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METHODS OF MEASURING STOCK ABUNDANCE OTHER THAN BY THE USE OF COMMERCIAL CATCH AND EFFORT DATA

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METHODS OF MEASURING STOCK ABUNDANCE OTHER THAN BY THE USE OF COMMERCIAL CATCH AND EFFORT DATA

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CONTENTS

Abstract

The paper reviews methods of monitoring the abundance of fish stocks other than by the analysis of catch and effort data. The main methods considered are: fishing surveys; acoustics, sightings and aerial surveys; egg and larval surveys; and tagging experiments. For each method consideration is given to the precision obtained, the possible causes of bias, and the costs involved. A tabulation is given of the advantages and disadvantages of different methods in respect of different types of stock. The ultimate choice of method depends on the biological and environmental characteristics of the situation, as well as the specific purpose of the work, and the resources of personnel, expertise and equipment that are available.

1. INTRODUCTION

The classical method of monitoring changes in fish stock abundance has been the use of catch and effort statistics from the commercial fishery. This has two big advantages: it can be cheap, since the basic data may be collected for other purposes, and because it may be based on the operations of hundreds of vessels, and tens of thousands or more fishing operations, the sample variance can be very small. Against this, there are serious disadvantages mainly associated with changes in vessels, gear and method of operation. These changes are in many fisheries becoming more frequent and more drastic, so that the use of catch and effort data is becoming more difficult. Thus other methods of monitoring abundance are potentially of increasing importance, and modern technology, e.g., in acoustics, is increasing the practical feasibility of using them.

The problems in using catch and effort data have been reviewed by a working group of ACMRR (FAO Fisheries Technical Paper No. 155). The present paper, which has been reviewed by the ACMRR Group, is meant to complement that report. It should be read with it to provide a balanced guide to the best methods of estimating abundance and monitoring changes under different practical conditions and for different purposes.

2. FISHING SURVEYS

2.1 Introduction

Fishing surveys, especially with bottom trawl, have been used extensively for measuring both long-term and short-term changes in fish abundance. The method may be applied to get relative abundance indices of fish resources consisting of several species within a defined area (e.g. the total groundfish resource) and also of single species or single age-groups of a species. Two different sampling designs, systematic sampling and random sampling, the latter often combined with stratification of the area, have been used. Systematic sampling may be efficient and lead to more precise estimates than random sampling because of the systematic coverage of the area. The main drawback of the method is the lack of valid estimates of precision. The need for such estimates led to stratified random sampling designs which are the most used at present.

2.2 Stratification of Trawl Surveys

Stratification has several advantages compared to purely random sampling. By dividing an area into strata that are as homogeneous as possible with respect to fish density and, allocating the sampling effort between strata according to an optimum sampling scheme (Cochran, 1963) the precision of the abundance indices estimated from a given number of trawl hauls will be increased. The stratification must be done before the survey is done, or at least before the data are examined, (otherwise any statistical calculations e.g. of confidence limits, become invalid), but may be done on the basis of a small-scale preliminary survey. Very often stratification of bottom-trawl surveys is done on the basis of depth, with which the abundance of many species is strongly correlated. By using a stratified random sampling scheme, one is assured that the sampling is spread out over the whole area, and one can calculate abundance indices for parts of the total area consisting of subsets of strata. If a survey is directed towards a group of species a stratified sampling scheme which would be efficient for one species could be very inefficient for others and the sampling scheme has to be a compromise between different interests. An example of a relative complex survey design is found in Jones and Pope (1973). In ICES (1974) is given an example on how to stratify the total area of distribution of one species into a few sub-areas according to historical data on relative fish densities. Doubleday (1976) discusses how relative abundance indices by area from acoustic surveys may be used to stratify a trawl survey.

2.3 Precision and Accuracy of Relative Abundance Indices

2.3.1 Sources of variation in number of fish caught per trawl haul

Trawl catches are usually highly variable even within relatively small areas because of the heterogeneous distribution of fish. Even in replicate hauls at the same station a large variation in the number of fish caught will usually be observed. Relative abundance indices from trawl surveys will get an additional variance from differences in fish density between areas and/or depths and from more or less pronounced diural variations in fish distribution. The diurnal migrations may change with age. The variance connected with the diurnal variations may be eliminated or strongly reduced by restricting fishing to times of day when the availability of fish to the gear is constant (and preferably is also high). The drawback to this would be loss in vessel time unless something else could be done during the rest of the day (for example fishing for other species).

2.3.2 Observed levels of precision in trawl surveys

A lot of data exists on the variance in numbers caught per haul in bottom trawl surveys. The frequency distribution of catches from such surveys are highly skewed with a standard deviation approximately proportional to the mean catch per haul. Hennemuth (1976) found coefficients of variation of approximately 100% (i.e. standard deviation equal to the mean) in the numbers caught of the different demersal species per tow within a stratum during stratified bottom trawl surveys, and a little higher variation (approximately 150%) in the catches of pelagic species such as herring and mackerel. The observed relation between standard deviation and stratum mean catch was very consistent throughout the range of the data which covered four orders of magnitude for mean stratum catch per tow. These observations are also consistent with what has been found by others and with what should be expected theoretically with the skewed frequency distribution of catches. With this high variation within a stratum the total number of trawl hauls required to be able to detect moderate changes in relative abundance for the total area of distribution will be rather high.

Because of the highly skewed frequency distribution of trawl catches, data are often transformed by logarithms before averaging to calculate an index of abundance. This stabilizes the variance (i.e. makes the variance independent of the mean), and permits estimation of confidence limits. The transformation converts multiplicative effects into linear additive effects, which is convenient for some analyses. However, since the geometric mean (obtained from the logarithmic transformation) is not equal to the arithmetic mean, if the former is used to estimate abundance (e.g. multiplying mean catch per haul by the ratio of the total area to the area covered during one haul) bias can be introduced. The ratio of the arithmetic mean to the geometric mean depends on the variability of catch.

Based on data from bottom trawl surveys on Georges Bank, Grosslein (1971) calculated the number of trawl hauls required to reach certain levels of precision in the estimates of indices of abundance for haddock and yellowtail flounder. A 95% confidence interval of ±20% each side of the central estimate would require 338 and 253 trawl hauls for haddock and yellowfin flounder respectively, and to reduce the confidence interval to ±10% more than 500 hauls would be required for both species. The actual numbers of hauls taken during the surveys gave a confidence interval of approximately ±50% for haddock (65 hauls in the haddock strata).

Broadly similar variances to those on Georges Bank were found by Jones and Pope (1973) during a bottom trawl survey of Faroe Bank.

The precision of estimated abundance indices from single surveys tells us what the probability is of detecting short-term changes of a certain size in stock abundance, and the evidence presented above shows that a rather intensive sampling would be necessary to discover moderate changes. However, as pointed out by Grosslein (1971), we are also concerned with consistent trends in abundance over medium to long periods. Given annual surveys we have a number of points in a time series with which to test for a slope or trend and the precision of such a test would be greater than that indicated for a single survey.

2.3.3 Potential sources of bias

The relative abundance indices are unbiassed if there is a constant proportionality between the index and the absolute abundance of the stock. A bias will be introduced if the average availability to the sampling gear (the catchability coefficient) of the species in question changes between surveys.

Many species show strong diurnal or seasonal variations in availability to the gear. If there are changes in fishing pattern between surveys with respect to the amount of fishing during day or night or in the seasons in which the surveys are made, bias can be introduced. Changes in fish distribution due to changed environmental conditions may also introduce a bias. Biasses due to the above-mentioned factors can be reduced by careful choice of time of year for the survey and repetition of the surveys at the same time of year in different years, and with the same pattern of fishing throughout the day.

The most serious form for bias would occur if the catchability coefficient varies with stock abundance.

This could for example occur in bottom trawl surveys if the percentage of fish distributed above the water layer covered by the trawl increased with increasing abundance. Such an effect would result in underestimation of changes in abundance.

A bias can only be discovered by comparing the indices with other, and independent, estimates of changes in abundance. Research vessel indices of abundance have in a number of cases been compared with abundance indices from commercial catch per unit of effort data or with estimates of absolute stock size from VPA. The main problems with the first form for comparison is that indices based on commercial catch per unit of effort data in most cases are more likely to be subject to bias than the research vessel indices. VPA estimates may also be biassed (Ulltang, 1976), but in most cases where such estimates are available they would probably make the best basis for comparison. Comparisons whichhave been done indicate that abundance indices based on trawl surveys generally are not biassed to any high extent if proper attention is given to the possible sources of error when planning the surveys.

2.3.4 Relative abundance indices from fishing surveys with other gears than bottom trawl

Although bottom trawl is the gear which has been used most extensively for abundance estimations, other gears such as pelagic trawl, purse-seine, gill-nets, longline and traps have to some extent been used for establishing relative abundance indices. The variation in number of fish caught may vary from gear to gear but will generally be as least as high as in bottom trawl catches. The sources of bias will vary from gear to gear, In pelagic trawl fishing the depth fished in relation to the vertical distribution of the fish is critical, and if the vertical distribution of fish is not known from, for example acoustic equipment, care has to be taken to cover the different depths with the trawl to avoid errors from changes in vertical distribution of fish over space and time. Random fishing with purse-seine on schooling fish to establish abundance indices is not a practical undertaking, but purse-seine may be used to estimate sizes of schools already located by other methods (e.g. by sighting or acoustics) and for non-schooling fish in favourable circumstances (e.g. Hitz and French, 1965). Errors may be introduced if the proportion of the school which is caught by the gear varies.

For gears such as gill-nets, longline and traps the variation in the catchability coefficient with the number of fish already caught by the gear (gear saturation) create difficulties in interpreting the results (variation in catches may underestimate changes in abundance).

Kennedy (1951) and Murphy (1960 have given examples of decreasing fishing power with time in sea for gill-nets and longlines respectively. Gulland (1955) suggested an adjustment of catch per unit effort in order to produce an index of density undistorted by gear saturation. Murphy (1960) suggested adjustment for baited longline which in addition to gear saturation also took into account the various sources of loss of bait. He concluded however, that in many instances it will not be practical to precisely correct for the various factors effecting the fishing power, although the relative magnitude of the various effects may be estimated enabling the investigator to either disregard them as minor, make approximate corrections, or simply utilize the knowledge in a cautious way when interpreting the data.

2.4 Calculation of Absolute Abundance from Relative Abundance Indices

As soon as an empirical relation can be established between relative abundance indices from trawl surveys (or other types of fishing surveys) and estimates of absolute abundance from for example VPA, a relative abundance index may be used to calculate absolute abundance. The calculated absolute abundance will have two components of variance, the variance connected with the estimated index of relative abundance and the variance connected with the estimated empirical relation. The latter variance will decrease with increasing number of data points available for establishing the empirical relation, but may still be considerable at extreme levels of abundance. If the estimates of absolute abundance which were used to establish the empirical relation are subject to bias, a calculated absolute abundance using this relation will also be biassed.

2.5 Direct Methods for Estimating Absolute Abundance

Absolute abundance may be estimated directly from fishing surveys by the "swept area" method. The method has been most extensively used for bottom trawl surveys. The absolute number of fish per unit area is calculated from the catches and the area swept by the trawl during one haul. The variance of such estimates will be the same as for relative abundance indices from trawl surveys.

Large systematic errors may occur from the following sources:

i) Errors in the calculation of the area or volume of water actually swept by the gear.

ii) Escapement of fish from the water volume swept (gear avoidance).

iii) Unknown proportions of fish being distributed below the footrope or above the height of the headline of the trawl.

iv) Differences in fish density between areas where it is possible to trawl and other areas.

Factors (iii) and (iv) may of course also influence estimates of relative abundance indices. These estimates will, however, be unbiassed as long as there is no significant differences in fish distribution (by area and depth) between years, while for absolute abundance estimation the actual proportions of fish which are outside the volume of water swept or outside the areas where it is possible to trawl have to be known. By assuming that all fish which are present in the area swept by the trawl are caught, a "swept area" estimate will most likely be an underestimate of stock size.

By comparing catches with direct underwater observations of fish density (e.g. by underwater photography or TV), catches may be converted to absolute density without making any assumptions on area swept or escapement. One additional source of variance, the variance of the estimated conversion factor, will, however, be included. The conversion factor has to be based on a large number of underwater observations and subsequent fishing over the whole range of fish densities. A serious bias may be introduced by the method if the technique used for underwater observations influence fish behaviour (e.g. if the fish avoid or are attracted by a camera).

2.6 Costs

The costs of fishing surveys are generally high because of the large variance in numbers of fish caught and, therefore, the large number of fishing operations required to achieve a high precision. Grosslein (1974) presented some figures which illustrate the cost level. To complete a 300-haul bottom trawl survey over an area of nearly 75,000 mi^2, required 40-45 days at sea (7 stations per day), and a total of about 800 man-days (scientists) to collect the data and carry out the preliminary basic data processing. This included, however, manpower required to obtain a variety of special non-routine biological samples.

2.7 Conclusions

The main disadvantage by the method is the large sampling errors (variance) and the resulting high costs involved if one wants to improve the precision by taking many samples. The method has been extensively used to obtain abundance indices for demersal species by carrying out stratified random bottom trawl surveys. Results from such surveys indicate that fairly unbiassed indices of abundance can be obtained if the survey design is properly planned though bias due to avoidance of the gear cannot be eliminated. At present fishing surveys are in many situations the only method available to get information on the relative abundance of age groups not yet recruited to the commercial fishery. Such information is extremely important for making any prognosis for the coming years, although the high variance of the estimated indices reduces their value for such purposes. Long-term trends in fish abundance may be estimated efficiently by annually-repeated fishing surveys. In cases where acoustic methods are not applicable fishing surveys may be the best method to get information on the abundance of unexploited resources. During fishing surveys for abundance estimation a lot of general biological information on the fish species caught can be collected without any increase in that part of the costs which is directly related to the number of days at sea. In principle these surveys can also be used to estimate the catch <u>rates</u> (i.e. the catch per day or per year of an individual) to be expected in a new fishery. In practice it can be difficult to predict catch rates from surveys designed to estimate stock size (or potential <u>total</u> catch), and vice versa, and the two types of surveys are usually best kept separate.

3. ACOUSTIC ABUNDANCE ESTIMATION

3.1 Introduction

Acoustic abundance estimation is historically the latest of the direct methods for measuring fish abundance, and much research effort is presently directed to further development of the technique. The two commonly used acoustic techniques are <u>echo counting</u> and <u>echo integration</u>. Echo counting is generally effective only when fish can be resolved as individual targets. Echo integration may provide an accurate estimate also at higher fish densities and this technique is most commonly used at present. A third technique was introduced by Smith (1970). He used the sonar for counting schools and measuring school size in terms of area or volume. By using commercial catches to obtain an index of average school size in tons, he was able to obtain estimates of absolute abundance. Some criticism has recently been raised to the applicability of acoustic methods in fish abundance estimation (see, for example, Lozow and Suomala, 1976, and Suomala, 1975).

3.2 Echo Integration

This implies integration of squared voltages and the output (M) can be considered proportional to fish density as long as this follows the "square voltage law", (Forbes and Nakken, 1972). Variance in the estimates of M is considered theoretically by Bodholt (1973) and Ehrenberg and Lytle (1973). It seems fair to conclude that errors created by this variance are negligible. This conclusion has been supported by the high correlation between observations of M from different ships during intercalibration runs.

3.3 Sources of Errors in Absolute Abundance Estimation

3.3.1 Target strength

Before the total output (M) can be converted to absolute density, the contribution to M from a unit fish or fish density has to be known. This contribution can be found at sea when the fish are scattered by dividing the output M with the number of fish which are counted on the echogram and taking into account the volume of the sound beam. The contribution from a unit density can also be found by measuring the output from a known number of fish within a cage (Johannesson and Losse, 1973). The ability of a fish to reflect sound energy is usually expressed as target strength, and a lot of research has recently been done in this field.

It has often been assumed that target strength for a species increases roughly as the volume of the fish. There is, however, no simple general relationship between target strength and length or weight of the fish, and the relation between target strength and size of fish should be established empirically for each species. Reliable estimates of target strength of individual fish at sea can only be obtained when the fish are scattered. Nakken and Olsen (1973) and other workers have shown that changes of tilt angle[1] distribution may have considerable effects on mean values of target strength. This may lead to serious errors in abundance estimation if for example the tilt angle distributions are different for scattered and schooling fish, and the abundance estimates of schooling fish are based on target strength measurements of scattered fish. More information on tilt angle distribution within fish concentrations and variation with time, physiological state, age etc. of the fish should therefore be collected.

3.3.2 Mixture of species and size groups

No method exists yet for identifying fish acoustically, although different species in an area often present signals with different characteristics. For example, different species may form schools of different shapes, densities etc., and therefore give rise to distinctive types of trace on the echo-sounder paper. Where a mixture of species or size groups occurs, the proportion of different species or sizes therefore has usually to be determined independently by capturing the fish, and/or by underwater photography and TV, although target strength measurements potentially may be used to separate different size components in a population. The assumption that the samples caught show the true ratios between different species or year classes may in many cases be invalid due to differences in behaviour and selectivity of the gear used. Thus the technique is most useful when only one species, or only a few species, are important in the survey area. It is possible that improved acoustic techniques, e.g. observing target strengths at different frequencies may help identify species.

3.3.3 Dead zones

With the present echo-survey techniques fish concentrations near the surface (shallower than 10 m depth) or less than 2-3 m from the sea-bed will not contribute to the echo. The first problem is of special importance in tropical waters. The use of towed transducers may help to overcome this problem. In situations where the main fish concentrations are found in shoals near the surface the sonar counting technique of Smith (1970) may be applied. The dead zone near the bottom at present limits the use of acoustic techniques on groundfish resources. The importance of the dead zone will depend on the behaviour of the fish, which may vary with species, area, season or time of day.

3.3.4 Fish avoiding the vessel's track

Fish near the surface may spread out from the vessel's track to avoid the noise. The effect would be underestimation of abundance. The size of the possible error has to be estimated experimentally.

1/ The tilt angle measures the degree of departure from a horizontal position and its direction (head up or down).

3.3.5 Air bubble blocking

Under bad weather conditions air bubble blocking of acoustic energy may cause serious bias in the estimated fish densities. The problem may be solved by using a towed transducer.

3.3.6 Shadowing effects

At high fish densities the linear relation between density and the output from the integrator may break down (shadowing effect, Røttingen, 1976). Fish in the deeper part of a school may be shadowed by scattering and absorption of sound energy by fish which are nearer the transducer. If the linear relation is assumed to hold at these high densities a serious underestimation of stock size may take place. Research is at present directed towards determining this critical value for the fish density. Røttingen (1976) suggests that the shadowing effect is not due to the density as such, but rather to the total number of fish within the sound beam and thus depends on the vertical extension of the school.

3.3.7 Sampling errors

Although the water volume usually sampled during an acoustic survey is many times larger than for any other type of survey, there will still be a sampling error (variance) connected with the incomplete coverage of the area. Research is currently directed towards the problem of estimating this variance and of determining the "best" survey design (e.g. Bazigos, 1975). There are theoretical problems connected with the variance estimation because of the systematic (non-random) sampling during acoustic surveys. Further, movement of fish during the course of an echo-survey may invalidate the assumption that the observations of fish density give a synoptic chart of fish distribution over the area covered.

3.4 <u>The Best Conditions for Acoustic Surveys</u>

Because of the problems mentioned above, it is of the greatest importance to take into consideration the patterns of distribution and behaviour of the fish and to carry out the surveys when conditions for abundance estimation are as favourable as possible. The surveys should, therefore, be based on a thorough knowledge of the distribution and behaviour of fish, and pilot surveys should be carried out when there are important gaps in this information. The best conditions for acoustic surveys occur when the fish stock in question is distributed within a defined area, unmixed with other species and in scattering layers in midwater. The conditions may be linked to seasonal or diurnal changes in behaviour.

3.5 <u>Estimates of Precision and Accuracy</u>

It has not yet been possible to work out estimators of the precision and accuracy of the results from acoustic surveys. There clearly are several sources of variance and possible bias, and some of the most important ones are mentioned above. By comparing results from repeated surveys one may get an idea of the variance. If proper attention is given to the statistical aspects of echo-survey design, to the calibration of the acoustic equipment and to the fish behaviour (e.g. differences in schooling behaviour between night and day), the variance may probably be reduced to a very low level compared to other methods for fish abundance estimation. Large differences between estimates from two surveys on the same population may often be explained by different degrees of bias due to changed conditions (e.g. migrations into or out of the area surveyed). A more or less constant bias can only be discovered by comparing the results with estimates of stock size obtained from other, and independent, methods and with fisheries data. Unfortunately, few other reliable stock size estimates have been available for the stocks which have been studied most intensively and regularly, by acoustic means.

For the Barents Sea capelin stock it is, however, possible to make some comparisons. This stock has been regularly studied by acoustic surveys each autumn since 1971, and since 1973 surveys in May-June have also been carried out. In late summer and autumn the capelin is distributed in continuous scattering layers in midwater over a wide feeding area in the

Barents Sea, and there is very little mixture with other species. The conditions for acoustic surveys should therefore be the most favourable. The main purpose of the autumn surveys has been to estimate the spawning stock in the next winter season, and estimates have been made for each age-group. Age and size composition of the stock has been estimated from trawl catches. The spawning stock has also been estimated by tagging experiments and by egg and larval surveys. In the table below are shown the different estimates (in millions of tons) together with the catch from the spawning stock (Figures from Nakken and Dommasnes (1975), Dommasnes (1977) and Gjøsaeter and Saetre (1974). The estimates from egg and larval surveys for 1973-1974 are not yet published (Gjøsaeter and Saetre) and should be considered as approximate figures only.

Year	Acoustic Surveys	Tagging Experiments	Eggs and Larvae	Catch (Norway)
1972	1.7		1.7-1.8 (0.5-0.6)1/	1.2
1973	3.7	2.2, 4.1	1.3-1.4 (0.2-0.3)1/	1.1
1974	1.0-1.5	1.1, 1.9	0.8 (0.03-0.04)1/	0.75
1975	0.8	1.1, 1.1		0.56
1976	1.9-2.3			1.1

1/ Figures in brackets give the direct estimate from egg and larval survey of the amount of capelin which spawned. To these figures are added the catch of prespawning capelin to give the total spawning stock at the beginning of the season.

Taking the catch as an absolute minimum estimate of stock size and taking into account the egg and larval surveys at least showed that some capelin escaped the fishery to spawn along the Norwegian coast and that in addition some capelin spawn along the Murmansk coast outside the range of the Norwegian fishing fleet, the data from 1972, 1975 and 1976 indicate that the acoustic estimates on the Barents Sea capelin cannot be seriously biassed upwards. In 1973 data indicated that most of the capelin spawned along the Murmansk coast and this may explain the big difference between the acoustic estimate and the figures of catches and from egg and larval surveys for that year. As the estimates from the tagging experiments are more likely to be biassed upwards than downwards, the data given in the table indicates that the acoustic estimates have no serious bias downwards. The precision can be judged by comparing results of different surveys. Nakken and Dommasnes (1975) concluded by comparing estimates of the number of fish in each year class for different years that a reasonable reduction took place from the estimated number of 2 years' old to 3 years' old. At present the acoustic surveys are considered to give more reliable estimates of the stock of the Barents Sea capelin than any other method.

3.6 Simple Methods for Relative Abundance Estimation

For relative abundance estimation experience has shown that fairly reliable density classifications can be made by simple methods. The simplest method is to establish a system of visual grading of the echo recordings (e.g. Cushing, 1952). This has been used successfully, for example, to assess relative year class strength of O-group fish in the Barents Sea (Haug and Nakken, 1973). Relative abundance estimates by areas from acoustic surveys may be used to stratify a trawl survey. For example, in a situation where the fish are distributed near the sea bed during daylight hours but undertake a vertical migration during the night, acoustic surveys during the night might be used to stratify bottom trawl fishing during the day. Considerable work has been carried out on estimates of relative abundance using sonar, essentially by recording the number of schools detected in the area examined.

3.7 Costs of Acoustic Surveys

The costs in relation to the water volume sampled are much lower for acoustic surveys than for any other type of survey. The acoustic survey work is in itself not very time-consuming, and acoustic surveys can be combined with other research activities, particularly those that can be carried out continuously while under way. However, acoustic equipment, especially that involved in the more advanced survey techniques (e.g. echo-integration) is expensive, and can be difficult to maintain adequately when suitable technical expertise is not available.

3.8 Conclusions

Intensive research on the use of acoustics to measure fish abundance is underway in a number of countries, and some estimates of absolute abundance have already been obtained using the method. Clearly the most suitable situations for such work are for pelagic fish populations of one, or a limited number of species, occupying well defined areas and distributed in scattering layers in midwater. Although several possible sources of bias and variance are known and methods for estimating confidence limits for the stock size estimates are lacking, there are indications that acoustic surveys made under the most favourable situations (e.g. the Barents Sea capelin) provide more precise estimates of abundance than other methods. Further, estimates of stock are independent of data from the commercial fishery and can be made by age groups before the fishing season starts (in contrast to, for example, estimates from tagging experiments and egg and larval surveys). The costs of acoustic surveys are favourable compared with other methods.

When several species occur in the same area the application of the technique to estimate the abundance of a single species depends on (i) proper sampling by capturing to get information on species and size composition and (ii) knowledge of the target strength of the different species and size groups. The total biomass of the whole group of species present (e.g. the total biomass of small pelagic species in tropical waters) may however be estimated as soon as the mean target strength of the species' mixture is known. Such estimates are very useful if there is, or will be, a fishery directed towards the group as a whole without any great preference for any particular species. If not all species present in the mixture are exploited, the usefulness of the acoustic estimates depends on whether one has an idea about how much these should be reduced to get the exploitable biomass.

Acoustic surveys may be extremely valuable for getting information on the order of size of an unexploited resource. Further, combined acoustic and fishing surveys have proved to be useful in certain situations to estimate at least relative abundance indices for young fish. One example of such surveys is the O-group surveys in the Barents Sea which give relative abundant indices of a number of species of O-group fish.

In many situations (e.g. where fish are distributed close to the bottom), however, there still are serious limitations and shortcomings of the acoustic survey technique. Therefore, at present the number of cases where other, more traditional, methods may be replaced successfully by acoustic surveys are limited, although acoustic surveys in many cases could be extremely useful for getting an additional check on other estimates.

4. SIGHTING AND AERIAL SURVEYS

Direct visual or photographic observations from an aircraft or a survey vessel, of the number of fish or fish schools may give some information on stock abundance of fish which are at the sea surface at least during some time of the day. The technique may be effective for fish which show a strong schooling behaviour on the sea surface. In many cases, however, the technique could give seriously biassed results due to uncertainties about how large a portion of the number of fish one is able to see. This bias may vary with the time of the observations, depending on diurnal or seasonal variations in schooling behaviour or vertical distribution of the fish.

Sighting has been most extensively used for whale assessments. Doi (1974) developed a sighting theory, taking into account both whale biology and characteristics of the observation situation (e.g. visual angle and angular velocity of observer, ship velocity).

In cases of counting the schools an estimate of absolute abundance would require estimates of the size of the schools. Cram and Hampton (1976) propose a combined aerial/acoustic strategy for assessment of schooling pelagic fish stocks. Results of acoustic surveys may be invalidated by extreme patchiness of the schools, the mobility of the fish and their tendency to avoid vessels. It is suggested that these errors can be reduced considerably by employing a strategy where the aircraft locates and measures the school area, and the vessel makes synchronous measurements of school thickness and packing density from as many schools as possible. The combined data provide a direct estimate of stock size. In some areas e.g. Gulf of Mexico and California, aircraft are used for spotting for commercial fishermen. Experienced spotters can be very accurate in estimating school size. It may also be noted that when the fishing method depends on the fish being at the surface e.g. pole-and-line fishing for tuna, and therefore availability of fish at the surface is as important as the total abundance, aerial surveys can be particularly useful (see for example Sivasubramanian, 1971).

5. EGGS AND LARVAL SURVEYS

5.1 Introduction

The basic concept for estimating stock size from egg or larval surveys is relatively simple. The total number of eggs produced during one spawning season is given by

Number of eggs produced = Spawning stock size x percentage females in the spawning stock x number of eggs produced per female

Thus, if the number of eggs produced during the season can be estimated, and the percentage of females and the number of eggs produced per female are known, the size of the spawning stock can be calculated. An estimate of number of eggs produced may be obtained by sampling egg or larval density at a series of points in space and time, and then integrating over space and time to get the total sum. The estimate may either be based on egg surveys or surveys on abundance of larvae of a certain stage. The observed numbers should be corrected for any mortality occurring up to the end of the stage in question. The number of days the spawning products remain in that stage must also be known in order to be able to estimate how many days production the observed numbers represent. Total stock can eventually be estimated from the estimated spawning stock and an estimate of percentage mature fish in the stock. A relative index of abundance of eggs or larvae may be used to estimate relative changes in abundance from year to year.

Saville (1964) points out that before an attempt is made to estimate spawning stock size from egg and larval surveys, certain basic features of the spawning biology of the stock in question must be adequately known. One must be able to identify the spawning products, and the extent of the possible spawning areas and the period of time over which spawning may take place should be known to give a firm basis on which to plan an adequate sampling programme. Further, the rate of development of the spawning products over the range of temperatures encountered in the survey area must be known.

The techniques for sampling eggs will be different for species with planktonic eggs and species with demersal eggs.

5.2 Errors in Estimated Production of Eggs and Larvae

The errors involved in estimates of production of eggs or larvae have been discussed by a number of authors, e.g. Saville (1964) and English (1964).

5.2.1 Sampling errors (variance)

The main sources of variance are:

i) the variability of a single haul taken with a plankton gear (or a grab haul in case of sampling demersal eggs);

ii) the variability of egg or larval abundance in space;

iii) their variability in time.

The first two sources of variability will give a variance on the estimated egg or larval abundance at the time a single cruise is carried out. The main contributor to this variance is usually the variability in space. The size of the variance on an estimated cruise total will depend on how good the coverage of the area is. Depending on the sampling effort, 95% confidence limits of the order of one half and double the estimated mean have been found in a number of cases (Saville, 1964).

The main contribution to the variance of an estimated seasonal egg production will, however, in most cases be the variability in time. This variance has often not been accounted for or inadequately estimated. Its importance was clearly demonstrated by English (1964). It is difficult to assess this variance both because of the large resources which would be necessary to do repeated sampling over short time intervals and because egg or larval abundance cannot be treated as a random variable with respect to time. If the curve of relative egg abundance with time is known, the estimates of egg abundance for each cruise can be combined to give a total for the whole season. The curve has often been assumed to be normal. The expected curve can however be distorted by environmental factors and may change from year to year. It is obvious that large errors can be introduced if sampling is confined to a relatively short period. One may happen to sample the eggs or larvae at the peak of production one year but miss it another year because of variations between years. Thus, both absolute or relative estimates of abundance may be subject to large errors.

5.2.2 Sources of bias

Egg and larva mortality together with possible escape of active larvae, are the most important source of possible bias. An estimated number of larvae of a certain stage has to be corrected for any mortality which occur up to the end of this stage. This mortality may vary within wide and unknown limits, and for this reason and because of possible escape assessments based on larval stages are generally less satisfactory than those based on eggs.

Another bias may be introduced by wrong assumptions about the time needed for the spawning products to develop through the actual stage. The time needed may vary with temperature and other environmental factors.

Other sources of error are incorrect estimates of fecundity and of sex ratios, and errors in the assumptions made about sampling volume used in calculating the absolute abundance of eggs or larvae from the sampling data.

5.3 Conclusions

The methodological problems and the size of the errors involved in assessments based on egg or larval surveys will depend very much on the extension of the spawning in time and space and the complexity of the hydrographic structure. In cases where the spawning intensity curve is not known repeated sampling over the whole spawning period is necessary to avoid large errors. This will require large sampling effort if the extension of the spawning is wide in both time and space.

There are obvious difficulties in establishing representative sampling times or locations. Real changes in abundance may lead to egg concentrations at unusual locations or times.

English (1964) found the common procedures for estimating the annual production of planktonic fish eggs to be unsatisfactory. He developed a theoretical model (a mixed model for a partially hierarchical analysis of variance) of sufficient generality to be of broad applicability for studies of annual egg abundance. He concluded that the complex variability he found in space and time and the large variability associated with the time the eggs remain in the plankton suggest that attempts to measure the abundance of fish stocks by plankton egg surveys may not be a practical undertaking. He suggested, however, that it would be of some interest to apply his model on a less complex situation than he studied to get a more precise assessment of the utility of egg surveys.

Gjøsaeter and Saetre (1974) developed a new method for estimating the spawning stock of a species with demersal eggs, which they applied on the Barents Sea capelin. The spawning stock is calculated from an estimate of eggs spawned at a single spawning bed and the number of larvae released from this spawning bed relative to the number of larvae released from the total area. By this method the difficulties in counting eggs over a widely distributed spawning area are avoided, and the bias introduced by sampling larvae (unknown net avoidance etc.) is strongly reduced. The method also obviously reduces a bias caused by mortality of eggs and larvae. A main source of errors will be assumptions made about the hatching intensity curves (relative to the time of larvae sampling) for the subarea and the total area. It may further be difficult to distinguish between larvae from the single spawning bed under study and the larvae from surrounding spawning beds.

To conclude, available data suggest that egg or larval surveys have not yet shown to be useful for monitoring short-term changes in stock size in situations where there is a large variability in spawning in space and/or time. The costs involved in reducing the errors by a dense sampling coverage in space and time will be high.

Despite the large errors which may be involved there are, however, a number of examples which show that such surveys can be useful for detecting longer term changes in abundance (see for example Saville (1964), Zweifel (1973) and Tanaka (1974). Further, as pointed out by the ACMRR Working Party on Fish Egg and Larval Surveys ACMRR(FAO) 1970, such surveys may be a convenient means of detecting fishery resources in little known areas. At no other time during their life histories can so many kinds of fish be sampled in such abundance by a single gear. They may also provide important biological information, especially information to get a better understanding of the factors which regulate year class strength.

6. TAGGING EXPERIMENTS

6.1 Introduction

Estimates of stock abundance from tagging experiments are based on the assumption that the density of tagged fish in the sample of fish caught is equal to their density in the fish population, and that the tagged and untagged fish have the same natural mortality and/or emigration rate and are equally liable to capture. Estimates of stock abundance and mortalities may be based on a single release of tags or on tag releases carried out at regular intervals (for example annually). Sampling for recaptures may either be based on a commercial fishery or on experimental fishing. Various estimates which can be made from different sorts of experiments are described by Ricker (1958), Hamre (1975) and Jones (1976). From recaptures from a single release of tags the stock size at the time of release may be estimated by the Petersen method. If M individuals are tagged in a population of N individuals, and m tagged fish are found in a sample of n fish caught, the method assumes that:

$$m/n = M/N$$

and therefore

$$N = \frac{M.n^{1/}}{m}$$

1/ This equation gives a statistically biassed estimate for which, however, corrections can be made. A number of modifications to correct for the bias are given in the literature, (see for example, Jones, 1976).

There are a number of methods of estimating mortality rates based on the assumption that the rate is constant over the recapture period (see Jones, 1976).

Regularly repeated tag releases and tag recaptures may give estimates of annual mortality rates, recruitment rates and stock sizes (see for example, Hamre, 1975).

6.2 Sources of Errors

6.2.1 Single tagging experiments

If the number of tagged fish is very small compared with the number of fish in the population, as usually will be the case in marine fish stocks, the coefficient of variation in an estimate of stock size based on the Petersen method will be approximately equal to $m^{-\frac{1}{2}}$, where m is the number of recaptured tags. Thus, 100 recaptures will give a coefficient of variation of approximately 10%. If one has the opportunity to tag a large number of fish and can base the recapture on a large scale fishery and automatic devices for discovering recaptured tags, the sampling error (variance) may be reduced to a very low level.

There are however, different sources of systematic errors (bias) which can lead to large errors in the final estimate, of which the most important ones are:

i) Incomplete mixing - If the tagged fish are not distributed at random among the untagged fish and the fishing effort recapturing the tag is not randomly distributed, the ratio of tagged fish to untagged fish in the population may be strongly under or overestimated, resulting in over or underestimate of stock size. This type of error will often occur if the catches are taken just after the time of tagging.

ii) Mortality caused by tagging - The catching and tagging operation may cause a certain mortality just after the time of tagging, and also, in some cases, a higher natural mortality later in the life of the tagged population. The first form of mortality can be estimated experimentally. These estimates may include only mortality caused by tagging and not mortality caused by catching and handling the fish before tagging. Possible higher natural mortality occurring later is not usually taken into account. Errors caused by this mortality will increase with increasing time between tag release and tag recapture.

iii) Incomplete reporting of recaptured tags - In cases where the recaptured tags come from a commercial fishery one rarely, if ever, gets a 100% efficiency in discovering recaptured tags. Unless the efficiency of detection and reporting is known - even roughly - and appropriate corrections made, the estimates of stock size may be largely biassed. The efficiency may be tested experimentally, for example by introducing a known number of tagged fish into the material being processed at a fish meal plant, and, in this way, testing the efficiency of the magnets picking up the tags at the production plants. Such tests should be carried out regularly in order to discover possible changes in the efficiency. They are fairly readily done at fish meal plants, but tests of efficiency may be less easy to make in fisheries for direct human consumption.

iv) Recruitment to the population between time of tagging and time of recapture - If there has been recruitment between the time of tagging and time of recapture and this is not corrected for, the effect will be to overestimate the stock at the time of tagging. The number of recruits can be estimated and corrected for from, for example, age or length compositions. In cases where recruits cannot be identified, changes in the ratio between tagged and untagged fish with time can be used to correct the estimate by extrapolating any observed trend back to the time of tagging (Parker, 1955).

Unequal vulnerability of individual fish to capture can cause difficulties in tagging experiments, and the existence of "trap-happy" individuals is a well-known problem in making experiments with small terrestial mammals. It does not seem to have caused similar difficulties with fish; potential problems would be minimized by using a different method in catching for tagging from that used by the commercial fishery likely to recapture tags.

Single tagging experiments for getting abundance estimates have, in a number of cases, been applied on stocks fished for fish meal production, mainly because in such cases there are excellent chances to estimate the efficiency in reporting recaptured tags by testing the magnet efficiency at the production plants. The quality of such abundance estimates has varied widely according to the degree of control of the various sources of errors listed above.

Estimated confidence limits have often taken into account only the sampling errors and not the various systematic errors.

In several cases the estimates of magnet efficiency has been based on only a few experiments, and the resulting errors in the estimate could probably have been reduced considerably by additional experiments involving relatively small extra costs.

Abundance estimation by tagging experiments requires, perhaps more than any other methods, careful planning at all stages, and it may also be necessary to carry out a small-scale pilot experiment before the main one to gain information on the possible sources of error and on how best to minimize them.

6.2.2 Tagging experiments based on regularly-repeated tag releases and tag recaptures

One example of such an experiment is the Norwegian tagging programme on North Sea mackerel (Hamre, 1975). The programme gives recapture data from successive releases, the time period between releases being one year. In such an experiment the different sources of errors listed above will be present, but the resulting errors in the estimates may be reduced as follows:

i) By comparing recaptures made within a fishing season from different tag releases, one can obtain estimates of annual survival rates which are not influenced by the percentage of tagged fish that are caught but are not detected or if detected are not reported. The estimates are also independent of tagging mortality occurring just after tagging if this mortality does not vary between releases. Accordingly, standardizing of the capture and tagging process is particularly important.

ii) By comparing recaptures from two fishing seasons one can obtain an estimate of recruitment between the two seasons which is independent of tagging mortality. The estimate includes the ratio between the magnet efficiencies for the two seasons and is thus influenced by random errors in measuring the efficiency, but not influenced by any systematical error in this parameter.

iii) The stock size in any fishing season can be estimated from the number of recaptured tags during that season from all previous releases and the estimated survival rates. This estimate will, however, depend on tagging mortality and detection and reporting efficiency. (Alternatively, the stock size can, of course, be calculated from the estimated survival rates and the estimated recruitment, given the total catches and assuming some value for the natural mortality).

In cases where one has recaptures over a series of years from the different tag releases, Virtual Population Analysis or cohort analysis (e.g. Pope, 1971, Gulland, 1977) on the tagged population may give valuable information on the probable levels of natural and tagging mortality. For example, if one, when calculating backwards, finally arrives at a higher figure than the number of tags released, the assumed natural and/or tagging mortality must be too high.

6.3 Costs

The costs involved in a tagging experiment will consist of:

i) Costs in planning and experimental work (e.g. experiments for estimating tagging mortality).

ii) Costs connected with catching and tagging fish.

iii) Costs connected with recapture and recovery of the tags (including rewards).

The number of tags which have to be released to get a desired level of precision, and also the cost item iii), depends, very much, on what facilities already exist for recapture and recovery of the tags, for example whether a commercial fishery exists in which tagged fish may be recaptured, and also whether there existsan efficient system for finding and reporting the recaptures. Costs involved in a single large-scale tagging experiment where much work has to be done at all the different stages will be very high, while the annual costs by running a tagging programme, based on equipment and procedures already in existence, will be low.

6.4 Conclusions

There are a number of requirements which should be fulfilled before a large-scale tagging experiment is carried out. If the errors arising from the different factors discussed above are likely to be large and unknown, the abundance estimate will have little value. Under certain conditions, however, a carefully planned tagging experiment may give more precise and accurate estimates of absolute abundance and changes in abundance than any other method. It should, however, be noted that tagging experiments are usually best suited for monitoring past events, but are less well suited for providing early forecasts or predictions of future changes. For example, when the tag returns are based on a commercial fishery, the tagging experiments will provide estimates of the recruitment to the fishable stock between two fishing seasons only after the second season has started, and there are some returns of tags caught during that season.

Release of tags combined with experimental fishing for recapture of the tags may be the only way of getting an absolute abundance estimate of a stock which is not exploited commercially and where acoustic surveys are not applicable. The costs will, however, be high unless the stock is small but nevertheless can be found in suitable concentrations for fishing at some time of the year.

Successful management of marine fish stocks is, in many cases, extremely dependent on knowledge of stock migrations and stock identification. For example, if two stocks are separated throughout parts of theyear but mixed in other parts, and there is a fishery on the mixed population, it may be important to know the proportion of the catch taken from each of the two stocks. In cases where the fish cannot be separated by some biological criterion, tagging experiments may be the only way to get information on this. If one is not able to determine how much of the catch is taken from each stock, all methods using catch data when analyzing changes in stock abundance will break down.

7. SUPPLEMENTARY BIOLOGICAL INFORMATION

In addition to the types of information discussed in the preceding sections, there are a variety of other biological information, which, while generally insufficient to estimate absolute stock abundance, can provide fragmental information and circumstantial evidence of changes in abundance. The stomach content of a predator could indicate changes in abundance of prey species. The order of size of the standing stock of a prey species can, in some cases, be indicated from estimates of total consumption of the species by its various predators. For example a lower limit to the production of Antarctic krill has been estimated from the consumption of krill by whales, seals and other predators, and changes in the abundance or net reproductive rate of these predators have been used as guides to changes in krill population (Everson, in preparation). An estimate of absolute abundance with any degree of precision can, however, very rarely, if ever, be expected from this method. In cases of density-dependent growth and/or age at first maturity, observations of these parameters could indicate changes in abundance. This would, however, only be circumstantial evidence because growth and maturity will usually vary with environmental factors. Age and length compositions will show the relative strength of recruiting year classes. However, these cannot be converted to absolute numbers unless the absolute size of the already-recruited stock is known.

8. CONCLUDING REMARKS

The preceding sections have discussed the general characteristics and the sources of variance and bias in the various direct methods used for stock abundance estimation. For each method the size of the variance of the final estimate will depend critically on the research effort put into the survey or experiment, although careful planning and design may reduce the variance appreciably in certain situations. The planning and design may be even more important in reducing or avoiding a significant bias in the method. For some methods (e.g. acoustic surveys) further reductions of bias may depend critically on future technological improvements and research. While the variance in most situations may be estimated, although only very roughly in some cases, the bias will be unknown (an estimate can be corrected for any known bias), and calculated confidence limits of the estimate may not give the limits within which the true value most probably lies.

In certain situations one may have to choose between a biassed, but rather precise, measure of abundance, and a measure which is unbiassed but highly variable. The choice depends of course on the degree of variability and probable bias, but also on the intended use of the estimates, and in particular whether the need is for an estimate of the absolute abundance, from one, or a set of surveys, or whether the need is to detect and measure trends in abundance over a period. In the latter situation the output from each survey need be only an index of abundance (e.g. catch per hour of a standard sized trawler, or integrated acoustic signals), which, at least so far as any single survey is concerned, cannot be said to be biassed. However there may be changes in the relation between the index and the absolute abundance (e.g. increases in the fishing power of the standard trawler), which will have similar effects on subsequent interpretation as a bias in an estimate of absolute abundance.

In studying trends reducing variance is usually less important than avoiding bias especially in the sense of a changing relation between the index and the absolute abundance, which can cause an apparent trend in abundance which is quite different from that which actually occurred. In this situation an index with high variance but no risk of a spurious trend (e.g. indices from trawl surveys by a research vessel using an unchanged gear) may be preferable to indices, which while less variable, may introduce false trends (e.g. catch per unit data from a commercial fishery, in which the gear is being continually modified and improved).

In other situations a decision may have to be taken, based on estimates of the absolute abundance, from one, or a set of surveys, e.g. the government may need to introduce a catch quota or know whether to encourage the construction of ships for a new fishery. For this, a large variance may cause more trouble than a moderate bias, particularly if the direction of bias is known.

The usefulness and applicability of the various methods depend ultimately on:

i) The biological and environmental characteristics of the situation.

ii) The purpose with the evaluation of the stock and the precision required.

iii) The equipment, expertise and economical resources available.

For example, if a fishery depends on one or two year-classes, which can vary widely in strength, many management decisions, e.g. setting annual catch quotas will require an estimate of the strength of the incoming year-classes <u>prior to</u> the main fishing season if the management measures are to be effective. A tagging programme depending on recaptures from the fishery would therefore be inadequate even if it could give precise estimates. Under certain conditions acoustic surveys prior to the fishing season could provide the necessary information. If acoustic surveys for some reasons were not expected to give reliable results fishing surveys could be the only solution. However, in order to achieve any satisfactory degree of precision on a single abundance index such a fishing survey had to be rather extensive. For long living species with gradual recruitment to the fishery, fishing survey indices with a much lower degree of precision, combined, if possible, with commercial catch per unit of effort data, could give a satisfactory basis for estimating year to year changes in the stock. In this case the required degree of precision of the single indices might be lower because one would have several indices of abundance of a single year-class before it was fully recruited to the fishery.

APPENDIX I

Summary Table of Advantages and Disadvantages of Each Method

Method	Applicability	Discrimination between Species	Result Obtained		Time/ Spatial Coverage	Craft and Equipment	*Operation Cost	Time for Data Processing
			Variance	Potential Bias				
Fishing Survey	Demersal and to some extent Pelagic Fish	Excellent	Large	Small	Limited	Vessel and Fishing Gear	High	More or less long
Acoustic Survey	Pelagic and to some extent Demersal Fish	Poor	Small	More or less large	Good	Vessel and Acoustic Instrument	Low 1/	Short
Sighting Survey	Pelagic Fish	Poor	Large	Large	Good	Aircraft or Vessel	Variable	Short
Eggs and Larval Survey	Demersal and Pelagic Fish	Excellent 3/	Large	Large	Limited	Vessel and Collector	High	Long, laboratory work
Tagging	Demersal and Pelagic Fish	Excellent	Highly variable 2/	Highly variable, often large		Vessel and Fishing Gear for Releasing, Fishery and Eventual Equipment for Recovery	Variable	More or less long

1/ Cost of acoustic instruments is rather high and not included in the above*

2/ Is directly related to number of recaptures.

3/ Except in cases where the eggs or larvae of different species cannot be reliably identified. This is a bigger problem for eggs, particularly in early development stages than for larvae.

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