

CONCEPTS OF FISHERIES DEVELOPMENT SURVEYS
AND MANAGEMENT STRATEGY

by

D.L. Alverson,
Northwest Fisheries Centre,
U.S. National Marine Fisheries Service,
2725 Montlake Boulevard East
Seattle, Washington 98112
U.S.A.

ABSTRACT

The goals of fisheries development and fisheries management are varied. The concepts of development and management are reviewed and the events one should follow in the survey, development, and management phases are discussed. In the management area, the paper points out the need to utilise yield forecasts, even when these estimates are preliminary, in developing preliminary management policies to cope effectively with the conservation aspects of the resource. A method to determine a rough approximation of the maximum biomass of a resource is discussed.

1. INTRODUCTION

In recent papers on fisheries, Gulland (1971), Rothschild (1971), and others noted that fisheries management may have a variety of goals, including those of a socioeconomic character and goals designed to achieve political objectives. As a counterpart to management objectives, we might ask: What are the goals of fisheries development? The responses to an inquiry of this type are likely to be even more varied than the objectives stated for fisheries management. At a national level, fisheries development may be encouraged as an option to earn needed foreign capital and to improve the general economy. It might, however, be promoted to deploy an un-utilised labour force and be designed to maintain a labour-intensive fishing activity. Another objective of fisheries development may be to produce animal protein needed to improve the nutrition of a nation's population.

In considering planning aspects of fisheries development and management strategy, it becomes apparent that a thorough systems study of both the objectives and options for achieving the stated goals should be undertaken. In the broad sense, this may include such subsystem inputs as resource identification (survey), fishing gear, and vessel needs, harbour and port facility requirements, identification of processing and distribution needs, etc. These inputs must interface with the selected management strategy of which resource conservation or rational resource-use may be only one of several desired goals.

A study of this character would be a timely contribution to IPFC. We, however, lack the ambition and time to undertake a comprehensive study of development and management strategies for IPFC member countries. We have therefore limited the subsequent discussion to contributions or inputs on development and management rationale which one might expect from investigations of resources.

As recent fisheries literature has dealt in depth with problems of fisheries survey and management, the author has quoted extensively from papers dealing with this subject. In this sense, this paper should be considered as a compilation of information considered of interest to IPFC rather than an original research paper.

2. SURVEYING AND DEVELOPMENT OF FISHERIES

The question of how we encourage fisheries on under-utilised stocks might have been more pertinent a decade ago than it is today. Nevertheless, there are a number of conventional marine species, which we are accustomed to fishing, that are still under-exploited in many areas of the world (Alverson, in press).

There are a number of ways in which fisheries researchers, private industry, and governments can encourage better use of such resources. If it is considered important enough, that is, if a government makes a policy decision to encourage use of such resources, it may be stimulated by subsidising fishermen or processors who engage in fishing for species classified as being under-utilised. Such a subsidy would reflect an added economic incentive to fish and to process species having low value or which processors or fishermen consider risky in exploiting. The risk may result from uncertainty as to magnitude, distribution, and availability of the resource to extant harvesting systems. A relevant question then is: How can government or private enterprise reduce the risks involved in fishing for under-utilised species?

An investor must consider a number of important questions prior to fishing latent or under-utilised resources, e.g.; (1) what is the magnitude and distribution of the latent or under-utilised resource; (2) can the resource be harvested using traditional techniques, and (3) is there adequate demand within existing markets.

Information concerning the distribution and magnitude of under-utilised resources can be derived from a number of sources. Often the fishermen themselves can provide qualitative and some quantitative information regarding species not normally accepted by processors and that they traditionally discard on sporadic encounters during fishing. Often, such information is useful in planning surveys designed to further investigate latent resources. Oceanographic and fishing investigations can yield valuable information regarding potential fish resources. Such studies may include egg and larva surveys, examination of the stomachs of large marine predators, and direct and indirect field surveys (acoustic or aerial). Exploratory surveys which collect biological information of growth and natural mortality of species studied can provide the basis of first approximation of stock size, possible yields, and potential stability of a resource.

The FAO "Manual of Methods for Fisheries Resource Survey and Appraisal" (Alverson, (1971)) states:

"When properly planned, fisheries charting and surveying can provide useful information on:

- (1) the community of fish available in a specific geographic area;
- (2) their distribution in time and space;
- (3) the magnitude of the exploitable portion of the stock;
- (4) yield potentials which may be anticipated;
- (5) feasibility of commercial exploitation;
- (6) fishing strategy required, and thereby provide the basis for development of an ultimate management rationale.

Assessment of fisheries potential is the starting point for obtaining information upon which industry can design and plan expanded operations and upon which government can acquire the necessary preliminary information for ultimate management of such resources. The design of resource assessment projects should therefore be considered in the light of existing resources demands and economic problems confronting their utilisation. However, the design must not be restricted to the satisfaction of immediate needs. It must provide the maximum possible information on the totality of aquatic resources having current or future potential to supply man's needs and natural factors influencing their availability."

We have felt that the general information provided in the FAO Technical Manual on exploratory fishing provides an adequate background on the nature of direct survey and hence can be used as a planning guide for nations undertaking direct survey activities. The section on exploratory fishing (below) has been taken entirely from the FAO Technical Manual.

Exploratory Fishing Surveys

The term exploratory fishing is used here in the sense of a planned study by fishing gear of the fish resources inhabiting a defined area of the ocean. It is important here to differentiate exploratory fishing from resource assessment activities or gear experiments which are conducted to support on-going fishery activities, e.g.:

- (1) fisheries monitoring - year-to-year and long-term studies of changes in the abundance of species;
- (2) fisheries forecasting - pre-season forecasting based on preliminary assessment of the strength of incoming year-classes (recruitment), or on the basis of environmental conditions;
- (3) fisheries scouting - the use of research or commercial vessels to locate concentrations of commercial fish and disseminate such information to the commercial fishing fleet;
- (4) experimental fishing - activities designed to explore the utility of various types of gear or fishing strategy to increase the efficiency of the extractive phase of a particular fishery.

Some of the difficulties in undertaking exploratory fishing relate to the design of a programme that will satisfy two primary data users - the commercial fishing industry (both the fishermen and the processor) and the scientific community. The scientific aim is to carry out a programme which will most effectively describe the community or complex of animals inhabiting a particular area and at the same time derive a fundamental understanding of spatial distribution, determine how distribution patterns change with time, and quantify as best as possible the various elements that constitute the fish and shellfish complex.

The objectives of the fishing industry are more restricted. Although the fishermen may also desire information on long-range forecasts covering the magnitude of the resource for investment planning, he is more immediately interested in the distributional and catching aspects, such as where the fish of commercial size aggregate, and their availability to his fishing gear. He wants to know how much he can catch in what period of time, where and how he should deploy his vessels to maximise the usable catch, and whether the anticipated catch is of sufficient value to justify his participation in the fishery. He is not as interested in the total bathymetric or geographic range of the species as he is in the bathymetric zone in which the fish tend to concentrate, the various densities of fish throughout this zone, and the seasonal distribution pattern of the exploitable stock.

The processor has a more specific need for general information on the seasonal geographic distribution of the stocks including areas and times of the year where maximum densities occur. He also will want to know the potential harvest and sizes of individuals from these stocks so he can plan his processing operation to maximise returns.

Operational limitations and facilities

In planning a fishery survey to investigate distribution and abundance of a potentially important fish or shellfish group, a variety of factors beyond those of a technical nature must be considered. To begin with, the investigator must take into account the terms of reference under which the surveys are to be conducted; that is, the restrictions imposed by the supporting government or international body.

These restrictions may limit the survey area, the species to be surveyed, the time periods in which the survey may be conducted, and the manner in which the work will be conducted. Certain operational constraints are inherent, which for the most part are not subject to change by the investigators responsible for executing the field work.

Although it is expected that certain operational limits must be established by the supporting body, it is desirable that these terms relate only to the general goals of the study; e.g., (1) investigate the potentials of the south coast of Argentina, (2) investigate the shrimp potential in the Gulf of Guinea, (3) investigate the distribution and abundance of skipjack tunas in the mid-Pacific Ocean, or (4) study the clam potential within Cook Inlet, Alaska.

The methodology required to reach these goals should be established at the planning stage. If the programmes are rather tightly defined, as in item (4) above, the investigator will not have to concern himself with area selection other than that of a local nature.

Although general operational guidelines are frequently provided as above, more specific goals should be defined or individual cruises or sets of cruises. These goals should be clearly formulated in terms of specific questions about the resource being investigated; e.g., (1) what demersal fish inhabit a particular region and bathymetric range during a specified time period, (2) what catch rate can be achieved for a particular species with a specified sampling device in a certain area, (3) what sizes of fish are available on a seasonal and/or annual basis, (4) what behaviour or distribution patterns prevail that may affect use of the resource, and how are these patterns influenced by environmental factors, and (5) what is the magnitude of the defined resource and what yield potentials can be expected. The character of the questions and the priority for answering them must, of course, relate to the general programme goals.

Planning at the field level (within the general terms of reference given) must start with a consideration of the facilities and staff at one's disposal; that is, (1) level of programme funding, (2) number and competence of personnel, (3) time allocated, (4) physical facilities available, (5) survey methodology, and (6) local, legal, and operational problems. These factors will determine the character and size of programme that can be mounted. In this sense the question is not what is the most effective and logical manner to accomplish the mission, but what is the best plan considering the resources at one's disposal and the constraints. Adequate and intelligent planning will contribute to the success of a programme and to making optimal use of available manpower and equipment. It does not necessarily mean, however, that the job will be accomplished in a manner that will satisfactorily answer all the questions concerning the character of the resource being investigated.

It is important that one does not over-programme; that is, one should establish objectives and work-plans that are realistic. If the objectives established by the supporting agencies are too ambitious relative to funds available, and if additional funding cannot be obtained, the investigator should consider other options; e.g.:

- (1) narrow the objectives and limit the scope of observations to be made;
- (2) consider cooperative possibilities with other agencies, academic institutions, governments, etc.

Finally, the field investigator should state clearly to the administrator just what he believes can be accomplished with physical facilities and funds at his disposal.

In choosing personnel to carry out the field studies it should be borne in mind that the character of personnel will, to a large degree, control the scope and quality of observations that can be effectively made. Fisheries resources surveys require investigators with a knowledge of the fauna in the area being investigated or ability to use taxonomic literature, experience in sampling animal populations, and in making

oceanographic observations. In addition, knowledge of using and interpreting echo sounder and sonar data and of fishing gears and their operation is essential. The field programme leader should be a competent scientist with a background in marine biology, experimental design, general field of oceanography, and have an analytical capability. However, success of the mission requires more than just scientific knowledge and technical skills. It will also require a mixture of talents and experience in working and living at sea, at times on small boats in cramped quarters, and knowledge of design and use of fishing gears.

Selection of species

If operational limits narrowly define the field to be investigated, establishment of work priorities among species, species group, etc., may not require special attention. On the other hand, if the assignment given is general, e.g., investigate the fishing potential of a particular locality, a judgment has to be made concerning the order in which to survey certain species, ecological, and taxonomic groups. For such a general type of assignment a number of factors must be evaluated. Important among these are:

- (1) What information exists concerning the fauna of the region?
- (2) What species are of local interest and use?
- (3) Can adequate sampling systems be devised for species of interest and what are the logistic and operational problems?
- (4) What factors limit the use of the several species once information on the resource base has been established?

For planning the fisheries surveys, it is helpful for the field investigators to make a brief compilation of information on distribution and behaviour of the same or related species in other areas where they are already extensively harvested. One example is given on southern bluefin tuna (Appendix I). Such tables compile knowledge of the oceanographic features of one or more sea areas thought to be similar with the areas to be surveyed. If little or no information exists concerning the nature of the local fish and shellfish populations, it is desirable to schedule a preliminary survey to obtain qualitative information on the character of the local fauna.

In practice, it is usually found most convenient and efficient to carry out surveys for one main species only or for a group of ecologically associated species, rather than attempting to survey the entire fish fauna in an area.

The selection of species (or main objectives) will also depend on the fishing gear and other facilities available, including a tested survey methodology.

It is, nevertheless, possible to investigate a variety of benthic invertebrates, demersal fish, and pelagic shelf forms during a single cruise and such multi-species surveys may in some cases be the most economic way of investigating these resources. Such cruises, however, set high demands on scientific and technical skill, and the distribution of effort required to investigate the various fauna elements may result in less than optimal sampling for any single species group. This can only be overcome by increasing the effort, i.e., by extending the survey time or the capacity and/or number of vessels used.

Regardless of physical facilities and personnel available, however, the concept of "total assessment" is not realistic with existing survey techniques. The establishment of priorities among species, then, is relegated to a subjective decision. Such factors as the importance of a particular species or species group to a local industry, to a nation, or to the world community; the availability of fleets to take advantage of the defined resources; and the adequacy of the survey systems available, should be considered. In the final

analysis, anticipated benefits, feasibility, and relevance as they relate to the assigned mission will be determining factors.

Selecting the study area

The field investigators often do not have to make decisions about the area in which to conduct a survey. This is frequently laid down by the operational limitations given. There are times, however, when options are given in selecting the survey area. In such instances the investigator must consider the known distribution or behaviour patterns of the species or species groups to be studied, its (or their) distribution pattern relative to oceanographic and/or substrate features. Often the information will be fragmentary but adequate to localise surveys in the most promising zones, i.e., demersal fish studies will be restricted "a priori" to the continental shelf and upper slope regions, certain tunas or other pelagic fish are restricted to known thermal ranges, etc.

For demersal studies, the survey may be further limited if data are available concerning the distribution of a species related to substrate or the bathymetric range of the exploitable sizes of the population. If the total demersal fish complex is the objective of the survey, then it is important to recognise that existing demersal fisheries frequently operate to depths of at least 1000 m. Hence, the selected survey area may well include the greater part of the continental shelf and slope down to this depth. Modification of the study area may take place as a result of feedback from early survey activities. Similar consideration must be given to shellfish surveys. (See next section on factors governing sampling activity).

For pelagic fish studies, the investigator may have less tangible reference points; and, hence, must rely on antecedent knowledge of distribution patterns of species or species groups related to hydrographic factors (temperatures, currents, upwelling zones, areas of high basic productivity, convergences, etc.). A number of oceanographic atlases are now available which incorporate both physical and biological information of this character.

In addition to those factors that relate to the general ecology of the species being sought, the investigator should consider the logistic problems of the research vessel, as well as those of the fishing fleet that might take advantage of positive results achieved. Quite often, however, in some areas there is no suitable fleet available to take advantage of a newly discovered fishable stock. The type, range, etc., of the future fleet required to exploit the resources discovered will have to be decided on the results of the exploratory work done, but the primary task of the survey is to map the resources wherever they might be within the overall limits of the survey area. However, if there is no clear choice provided by the available information on the distribution patterns of the species to be studied, and a local fishing capacity exists, then it is better to initiate the investigation in areas which are adjacent to port facilities and for which logistic aspects are such that they are likely to enhance fisheries development. Systematic expansion over alternate areas can be similarly selected.

Selecting vessel and gear

The choice of a vessel for exploratory fishing is important since it will have a direct influence on survey range and duration, the types of sampling gear that can be employed, etc. However, in most cases, this selection is predetermined by the vessels already available or by the type of vessels to be chartered. Only in some instances have vessels been specifically designed for selected projects. In considering selection of a platform to conduct survey activities, one must, of course, consider the operational logistics in the area of operation, type of gear to be used from the vessel, and the needs of scientists as related to laboratory space, etc. If advanced acoustic equipment is to be employed, space required for equipment and operators must be included.

For many surveys, a trawler will be the best choice because of its greater versatility compared to other types of vessels. With suitable deck arrangements, a trawler, particularly of the stern trawler type, is able to effectively operate and handle all types of bottom trawls, including shrimp trawls and high opening trawls for demersal species, midwater trawls for small pelagic species, as well as dredges and bottom samplers.

Once the area of investigation and survey objectives have been determined, plans must be laid for the sampling activity. The type of gear selected depends on the scientific objective and the purpose for which the sampling gear will be employed. For example, if the sampling devices are to be used to develop indices of abundance, the selection of the gear may be different from that required for merely identifying targets detected during acoustic surveys.

The selection of sampling devices is always difficult and will depend on the objectives of the investigation and on the anticipated user of the information. From a scientific standpoint, one might want to use the most up-to-date trawl or other sampling devices, or a scaled-down version of some particular commercial gear. One should, however, be aware of the fact that if the equipment is too atypical of that normally employed by fishermen, both the scientist and the fisherman may have difficulty interpreting results because they may not reveal the commercial potential of the stock (Alverson and Pereyra (1969)). That is, they may provide information on the relative abundance, but they may not readily be interpreted in terms of harvest rates that might be sustained by commercial gears. Hence, in most instances, it is advisable to use gears of a size normally employed by commercial fishermen and which are in relatively standard use in many areas of the world (trawls, seines, long lines, dredges, etc.). On the other hand, there are times when new sampling schemes must be considered as existing commercial methods may not be applicable. In such instances, exploitation of the resource located may be contingent on the evolution of new fishing gear or strategy.

Once the investigator has selected and tested his gear and is reasonably satisfied with it as a sampling device, it is important that gear and procedures be standardised.

It should, in this connection, be emphasised that resource assessment surveys do not constitute a programme in gear design, nor can one continue to experiment "ad infinitum" in an attempt to refine the gear to optimise catch rates. Such surveys have as their primary objective the determination of distribution and relative abundance patterns as well as first approximations of exploitable stock sizes. In this purpose, the sampling device does not necessarily have to be the most efficient fishing system and/or the fishing strategy perfected. In most instances, these problems will be considered during the subsequent stages of development of the fishery.

Regardless of what type of sampling gear is chosen, it is important that the investigator be familiar with its structural and fishing characteristics. For example, if a trawl is chosen, what are its dimensions, mesh sizes and tapers, what bridle system is employed, and what size of doors are to be used with the trawl? In this latter regard, the spreading device, doors, or floats, must be large enough to achieve an adequate spread of vertical opening of the net. It is also important to know the attitude of the gear during fishing; e.g., under normal towing speeds, what vertical and horizontal openings are actually achieved.

For purse seines, similar information is required concerning its length and depth, mesh size, hanging ratios, etc. The sinking rate, time required to complete pursing, and potential sampling volume are all important factors.

If the gear or vessel to be used for the survey are not of a type in commercial use, comparisons with commercial vessels should be conducted whenever possible. Selection of a relatively standard fishing gear is generally advisable since it allows some immediate interpretation of the economic aspects of resources.

Distribution of sampling activities

It is not necessary, nor often desirable, to choose the positions of sampling stations by a simple random selection of latitudes and longitudes from the entire survey area. More precise estimates can usually be made by using the well-known technique of stratified random sampling. Under this system the survey area is divided into a number of homogeneous sub-areas or strata which are treated independently. When the strata have been determined, the positions of stations within them are drawn at random.

The question arises as to what is the best characteristic for constructing the sub-areas or strata. For estimating a single item, such as the abundance of a particular species, the best characteristic is the relative distribution of the species itself. The next best is the relative distribution of some other characteristic highly correlated with the species distribution. In practice, however, we seldom seek a single estimate, nor do we know the relative abundance of a species before the survey. Sometimes we do not even know the distributions of depth, bottom types, or oceanographic features. In these cases the stratum boundaries can be determined after a preliminary survey to determine the distribution (over the entire survey area) of the characters used for stratification. Of course, among the characters one can use is that of a measure of relative fish abundance. Other statistical techniques such as stratification after sampling or regression estimates are also available. The search phase is therefore an integral part of the total sampling effort and it may rely on acoustic devices, direct or indirect optical observations, test trawling with net, dummy chain, etc., (Hitz, et al., (1961)), and on observations of environmental factors. Especially during pelagic fish surveys there will always be a search phase to determine relative abundance. The fishing is done here to identify detected target and/or to establish finer measurements of abundance. This in general also applies to demersal fish and shellfish surveys, except that flatfish and, in most cases, shellfish, cannot be quantitatively detected with the present acoustic instrumentation. However, even when surveying for such species, a search for suitable depth and bottom conditions may at times be required in order to make the most efficient and economic allocation of fishing time. It should, however, always be borne in mind that the search phase of either pelagic or demersal study is an aid to allocating sampling effort by estimating the distribution of the characteristics used for stratification. The total number of samples are allocated among the strata either proportionately to the size of the strata or based on the expected variation of the character being estimated. In the latter case, more samples can be allocated to the strata for which more precise estimates are needed.

In a historical sense, most pelagic fish investigations have been designed to investigate concentrations of schooling fish or species that tend to form large aggregates. For this reason, the concept of a predetermined sampling schedule is not practical as the probability of encountering a concentration precisely at a sampling station which has been pre-scheduled is extremely small. For this reason, investigations designed to study pelagic schooling fish must incorporate a search phase. Sampling gears can then be used to identify targets and to make estimates of their abundance. The search pattern itself is, however, often planned prior to the survey (Figure 1).

If little is known concerning the description of the species being investigated relating to environmental features, then the search pattern may merely constitute a number of evenly-spaced track lines running normally to (offshore, from) the general coast lines.

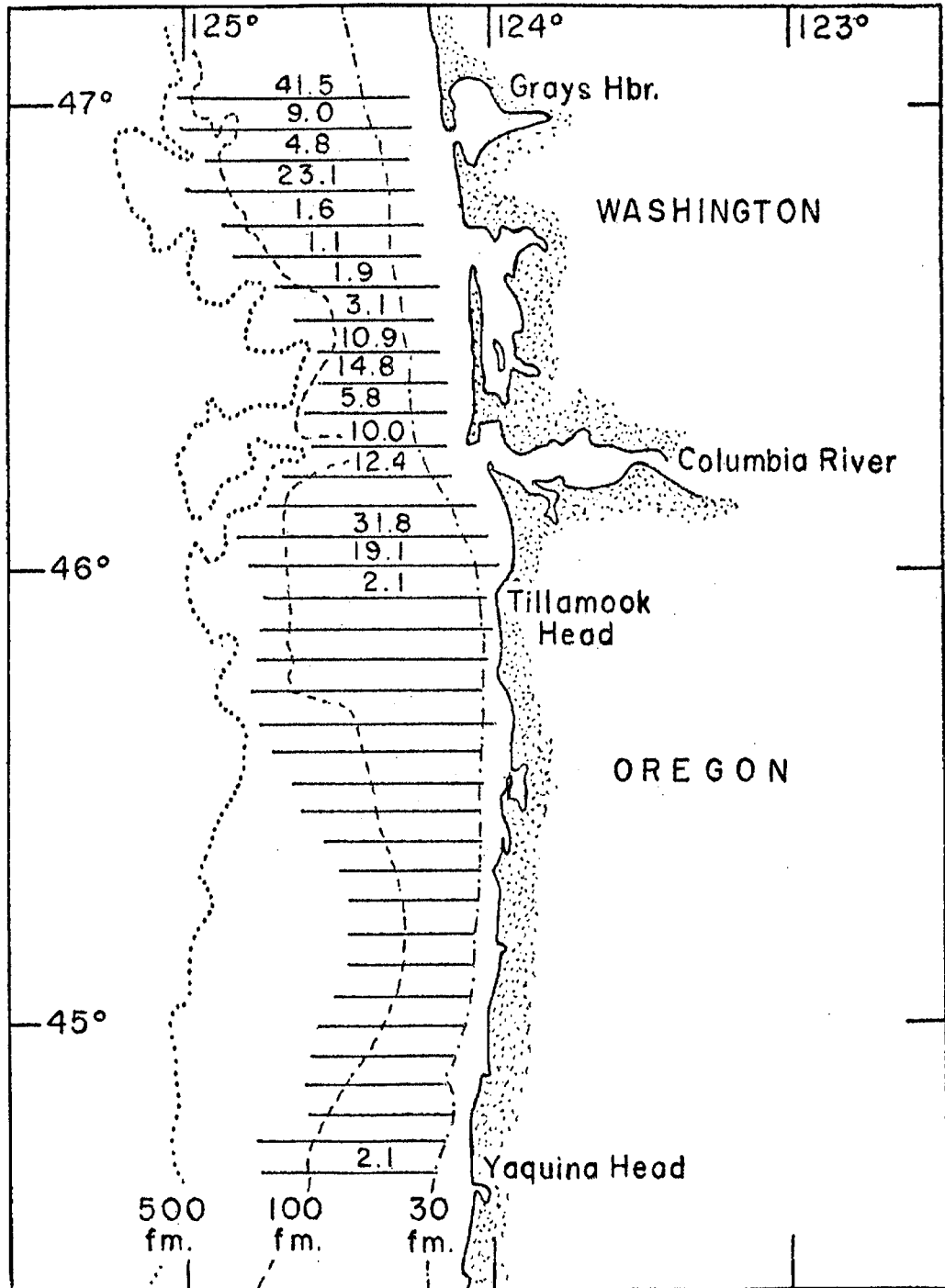


Fig. 1 - Positions of acoustical transects run by Soviet and U. S. scientists off the coasts of Oregon and Washington during calendar year 1969. Values shown are relative abundance of Pacific hake.

In instances where previous information provides a clue as to the environmental features which tend to concentrate the species, the search pattern may be more non-random in a sense but respond more effectively to observed changes in the environment (Figure 2).

If the pelagic species being studied do not form schools or aggregates, then a predetermined sampling schedule will be desirable. From a logistic standpoint, the establishment of such a grid will depend on the size of the area to be studied, time available to the investigator, ship speed, time to set and use the sampling gear at each station, etc. If the hydrographic features throughout the area studied appear to be similar in character (homogeneous) the stations may be established at fixed intervals. If current boundaries, upwelling zones, or thermal boundaries appear to exist, then the investigator should increase the number of stations in such areas so as to more effectively measure changes in abundance that relate to these changing environmental features.

If the resource can be effectively surveyed with harvesting gears (sampling gear), then maintenance of catch/effort data can serve as an index to fishermen as to availability of the resource to fishing systems. That is, he can relate to the data in terms of his own fishing experience. It may also be advisable to conduct a series of fishing production tests on concentrations, or schools, of under-utilised species to traditional gear. In these instances, where traditional gear is not suitable, development of new gear types or fishing strategy may be required to induce utilisation of under-utilised species - this may be particularly appropriate for "unconventional species" (krill, red crabs, lanternfish, etc.).

Market survey can help to determine demand factors. If the species is under-utilised or latent, there may be a need to develop markets or new products that can compete with other animal protein forms. Frequently, however, it turns out that many forms considered as exotic or unacceptable in one area of the world, are traditionally eaten in other parts of the world and markets do exist. In such cases, better dissemination of information could encourage fuller use of so-called "trash species".

If survey information has been properly collected, it is possible to develop some preliminary estimates of vital population parameters, including size of the standing stock and their potential yields. An area of data interpretation and display techniques are recommended in the FAO "Manual on Fisheries Resource Surveys and Appraisal". In addition, we strongly urge that before attempting to make preliminary forecasts of standing stock size, yields, etc., that the investigator be at least familiar with the FAO "Manual on Sampling and Statistical Methods for Fisheries Biology" and "Manual on Methods for Fish Stock Assessment" (Gulland (1966) and (1969)).

Alverson and Rothschild (in press) have recently proposed a number of equations to estimate vital population parameters, particularly for species which follow growth characteristics which are reflected by the von Bertalanffy growth curve. Their analyses are generally based on assuming instantaneous change in biomass with time (Figure 3). To explore the growth and decay phases of population cohorts, a variety of instantaneous mortality rates (M) and von Bertalanffy growth functions (K values) were coupled and a series of associated curves generated. To compute changes in biomass (P) we may use the equation

$$P_t = N_0 e^{-mt} \times W^{\infty} (1 - e^{-kt})^3 \quad (1)$$

where P_t equals population weight at any specified time, N_0 the input in numbers of individuals, and W^{∞} the maximum average weight of individuals at their maximum average

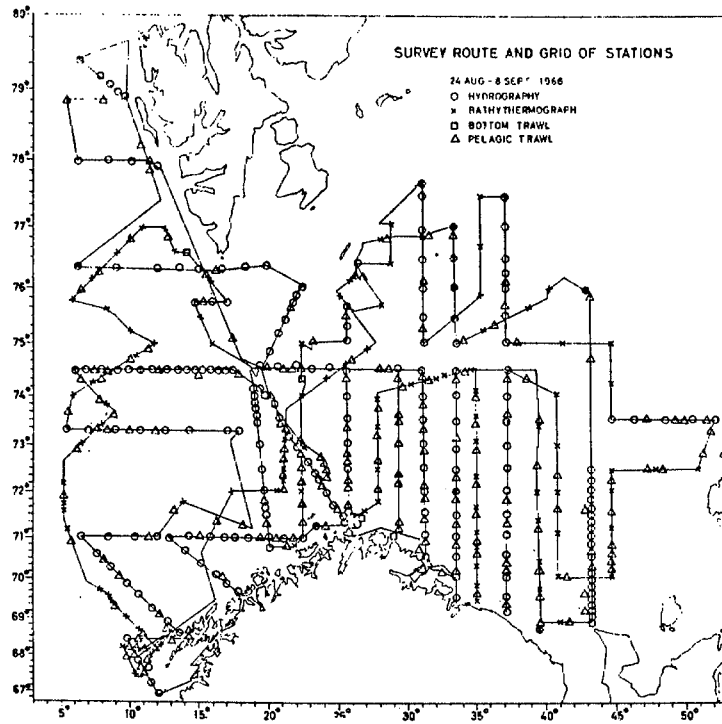


Fig. 2 Survey route and grid of stations (from Preliminary Report of the Joint International J-group Fish Survey in the Barents Sea and adjacent waters, August/September 1966, ICES, CM, 1966)

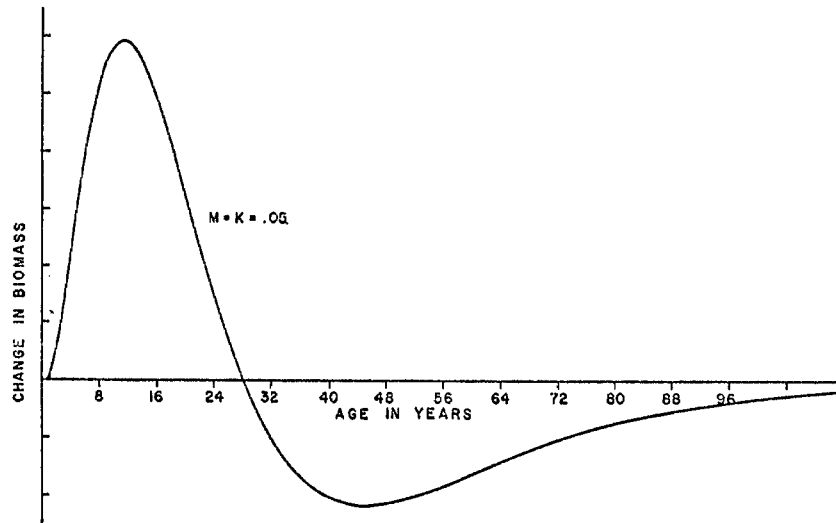


Fig. 3 Relative changes in biomass expected for species having a natural mortality of .05 and K value (von Bertalanffy growth function) of .05.

theoretical size (L^{∞}). When used to calculate distribution of biomass with time, Equation 1 was simplified by setting $N_0 W^{\infty}$ equal to unity, and expanding to the form:

$$P_t = e^{-mt} - 3e^{-t(M+K)} + 3e^{-t(M+2K)} - e^{-t(M+3K)} \quad (2)$$

The derivative of this equation,

$$\dot{P} = \frac{dP}{dt} = Me^{-Mt} + 3(M+K)e^{-t(M+K)} - 3(M+2K)e^{-t(M+2K)} + (M+3K)e^{-t(M+3K)} \quad (3)$$

yields an expression describing the instantaneous change in biomass with time for any specified input.

The time at which the cohort maximises its weight and the average individuals of the population have reached their critical size (C_{mt}) can be calculated by solving Equation 3 for the point in time when there is no net change in the population biomass; that is, $\dot{P} = 0$. This will occur when:

$$C_{mt} = \frac{1}{K} \ln \left(\frac{M+3K}{M} \right) \quad (4)$$

We have found, however, through an iterative process, that this value can be roughly approximated by the equation:

$$C_{mt} = \frac{1.38}{K+M} \quad (5)$$

If M and K are equal, the equation can be simplified to the form:

$$C_{mt} = \frac{1.38}{M} \quad (6)$$

The times at which \dot{P} is maximum, in terms of additions to or subtractions from the population cohort, can be determined by differentiating Equation 3 and setting

$$\frac{d^2P_t}{dt^2} = 0.$$

$$\frac{d^2P_t}{dt^2} = M^2 e^{-Mt} - 3(M+K)^2 e^{-t(M+K)} + 3(M+2K)^2 e^{-t(M+2K)} - (M+3K)^2 e^{-t(M+3K)} \quad (7)$$

If $M = K$, then the maximum increment (\dot{P}_m) will occur when $t = \frac{.58}{M}$ and the maximum decline ($-\dot{P}_m$) when $t = \frac{2.23}{M}$.

The net biological material produced for any set of M, K values can be calculated by substituting C_{mt} into Equation 1. When M and K are equal, the equation will have the form:

$$N_0 e^{-1.38} W_{\infty} (1 - e^{-1.38})^3 \quad (8)$$

If $N_0 W_{00}$ is set equal to unity, the remainder of the equation will be a constant, regardless of the values given M and K. If M and K are equal, the maximum biomass achieved per unit input at (t_0) will be :

$$.11 W_{00} \quad (9)$$

or

$$.42 W_{00} \quad (10)$$

per unit number of individuals at C_{mt} .

Assuming that one has sufficient data to develop some estimates of standing stock, some rough approximations of yields can be forecast using the relationships proposed by Gulland (1970) or Alverson and Pereyra (1969) that the maximum sustainable yields should be .4 to .5 times the instantaneous mortality rate times the virgin stock levels. These estimates may be sufficiently accurate to develop some concept of resource potential and development, particularly if there appears to be year-to-year stability in recruitment - that is, large fluctuations in recruitment do not occur. If it is apparent from the age-class structure of the population sampled that large variations in year-class strength occur, the survey data may only provide a temporary forecast of the availability of the species in question.

3. FISHERIES MANAGEMENT

Fisheries management, just as the other problems to which we have alluded, has also increased in complexity from the days when students considered the resources of the sea to be inexhaustible; when fisheries management essentially involved examining the dynamics of relatively few species in vacuo; or when the limited mobility and moderate fishing power of fishing vessels virtually obviated the need for considering international aspects of fisheries management. By contrast, we have today a situation in fisheries where individual fishing operations can exert tremendous intensities of fishing effort and deplete a stock in a matter of weeks or months; where the number of overexploited stocks continues to grow; where some stocks continue to become virtually extinct; and where the community of individuals who harvest and process the stocks are, in many instances, neither held accountable nor do they demonstrate a responsibility to conserve the stocks by not overfishing, by not insisting on and supporting research of relevance to fishery problems; and by not contributing needed management data or contributing data that either contain an inordinate amount of errors or are not timely. These complexities require that the contemporaneous manager face the above questions, and answer even more complex questions concerning how resources should be allocated in the time stream, how resources should be allocated among the states, and how criteria should be established to evaluate the resources so that appropriate allocations can be accomplished (Rothschild (1971)).

The question of how and when limits should be placed on fisheries which are in a state of development has plagued managers, particularly in the past decade. The fishery manager faces the dilemma of not wishing to allow the stocks to be overexploited so that the productivity of the stock is diminished. On the other hand, he must consider whether or not the developing fishery has had the opportunity to expand over the geographic range of the stock species - that is, are all components of the population being effectively used. If management is instigated too early in the history of a fishery, it may discourage investment that is needed to fully utilize and develop a potential of a particular resource. On the other hand, if action is not taken sufficiently early, the stocks could be materially reduced in size and the maximum sustainable yield greatly exceeded.

If preliminary yield forecasts can be made, preliminary management policies may be appropriate if yields reach the forecasted MSY levels. Indeed, situations exist today where one would want to introduce preliminary quotas on fishing, particularly where intense fishing efforts could be applied to the resource in question. This might be most appropriate in instances where long-lived species were involved. In all such instances, it will be important to carefully document the fisheries in question so that more precise management data can be formulated and early management policies altered when required.

Implementation of effective conservation measures for living ocean resources is frequently confused by semantic problems. The term "overfishing" is used in a variety of ways. In one sense, overfishing implies that the size of stock has been reduced to a level where it is no longer economically feasible for the fishermen to engage in fishing (economic overfishing). Overfishing used in this sense does not imply any biological damage to the reproductive status of the stock or misuse of the resource that is available. It reflects an economic condition whereby man, with present technology, is no longer able to extract the resource; i.e., cost of harvest exceeds value of raw material.

Overfishing may also be used to imply a situation where harvesters of a resource misuse the potential that is available. That is, every stock has a theoretical surplus production which can be harvested by man. This surplus production, however, will be maximised only if the strategy of fishing is designed in a manner so as to allow the stock to maximise its growth potential. This can be analogised with picking fruit from an orchard. If the fruit is picked too early, it will not mature and achieve its weight potential. On the other hand, if picking starts too late, much of the fruit will have fallen from the tree. Hence, the rate of fishing on the stock must be considered in light of the growth rate and natural mortality of the population, and of the size spectrum of fish being harvested.

Finally, overfishing may reflect a situation where the biological productivity of the stock has been impaired. This means that the number of young entering the fishery have been reduced as a result of overfishing of the parental stock.

There are obviously a variety of management systems that can be evolved to effectively cope with the conservation aspects of living marine resources of the sea. What is important in terms of the resources is that the institutional arrangements function in a timely fashion and that the consequences of such actions are properly interpreted in light of the life history and dynamics of the resources being harvested. Whatever systems are adopted, we must recognise the need for timely action so that the resources are not overfished with subsequent decrease of food production and economic losses to those who harvest the resources.

The traditional pursuit of problem solving in fisheries generally involved attempts to satisfy the scientific curiosity of a small subset of the very broad community of individuals associated with resource problems. The questions that were asked and the problems that were chosen for solution were philosophically oriented toward the scientific approach. Thus, the view of a problem was borne forth on a spark of intuition; hypotheses were formulated and tested, and the hypothesis which was better than the alternatives was submitted to the scientific community to await inevitable successor hypotheses. The modus operandi in the scientific approach is to search for knowledge and the solution of problems or the generation of advice was not a primary output of the investigation and, furthermore, inquiries into the interfacial areas between natural phenomena and the more mundane circumstances of everyday human affairs tended to be discouraged. It is, of course, not our purpose to cast what certainly must be petty aspersions on the scientific method, but rather to point out that adherence to the scientific method may have led to asking the wrong questions about the real-world problems of resource management.

An important alternative to the scientific method is systems analysis, which I believe contains the scientific method as a subset. In this context systems analysis becomes a mechanism which guides which "science" should be attacked by the scientific method. The distinction between the scientific method and systems analysis has been of fundamental importance to the development of systems analysis. Table 1 follows Quade (1964) in contrasting systems analysis and the scientific method. It is of interest that Gulland (in press) recently drew attention to the scientific method approach in fisheries.

Since systems analysis is a technique for investigating complex problems, and we acknowledge the complexity of the fishery management problem, it seems quite appropriate to apply this sort of analysis to fishery management (Rothschild (1971)).

A full discussion of a system view of fisheries management has been published in FAC Fisheries Technical Paper No. 106 (Rothschild (1971)).

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