAL FISHES: SPRING MIGRATION ACOUSTIC RESEARCH ON NE NFLD SHELF

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Acoustic methods have been used to locate and map the distribution of cod on the NE Nfld shelf and northern Grand Banks during the springs (May to July) of 1990 and 1991 (Rose 1993). Dual-beam echosounders (SIMRAD EK400 (49 KhZ) and BIOSONICS 102 (38 /120 kHz)), coupled with BIOSONICS ESP processors have been used to do integration and target counting and target strength estimation. Sounders are typically run at full power (1 kW) with pulse widths between 0.4 and 0.8 ms (bandwidths from 5 to 2.5 kHz selected). Noise levels are typically low (< 50 mV at 300 m with 40 LOG R applied). Towed bodies are used in all cases. Several different deployment systems have been used, depending on the type of deck gear available and environmental conditions. Three vessels (Gadus Atlantica, Lady Hammond and Petrel V) equipped with stern trawls for biological sampling have been used as acoustic platforms. The Gadus is capable of towing either the Endeco fibreglass V-fin housing the 2 BIOSONICS transducers (120 and 38 kHz) or the FATHOM stainless steel ice resistant body over the stern (housing the 49 kHz transducer). The Lady Hammond and Petrel V are capable of towing only the ENDECO V-fin.

From 1990 - 1992 large aggregations of cod were located. In both years, fish were concentrated in waters having total depths ranging from 350-200 m. For the most part, bottom conditions were relatively flat where fish were located. The cod distributions encountered can be characterized as follows:

1) highly aggregated - it appears that most fish are located within a relatively small number of large aggregations,

2) densities vary from < 0,01 to > 1.0 fish/m^2 (the lower densities appear to be countable - higher densities will require integration),

3) vertical distributions also vary - but in most cases fish are distributed from bottom up to 25-50 m off bottom, in some cases to 150 m off bottom. In other cases densities peak well off bottom,

4) aggregation shapes are plastic and structures are dynamic - nevertheless, there appear to be recognizable patterns to the "formations" at all times.

Considerations for acoustic work can be summarized:

1) As a consequence of the flat (and hard) bottom, a very strong and consistent signal echoes back from most areas of the NE Nfld Shelf. Side lobe echoes are not a problem. In most

cases, bottom tracking problems are not difficult to deal with. To avoid losing too much fish signal, I have set the bottom limit to within 2 m of bottom in most cases with few problems. However, this does vary - there are areas where "boulder grounds" require careful attention and a wider bottom window to limit the integration of bottom signal. The loss of cod signal attributable to bottom window exclusion is difficult to quantify. We have tried a few experiments simultaneously employing different bottom windows and taking adjacent trawl samples but the results have not been worked up.

2) Target strengths at high resolution are easily assessed at the working depths for all size classes of cod that have been and are expected to be encountered (20-150 cm) (except in rare cases of very high density).

3) Target strengths vary considerably (> 10 dB) over space and time - averages or experimentally determined "blanket" values should be used with caution.

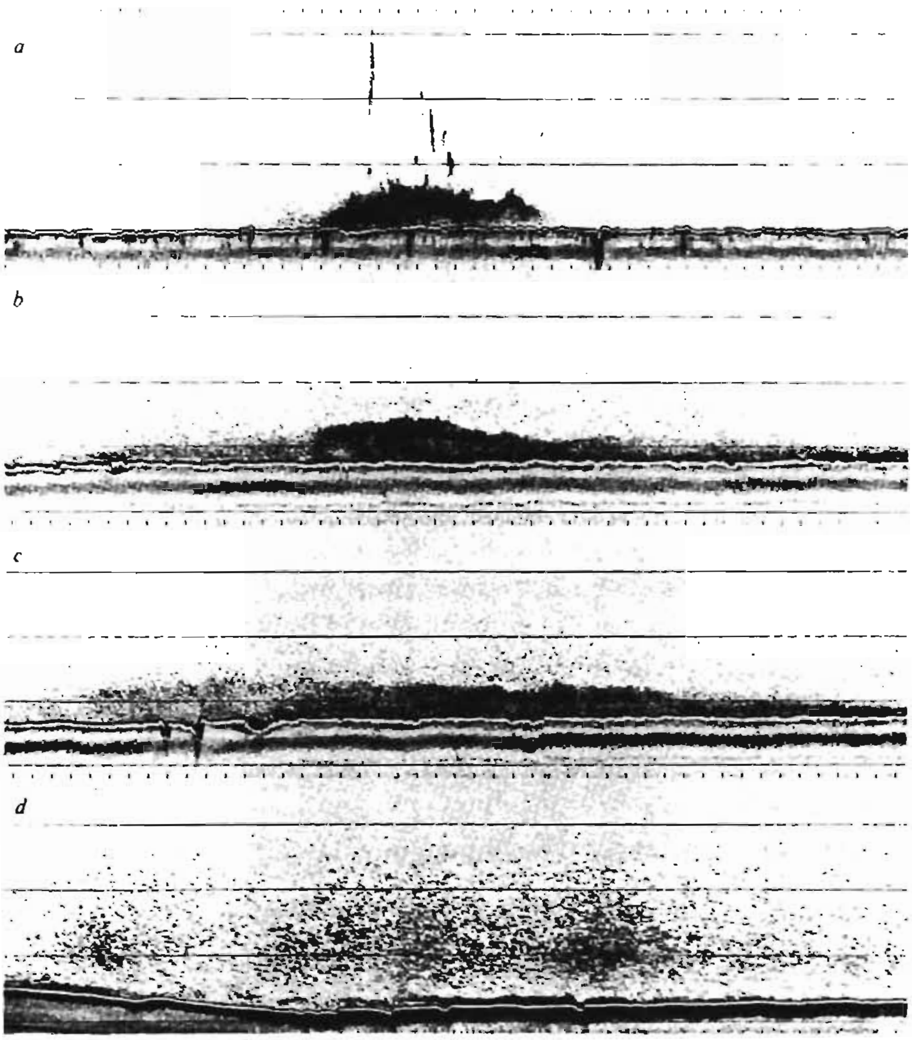
4) Species recognition is seldom a problem. In most cases, concentrations of other species are spatially separate from those of cod. Capelin and small sound scatterers are reliably recognized by signal pattern recognition techniques. There is a problem with the separation of redfish from cod (at present there is no technique to separate these 2 species that at times mix together - we rely solely on trawl samples in this case to portion densities). Turbot also mix with cod in this area - their signal has not been qualified. However, in most cases, the portion of other species in directed sampling for identified cod has been < 10% (excluding bottom dwelling flatfishes).

5) Ice conditions can prevent unlimited access to the entire Grand Bank-NE Nfld Shelf area in spring. In most years, ice is gone from NAFO 3K and 3L by early June, and from the Hamilton Bank area (2J) by mid-July. However, in extreme years (eg 1991), ice can persist much longer and hamper acoustic work, especially in the northern area. It appears that onshore movements of cod are correlated with environmental conditions (eg. later ice later migration) - hence, it may be that standardizing environmental survey conditions, rather than calendar time, would allow comparable survey conditions from year to year.

6) Sea conditions during the spring period are typically calm and, thus, very suitable for acoustic work.

Several photocopies of echograms from the 1992 spring acoustic research are enclosed (from Rose, 1993). These particular images demonstrate the plasticity of the overall structures of cod aggregations.

FIGURE 1. Echograms of cod in the migration highway in the spring of 1992. All panels share common features: total water depth, 350 - 375 m; horizontal grids, 50 m (only bottom waters shown); total horizontal view, 7.5 km; dense masses of fish appear as black, with lower densities greyer; single fish are smaller traces. a. The spawning school that formed the kernel of the migration aggregation and its characteristic columns (maximum internal school densities ~1 fish per m^3), on 11 June at 13:00 h.b, The first evidence of some dispersal of the spawning school, on 14 June at 03:00 h.c, Onset of pre-migratory behaviour and joining up with smaller fish, on 15 June at 22:00 h.d, The migration formation, with single fish well spaced and off the bottom, on 9 July at 22:00 h.



SCALES OF VARIABILITY IN TARGET STRENGTHS FOR NE ATLANTIC COD

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INTRODUCTION

A key source of error in the "relativity" of integrated voltages and their conversion to fish numbers or biomass is the target strength scaling factor. The target strength value used in acoustic surveys has traditionally been derived from experiment studies, theoretical consideration, and large scale field work (or some combination of these). However, it has become increasingly clear in recent years that variability in target strength is perhaps too high at many temporal and spatial scales (and too unpredictable) to rely on broad scale and general averages to interpret the integration results from specific acoustic surveys. Hence, I conducted a series of experiments to assess the scales of the variability in the target strengths of cod on the NE Newfoundland Shelf. In this brief presentation, I will present the results from the analysis of a single transect to show how within transect variability in observed target strength can affect consequent abundance calculations and interpretations of size structure based on acoustic data.

METHODS

A 42 km acoustic transect was run twice over a large and relatively stationary aggregation of cod on June 6, 1990 on the outer portion of the NE Newfoundland Shelf using the vessel Gadus Atlantica steaming at approximately 5 knots. The total water depth was approximately 325-350 m. The cod were within the bottom 50 m of the water column. The echosounder used was a Biosonics model 102 dual-beam echosounder (38 kHz) issuing 0.4 ms pulses (bandwidth 5 kHz) at a rate of 1/s. The transducer was housed in a V-fin towed at an approximate depth of 25 m below surface. Single fish echoes were counted, tracked and target strengths were measured on the first pass using a Biosonics ESP signal processor. Voltages were integrated on the second pass with the ESP and simultaneously sampled signal patterns were stored at 40 kHz via a Metrabyte A/D converter for species pattern recognition analyses (Rose and Leggett 1988). Some capelin were identified near the Western end of the transect and these voltages were excised from the present analysis. Both single fish and integrated data were then "binned" over a high resolution (but somewhat arbitrarily defined) grid measuring 20 m vertical by 80 m horizontal. To collect biological samples and information to support the acoustic data, three short bottom trawl sets (10-15 minutes) were made along the transect (Engels high rise).

RESULTS/DISCUSSION

Mean target strength varied from approximately -20 dB to -60 dB over the full transect (a total of 26116 single targets were measured). For the cod aggregation only, mean target strengths ranged from -20 to -37.5 dB (Fig. 1). The spatial series of target strength means (reduced to 1 dimension) were not stationary (Fig. 2). Both the mean and the variance appeared to change over space and time. The variance of the target strength series changed in relation to the number of single targets measured (compare Figs. 3 and 4). The portions of the transect which displayed low spatial variance had high numbers of targets measured - conversely, low numbers led to high variance. The coefficients of variation of the target strengths were found to become relatively constant (at approximately 0.8 to 1.0) at sample sizes > 100 (Fig. 5). It is of note that taking the entire 26116 single targets measured, the CV is also within this range (1.0). At this level of variation > 100 targets will be required to estimate the mean target strength within 1 dB of the true mean in 95% of cases (Rose, 1992). Variability in the vertical plane was also observed but was relatively stable over the horizontal plane - for simplicity it is not dealt with here.

The relative fish densities as measured by integration scaled by the mean target strength ranged from 0.01 to 0.45 fish/m^2 (Fig. 6). Using the high-resolution target strength values to scale the integrated voltages gave a range of approximately 0.02 to 0.40 fish/m^2 (Fig. 7). The mean density computed using the high resolution target strength (0.060 fish/m^2) was greater than the density scaled with the overall mean target strength (0.049 fish/m^2) (t-test, $P<0.01$).

CONCLUSIONS

1) Mean cod target strengths can exhibit large systematic variations (> 10 dB) even over relatively small spatial and temporal scales (as a result of structure within the aggregation - and also - potentially - as a consequence of changes in behaviour). Non-random variations have been identified in all 3 dimensions.

2) The precision of the mean target strength is dependent on the number of samples averaged. For free-ranging cod, it appears that a CV near unity is common - hence, > 100 samples are needed to estimate the mean within 1 dB (95%).

3) The use of high resolution target strengths vs. overall averages to scale the same integrated voltages can yield differing results.

4) Optimum scaling will maximize resolution at a target level of acceptable variability. Our data analyses to date indicate that this scale will be dynamic over space and time in 3 dimensions - this is being worked on.

```
TSC                                                           CUM                 CUM
DPOINT                                            FREQ       FREQ  PERCENT    PERCENT
       |
22.5   | ***                                        611        611     2.49       2.49
25     | **********                                2001       2612     8.16      10.65
-27.5  | *************************                 4962       7574    20.24      30.89
30     | ***********************************       7080      14654    28.87      59.76
32.5   | ***************************               5456      20110    22.25      82.01
-35    | **************                            2714      22824    11.07      93.08
37.5   | ******                                    1160      23984     4.73      97.81
40     | **                                         409      24393     1.67      99.48
-42.5  |                                             91      24484     0.37      99.85
-45    |                                             27      24511     0.11      99.96
47.5   |                                              6      24517     0.02      99.98
-50    |                                              3      24520     0.01     100.00
-52.5  |                                              1      24521     0.00     100.00
       ----------+---------+---------+-----

               2000      4000      6000

                    FREQUENCY
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FIGURE 1. Frequency histogram of target strengths registered from cod aggregation along a simple transect (42 km) on June 6, 1990 on outer NE Newfoundland Shelf (T6)

FIGURE 2. MEAN TS OVER 80 METER BLOCKS ALONG T6
JUNE 6, 1990 - COD

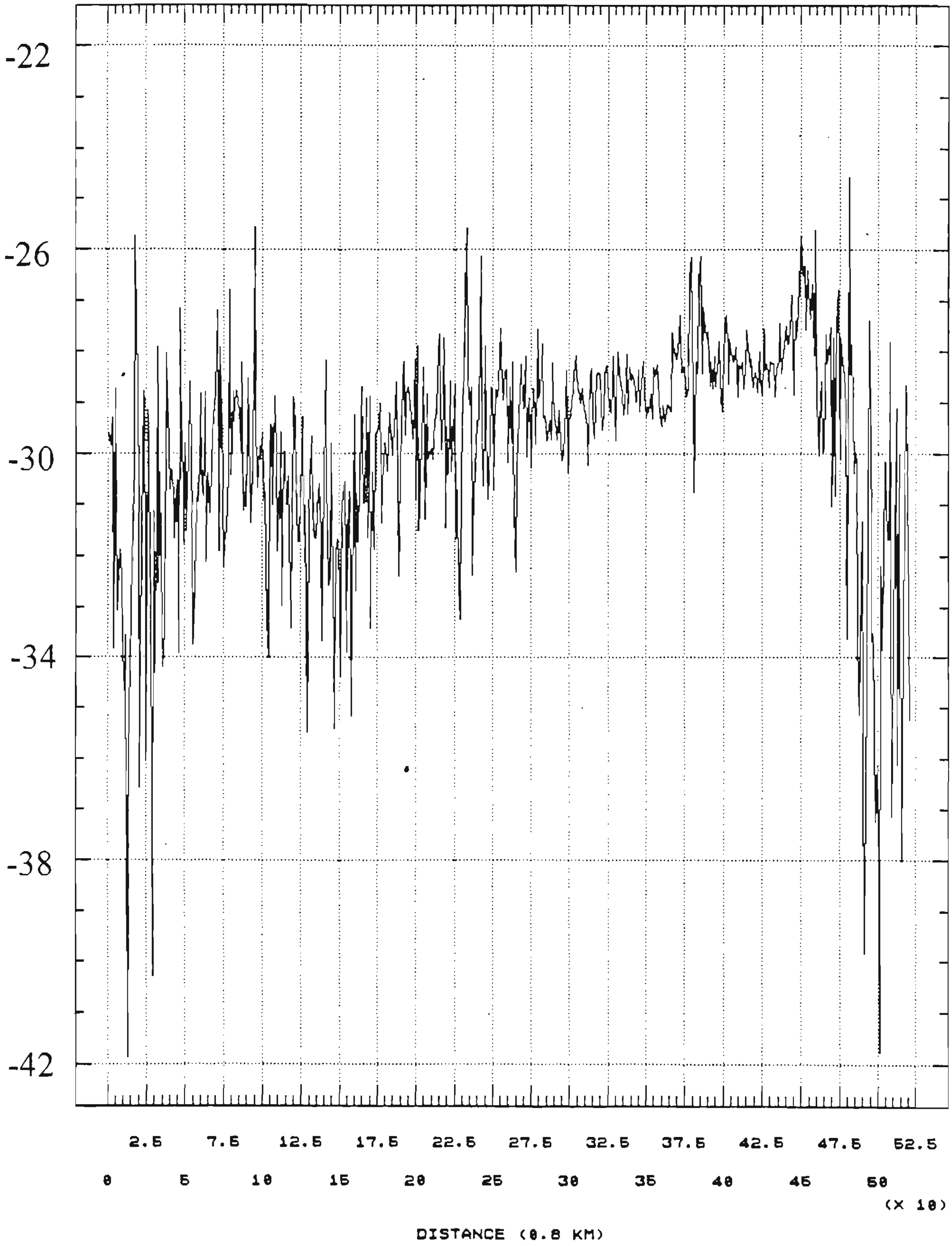


FIGURE 3. MEAN TS OVER 80 METER BLOCKS ALONG T6 JUNE 6, 1990 - FIRST ORDER DIFFERENCES

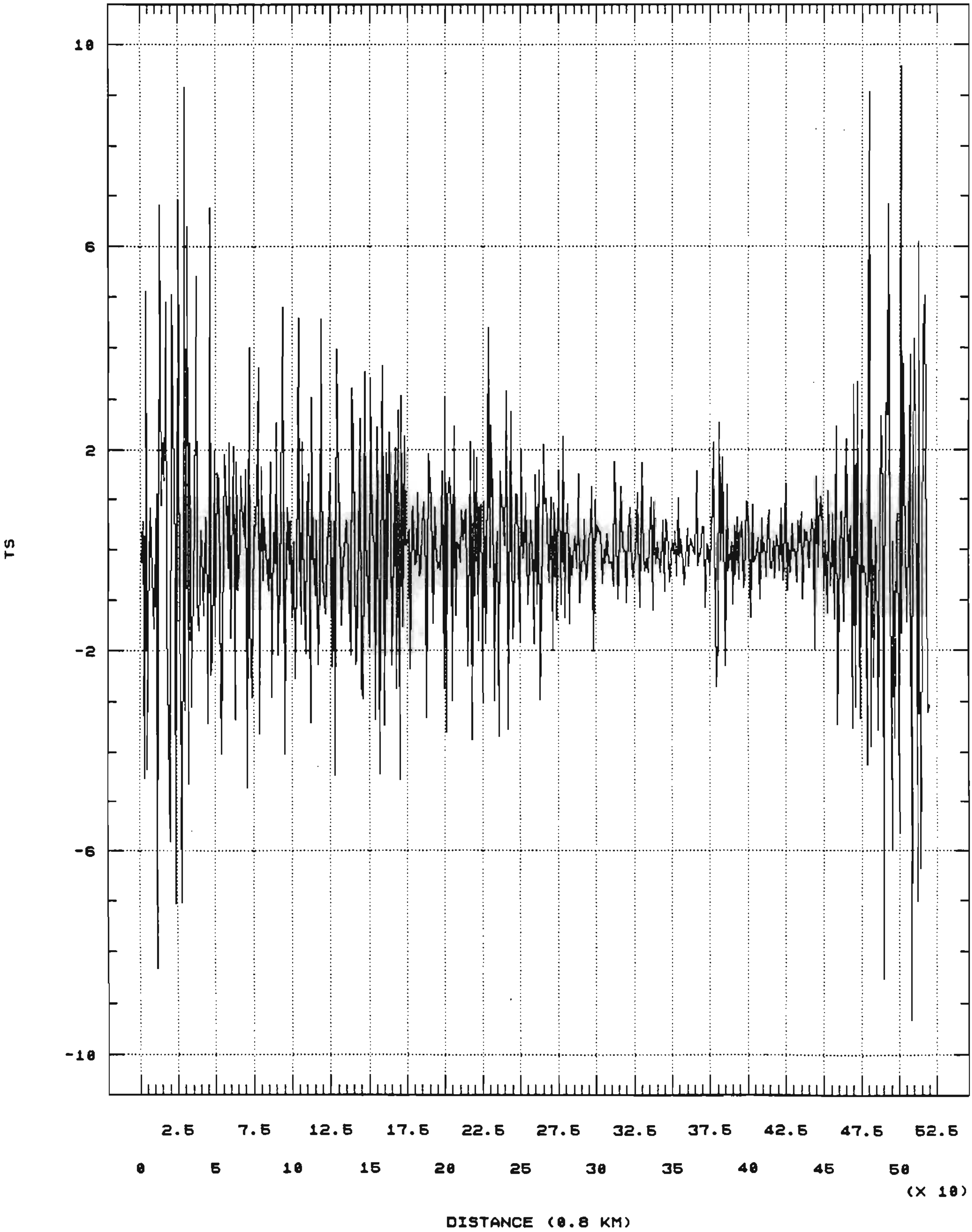


FIGURE 4. MEAN TS "N" ALONG T6
JUNE 6, 1990 - COD

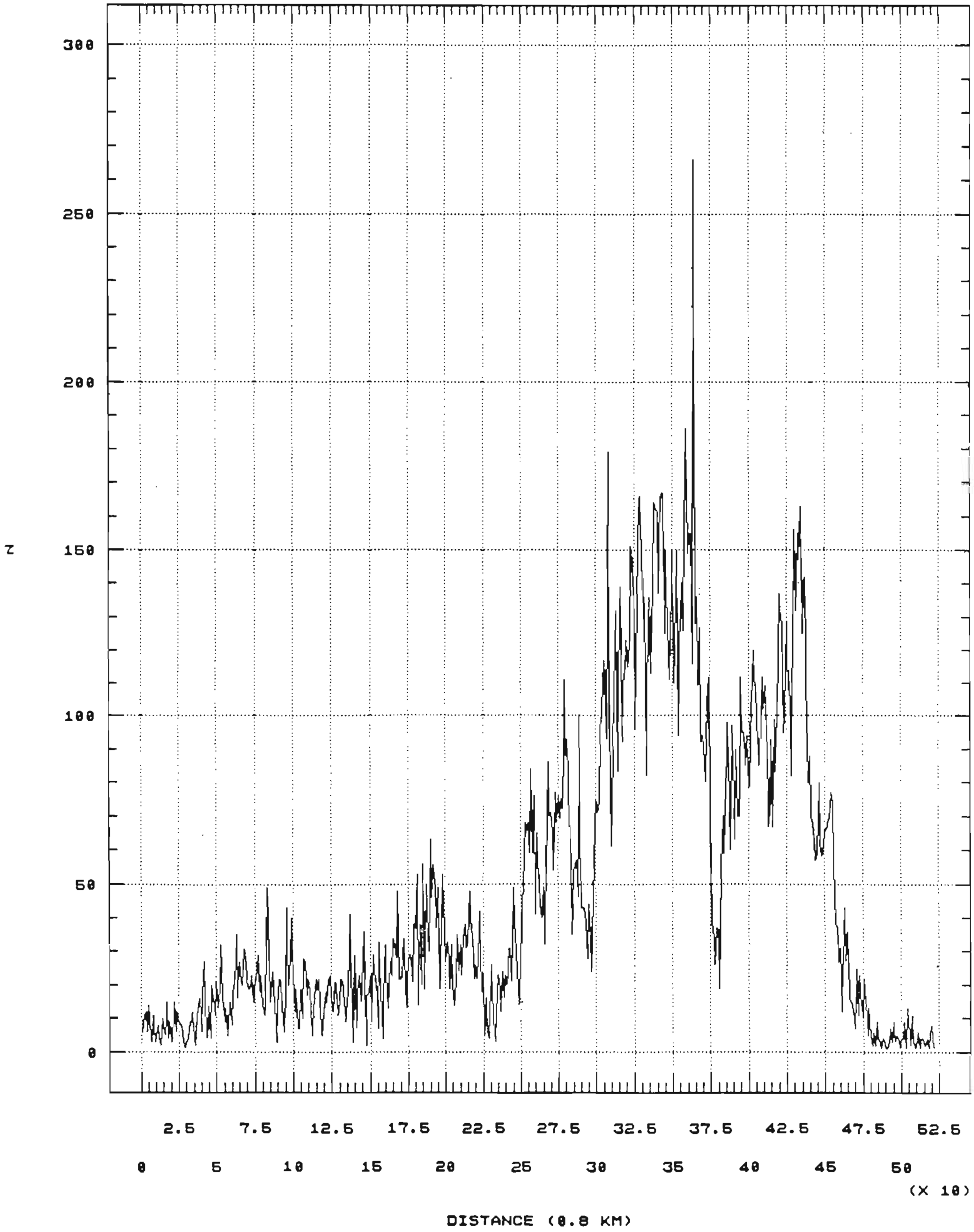


FIGURE 5. CV MEAN BACKSCATTERING CROSS-SECTION VS. "N"

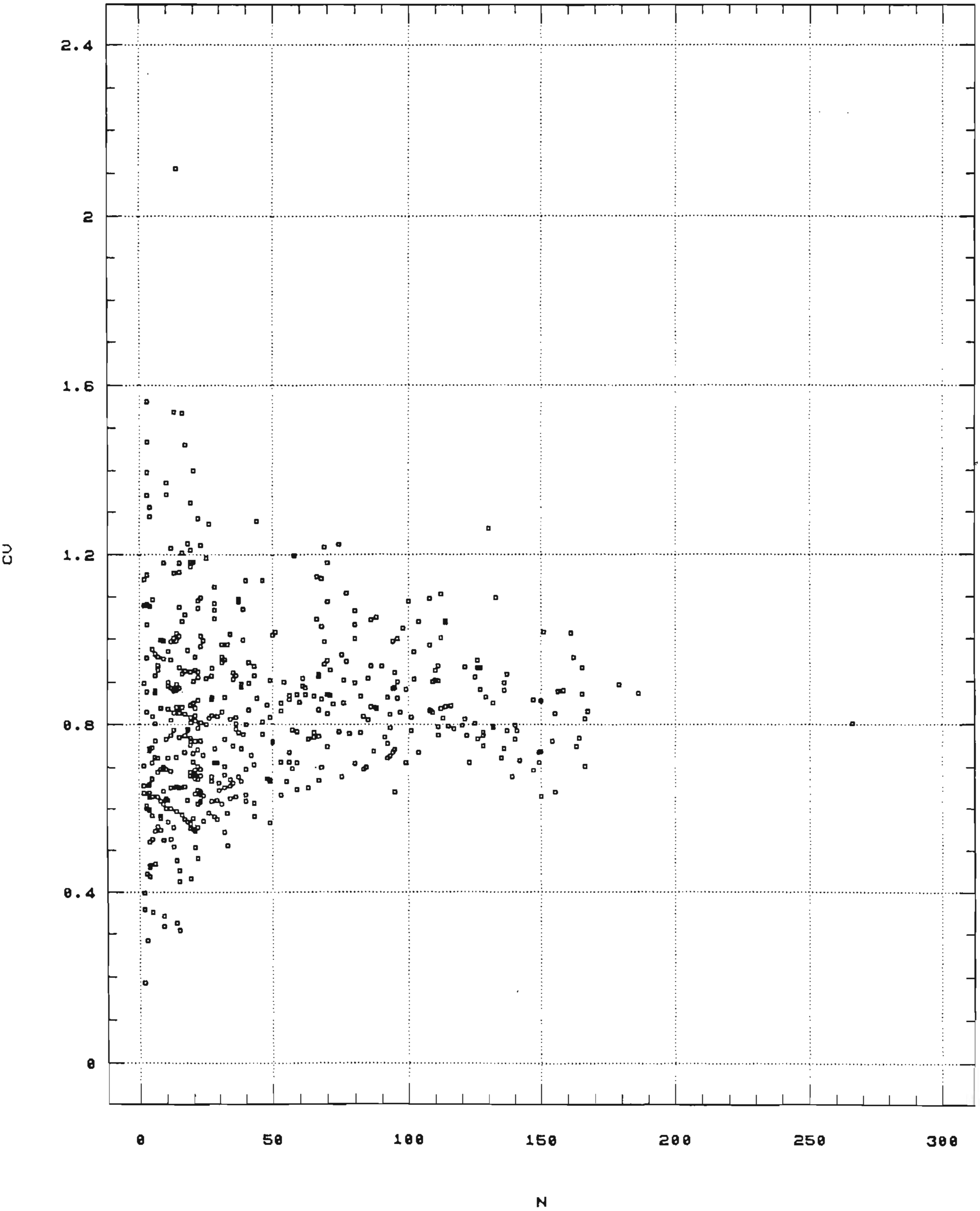


FIGURE 6. COD ABSOLUTE NUMBERS/SQUARE METER, T7, JUNE 6, 1990 - TS SCALE (OVERALL MEAN)

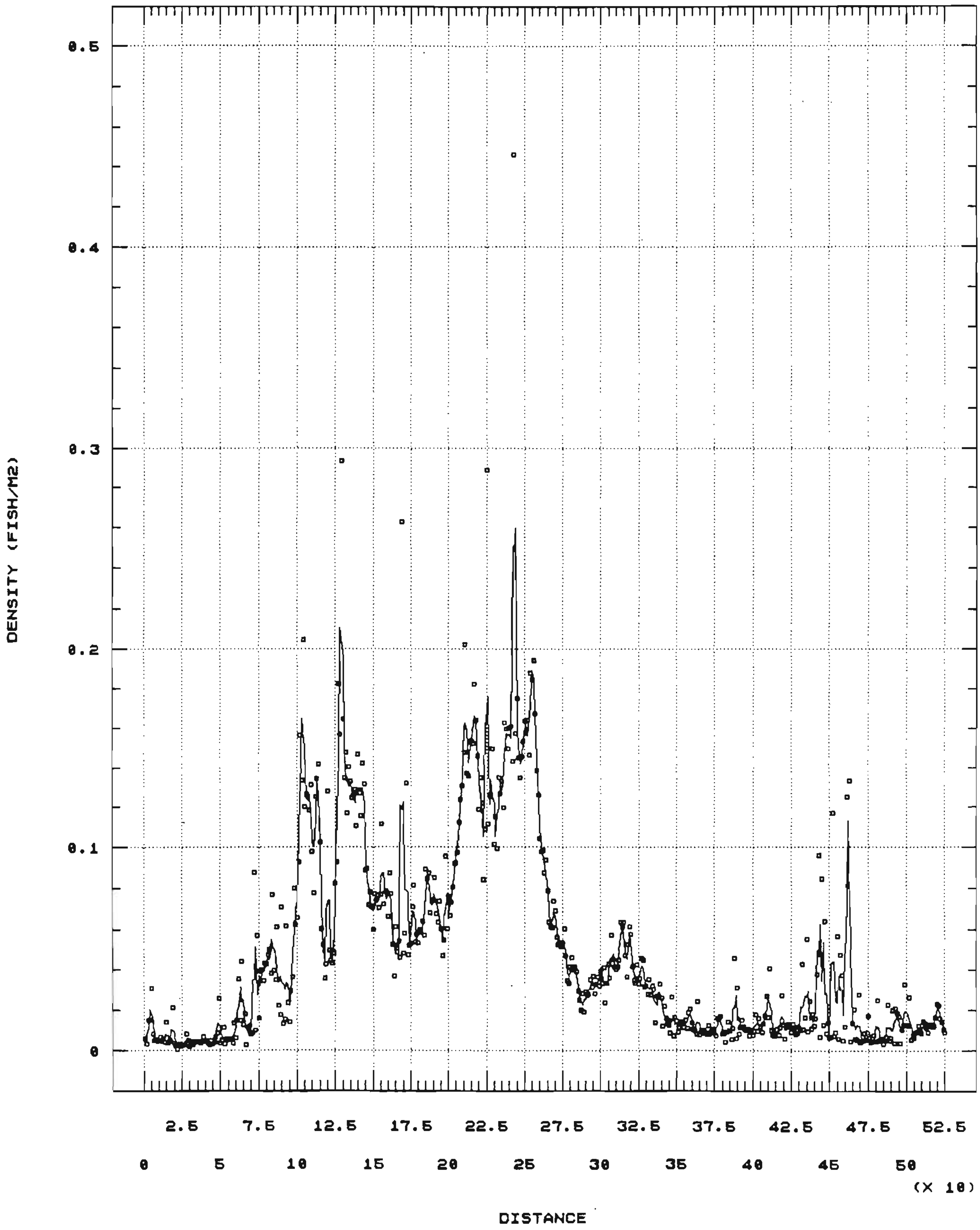
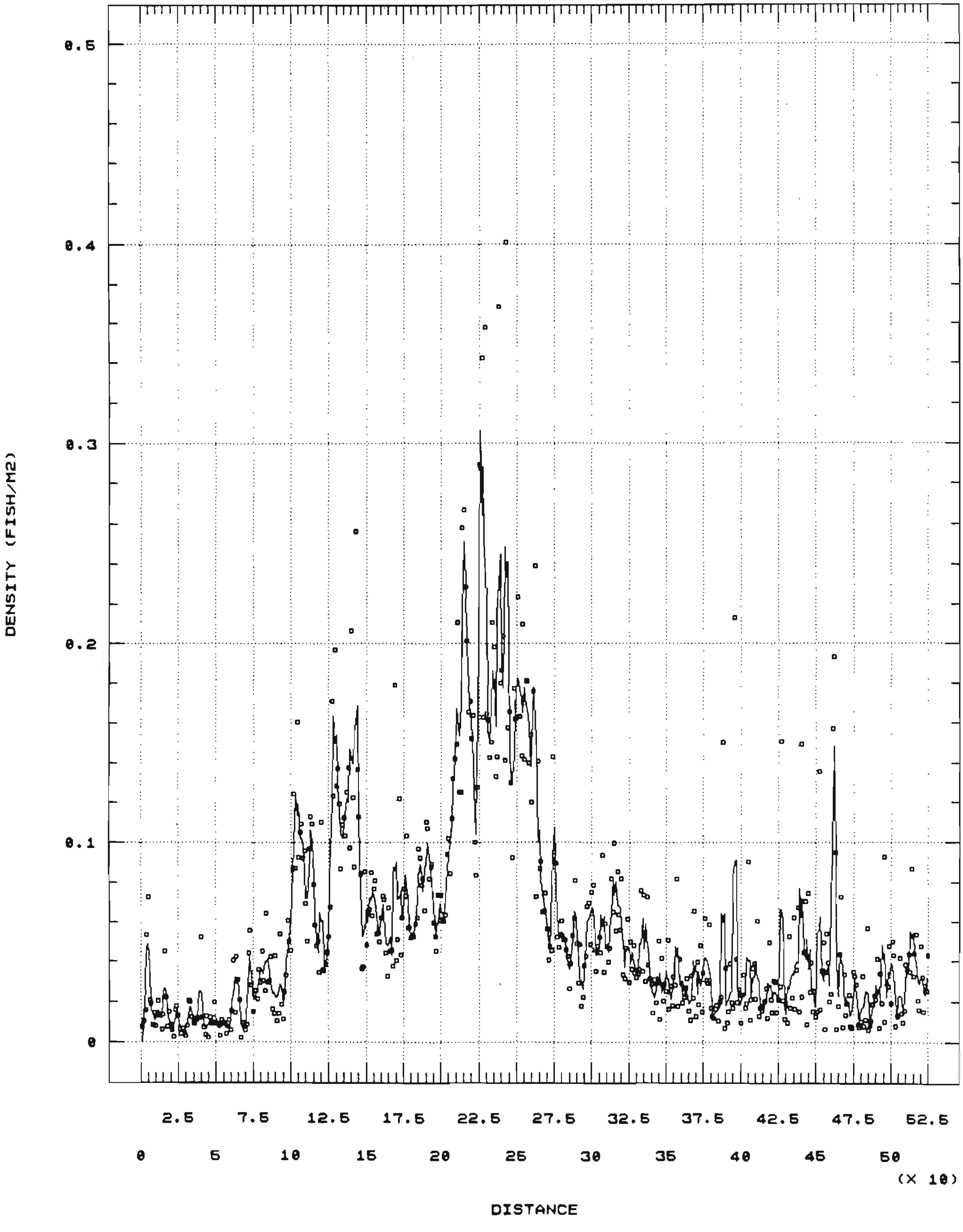


FIGURE 7. COD ABSOLUTE NUMBERS/SQUARE METER, T7
JUNE 6, 1990 - TS SCALE (80 BY 20 M)



BASIC PRINCIPLES FOR THE DESIGN OF ACOUSTIC SURVEYS FOR PELAGIC FISH STOCKS IN THE CAFSAC MANAGEMENT AREA

by

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ABSTRACT

Prior to August to 1988, acoustic surveys for pelagic fish stocks under CAFSAC (Canadian Atlantic Fisheries Scientific Advisory Committee) jurisdiction had been carried out according to a variety of survey designs and for a variety of purposes. Definitions of the basic sampling unit and methods of data analyses varied considerably as well. As population abundance estimates from acoustic surveys were introduced into the stock assessment process, the need for estimates of the precision of these abundance estimates was identified. Unfortunately, there does not appear to be general agreement in the scientific literature on how this precision should be estimated. The CAFSAC Pelagics Subcommittee adopted a stratified random parallel transect survey design in 1988 as the standard for pelagic fish acoustic surveys. The variance estimates from this design were recommended as the most robust way of estimating precision because they require very few assumptions to be valid. This choice of survey design was, to say the least, controversial (as are all topics associated with acoustics). The major criticism has been that since the design does not incorporate the spatial distribution of the fish into the estimates, these estimates are biased or at least non-optimal in some sense. In this paper I show that the main aspects of the spatial structure such as non-stationarity, spatial autocorrelation or probability distribution of the fish do not result in biased estimates of the mean or variance from the stratified random parallel transect design.

Key words: Finite population sampling, model-based methods, design-based methods, spatial autocorrelation.

ICES ACOUSTIC SURVEY PROCEDURES

by

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The subject of design and data analysis for acoustic surveys has been addressed by a recent review by Simmonds, Williamson Gerlotto and Aglen (Simmonds et al. 1991). The brief discussions presented here contain information extracted from this review. The subject is restricted primarily to a review of the choice of survey design and the methods for spatial averaging. For a more complete statement of the arguments and a review of the literature, reference should be made directly to Simmonds et al. 1991. 'Survey design is necessarily linked to the analysis of the data collected. A poorly designed survey will preclude meaningful analysis. An optimal design will provide unbiased estimate of abundance with minimum variance. Any adopted survey design and method of analysis require that certain assumptions be satisfied.' 'There is no one optimum combination of survey grid and spatial averaging method applicable to all stocks, or survey areas. There is no safe solution, free from assumptions, which may be justified as theoretically the best method. The best method will be found by understanding the nature of the fish stock and survey area and choosing the most appropriate solution.'

SURVEY DESIGN

The major works on survey design and analysis are Shotton and Bazigos (1984), Johannesson and Mitson (1983). Track design has been discussed in detail by Shotton and Dowd (1975), Nickerson and Dowd (1977), Kimura and Lemburg (1981), Francis (1984), Simmonds and MacLennan (1988), Jolly and Hampton (1990) and Conan (1990). From these papers and a general consideration of real fish distributions, a number of guidelines can be drawn. In general, most stocks can be surveyed by predetermined strategies, adapted only by the constraints of weather and equipment breakdown. In a number of notable exceptions, adaptive strategies may be employed. The choice of time and area for an acoustic survey are critical. Choosing a time when the stock is most available in time and space is essential. The ideal cited from Suomala and Yudanov (1980) is: calm seas, single species, of uniform size and stable behaviour and distributed in a uniform layer away from surface or seabed. Although these criteria are seldom met, it is useful to organize the survey to obtain the closest approximation to these criteria.

Stratification

The division of the area into strata both for sampling effort and for data analysis is advantageous. Most fish stocks exhibit some non-stationarity and some contagion in the distribution. If total abundance with minimum variance is the aim of the survey, stratification will assist unless the stock has a uniform distribution. Expected overall density from a priori information is the best method of stratification. The number of strata should be small and if different levels of sampling intensity are required, these should be limited to factors of 2.

Transect Direction

The transects should be in the decided by the following criteria taken in order of priority 1) In the direction to minimize between transect variance, ie in the direction of greatest change, (this is often normal to the general run of iso-depth lines). 2) With and against any migration direction. If 1 and 2 are in conflict then an interlaced double survey should be considered. 3) In the absence of 1 and 2 in the direction that minimized inter-transect time, ie. along the shortest axis of the area. A further modifying criteria is that weather conditions may dictate the choice of transect direction.

Systematic/Random

If the stock exhibits randomness of distribution on the scale of the transect spacing a uniform systematic survey grid is the optimum sampling method. If the stock exhibits contagion linked to fixed geographical features (like the seabed) on the scale of the transect spacing a randomly placed transect within a systematic grid is the best method. Stocks do not exhibit periodicity on the scale of transect spacing and this does not need to be taken into account.

Zig-zag/Parallel

In wide areas with transect spacing is less than 5 times transect length parallel grids are preferred. Conversely in narrow areas where transect spacing is small and the inter-transect dependence at the apexes is small zig-zag grids are preferred. Generally transects should be extended to the boundaries of the survey area. Inter-transect sections of survey track should be excluded from the data for parallel transects. For zig-zag transects, it is particularly important that the random location of stock is correctly assumed. Wherever possible, the apex of a zig-zag grid should be placed beyond the boundaries of the stock. A special case for 'administrative boundaries' such as national or economic zone boundaries may allow the use of inter-transect sections, in areas of uniform density, in which case the transects may be terminated a half transect spacing from the boundary and used in the data analysis.

Adaptive Strategies

When the distributional behaviour of a stock is well understood and found to be very variable, an adaptive approach may be appropriate. For example, the major concentrations may occupy under 20% of the area and be located in widely different locations in different years. A number of adaptive strategies have been employed, these are discussed more fully in Simmonds et al. 1991. Adaptive strategies depend heavily on the correct assumptions and are particularly sensitive to stock migration. In all cases it is essential that the low level of coverage in parts of an adaptive survey provides sufficient information to decide on subsequent sampling. In addition, it may be impossible to estimate the precision of the estimate from adaptive surveys.

The range of possible stock types and the best method of survey design are summarized in table 1.

MacLennan (1988). There is an important interrelationship between survey design and data analysis method. Table 2 summarizes a number of preferred methods. Table 3 provides a guide to the main assumptions in each technique.

It is important to remember that the results from the survey may take a number of different forms and these may be best provided by different methods. 1) Geographical map of distribution, 2) abundance estimate, 3) a measure of precision. It may be that a different analysis is required to provide a map and abundance estimate. However, the calculation of precision depends on the method for calculating abundance.

The Data

This may consist of transect averages or averages obtained from sections of transect normally described as Elementary Sampling Distance unit (ESDU). The choice depends on the general requirements from the data analysis, such as geographic detail required and validity of assumptions.

A number of averaging methods have been used. They are:

a) No stratification

Either transects or ESDU may be treated as samples all. This is rarely applicable as it requires a uniform survey grid and provides limited spatial information.

b) Stratification in Blocks or Rectangles

There is some similarity between these two methods. Largely arbitrary regular shaped strata are constructed in the area. Blocks are usually large and contain complete transects rectangles are small and contain only part transects. The assumptions are similar. These methods are applicable for non-stationary data. Blocks are applicable when large areas may be regarded as stationary. Rectangles are useful for finer scale change and some mapping information.

c) Contouring

A contouring criteria must be selected. If the density values themselves are chosen as part or as the contouring criteria then abundance estimates may be biased and any calculation of precision is precluded. Water temperature or depth, however, may provide very good contouring criteria. The more closely correlated the contouring variable and the stock density, the better will be the results.

This method is most useful for mapping stocks and generally should not be used for abundance estimation except when density data is not included in the strata definition.

d) Geostatistics

A comprehensive review of geostatistics is outside the scope of this document. This powerful mapping and averaging technique does not generally suffer from bias as do other mapping methods. It may be used easily with data exhibiting anisotropic distributions. It suffers from problems caused by temporal change both circadian and migration because these changes are modeled as spatial variation and can completely dominate the otherwise useful spatial.

TABLE 1. RECOMMENDED TRACK DESIGNS FOR DIFFERENT SURVEY AREAS AND STOCK DISTRIBUTIONS FROM SIMMONDS ET AL 1991.

Survey Area	Stock Distribution	Track Design
Narrow Shelf/Fjord	Low Contagion[1]	Systematic Zig-zag[2]
	High Contagion[1]	Systematic Zig-zag[2]
	Non-stationary[1]	Systematic Zig-zag[2] (with stratification)
	Very High Contagion[1]	Adaptive Outline survey followed by Systematic Zig-zag[2]
Wide Shelf/Open Sea	Low Contagion[1]	Systematic Parallel
	High Contagion[1]	Systematic Parallel
	High Contagion[1]	2-Stage Random Parallel
	Non-stationary[1]	Systematic Parallel (with stratification)
	Very High Contagion[1]	Adaptive Outline survey followed by Systematic Parallel or Adaptive (spacing or lengths)

Notes

1. Stock distribution is assumed random with respect to transect locations.
2. Zig-zag designs must be used with caution (see section 3.2.1.7 in text).
3. Stock distribution is assumed non-random with respect to a regular grid.

Sampling Effort

A good guide to sampling effort can be found in Aglen 1989 where the expected Coefficient of Variation (CV) is given as:-

$$CV = a\ (N/\sqrt{A})^{0.5}$$

where N is the distance sailed, A the area to be surveyed and a varies from 0.4 to 0.8 depending upon the extremes of contagion found in typical fish stocks. The extremes are characterized by smooth continuous layers (0.4) to single widely dispersed shoals (0.8). This simple guide can indicate the effort required for a desired precision given a sensible choice of a.

SPATIAL AVERAGING

A number of methods exist for determining the mean density from the acoustics samples obtained from a survey. The problems have been addressed by Shotton and Bazigos (1984), Johannesson and Mitson (1983) Maclennan and Mackenzie (1989), Dalen and Nakken (1983), Laloe (1985), Gohin (1985), Conan (1990), Foote and Stefansson (1990), Simmonds and properties of the data. Geostatistics in its simplest form assumes statistical stationarity but quasi-stationarity may be assumed by using only those values within a neighbourhood window and modelling only variogram within the distances defined by the size of the window. This may be adapted further by scaling the variogram by a proportional link in order to take account of possible links between mean and variance in the data.

Geostatistics may prove to be the best method for mapping and analyzing acoustic data, particularly for demersal stocks as migration is less of a problem. However, care should be taken at the design stage to collect data in a way that minimizes the effect of any changes with time.

TABLE 2. PREFERRED METHODS FOR SPATIAL AVERAGING FROM SIMMONDS ET AL 1991

Type of Stock		Type of Grid				
Statistical Stationarity	Stock Spatial Structure	Regular Parallel	Regular Zig-zag	Random	Stratified	Adaptive
Mean and Variance Stationary	No Spatial Structure	N1 N2[4]	N1 N2[4]	N1 N2[4]	-[5]	-[5]
	Some Spatial Structure	T C1 C2 R G	T C1 C2 G	T[3] C1[1] C2[1] G	C1[1] C21 R[2] G	C2[1] R[2]
Mean and Variance Non Stationary	Some Spatial Structure	T C1 C2 R G	T C1 C2 G	T[3] C1[1] C2[1] G	C1[1] C2[1] R[2] G	C2[1] R[2]

N1: no stratification, data is ESDU
N2: no stratification, data is transect
T: stratification in blocks, data is transect
C1: stratification by contouring using depth and/or hydrology
C2: stratification by contouring using densities and ecology
R: rectangles
G: geostatistics

1) Any stratification of the survey grid must be linked to the contouring method
2) Any stratification of the survey grid must be linked to choice of rectangle size
3) Any stratification of the survey grid must be linked to choice of analysis strata
4) Stratification is not applicable when there is no spatial structure
5) Stratified coverage or adaptive strategies are not applicable when there is no structure

TABLE 3. THE MAIN ASSUMPTIONS FOR DATA ANALYSIS THE METHODS FROM SIMMONS ET AL 1991.

Estimation method	Assumptions for unbiased estimation of variance related to spatial sampling
No stratification, each transect one sample each ESDU one sample	The samples are independent estimates of abundance in the total area.
Transects as strata, each ESDU one sample	The samples are independent estimates of within strata abundance. Strata abundance estimates are independent.
Stratification in blocks, each transect one sample	
Contouring	
Stratification in rectangles each ESDU one sample, or each transect one sample	
Multiple or repeated surveys	The surveys give independent estimates of total abundance.
Bootstrapping	Simulated (resampled) estimates are independent. Individual samples (ESDUs or transects) are independent.
Degree of coverage	Empirical precision - effort relationships based on repeated surveys (or resampling of subsets of data) considered representative for a particular survey.
Cluster analysis	Consider each transect as a cluster of sampling elements (ESDUs). Take account of within transect and between transect dependence (correlation).
Ratio estimator	Transect sums are assumed to be independent and identically distributed throughout the survey area.
Transform methods	Independent samples. More efficient variance estimates obtained by transforming data from underlying PDF to Gaussian PDF. Assumes that zero and non-zero values belong to different PDFs, that the PDF is correctly estimated and is stationary.
Geostatistics	Spatial correlation between samples is taken into account, assuming it only depends on the distance (and direction) between samples. Assumes stationarity.

ESTIMATION OF PRECISION

Table 3 provides a list of methods and the main assumptions. Simmonds et al. 1991 provides a guide to these methods. For more detail on each method, see the following: Multiple surveys and degree of coverage see Aglen (1989) and Aglen 1983, for Bootstrap see Efron and Tibshirani (1983), for cluster analysis and ratio estimator see Williamson (1982) and for geostatistics see Conan (1990), Armstrong (1990, Armstrong et al. (1989) and Petitgas (1990).

CONCLUSIONS

Although every stock exhibits slightly different characteristics, some general conclusions to survey design can be drawn. The choice of cruise track and analytical method are closely coupled and must be based on a knowledge of the stock distribution in the survey area. Tables 1, 2 and 3 are provided as a guide for this purpose. If random spatial distribution of stocks on the scale of transect spacing is an acceptable assumption then systematic parallel survey grid is preferred. If the stock distribution cannot be assumed to be randomly distributed, local random positioning of parallel transects is required.

The assumptions implicit in the choice of survey design lead to different analytical approaches to spatial averaging. The four most useful area a) stratification in rectangles, b) contouring using ecological and density data, c) geostatistics, and d) using transects as samples. Stratification of the survey area both for survey effort and for analysis may give considerable benefits as most stocks exhibit some statistically non-stationarity in their distributions.

Estimation of sampling error in the chosen spatial averaging technique imposes even more assumptions on the data. The samples from an acoustic survey are by their very nature not independent. Some approaches to variance estimation, geostatistics and cluster analysis, make use of this characteristic. Alternatively, rectangular strata or the ratio estimator aggregate data to avoid this problem. Others, such as contour strata, based on density dependent criteria, or some adaptive survey designs, preclude any analysis of precision. The applicability of the numerical estimates of precision depend fundamentally on the validity of the assumptions inherent in each method. It is unclear at present how these assumptions might be tested in practice.

ACOUSTIC SURVEYING AT THE ALASKA FISHERIES SCIENCE CENTER

by

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The Alaska Fisheries Science Center (AFSC) has responsibility for assessing the major fish stocks off the west coast of the U.S. from California, through the Gulf of Alaska and into the eastern Bering Sea. In the Gulf of Alaska and the eastern Bering Sea, the most important species in midwater is walleye pollock (Theragra chalcogramma) while off the west coast, an important species is Pacific Whiting (Merluccius productus). The stocks are assessed using two complementary direct survey procedures. The bottom component is assessed using a demersal trawl and the midwater stock is assessed using echointegration/midwater trawl (EIMWT) survey procedures.

In the eastern Bering Sea, a bottom trawl survey is carried out annually to assess the walleye pollock. This survey is a multi-species survey designed to assess all components near the bottom. Every three years, an EIMWT survey is carried out in conjunction with the bottom trawl survey. Thus, total abundance for pollock, the most abundant species in the eastern Bering Sea, is estimated only every three years. Figure 1 shows the results of the bottom trawl surveys carried out since 1979 and the combined results in the triennial years, when both surveys were undertaken. by examining these results, it is apparent that the proportion of pollock estimated from the bottom survey have changed drastically from less than 40 per cent of the biomass to over 60 per cent of the biomass. In this area, the predominant midwater species is pollock. There are very few contaminant species.

In the Gulf of Alaska, bottom trawl surveys are carried out every three years. Because of a lack of funding and severe surveying difficulties in the Gulf of Alaska, EIMWT surveys have been carried out only during the winter months, when the pollock are observed primarily in schools located off-bottom. No attempt has been made to combine the results of these surveys.

On the West Coast of the U.S. a major resource is the Pacific Whiting. The midwater and demersal portions of the stock are surveyed once every three years. Figure 2 demonstrates the results of these surveys. Less than 20 per cent (and with one exception, less than 10 per cent) of the stock is estimated from the bottom survey. In this area, there are many other species in midwater. However, it is possible to assign echo sign to whiting with near certainty and trawl hauls made in this echo sign usually provide samples that are nearly 100 per cent whiting.

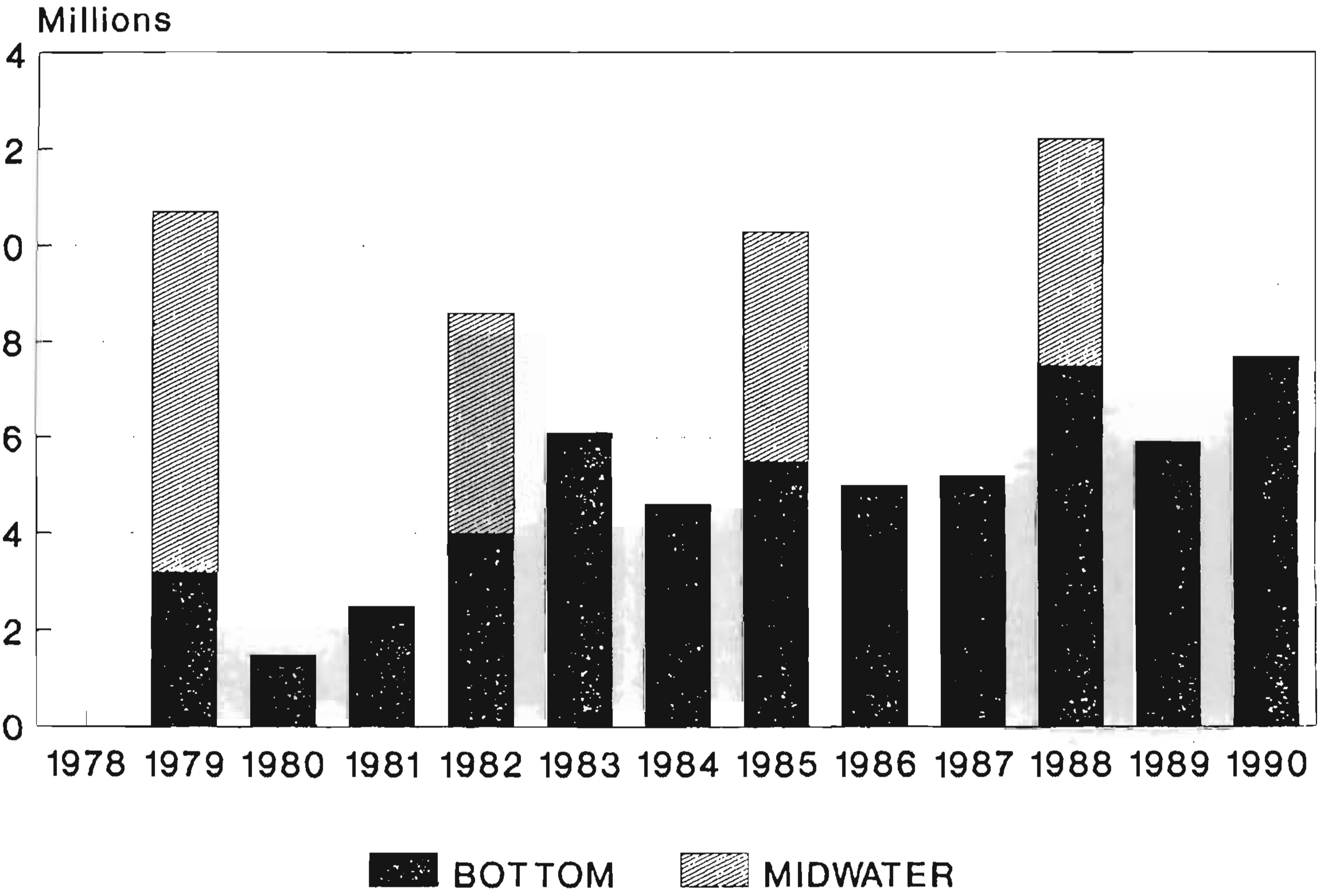
During the following, I will describe the procedures used for combining the two abundance estimates in the Bering Sea. The procedure is essentially identical for whiting off the west coast. The bottom trawl is assumed to assess the pollock within 3 m of the bottom and the midwater survey is assumed to assess the remaining water column. With these assumptions, the two results are additive. However, we know that the assumptions involved with these procedures are questionable at best. For example, we commonly observe pollock diving 10's of meters to avoid midwater trawl, only being captured when the midwater net is placed almost right on the bottom. It is likely that the reaction of these fish is similarly to a bottom trawl and pollock located in the water column are "frightened" down where they might be more vulnerable to the bottom trawl. At the AFSC, we are currently carrying out experiments to quantify this reaction for pollock. Work by Nunnallee from our group in 1990 demonstrated this type of behaviour by whiting in Puget Sound near seattle. In Figure 3, an echogram showing the movement of whiting as they confronted a demersal trawl is presented. Of course, the quantification of this result is difficult as it is difficult to determine lateral avoidance by these types of studies.

At the AFSC, we plan to continue these types of studies to examine the bias in our present procedures. From data collected this year in the eastern Bering Sea, we will attempt to estimate the abundance of pollock to very near the bottom. By making some assumptions about the distribution of pollock very near the bottom, we can obtain total abundance estimates using the acoustic system only and compare these results to the combined survey results.

Up to this time, there has been little effort at the AFSC to assess other midwater stocks using acoustic techniques. A primary reason for this has been the large scale nature of our survey efforts and the often patchy distribution of many of these species. For example, some rockfish species are often found only near particular bottom reliefs and a cost-wide survey of the type usually undertaken by the AFSc, only a few of these structures may be observed. In addition, the net sampling required to identify these isolated schools would be prohibitive. The ability to obtain species and biological composition for may also make the estimation procedure prohibitive.

In spite of the difficulties mentioned above, the AFSC plans to begin a pilot survey next year to assess certain rockfish species in areas of high abundance. The present plan is to break the acoustic effort into two major research areas: 1) the use of acoustic instruments to categorize bottom habitats (soft, hard, high relief, etc.) and 2) the estimation of density using echo counting techniques. To begin, only areas where the species composition is expected to be very simple will be surveyed.

FIGURE 1.


Millions
14
12
10
8
6
4
2
0
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
BOTTOM
MIDWATER

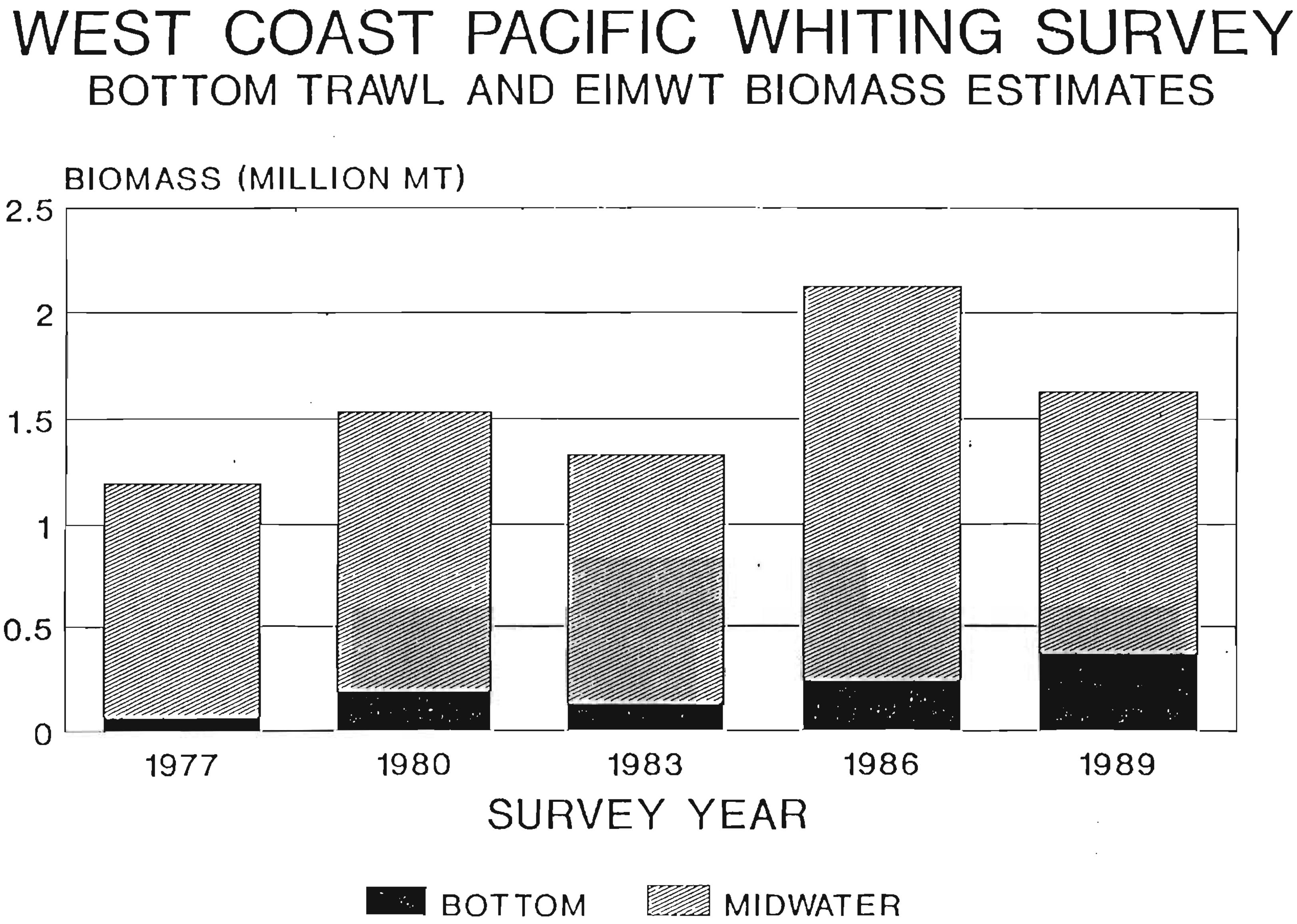

WEST COAST PACIFIC WHITING SURVEY
BOTTOM TRAWL AND EIMWT BIOMASS ESTIMATES
BIOMASS (MILLION MT)
2.5
2
1.5
1
0.5
0
1977
1980
1983
1986
1989
SURVEY YEAR
BOTTOM
MIDWATER

FIGURE 2.

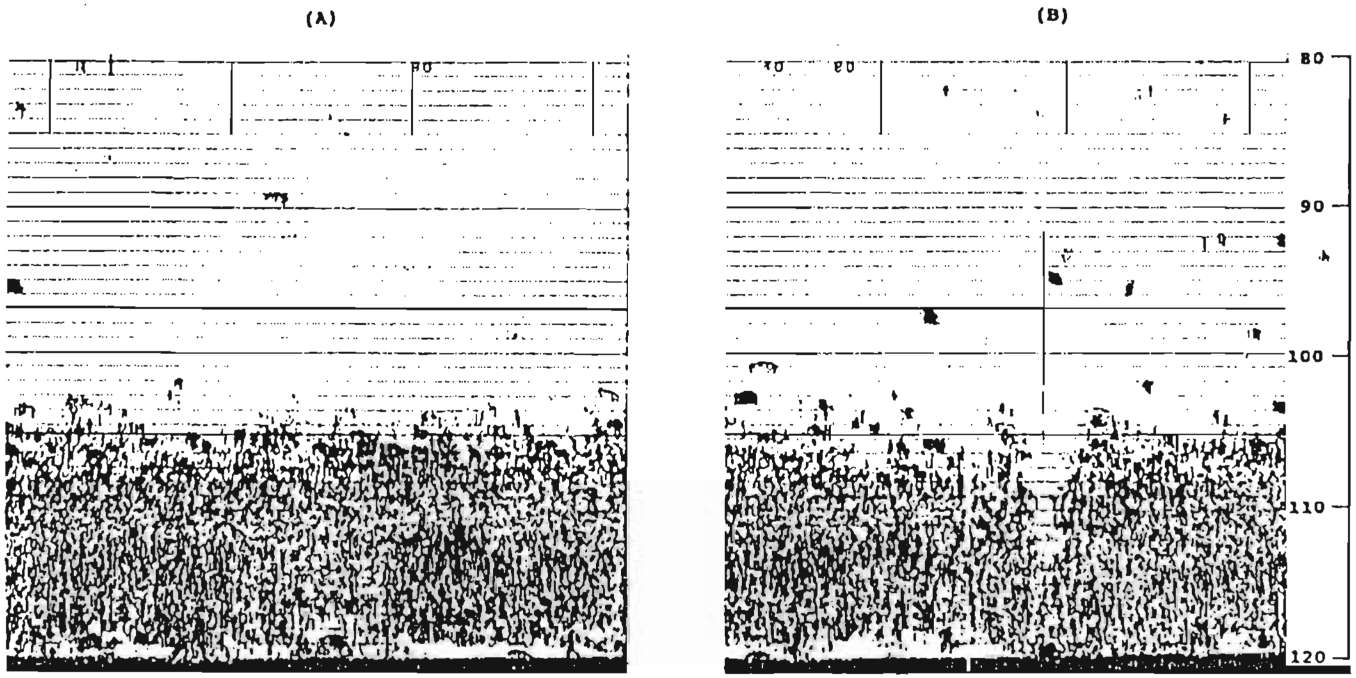


Figure 3. Echograms showing the daytime depth distribution of hake in Port Susan; "A" before they were disturbed by the demersal trawl, and "B" as they were confronted by the trawl. The "bump" on the bottom in echogram "B" indicates detection of the trawl. Transects were run across trawlers path.

FIGURE 3.

TRAWL SELECTIVITY

by

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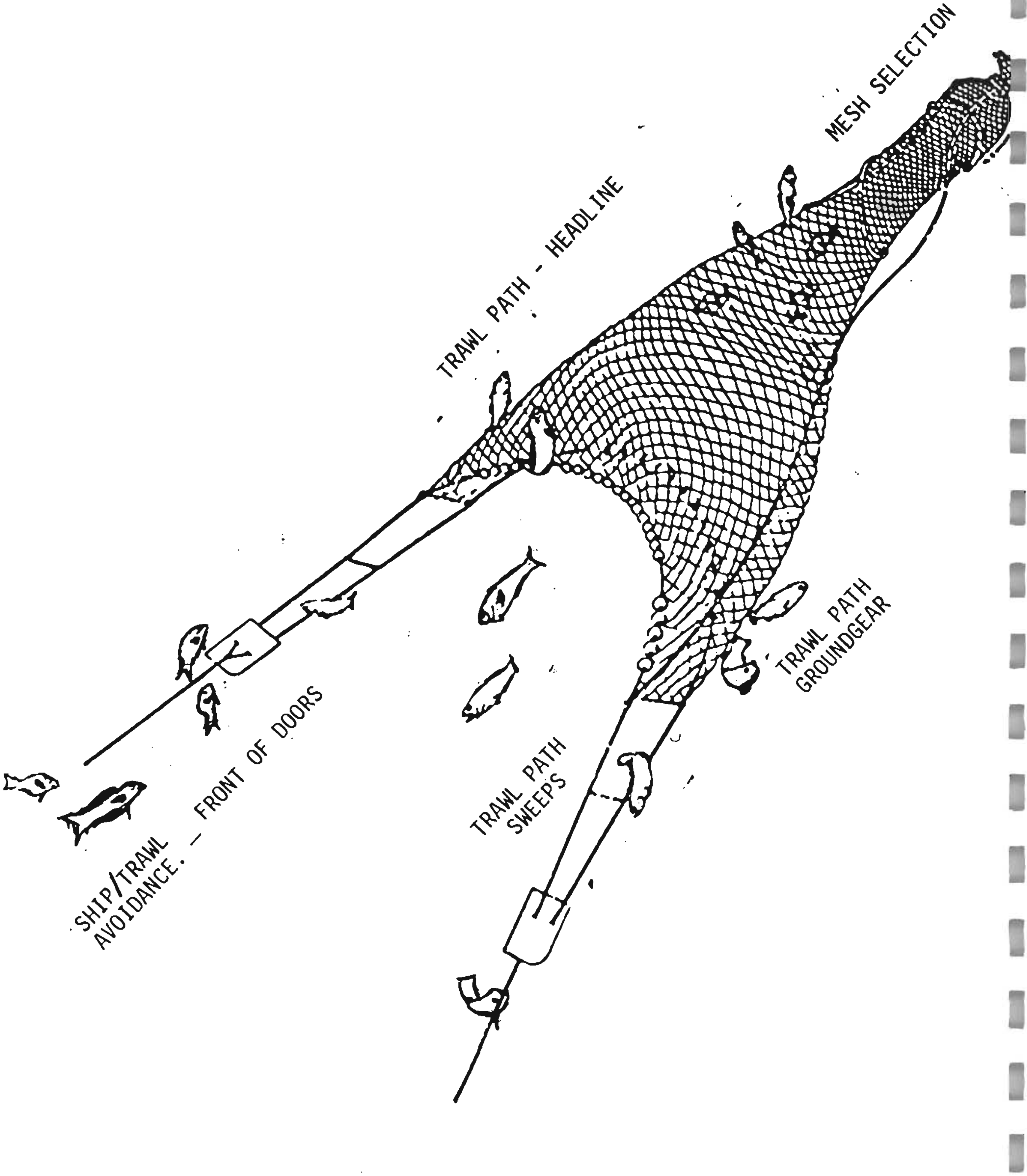
Trawls are highly selective fishing gears which can be designed to optimize efficiency for a particular species or size group. But optimizing for one species may reduce the measure of species composition in a community. Hence, compromises have to be made in the choice or design of sampling gears to make them multi-species (and multi-size) survey trawls.

The selectivity (or capture efficiency) of a trawl depends on the type of trawl, how and when it is used, the behaviour of the individual fish in the population, and the interaction of these factors in the fish capture process. Selectivity operates through the selection properties of the fishing gear, through areal and vertical distribution of fish in relation to the fishing gear and through fish behaviour in the vicinity of the fishing gear.

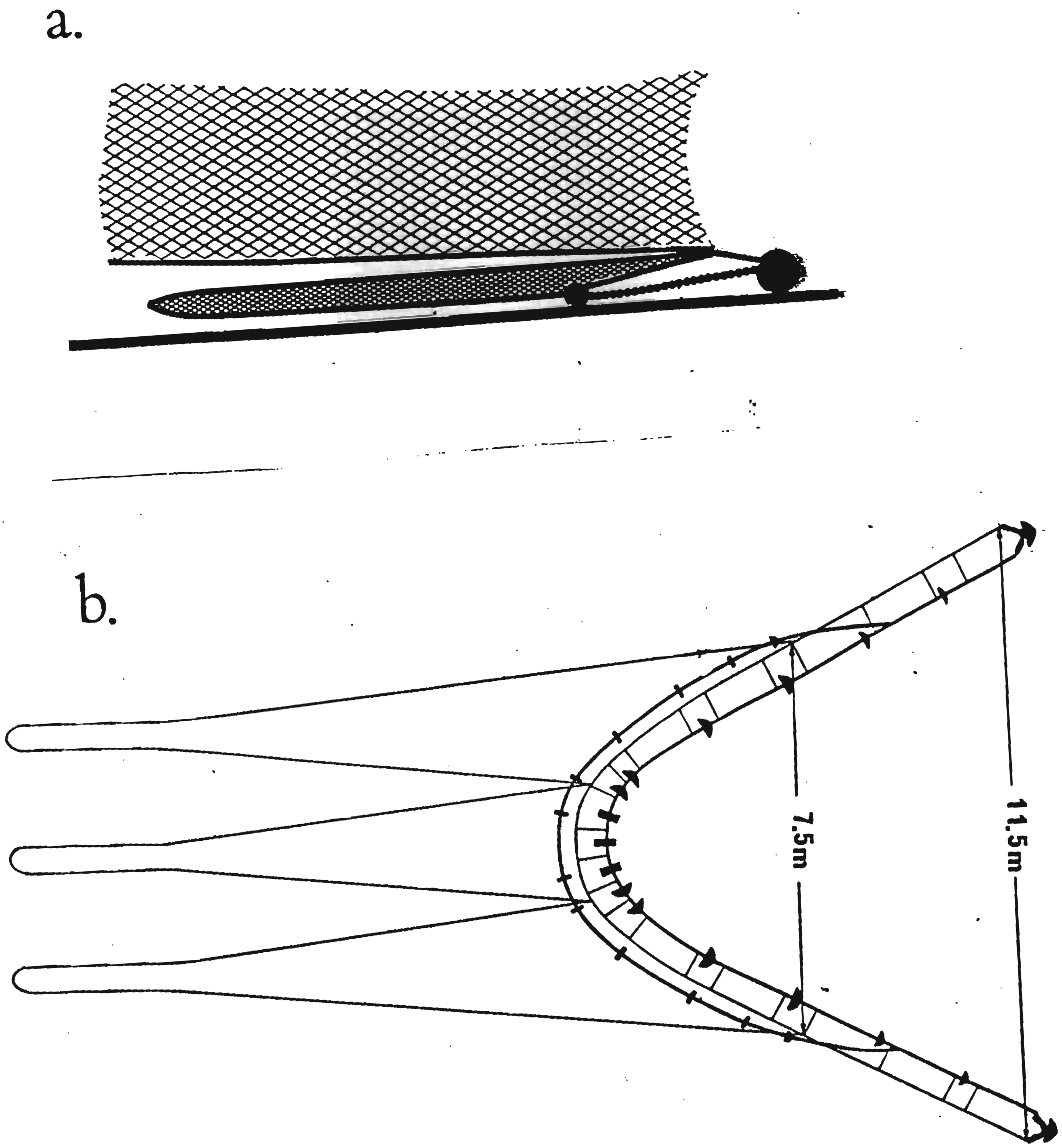
This presentation will summarize some of the recent experiments in Norway and Canada on survey trawl performance focusing on selection in front of the trawl doors, trawl path and through the meshes of the trawl in relation to species and size selection. Conversion of acoustic abundance to fish density depends on information on species and size composition, information normally obtained from trawl sampling.

OUTLINE

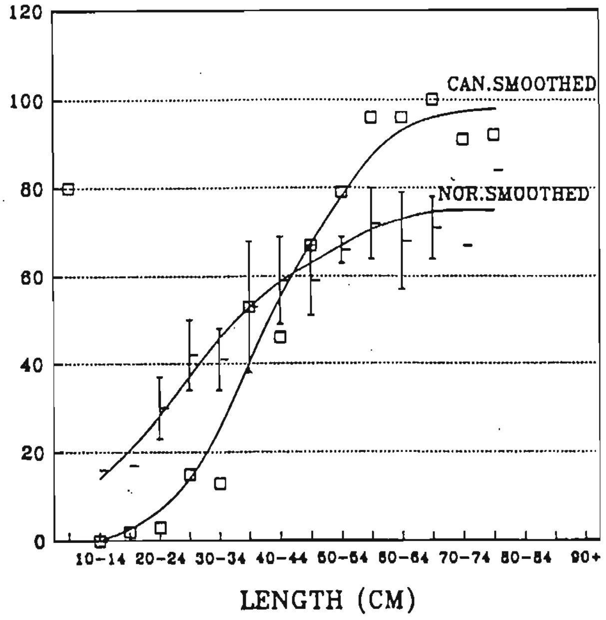
1) FISH CAPTURE PROCESS
2) DEFINITIONS
3) SELECTION PROCESS IN BOTTOM TRAWLS
4) SIZE SELECTION AT THE FOOTGEAR EXPERIMENTS
5) DIEL VARIATION IN TRAWL SELECTION EXPERIMENTS
6) EFFECT OF VARYING SWEEP LENGTHS ON SELECTION EXPERIMENTS
7) MESH SELECTION EXPERIMENTS
8) EFFECT OF TOW DURATION ON SELECTION EXPERIMENTS
9) SUMMARY OF RECENT RESEARCH
10) CONCLUSION


MESH SELECTION
TRAWL PATH - HEADLINE
TRAWL PATH GROUNDGEAR
TRAWL PATH SWEEPS
SHIP/TRAWL AVOIDANCE. _ FRONT OF DOORS

TRAWL BAGS EXPERIMENT IN NORWAY AND CANADA



SIZE SELECTION OF COD AT THE FOOTGEAR OF TWO SURVEY TRAWLS



1) Vulnerability is length dependent in cod and haddock (norway) and cod, plaice and yellowtail flounder (Canada).

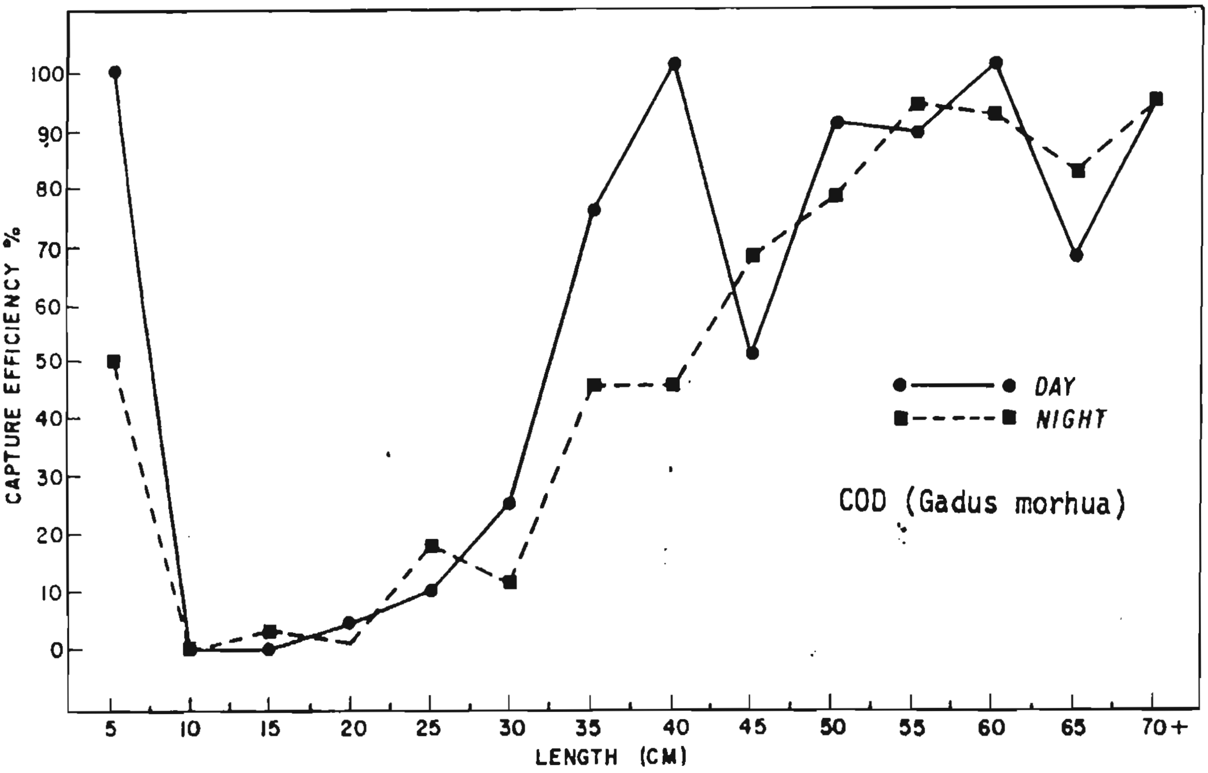
2) Cod ages 1 to 3 years are greatly underestimated in Norwegian surveys in the Barents Sea and Svalbard area.

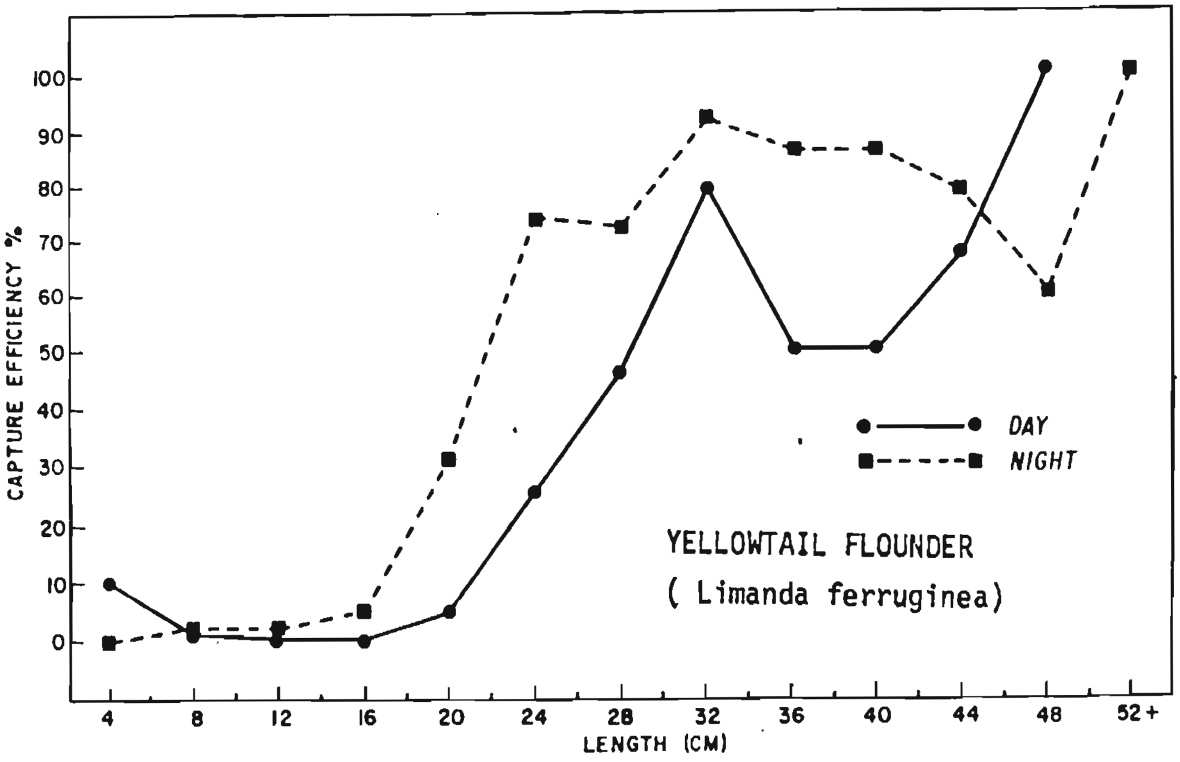
3) Cod ages 1 to 2 years are greatly underestimated in Canadian surveys of the Grand Bank.

4) In Canadian surveys, escapement under the footgear is a function of towing speed, height of the fishing line off bottom and unstable bottom contact. Mesh selection may also play a small role.

5) In Norwegian surveys, escapement is a function of unstable bottom contact.

6) Lower capture efficiency of the Norwegian trawl for large cod (75% vs 90% for Can. Trawl) may be related to difference in sweep lengths (40m vs 64m) and towing speeds (3K VS 3.5K).


CAPTURE EFFICIENCY %
100
90
80
70
60
50
40
30
20
10
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70+
LENGTH (CM)
●——● DAY
■----■ NIGHT
COD (Gadus morhua)


CAPTURE EFFICIENCY %
100
90
80
70
60
50
40
30
20
10
0
4
8
12
16
20
24
28
32
36
40
44
48
52+
LENGTH (CM)
●——● DAY
■----■ NIGHT
YELLOWTAIL FLOUNDER
(Limanda ferruginea)

DIEL VARIATION IN VULNERABILITY (TRAWL EFFICIENCY)

TRAWL BAG EXPERIMENT CANADA

NUMBER OF SETS: 12 DAY
14 NIGHT

COD	SMALL(<30CM)	MEDIUM (30-50CM)	LARGE (>50CM)
% ESCAPES			
DAY	95%	42%	10%
NIGHT	93%	66%	10%

PLAICE	SMALL (<23CM)	MEDIUM (23-43CM)	LARGE (>43CM)
% ESCAPES			
DAY	96%	35%	40%
NIGHT	95%	29%	20%

YELLOW-TAIL	SMALL(<23CM)	MEDIUM (24-29CM)	LARGE (>29CM)
% ESCAPES			
DAY	99%	65%	58%
NIGHT	95%	25%	22%

THE EFFECT OF VARYING SWEEPLENGTHS ON LENGTH COMPOSITION

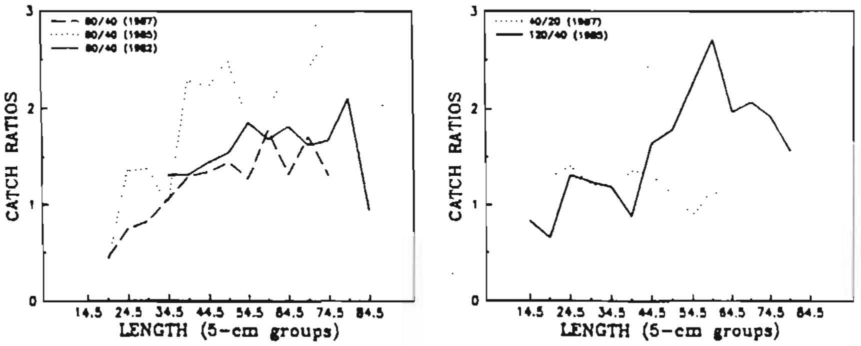


Figure 2. Sweep-length comparison. Catch ratios (catch with long sweep/catch with short sweep) of cod by length and experiment.

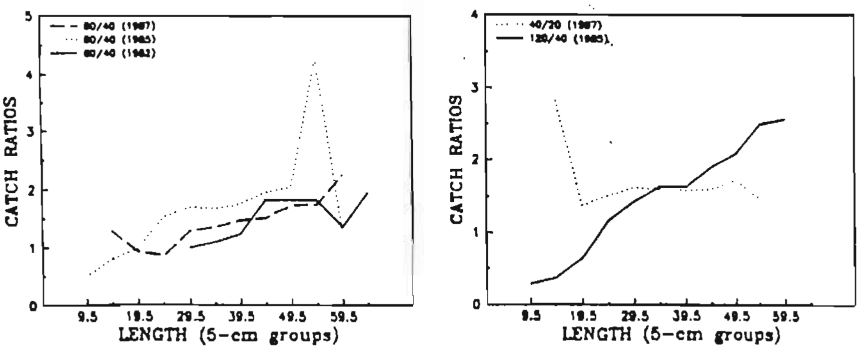


Figure 3. Sweep-length comparison. Catch ratios (catch with long sweep/catch with short sweep) of haddock by length and experiment.

- Catch ratios (and hence trawl catches) increased with increasing lengths of sweeps.

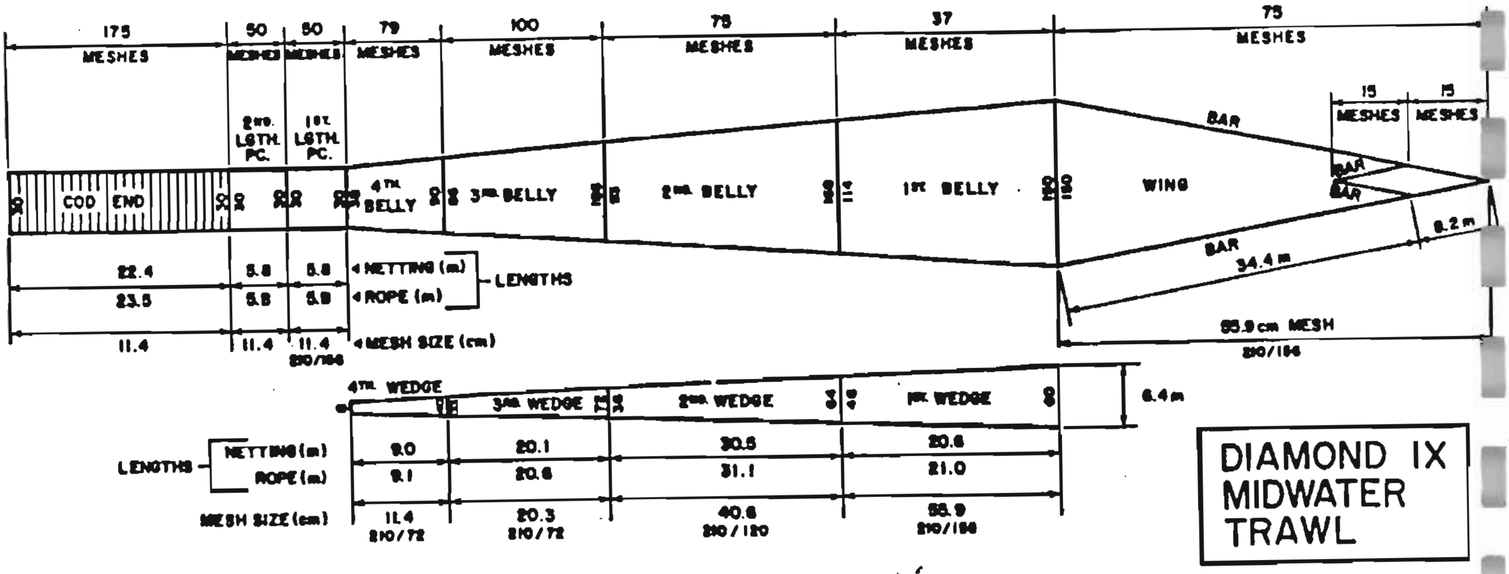
- However small fish were underestimated with catch ratios below 1. In the smaller length groups catches may even decrease with increasing sweep length.

- 120 m sweeps gave poorest catch ratios because small fish need stronger herding stimuli (door noise, sand clouds and sweep wire) and have lower swimming capacity than larger fish.

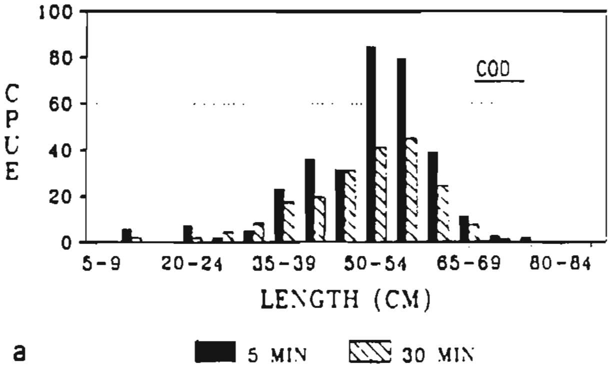
- Catch ratios in the 40-20 m sweep comparison were higher than 1 for small fish-increased herding effect by doors and sand clouds.

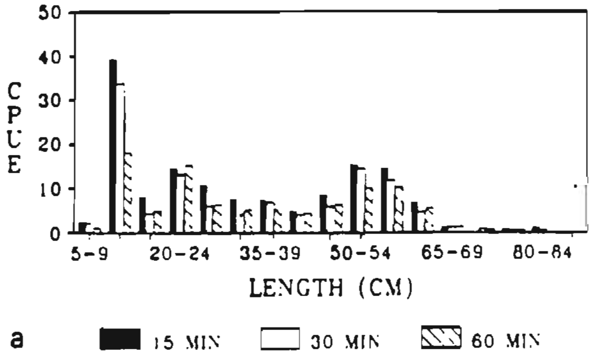
ESCAPEMENT FROM A MIDWATER TRAWL DURING CAPELIN ACOUSTIC SURVEY (B. Nakashima 1988)

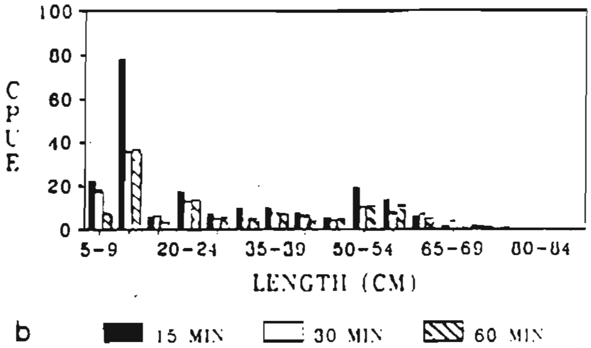
- Trawl bags (6.3 mm) sown outside the net on the top, bottom or sides of the trawl near the first, second, third and fourth wedges or bellies. 94 sets
- Escapement was restricted to third and fourth bellies near the codend
- Some differences seen in species composition between codends and bags
- Mean lengths of capelin in bags generally lower than codend
- What was acoustically 'seen' was not always represented in codend loss of small capelin suggests that age and length compositions biased to larger and older individuals. Same as Larsen 1984.



EFFECT OF TOW DURATION ON LENGTH COMPOSITION GODØ ET AL 1990

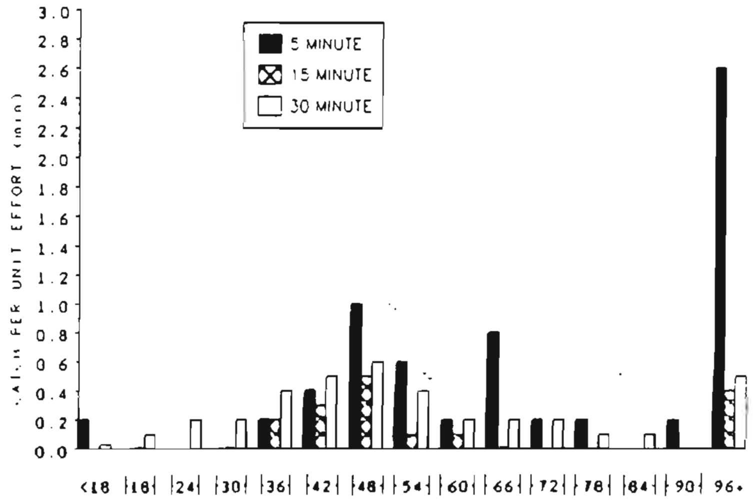




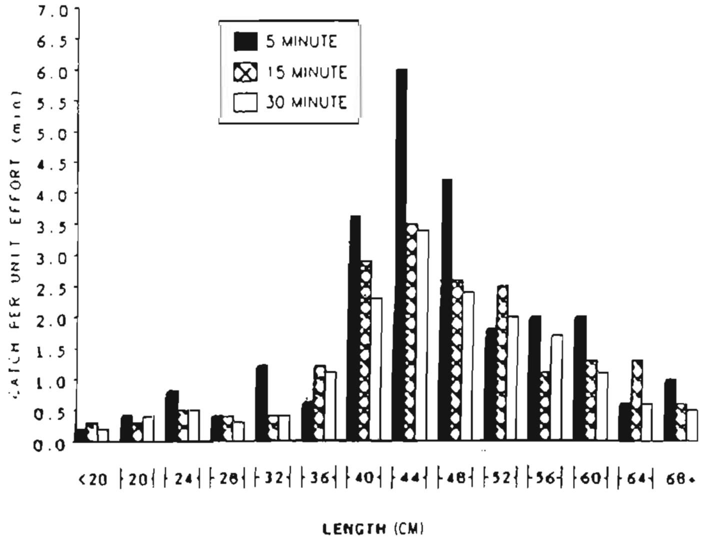


TOW DURATION EXPERIMENT IN CANADA (WALSH 1991)

ATLANTIC COD



AMERICAN PLAICE



CANADIAN EXPERIMENT

			Tow duration (min)
Species			
Cod		80.00 (6.63)	60.11 (7.06)59.23
(4.87)			
A. plaice	46.44 (1.45)		46.71 (1.07)45.89
(0.94)			
Yellowtail	35.30 (0.49)		35.51 (0.51)34.40
(0.42)			
flounder			
Thorny	50.93 (2.62)		47.41 (3.31)45.23
(2.63)			
skate			

NORWEGIAN EXPERIMENTS

Species	Ship[2]		Tow duration (min)	
Haddock	M.Sa		18.08 (1.17)	16.91 (3.62)18.81
(1.34)				
		A.Kr		18.81 (1.51)20.80
(2.16)	21.11 (1.90)			
Cod		M.Sa		26.33 (2.43)29.07
(3.29)	31.76 (1.69)			
		A.Kr		32.29 (3.77)32.35
(3.17)	34.59 (2.02)			
Long rough	M.Sa		24.15 (1.01)	24.37 (0.48)24.42
(0.49)				
		A.Kr		25.53 (0.99)25.31
(0.41)	24.92 (0.35)			
Haddock	Alb.[1]		33.23 (1.26)	33.23 (1.08)31.91
(1.28)	33.22 (1.73)			

---

[1] Estimates are based on subsamples for large catches.

[2] M.Sa = "Michael Sars"; A.Kr. = "Anny Kraemer"; Alb. = "Albatross IV".

TABLE 8

Estimated population mean length with standard error (in parentheses) for cod and haddock for the second Norwegian experiment (jackknife estimates).

Species	Tow duration (min)		
		5	30
Haddock	27.42 (3.26)		26.70 (2.86)
Cod		50.35 (0.85)	49.90 (1.61)

FACTORS INFLUENCING TRAWL SELECTIVITY

RECENT RESEARCH

Size and Shape of Meshes (Mesh Selection):

Main and Sangster 1985 measured flow in the Gov.
Net and found no difference in flow until just before the codend and proposed that small cod and haddock escapement took place.

Nakashima 1988 found smaller capelin in bag nets placed outside the net were smaller than that found in the codend. Similar to Larsen's 1984 capelin work. Also, species composition was not always the same.

Color of the Trawl Mesh Panels:

Wardle 1986 suggested that forward mesh escapement could be reduced in midwater trawls if the top panels were black and the lower panels white making the net visible.

Towing Speed:

Main and Sangster 1981 using underwater video found large cod and haddock would cruise back and forth between the wingends and could only be caught at the end of the tow when speed was suddenly increased.

Galbraith 1986 in Gov. study found that at high speeds, the net lifted off bottom permitting escapement of small fish while slower speeds caused the doors to collapse with reduction in herding of big fish.

Walsh 1989 in studying selection at the groundgear of a survey trawl by underwater video concluded that the standard towing speed of 3.5k was too fast for small cod and flatfish with the groundgear passing over them.

TOW DURATION:

Godø et al 1990 and Walsh 1991 compare short tows with long tows and found no significant change in mean length and short tows were as efficient as long tows at catching fish of any size.

TRAWL COMPONENTS:

Engås and Godø 1986 found that longer sweeps increase the catches of cod and haddock than shorter tows but at the expense of decreasing catches of small fish.

SIGHT LEVELS:

Engås et al 1988 found significant higher proportion of small cod and haddock were caught at night when both stocks were close to the bottom.

Walsh 1989 found that small cod and flatfish escaped underneath the footgear into trawl bags regardless of light conditions.

BOTTOM CONTACT:

Main and Sangster 1985 reported escapes of small cod and flatfish underneath the Scottish survey trawl rubber disc footgear and recommended rockhopper groundgear for better contact.

Engås and Godø 1986 and 1989 showed that the Norwegian survey trawl greatly underestimated young age groups of cod and haddock due to selection at the footgear. Recommended bobbin gear to be replaced by rockhopper gear to improve selectivity of small fish through better bottom contact.

Engås and Godø 1987 studied selection in a series of experiments using 1) bottom trawl, 2) pelagic trawl on bottom and 3) pelagic trawl. They concluded that bottom trawl was superior in catching all sizes of cod and small haddock.

Walsh 1989 found the large bobbin gear on the Canadian survey trawl had poor contact with bottom and increased the escapement of small and medium size cod, flatfish and skate.

SOUND:

Ona and several Norwegian researchers
Ship and trawl avoidance - sonar and echosounder observations of cod, haddock and herring

FISH BEHAVIOUR:

Main and Sangster 1981 and Engås and Ona 1987 found medium and large haddock pass over the top of trawl. Engås and Godø 1986 found small haddock passed under the footgear.

CONCLUSION

No fishing gear exists which exhibits equal selectivity towards fish of all sizes within a population. One should, therefore, consider gear selectivity experiments prior to estimating any population parameters.

ACOUSTIC SURVEY DESIGN AND TIMING FOR DEMERSAL FISHES: SPATIAL STATISTICS AND METHODS

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PREFACE

"Alexander to Aristotle, Greeting."

"You have not done right in publishing your acroatic lectures; for wherein, pray, shall I differ from other men, if these lectures, by which I was instructed, become the common property of all? As for me, I should wish to excel in acquaintance with what is noblest, rather than in power. Farewell."

"Aristotle to King Alexander, Greeting."

"You have written to me regarding my acroatic lectures, thinking that I ought to have kept them secret. Know then that they have both been made public and not made public. For they are intelligible only to those who have heard me. Farewell, King Alexander."

INTRODUCTION

The inclusion of this topic in this Workshop is, in at least one respect, premature. The ICES Workshop on the Applicability of Spatial Statistical Techniques to Acoustic Survey Data will be held in Reykjavik, Iceland, next week (5-9 September). It is hoped that some consensus on how acoustic surveys should be designed and analyzed will be reached at that workshop. At the present time, it is not possible to say what conclusions will be reached; for example, some of the sets being analyzed independently by the various participants comprise simulated data (albeit based on actual survey data) for which the true population values are n own, but have been kept as a closely guarded secret from the participants in order not to bias their analyses). While none of the data being analyzed are of demersal species *per se* the principles of design and analysis should be relatively independent of species. The technological problems of acoustically surveying demersal species, including those of signal interpretation, are being addressed in other sessions. For our purpose, it is assumed that an appropriate measure of fish density is available at regular (contiguous) intervals along the survey track(s).

1. THE NATURE OF THE SAMPLE

One feature that distinguishes an acoustic survey from a conventional trawl survey is that the echosounding equipment is (or should be) in continuous operation, i.e. the sampling is essentially continuous along the survey track. The continuous record that so eventuates can be arbitrarily divided into convenient intervals (lengths) or elementary units. We will described a straight line segment of the survey as a transect. In general, transects will not be of equal length, i.e. will contain different numbers of elementary units.

The transects may be dispersed in a regular fashion (Fig. 1 - although in actuality these are not as parallel or as evenly spaced as they appear). Alternate ends may be joined by perpendicular transects (Fig. 2 - simulated data). More commonly, perhaps, the situation might be described as semi-regular (Fig. 3). Zig-zag patterns have been used, either regular (with constant-angled corners) or irregular (Fig. 4). A special case is where the survey region has been stratified and (at least two parallel) transects placed at random within each stratum.

All the above, with the exception of the last mentioned, present problems for classical methods of estimation, particularly with respect to the estimation of the precision of the estimate of overall abundance or density. This last is a conventional stratified random sample with the transects as the sampling units. Recall that each transect, or sampling unit, is made up of elementary units but it is improper to regard these as the sampling units. The elementary units are contiguous and it is reasonable to suppose that density in any unit is, in general, much more like that of its neighbour than of units further removed from it. In other words, the elementary units are not independent and to regard them as so would likely lead to substantial overestimation of the precision, (i.e. too small a standard error).

The purpose of random sampling is, thus, through design, to eliminate the problem of spatial association (or spatial correlation). On the other hand, the objective of spatial analysis is recognize and exploit such spatial structure.

METHODS OF SPATIAL ANALYSIS

In one sense, stratified random sampling is a form of spatial analysis. Its superiority over random sampling is dependent on one's ability to demarcate, *a priori*, strata that are internally homogeneous relative to inter-strata differences. Our focus here is, however, on methods that more properly fall under the category of spatial analysis. These may further be subdivided into (1) response surface methods, and (2) interpolation techniques.

1. Response Surface Methods

The terminology here comes from the analysis of experimental data where the response (or output) is treated as some function of controlled and/or measured input variables. For the analysis of acoustic survey data, it is assumed that the measure of fish density can be expressed, apart from a random error, as a function of its location, possibly along with some other quantities, say depth, the values of which are known over the whole survey region. Instead of the actual measure of fish density, some transformed value, such as its logarithm, might be used. Thus we write

$$z(y_i) = f(\underline{x}_i, \underline{t}_i) + \epsilon_i$$

where $\underline{x}_i = [x_{1i}, x_{2i}]$ denotes the coordinates of the ith location and $\underline{t}_l = [t_{1i}, t_{2i}, \ldots t_{ki}]$ the values of k other variables. For example, one might assume that

$$\log(y_i + c) = a_0 + a_1x_{1i} + a_2x_{2i} + a_{11}x_{1_i}^2 + a_{12}x_{1i}x_{2i} + a_{22}x_{2_i}^2 + \epsilon_i$$

where c is some specified constant, common unity. If depths were known, a term b_lt_i might be added to the right hand side.

The above expresses the logarithm of the density as a simple quadratic function of its location. In reality, the "response" is unlikely to be anything so simple. Since the form of the function will generally be unknown, the usual approach is to approximate it by polynomials of successively higher order. Of course, any set of observations can be tracked perfectly by a polynomial of sufficiently high order, but the behaviour of such polynomials towards the boundary of the region is often highly unrealistic. The total abundance is then obtained by integrating the fitted function (back transformed if a transformation was employed) over the survey region. Thus the estimate is only as good as the ability of the function to represent the actual spatial trends.

2. INTERPOLATION TECHNIQUES

Our focus here will be on the method known as kriging although we mention in passing a spline approximation method that has been used by Stolyarenko (1988) and will almost certainly be one of those reported on at the forthcoming Reykjavik workshop.

In ordinary kriging it is assumed that the observations are a realization of a (two-dimensional) stationary process. The word "stationary" is used here in a specialized sense and has nothing to do with the mobility of fish. The latter is naturally a problem but for all current methods (stratification, response-surface estimation, interpolation) it is assumed that region of interest has been surveyed in a time that is sufficiently short in relation to the large-scale movement of fish for the effects to be inconsequential. By "stationary" is meant, essentially, that the expected value of the observation is constant (i.e. independent of location), $E(y) = \mu$, say, and that correlation between two observations is a function solely of the distance between them. Removal of these assumptions will be discussed later; for the moment, it is assumed that they are satisfied.

While it is reasonable to assume that observations at locations that are spatially close will be similar, it is also reasonable to assume that, beyond a certain distance, observations will be independent. In other words, the correlation between pairs of observations should be a decreasing function of the distance between them, but remain at zero for all greater distances. Kriging utilizes the "complement" of the "correlogram", namely the variogram which is an increasing function of the distance up to the critical distance, after which it remains constant. Specifically $\gamma(h) = Var\,(y_i - y_j)/2$ where h is the distance between y_i and y_j. A typical variogram is illustrated in Fig. 5. Note that, in general, $\gamma(0) > 0$ rather than $= 0$, as might be expected. This reflects the fact that there is generally measurement error in observations made at the same location and/or that spatial resolution is not perfect. The value of $\gamma(0)$ is known as the "nugget". The distance at which the maximum value of $\gamma(h)$ is first attained is known as the "range" and the maximum value as the "sill".

The estimate at some unsampled location, y_o say, is obtained as

$$\hat{y}_0 = \sum \lambda_i y_i$$

where $\Sigma\lambda_i = 1$ and the λ_i are chosen so as to minimize the mean squared prediction error $E[y_o - y_o]^2$; in this sense the estimate is "best". It can be shown that the λ_i can be obtained as the solution to:

$$\begin{matrix} \underline{\Gamma} & \underline{j} & \underline{\lambda} \\ \underline{j} & 0 & m \end{matrix} = \begin{matrix} \underline{\gamma} \\ 1 \end{matrix}$$

where

$$\underline{j} = [1,1,1,....1]'$$

$$\underline{\gamma} = [\gamma(y_1 - y_0), \gamma(y_2 - y_0) \ldots \gamma(y_n - y_0)]^1$$

and

$$\Gamma = [\gamma(y_i - y_j)]$$

Further, the minimized root mean square prediction error (kriging error) is given by

$$\sigma(y_0) = [\lambda, m]' \begin{matrix} \underline{\gamma} \\ \underline{1} \end{matrix}$$

The estimate is, thus, a weighted average of the observations with the weights calculated from the estimated variogram. In practice, it is unnecessary to sum over all *n* sampled locations; the estimate at any point is largely determined by the sampled points nearest to it. The variance of the estimate is also dependent on the distances to the nearest neighbours; the further away its neighbours, the greater the variance (or standard error).

The total abundance is then obtained by integrating estimates over the survey region, or in practice by summing over sufficiently fine mesh of locations. Unfortunately, the variance of this estimate is something more than the sum of the variances of the individual estimates and involves also the covariances of all possible pairs. (For pairs sufficiently far apart, the covariance will be zero, but for parts that are close together it may be substantial). Although the expression the variance of the overall estimate can be written down, its evaluation can present computational difficulties.

NONSTATIONARITY

In practice, we are unlikely to have stationarity; there will often be trends, possibly depth related or lower densities near the edge of an aggregation of fish with progressively increasing densities as one proceeds towards the centre of the aggregation. Failure to account to such trends will result in a variogram that describes the trend rather than the stochastic variation about it. Various methods of trend removal have been suggested. Median polish (Cressie 1986) is a relatively simple yet seemingly robust technique but, being a grid concept, is most effective when the sample locations fall on a grid (although the distances between the rows and columns of the grid need not be constant). If the locations do not constitute a grid, the observations may be "moved", within reason, to the nearest node of a grid. While the method may well be viable for relatively small regions, since the underlying assumption is that there are fixed and additive row and column effects, its appropriateness for large regions seems doubtful.

As with the response-surface analysis we may attempt to describe (and remove) systematic trends as a polynomial on the location coordinates (plus components for other known quantities, in particular, depth). Again there is the problem of determining an appropriate order for the polynomial. There is, however, a difference between what we are doing in these two cases. In the response-surface analysis we assume that all the structure is embodied in the fitted function and the residuals are independent random errors. Even if this is true of the final model, at the earlier stages of fitting (with lower-order polynomials), the errors will be correlated and the estimation inefficient. In the present situation, the trend (however determined) is taken as deterministic and all of the structural information is assumed to be in the correlation structure of the residuals. In practice, it is unlikely that this will be achieved and some of the trend effects will still appear in the variogram. The better the non-stochastic trend can be approximated, the better the kriging estimates; however, since the focus is on the residuals, incorrect specification of the trend may be less consequential than incomplete or overfitted response-surface models.

There are computer packages that attempt to do all this (universal kriging) but these would seem to have the dubious values of all such "black boxes".

Since, for a Gaussian process, the best predictor is a linear predictor, as with the fitting of response surfaces, there is a tendency to transform data to obtain approximate normality of distribution and, likewise, introducing all the inconveniences involved in back transformation.

RELATIONSHIP TO DESIGN

Let us return to Fig. 1 and ignore the fact that the transects are not exactly parallel. Clearly a variogram can be readily estimated in the direction of the transects. (Indeed, the stability of that variogram as one moves from transect to transect could also be explored.) But is the variogram (or correlation structure) perpendicular to the transects the same as along the transects? One might suspect not, since the transects are at right angles to the depth contours. The problem is that, if the inter-transect distance exceeds the range of the along-the-transect variogram, there is virtually no way of testing such hypothesis. The whole point of kriging is to interpolate between the transects, but if the variogram perpendicular to the transects differs from that parallel to the transects, the use of the latter would lead to false security in erroneous results.

The dependence of the variogram on direction (in addition to distance) is referred to an anisotropy. (If the variogram is independent of direction, the process is "isotropic".) Thus, if anisotropy is suspected, transects should be run in at least two directions (or some parallel transects should be sufficiently close to permit the estimation of the variogram in the perpendicular direction).

In this respect, the situation of Fig. 4 is somewhat better although, here, trend removal by median polish is impractical.

In Fig. 2, the "north-south" transects linking the ends of the "east-west" transects provide some limited ability to estimate a variogram in the direction perpendicular to the main transects. On the other hand, the fact that different starting points on the east-west transects results in at most 5 points aligned in the north-south direction works against median polish as a trend-removing tool.

In Fig. 3, we have transects in two predominant directions (perpendicular) plus a few others that run off at various angles. Clearly the variogram can be estimated in at least two directions and the assumption of isotropy checked. Trend removal by median polish is also a possibility although the size of the region might cause it to be ineffective. Removal by means of a polynomial is clearly feasible.

What then would be an optimal design for a kriging analysis? The answer would appear to be a set of parallel transects in one direction coupled with another set at right angles to these (see Figs. 6 and 7). The transects need not be equidistant (nor of equal length). Samples taken at the points of intersection of these sets would permit a direct estimate of the nugget (which can then be compared with the indirect estimate made by fitting some functional form to the remaining points of the variogram).

If the transects were equidistant, we would have a systematic design in two directions. This gives rise to the question "can valid estimates be obtained from such a design by other than spatial analysis?". The next section addresses this question.

ANALYSIS OF A SYSTEMATIC SAMPLE

Estimates of the mean (or total) from a systematic sample are commonly, although not universally, more precise than estimates obtained via random sampling. The difficulty is that the precision resulting from systematic sampling cannot be determined from the sample data *per se* and additional assumptions must be employed. In this systematic sampling is, perhaps, no different from response-surface fitting or kriging.

One approach to estimating the precision of a mean obtained from a systematic sample with a single random start is to assume a "stratification-effects-only" model, i.e. assume that each sampling unit (transect) is in a stratum over which the expectation of the response (density) is constant (Cochran 1977). This is not too different from the assumption made for stratified random sampling and, in many situations, should be a reasonable first-order approximation. Then

$$s_0^2 = \frac{N-n\sum (y_i - y_i \ + \ 1)^2}{Nn \ \ 2(n \ - \ 1)}$$

may be used as an estimate of the variance of the mean. Here N denotes the total number of transects required to cover the survey region; thus, in general, $(N - n)/N) = 1 - n/N \approx 1$. Under the assumption that the model is correct, this will usually overestimate the variance somewhat.

The idea can be extended to assumption of random fluctuations about a linear trend rather than stratification effects. In this case, an estimator of the variance is

$$s_1^2 = \frac{N-n}{N} \; \frac{n^1}{n^2} \; \frac{\sum (y_i - 2y_{i+1} + y_{i+2})}{6(n - 2)}$$

where, again, $(N - n)/N \approx 1$ and unless n is small n^1/n^2 may be taken as $1/n$.

The notion can be extended to quadratic, cubic and higher-order polynomial trends. In general, we have, with the finite population correction $(N - n)/N$ omitted (Kingsley and Smith 1980),

$$s_d^2 = \sum_{i=1}^{n-d} [\sum_{j=0}^{d} (-1)^j \binom{d}{j} Y_i+j]^2 / \binom{2d}{d} n(n - d)$$

For example

$$s_2^2 = \sum_{i=1}^{n-3} (y_i - 3y_{i+1} + 3y_{i+2} - y_{1+3})^2/20n(n-3)$$

and

$$s_3^2 = \sum_{i=1}^{n-4} (y_i - 4y_{i+1} + 6y_{i+2} - 4y_{i+3} - y_{i+4})^2/70n(n-3)$$

What is the appropriate order of the polynomial? The data will be tracked perfectly by a polynomial of sufficiently high order; specifically, as d increases and, indeed, $= 0$ when $d = n - 1$. Basically the estimator will be conservative if the underlying polynomial (given that such exists) has order greater than that assumed. If the order is less than that assumed, some of the random noise is being identified as systematic trend and the variance then underestimated.

Although decreases as d increases it also contains progressively fewer terms; if we treat these as analogous to degrees of freedom and multiply s_2 by the appropriate value of Student's t to obtain half-width of a confidence interval, we will find a point at which the width is minimized. It is tempting to take this as the appropriate value of *d* but, usually, the difference between this width and that at several smaller values of *d* is inconsequential.

A better approach may be to fit progressively higher order polynomials to the data and at each stage compare the sum of squares due to including the term of degree *d* with the residual mean square, and terminate the procedure when the former is comparable to (not "significantly" different from) the latter. Some caution is needed; consider Fig. 8 in which the linear and cubic components would be negligible but the quartic component considerable. Accordingly, one should always plot the data (and the fit). If there is any doubt, one's policy should be towards conservatism, i.e. the smaller value of *d*.

DISCUSSION

Spatial analysis appears better accomplished with systematic designs and, if there is any potential for anisotropy, transects should be run in at least two directions (generally at right angles). The use of systematic designs prohibits analysis by classical (design-based) methods which assume nothing more than random placement. In other words, classical analysis makes no use of the spatial information that is embodied in the data. The use of such information should result in better (i.e. more precise) estimates of mean density or abundance. In exploiting this information spatial analysis, on the other hand, requires additional assumptions; choices have to be made for which there exist no absolute criteria. How critical are these choices? In other words, how robust is one's spatial analysis to violations of the assumptions?

The other question is how much gain in precision can be obtained by a spatial analysis? Is the gain commensurate with the additional effort? Are there simpler but viable ways of using spatial information to keep the advantages of systematic sampling? It is hoped that a consensus on at least some of these questions will be reached at the Reykjavik workshop next month.

To conclude, it is perhaps worth recalling that the original purpose of kriging was to address questions such as where to drill the next oil well, or sink the next mine shaft. Estimation of the amount of some material in a region was not the intent, although it can be achieved via kriging methodology. Whether it is advantageous to do so in relation to other methods is an open question and, to the author's present thinking, rather doubtful.

FIGURE 1.

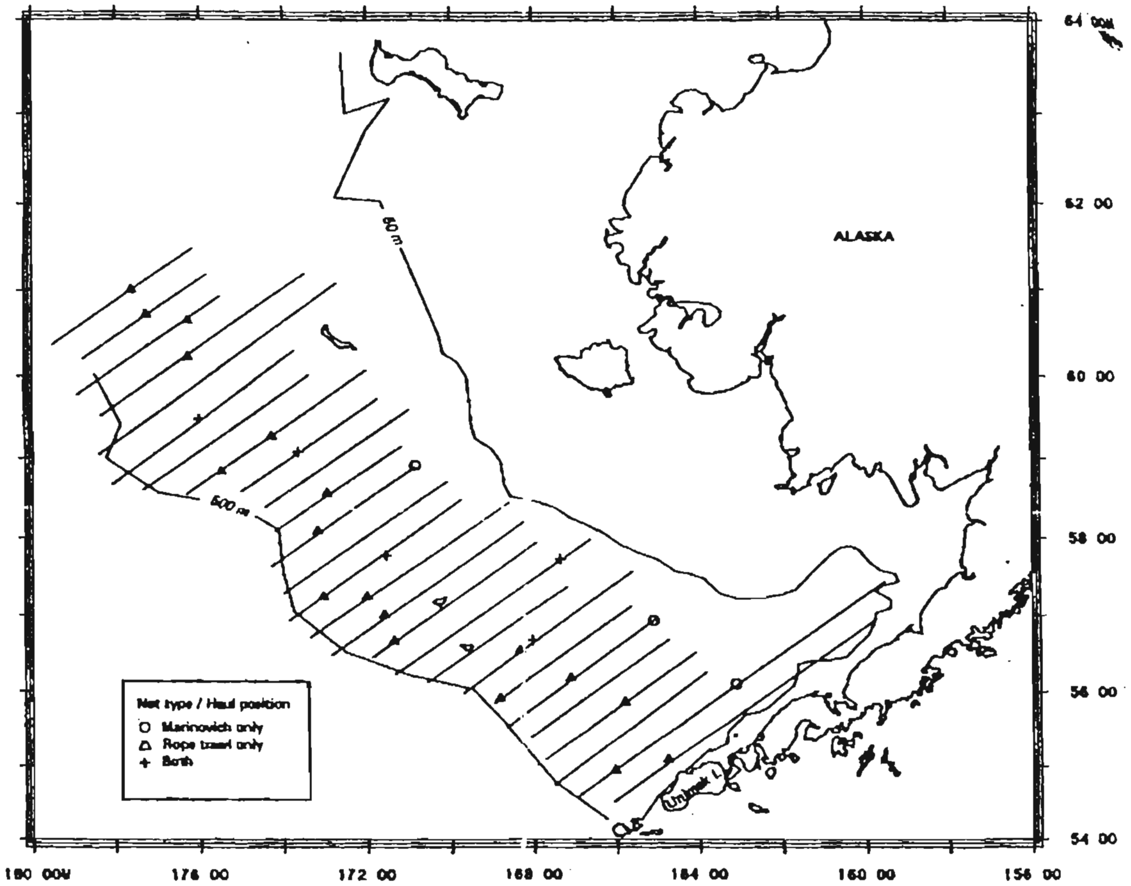


Fig. 1.--Transect lines surveyed during Summer 1988 echo integration/midwater trawl survey of adult walleye pollock on the eastern Bering Sea shelf and slope. Net type used at each haul postion also indicated.

FIGURE 2.

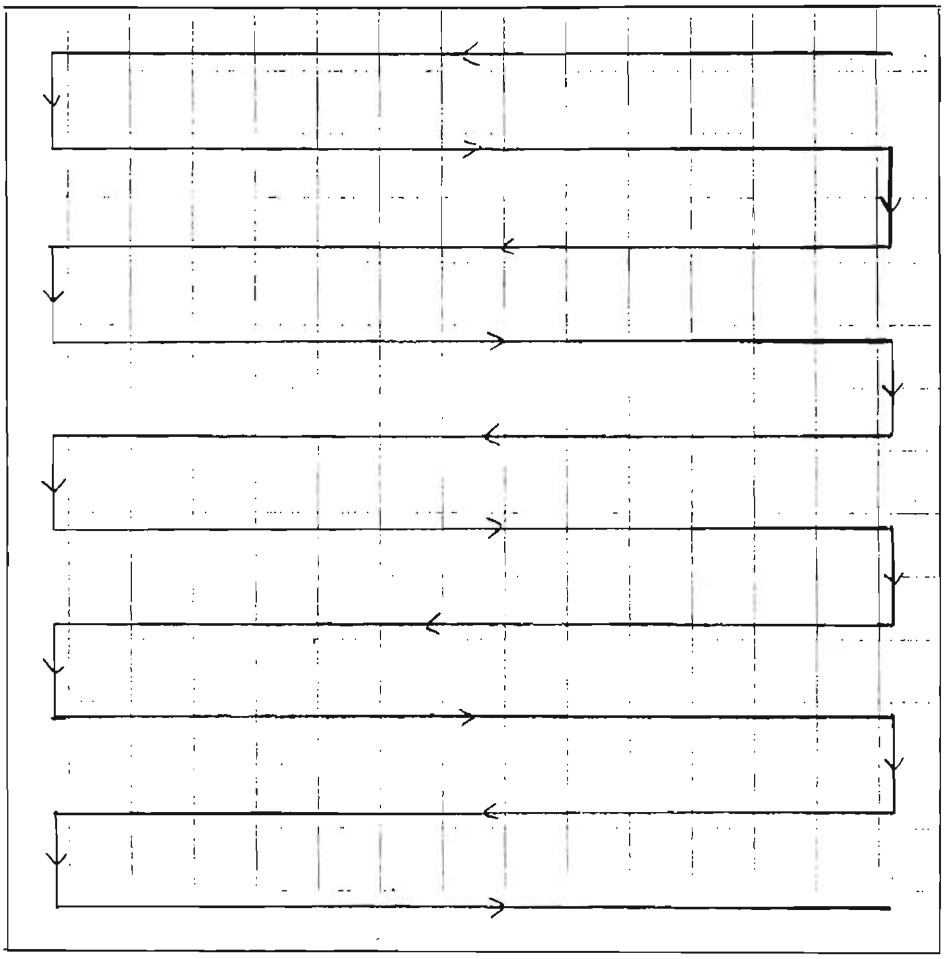


FIGURE 3.

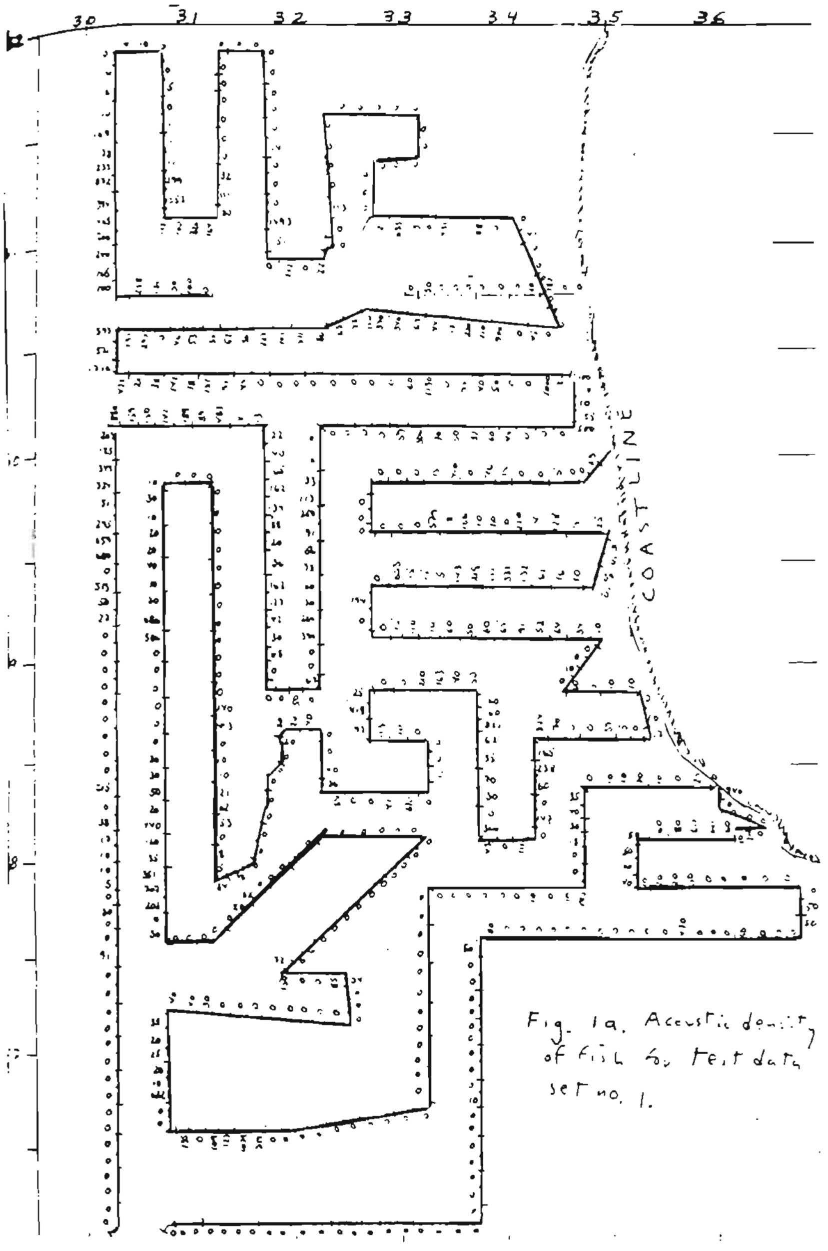


Fig. 1a. Acoustic density of fish for test data set no. 1.

FIGURE 4.

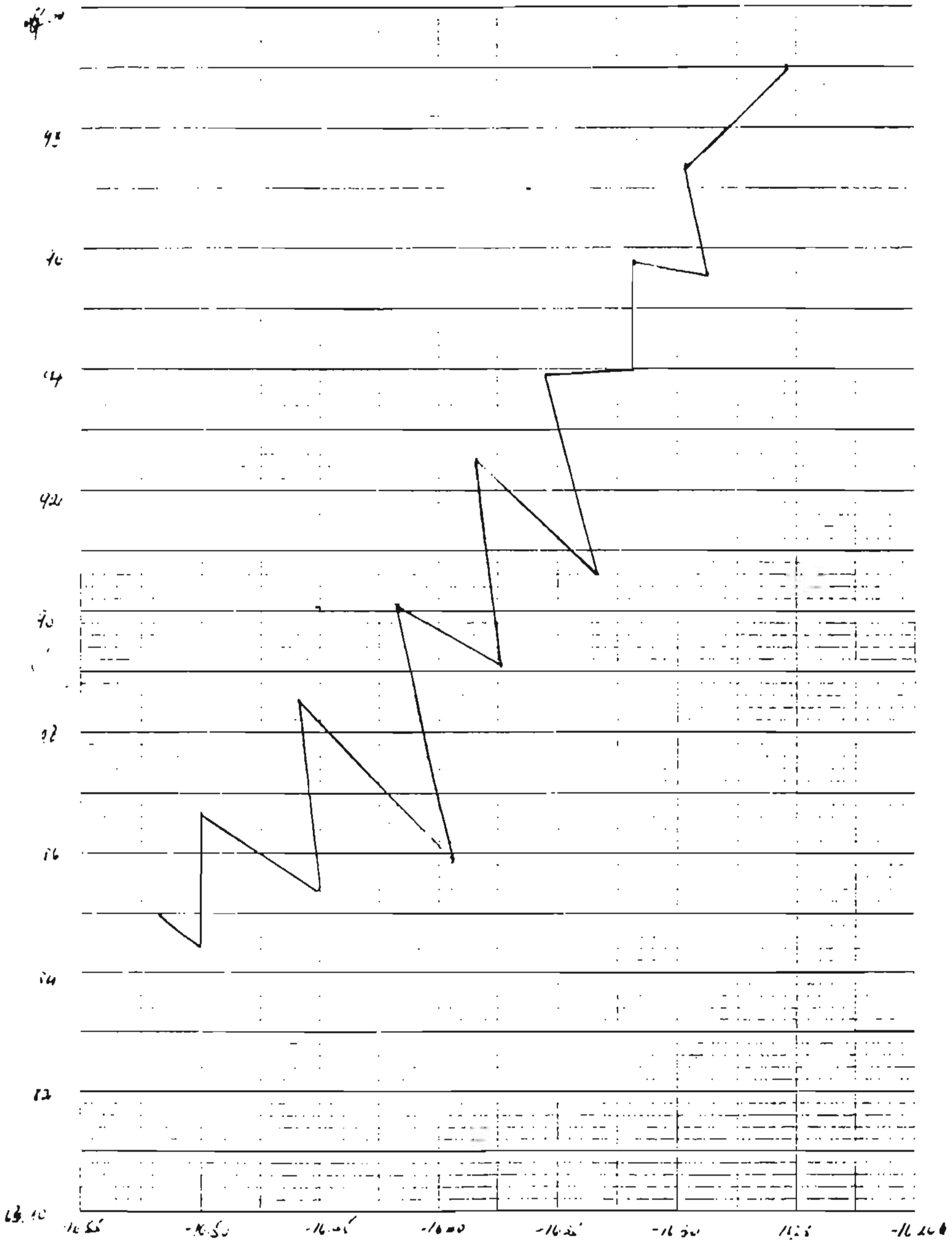


FIGURE 5.

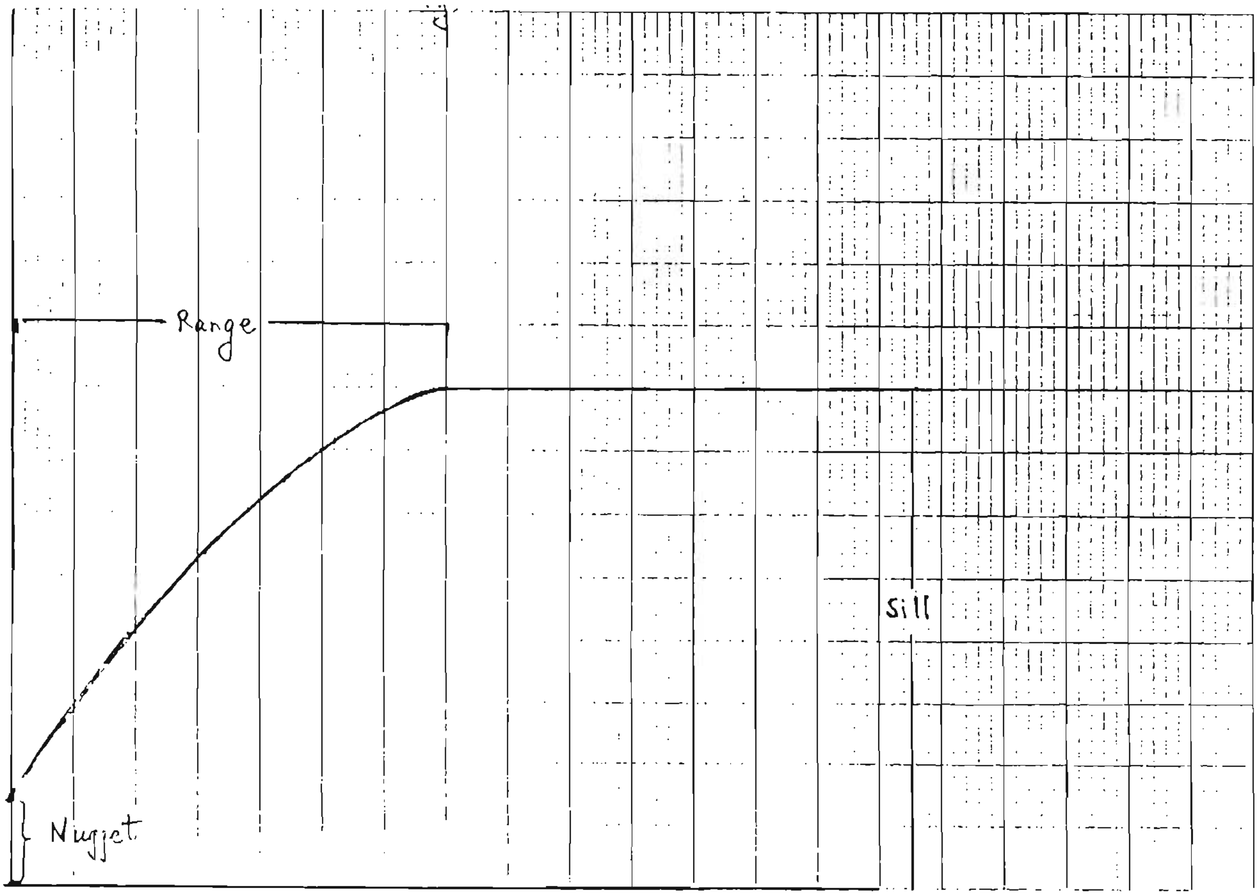
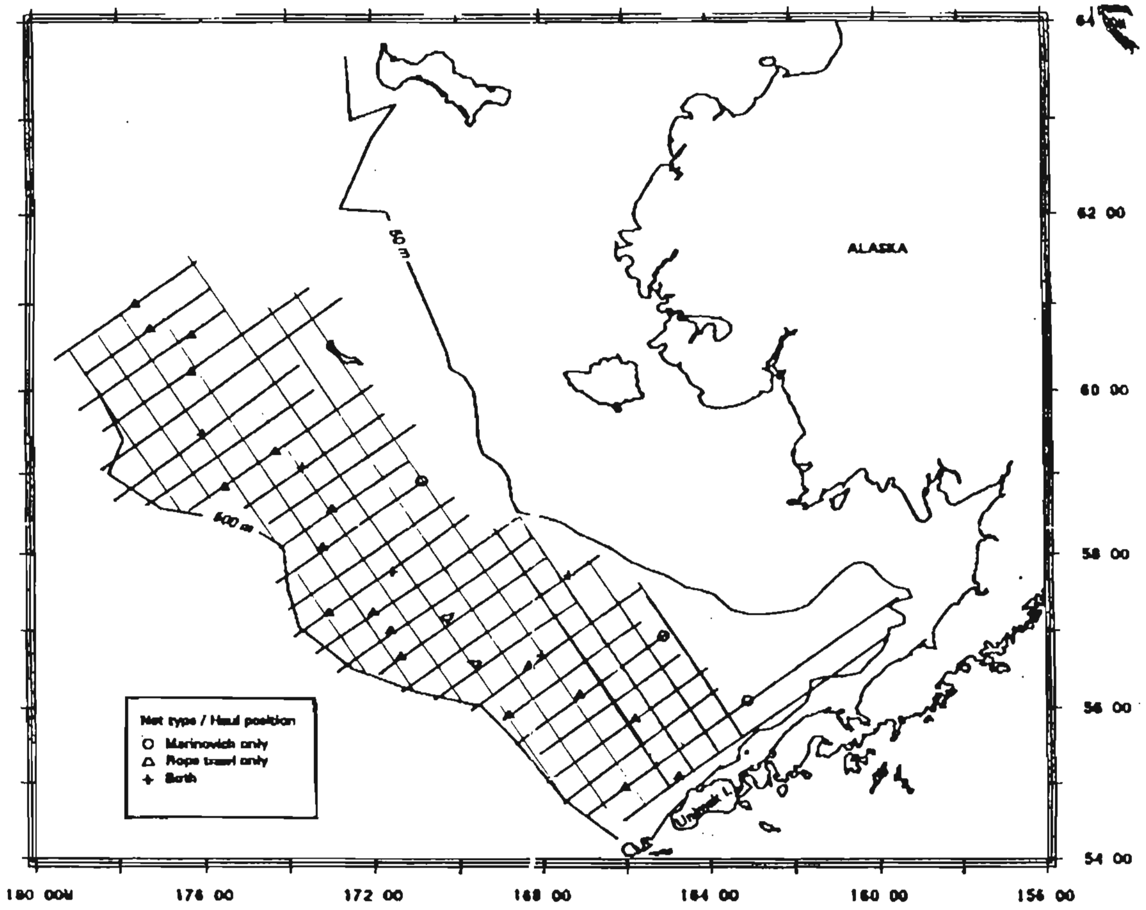


FIGURE 6.


64
62 00
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180 00W
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160 00
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ALASKA
60 m
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Unimak I.
Net type / Haul position
○ Marinovich only
△ Rope trawl only
+ Both

FIGURE 7.

Fig. 7

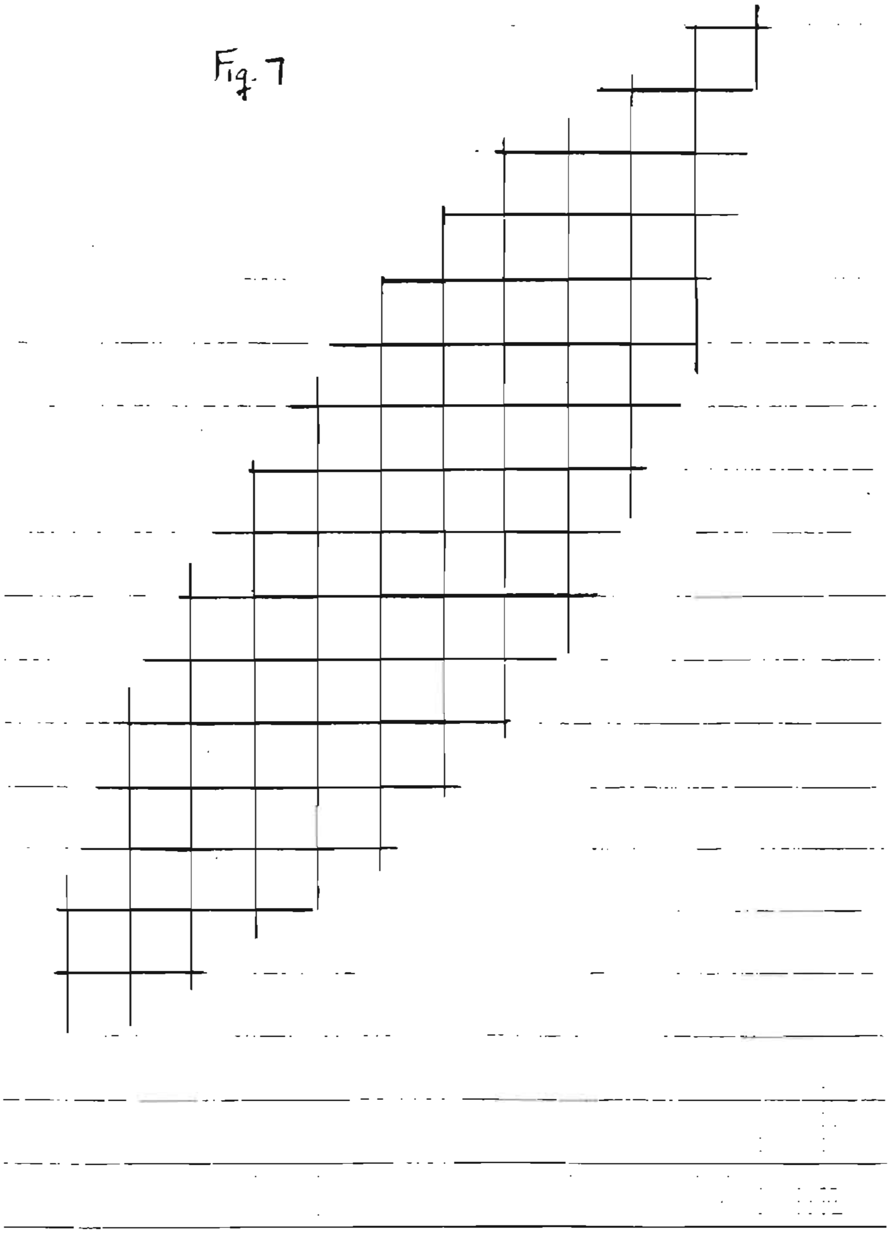
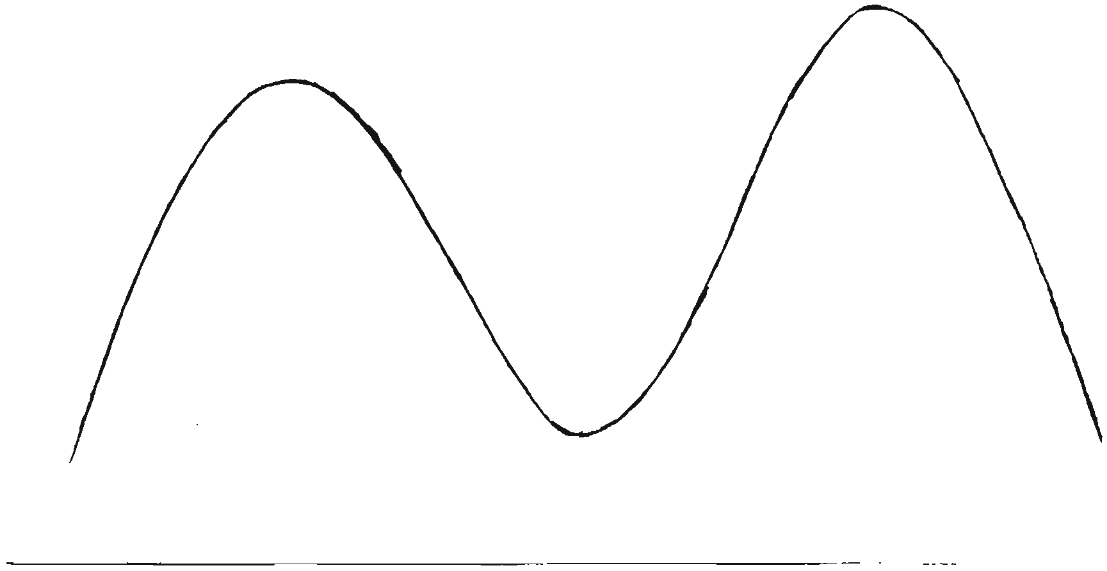


FIGURE 8.



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