PART II
REPORT OF THE WORKING GROUP ON RESOURCES STUDY AND MONITORING

by

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ABSTRACT

This report sets up major guidelines for the study and monitoring of variable fishery resources and provides information which may be useful in evaluating needs and assist in selection of appropriate methods and studies. Major symptoms of adverse changes and potential collapse in fish resources are identified, and a variety of topics on monitoring of resource studies, fishery operations, and biological sampling are discussed.

1. INTRODUCTION

To be fully effective, biological monitoring and studies require consideration of fishery context and alternative methods. This report examines some of these considerations, and reviews some recent developments. This discussion is intended as a supplement to the many manuals presently circulating. Recommendations are difficult to make outside the environmental, biological, and socio-economic context of particular fisheries. In some cases, general needs are clear. For the remaining cases, this document provides information which may be useful in evaluating needs and choosing between alternative methods and studies.

This document is the product of the Working Group on Resources Study and Monitoring which met during the Expert Consultation on Neritic Resources. The composition of the Working Group varied during the Consultation. In addition to their technical input, R. Jones and I. Tsukayama provided valuable service as rapporteurs. Many other people participated regularly in the Working Group and/or provided substantial sections of this document. These included J. Alheit, B. Brown, J. Carscadden, R. Crawford, P. Fréon, M.L. Garcia, J. Lleonart, J. Lopez, A. Menz, S. Saccardo, H. Santander, R. Serra, G.D. Sharp, P. Shelton, E. Ursin and many more.

1.1 Working criteria

Fishery science stems recently from the much older European tradition we call “science”. This tradition focusses almost exclusively on the academic pursuit of knowledge and the establishment of truth. However, fishery science extends beyond that tradition in that it forms a working basis for altering our world; that is, it is an applied science. The consequences of this aspect are not commonly recognised in fishery work, and in many respects call for a different approach to that which is taught in the university.

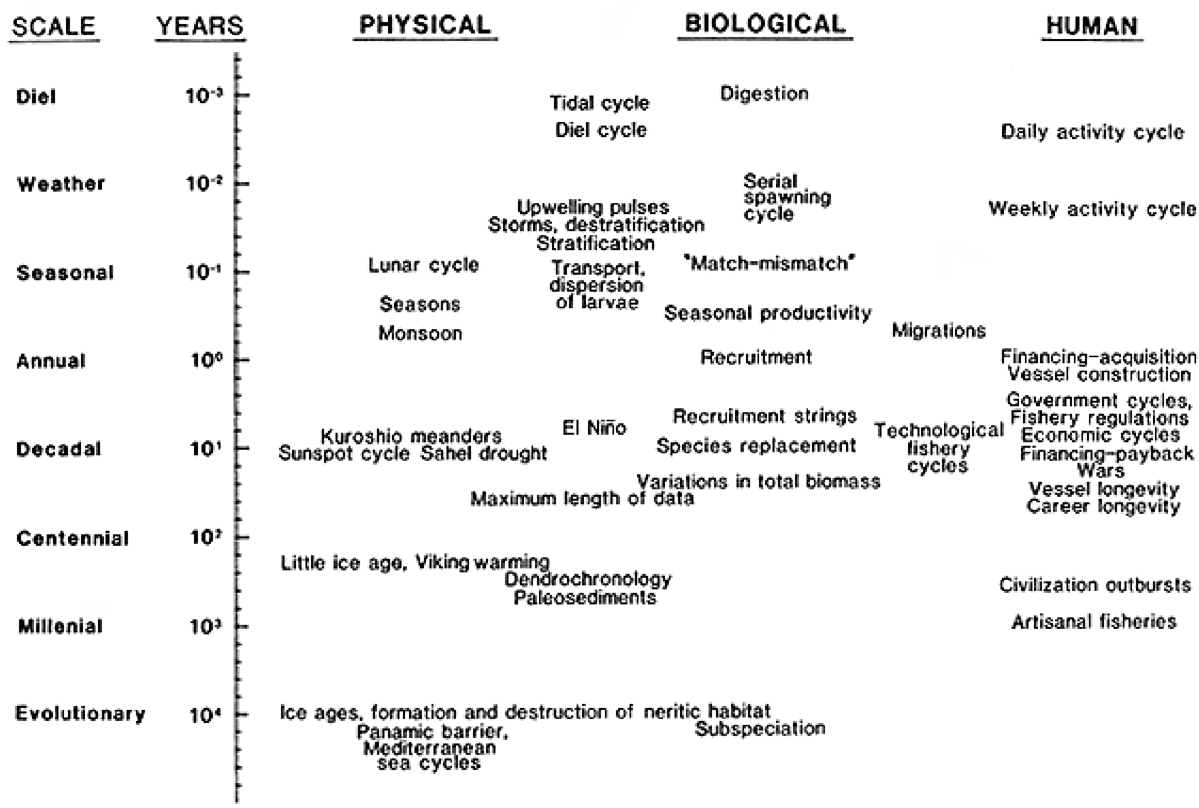

Table 1. Comparative time scales

In addition to the traditional scientific criterion of knowledge, there are other criteria which should guide our efforts. Because the results of our work may contribute to changes in society as well as ecosystems, fishery scientists bear a burden of responsibility which is generally lacking in normal academic science. An important aspect of this criterion is timeliness. Many fishery analyses and recommendations are specific to the current status of the fishery, and lose value if they are not communicated quickly. The next criterion is closely related, and will be called appropriateness. This criterion is particularly important to the task of this Consultation; recommendations must not only reflect existing knowledge and responsible interpretation/application, they must also be suited to the needs of the recipient.

Fishery science is the application of ecological principles (in the broadest sense) to particular fisheries. Thus fishery models specifically, and fishery science generally, must be viewed situationally like situational ethics in the philosophical sense; any technique or measurement should not be viewed in the abstract, but in relation to the particular fishery under consideration. Unfortunately, this document, being a general review, necessarily violates the last criterion.

1.2 A note on terminology

The use of broad terms like pelagic or demersal when referring to fish groups causes a dichotomy that does not exist in nature. For example, pelagics are said to be highly variable, but haddock on Georges Bank has been more variable than herring in the Gulf of Maine, and mackerel in the recruited ages has a lower natural mortality rate than cod. Therefore fishery scientists should be specific in discussing these groupings and use species group designations (i.e. sardine/anchovy) rather than terms like pelagic. The characteristics upon which the groups are based should be explicitly stated.

2. A PERSPECTIVE OF VARIABILITY

Variability of fishery resources occurs on nearly all time scales. Moreover, biological variability is strongly influenced by physical or environmental variability on one side, and variability in the human sector on the other side (Table 1). Much of the dynamics of fisheries and the difficulties in their exploitation and management histories (e.g. booms and collapses) can be inferred from the interaction of forces acting on different time scales. As in the classical ecology of predator-prey cycles, delays in fishery exploitation response to resource abundance creates an inherently cyclic or unstable system. By recognising the nature of these interactions and designing appropriate and effective regulations, management can control and minimize these technological fishery cycles, within the bounds of natural environmental variability.

3. CAUSES OF CHANGES IN FISH ABUNDANCE

Fishery and resource monitoring often covers a wide selection of biological variables. This activity is done with the implicit assumption that changes in monitored variables provides information on the status of the resource, with emphasis on productivity and abundance. In order to evaluate the utility of fishery monitoring activities, it is useful to more explicitly examine the relationship between biological variables and causes of change in fish abundance.

Causes of change in fish abundance fall into five categories:

- Intraspecific dynamics, which includes compensatory mechanisms such as stock-recruitment relationships, density-dependent growth and cannibalism.
- Competition among species, which is of considerable interest but in practice is difficult to demonstrate conclusively.
- Predation, which is generally treated as natural mortality in fishery analyses.
- Fishing, or exploitation
- Environmental fluctuations, particularly abiotic factors and lower trophic level biological factors.

Table 2. Monitored biological variables that provide evidence for causes of variability in abundance of Engraulis. Symbols qualify the relationship (XX = strong evidence; X = evidence; i = indirect connection; ? suspected)

MONITORED VARIABLE	CAUSE OF VARIABILITY IN ABUNDANCE				
	INTRASPECIFIC	COMPETITION	PREDATION	FISHING	ENVIRONMENT
Population size	X	?	X	XX	i
Age structure of adults			?	XX	i
Fishing mortality rate				XX	i
Natural mortality rate			XX	i	X
Predator indices[1]				X	X
Distribution (long term)		?		X	X
Distribution (short term)				X	XX

Recruitment strength	X	?	i ?	i	XX
Condition factor/fat content	X	?		i	XX
Diet	X	?		i	X
Growth rate	X	?		X	X
Fecundity	XX	?		i	XX
Age/length at maturity	XX	?		i	XX
Egg/larval mortality rate	XX	?	XX		XX
Larval growth rate		?			X
Co-occurrence with other species[2]	?	?	?	?	X
Sex ratio				?	
Seasonality of spawning				i	X

[1] Examples are guano production or seabird reproductive success

[2] This includes mixed schooling and geographic/temporal overlap

Biological variables, if properly monitored, can provide evidence of the causes of change listed above. Table 2 lists the most commonly monitored biological variables and the related causes of variability for the anchovy (*Engraulis*) fisheries. Nearly all variables are related to environmentally caused variation, and very many are related (at least indirectly) to fishing. Competition is a possibility in many cases, but no variable provides substantial evidence for competition. Intraspecific mechanisms are mostly evidenced by direct study of the fish, including its early life stages. Notably, the latter are some of the few variables not related to fishing. Some biological variables provide little useful evidence for causes of variability, for example, sex ratio is commonly monitored but is unlikely to provide useful evidence for causes of variability.

Table 2 would be different for other species of fish. Because *Engraulis* has been studied more than most species, the strength of evidence for other species will tend to be lower. In some cases additional biological variables would be appropriate. For example, northwest Atlantic herring have historically been impacted by disease, suggesting that monitoring for this factor would have some value.

4. SYMPTOMS OF ADVERSE CHANGES IN RESOURCE STATUS

Fishery stock assessment attempts to evaluate current stock productivity in relation to its potential productivity. This potential is estimated from historical resource monitoring, biological studies, and comparative information from similar species or fisheries. Experience has shown that fish stocks respond to exploitation in predictable ways, but environmental fluctuations often complicate the patterns. Because of this fundamental similarity among fishery responses, several models have been developed which concisely summarise the relationship between the fishery harvest and the resource. For example, as intensity of fishery removals increases, abundance decreases, mean age or size of fish decreases, and age at first maturity decreases. These changes in themselves simply reflect fishing pressure and compensatory responses. The level at which they reflect poor stock condition (i.e. performance falling below potential, due to excessive fishing) requires consideration of the context of historical levels and fluctuations as well as other features of the resource which may also have changed. For this reason, a generalised discussion of indicators of symptoms of adverse changes in stock condition is of very limited utility. However, for the purpose of discussion, Table 3 lists some common symptoms and indicators, their most likely interpretation, and some of the considerations that need to be taken into account.

Before concluding that a symptom signifies an adverse condition, the nature of the fishery and resource must be understood. Exploitation risk varies substantially with species and environmental characteristics, as shown in Table 4. With this background, the symptom in Table 3 must be examined for possible alternative causes such as environmental changes or changes in market demand. Once the symptom is accepted as a valid indicator of stock condition, the severity of the symptom must be judged on an objective basis. Usually this consists of using historical information in a fishery model which has well-established methods of interpretation. The model may also indicate the nature and extent of remedial action necessary to rehabilitate the stock.

The categories of diagnostic symptoms are few - relating to abundance, recruitment (incoming young fish), and relative intensity of harvesting. In addition, there are a variety of warning signs that are more difficult to interpret. Abundance is usually the most important indicator of stock condition, and for this reason a substantial portion of the research and monitoring effort should be devoted to this aspect. If a direct estimate of abundance is not available there may be other indicators such as the catch rate of the fishery, the geographic extent of the stock, or the status of more visible stock-dependent predators such as seabirds. Due to the relative imprecision of these auxiliary indicators, confirmation from more than one source is desirable. Analytical techniques such as production modelling may provide an estimate of “healthy” abundance levels (e.g. the level of abundance giving maximum productivity). Depending on the natural variability of the resource, a “warning” level of abundance might be half of the abundance giving maximum average productivity. A “danger” level could be similarly defined at a somewhat lower level.

Table 3. Most Common Signs of Deteriorating Resource Status and Potential Problems

SYMPTOMS AND INDICATORS		CONSIDERATIONS	INTERPRETATION
a)	Abundance decrease	- Environmental influence - Changes in availability and vulnerability	Warning, establish reference level
	Catch rate (CPUE) decrease	- History and definition of effort - Availability, vulnerability	Warning, Danger (CPUE often underestimates magnitude of actual decline), try production model
	Stock range decrease	- Environmental influence	Warning
	Change in species composition	- Environmental influence - Change in other species - Changes in market, regulations, fishing patterns	Warning
	Change in predator indices	- Environmental influence - Availability to predators	Warning
b)	Recruitment decrease	- Environmental influence - Availability, vulnerability	Warning, establish reference level, try stock-recruit relationship, compare replacement level
	Increase in mean age	- Market, regulations, fishing patterns	Danger, recruitment failure
	Anomalous fat cycle	- Environmental influence - Normal patterns	Danger
c)	Fishing mortality approaches natural mortality	- Environmental influence - Changes in availability, vulnerability	Danger, try yield per recruit, production model
	Mean age/length approaches age/length at first maturity	- Environmental influence - Availability vulnerability - Changes in market, regulations, fishing patterns	Danger
d)	Variable catch (after catch increase)	- Environmental influence - Market, regulations	Warning
e)	Deviations from normal patterns		Warning
	Changes in spawning of recruitment pattern	- Environmental influence - Availability	Warning
	Changes in age/length at maturity	- Environmental influence	Warning
	Changes in fecundity	- Environmental influence	Warning
	Changes in size composition of catch	- Environmental influence - Changes in availability, vulnerability - Changes in market, regulations, fishing patterns	Warning

Table 4. Comparison of “Contexts” for six Selected Fisheries (from Beverton, 1983)

	NORTH SEA PLAICE	NORTH SEA HADDOCK	NORTH SEA HERRING	ATLANTO-SCANDIAN HERRING	PERUVIAN ANCHOVY	CALIFORNIA SARDINE
MARINE ENVIRONMENT	Stable	Stable	Stable	Moderately stable	Unstable (upwelling)	Unstable (upwelling)
FISH POPULATION DYNAMICS						
- Degree of recrui-ment compensation	High	Indeterminate	Fairly high	Moderate	Low	Very low
- Variability of recruitment	Low	Very high	Moderate	Spasmodically high	Low-moderate (with failures)	Moderate
- Life-span (inverse to natural mortality rate)	Long (20+ yrs)	Medium (12+ yrs)	Medium (12+ yrs)	Medium-long (15+ yrs)	Short (4+ yrs)	Medium (10+ yrs)
- Pre-mature phase	Long (3–4 yrs)	Medium (2 yrs)	Medium (2 yrs)	Medium (2–3 yrs)	Short (< 1 yr)	Medium (2 yrs)
- % of growth (wt) span after recruitment	Large (90%)	Large (80%)	Small (40%)	Medium (60%)	Short to Medium (50%)	Medium (50%)
FISH BEHAVIOUR						
- Habit	Demersal	Demersal	Pelagic	Pelagic	Pelagic	Pelagic
- Environmental “shelter” or refuge	Partial	Partial	None	None	None	None
- Shoaling tendency	Slight	Some	Strong	Very strong	Strong	Strong
- Ease of detection	Undetectable	Limited	Easily	Easily	Easily	Easily
- Dependency (inverse) of catchability (q) on abundance	None	Probably none	Probably strong	Very strong	Strong	Strong
- Vulnerability to escalation of Fishing	Resilient	Resilient	Vulnerable	Very vulnerable	Very vulnerable	Very vulnerable
OVERALL FISHERY PROSPECTS	Steady and dependable in short and long-	Highly erratic in short to medium term; probably reliable in	Fairly steady in short to medium-term; long-term	Spasmodic; long-term reliability suspect	Unreliable in medium to long-term, with sudden	Unreliable; unstable in the long-term

	term	long-term	reliability uncertain		changes	

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Recruitment is the main source of fish biomass which replaces losses from the stock due to harvest and natural mortality. The higher the total death rate, the more sensitive is the resource to recruitment variability and/or failure. Recruitment fluctuations due to environmental variability are mostly unavoidable, although many resources show smaller relative recruitment fluctuations at higher parental stock sizes. When recruitment declines in parallel with decreasing parental stock abundance, there is a high potential for depletion ("recruitment overfishing"). When a history of recruitments is available, a plot of recruitment versus parental stock, with or without a fitted regression line, is useful to identify not only the average relationship, but often more importantly, to identify the existence of runs of above - or below - normal recruitment. Experience in Peru and Namibia have shown that anomalous fat or oil content patterns provide early warning of anomalous ocean conditions (e.g. El Niño) and related likelihood of future recruitment failure.

The activity of harvesting impacts a resource mainly due to the additional mortality (fishing mortality) imposed. There seems to be a consistent relationship between the magnitude of the natural mortality rate (M) and sustainable levels of fishing mortality rate (F). The relationship is the basis of the popular rule-of-thumb $F_{opt} \simeq M$, but fishery experience has shown this often to be an overestimate of optimal F. Thus, a symptom of overfishing is a fishing mortality rate which approaches the natural mortality rate in magnitude. An alternative indicator is when mean age or length falls near the age or length at first spawning. Besides being evidence of relatively high fishing pressure, this condition indicates imminent recruitment decline due to lack of spawning potential.

Several other stock conditions can be taken as warning signs, but do not provide specific diagnoses. For example, increasing fluctuations in catch suggest a possible loss of compensatory capacity, as well as increased risk of collapse. Similarly, deviations from normal physiological or behavioural patterns may be due to environmental fluctuation or may be normal responses to fishing pressure, but should not be dismissed without consideration of possible deterioration of stock condition.

Importantly, Table 3 is not exhaustive. There are many more possible symptoms and indicators, some of which may have general utility, and many of which have specific utility in particular fisheries. Once again, it must be stressed that every fishery is in some respects unique, and the relevant symptoms and considerations vary accordingly.

5. FISHERY INFORMATION AND MONITORING

Relevant information for monitoring a fishery can be obtained directly from fishery related operations, by sampling, and/or through biological studies. There is extensive interaction among these categories of information as they are all related to fishery activities.

5.1 Operations

5.1.1 Historical documentation

There are direct effects on fishery operations due to sequential changes in either market conditions, processing capabilities, legislation or regulations, and environmentally mediated events or processes which need to be documented in order to provide information on shifts from one state of affairs to another. The necessary documentation is of low cost (i.e. a simple diary of crises or events) but is rarely done. Long-term fishery data series will often have associated sharp changes due to such problems about which information will need to be available to persons utilizing these data for analyses; otherwise mis-interpretation and bias may well result from such studies.

Records of the historical developmental stages of fisheries should include such information as: changes in fishing methods or gear, market developments (i.e. new products, new processing methods, etc.); market perturbations (i.e. labour or transport strikes, resource collapses, contaminant related legislation, flooding due to over-production, etc.); management and marketing regulations; and environmentally mediated perturbations such as El Niño events and longer term changes in species distributions, composition and abundances.

5.1.2 Catch

The basis of the fishery-marketing production is the species-product. Even within closely related species there are very distinctive differences between product acceptabilities and hence values in local and regional market places. Products vary in processing and distribution based on their market product characteristics. Even within species there are differential uses and values, e.g. herring and capelin roe, premium sashimi quality versus canning or reduction quality.

In the less complex fisheries where only one or a few fish are sought and landed, the species identification problem is minimal. Multispecies and high volume fisheries (i.e. for reduction) often do not offer opportunities for species stratification in data collection. In other cases the catches of complex, multispecies catch are sorted at the market place. Interpretations of catch and landings data from complex fisheries is potentially important to the general topics of changes in species distribution, abundance and composition.

In most cases (some artisanal fisheries might be exceptions), catch is the most important fishery datum. While resource abundance may be estimated independently, the volume of catch is a direct measure of fishery impact on the resource, and little planning or assessment can be attempted without catch information.

5.1.3 Logbook systems

A well-designed and well-executed logbook system can provide valuable quantitative and qualitative data about the fishery. Information that can be derived from these surveys may include catch, landings, effort, location of catch, stock identification, distribution, co-occurrence of different species, and discards. Since the information is being collected by non-scientific individuals on a cooperative basis, there is danger that the information may be poorly collected and of no use, or worse, misleading.

Besides providing quantitative and qualitative information about the fishery, logbook surveys have the advantage of being relatively inexpensive in terms of equipment, and of providing long-term indices of abundance. However, logbook surveys depend on cooperation of non-technical personnel and this cooperation may change depending on perceived influence of logbook information on fishing regulations (e.g. quotas). They are also relatively labour intensive and difficult to validate.

Due to the well-documented unreliability of catch-per-unit-effort (CPUE) indices of abundance, it is recommended that logbook systems be supplemented by independent sources of abundance estimates.

The design of the logbook will probably vary from fishery to fishery depending on such factors as fishermen's activities, the literacy of the fishermen themselves and the desired amount of data. However, the key to a good logbook is simplicity while still providing adequate information. The design of the logbook will undoubtedly undergo an evolutionary process as the scientist learns what the fishermen can or will do and the value of the information derived. Multiple logbooks (e.g. by species or requesting institution) should be avoided; such logbooks can be combined to minimise confusion. The information collected will vary according to the fishery and content. The logbook designer should consult the literature on logbook design, effort determination (also see the following section), and is advised to contact fishery scientists who have had experience in similar systems.

There are a number of factors involved in proper execution of a good logbook system. It is imperative that the scientist have close contact with the fishermen, preferably involving personal visits when the logbooks can be collected and discussed. Confidentiality of the information should be assured. Since the scientist is relying on the cooperation of non-technical people (i.e. fishermen) to collect the data, some method of verifying the information is necessary. There is probably no perfectly adequate way to validate all information, but the problem is of primary importance and should be addressed. It may be necessary to use a variety of validation techniques. Once the data are analyzed the fishermen should be provided with the results of the year's work written in non-technical terms.

5.1.4 Determination of fishing effort

The literature on effort determination is extensive, but severe problems remain. One problem is simply the terminology. Beverton and Holt used the word “effort” to mean an index of the instantaneous fishing mortality rate (proportionality was assumed). Gulland and others later used “effort” to mean a measure of nominal fishing activity. This evolution has been unfortunate, as it first begged the question, and then generalised the usage. The term “effort” probably should be discarded, but its usage is now firmly entrenched. The next best solution is to reserve the word “effort” for nominal fishing activity (so as not to beg the question), and to refer to the fishing mortality rate as exactly that.

Catch-per-unit-effort (CPUE) indices are compiling a growing record of biased and misleading performance. One of the major reasons is the information content implied by the nominal unit of fishing activity. In terms of information theory, fishermen search the grounds so as to reduce their uncertainty of making a catch. If the gain in information is closely related to the time or distance of search, this may be a useful nominal unit of effort measurement. However, modern technology supplies the fisherman with substantial and often overwhelming additional information by means of radio communication and aerial reconnaissance, and usually this information is not incorporated in the nominal unit of effort. The result is a tendency for the CPUE index to be insensitive to changes in fish abundance. Three recommendations are relevant here: 1) it may be best to define nominal effort in terms of the least information content, e.g. trips occurring on Monday or following new moons, when the fishermen know the least about the location of the fish; and 2) whenever possible go directly to the source of the information, e.g. use aerial scouting logbooks, recording the flight path and estimated quantities of fish observed; 3) it may be more useful to define a precise measure of CPUE with known bias rather than an imprecise CPUE which may be less biased (more nearly proportional to abundance). If the bias is known, it can be taken into explicit account.

Two complementary studies of effort are recommended. The first study is an analysis of the biological and human behavioural components of the fishing operation. In some cases a simulation model can be constructed, and the performance of various CPUE indices can be evaluated. This was first done by Paloheimo and Dickie (1964), and has been attempted for various fisheries since then (e.g. the Inter-American Tropical Tuna Commission recently developed such a model for the eastern tropical Pacific tuna fisheries). The utility of such models has varied, and the exercise is not necessarily productive.

The second study would be a world-wide comparison of CPUE indices where reliable independent estimates of abundance are known. For each fishery a variety of CPUE indices could be derived and their performance evaluated. Patterns of similarity could be established among similar measures of nominal fishing activity and among resources with similar biology and/or fishing operations. Such a study would be useful not only to aid choices of nominal effort definitions, but would also help document the general reliability and performance of CPUE measures.

5.1.5 Selectivity

The problem of selectivity is well-known for demersal species and appropriate solutions have already been proposed. In pelagic fisheries, especially when purse seines are used, a common assumption is that there is no selectivity. In fact there may be three types of selectivity on length. First, there is indirect mesh size selectivity, which is rarely observed because mesh size is adapted to the target fish length, and gilled fish in the seine are highly undesirable for the fishermen. Secondly, the fishermen are often able to estimate fish length before setting the net. They release the fish when they realize that the length is too small for commercial purposes. So selectivity is not done by the gear but by the fisherman in this case. This form of selectivity tends to vary with stock abundance and economic conditions, complicating CPUE indices. Thirdly, the most important effect of selectivity is due to the fish behaviour. Fish school according to size, and the school concentrations tend to contain schools with similar mean length of individuals. Therefore, it is recommended to try to stratify the sampling as much as possible in order to take into account the whole population structure. In some cases, a selectivity in sex ratio has been observed in pelagic species, for example some schools have a significant predominance of males or females showing different vulnerability to the gear particularly during the spawning cycle.

5.2 Sampling

5.2.1 Species and stocks, multispecies considerations

The available monitoring and sampling schemes for most fisheries give reasonably useful information by species or generic category; however, in many situations, due to either the integrative nature of some fisheries or the overlap between closely related species, proper data have not been obtained which would make it possible to stratify the catch by species or, even more difficult, to subspecific or “stock” levels, which need consideration in resource modelling and monitoring.

In most cases proper categories can be established by visual identification, perhaps aided by information on location of capture. However, there are also cases where stock identification is exceedingly difficult, e.g. anadromous fishes such as salmon, and local spawners such as herring. Some methods of distinguishing among stocks are given in Section 5.3.3.

Fishery sampling to monitor the catches of important species should be designed in a multispecies context. Often only the dominant species has been sampled. Subsequently, as the fishery changes and other species become more abundant in the catch, the early information on those species which dominate later catch are not available. Therefore the species structure of the entire catch should be determined. Then for each species the age and size structure should be determined. Finally, the biological characteristics of selected species should be measured - length, weight, maturity etc.

The sampling scheme should be representative both in a biological and a statistical sense. Sampling should be consistent so that comparisons can be made among years or sites. Statistical consideration should be used to design the sampling and determine sample sizes, but the designs and sample sizes should not be changed from year to year. When sampling methods are changed, details of the changes must be recorded so that the data can be properly interpreted in the future.

5.2.2 Sampling at sea

For reasons of costs, it is usually suitable to obtain all the parameters from landings (market sampling). When not possible, because fish are processed at sea, sampling at sea may be done by on-board biological technicians. If it is not possible to monitor fishing boats at sea, a research boat must be used. Two approaches are then possible. It may be effective to determine correction factors between market information and at-sea information (i.e. transformation factors, commercial categories, mean length, etc.). As a last resort, all estimations may be done with research vessels. In any case, control of market data validity is recommended through work at sea.

5.2.3 Industry production

It is often of benefit to monitor the processed output of fisheries' landings. Examples include the production of fish meal, fish oil, fish fillets or canned products. This information is usually accurate and should be readily available from fishing concerns and processing plants. An historical time series provides resource managers with an immediate perspective of trends in the quality and value of fish offloaded. For example, in the southern African purse-seine fisheries, large depletions in pilchard (sardine) *Sardinops ocellata*, horse mackerel *Trachurus trachurus* and chub mackerel *Scomber japonicus* resources have resulted in a considerable reduction in the quantity of canned fish being produced, in spite of combined-species landings remaining relatively constant.

Fat content of fishes often reflects their physiological and spawning condition, and may be a useful indicator of spawning difficulties. Fat content of fish can sometimes be easily and inexpensively monitored from information concerning processed products. This approach becomes of less value if the fishery operates on more than one species, as differences in fat content may exist. In such cases, fat content for individual species is best monitored by sampling at the offloading points.

5.2.4 Age and length

Once established, ageing methods (particularly age-length keys) tend to become set into the monitoring system. This can be very misleading (Kimura, 1977) and should be avoided by building into the monitoring system periodic re-evaluation of methods and interpretation. As international and regional comparisons of fisheries are being used more often, and as many resources extend across political boundaries, standardization of methods for ageing and measuring the length of fish is highly desirable. When a resource is being monitored by two or more countries, it is essential that agreement be reached on measuring techniques (e.g. size groupings and nominal birthday).

Finally, the recent development of attractive methods based only on length composition for the analysis of fish stocks should not prevent a serious attempt being made to use more traditional methods to assign absolute ages to individual fish. Also, length frequency methods need close examination for their properties of bias and precision.

5.2.5 Fecundity

The determination of batch fecundity used to be problematic for multiple spawning fish. Commonly, size-frequency diagrams of oocytes were established and the most advanced mode was assumed to represent the next batch to be spawned. This method lacks precision and is extremely time-consuming. Recently, a new method has been developed (Alheit et al., 1983) wherein only hydrated oocytes are counted because they represent exactly the next batch to be spawned. This method requires that the females be collected at the right time of day, a few hours before they spawn.

5.2.6 Maturity

Maturity is commonly determined by means of macroscopic criteria. The disadvantage of this method is its subjectivity and lack of precision. Furthermore, its utility is doubtful because it was recently discovered that multiple spawning fish (e.g. anchovies) can spawn a new batch of eggs every 6 to 8 days at peak spawning time. This means they pass through 3 to 5 maturity stages - depending on the macroscopic criteria used - within a single week. Some stages are probably passed through within a few hours. The macroscopic criteria for maturity determinations are therefore of limited use for fish species with such a rapid oocyte development.

5.2.7 Sex ratio

Recently, some problems have been discovered in the determination of sex ratio of anchovies (*Engraulis*). Spawning behaviour includes segregation of males and females, which are ready to spawn, from the schools. These “spawning schools” have high vulnerability to capture, and usually have a preponderance of males. Also females have a higher vulnerability near spawning time than at other times during the oocyte development cycle.

5.2.8 Condition factor

Recent investigations have shown that gonadal hydration in anchovies can increase the female weigh up to 30% within a few hours. Furthermore, schools which have hydrated females usually have a very high percentage of them. Care must be taken to modify the sampling appropriately and/or to develop conversion methods for such cases.

5.3 Biological studies

5.3.1 Growth

Two areas in which studies of growth (excluding physiological work) have provided useful information are tagging and examination of daily growth rings. Tagging may provide information on growth in the absence of other sources such as annual growth markers, and is also useful in verifying other methods of age and growth estimation such as modal analysis of length frequencies. Examination of daily growth rings is potentially very useful, but not yet resolved. Some recent work suggests that the frequency of growth ring information may be correlated with growth rate, and other studies have shown incidence of discontinuities.

5.3.2 Stomach contents

Interpretation of stomach contents is notoriously difficult for two reasons. First, very often it is not possible, because of lack of time or sufficient expertise, to determine the food items down to the species level. However, most ecological similarity indices used for comparing food spectra of different fish species are meaningful only if they are applied on the prey species level. The second problem is that digestion rates are extremely hard to determine. However, quantification of food consumption is totally dependent on a reasonable estimate of digestion rates, which probably even vary for different types of prey.

5.3.3 Stock identification

In ultimate usage, a “stock” is simply the segment of the population that is the basis of analysis and management. Thus, stocks may be defined in many ways, and some ways are more useful than others. There are a variety of issues to be considered, not all of which may have a biological basis.

Recently Booke (1981) defined the word stock for the Stock Concept International Symposium for application in fishery science. The general definition (i.e. vague) he gave was that “a stock is a species group, or population of fish that maintains and sustains itself over time in a definable area. In a more precise manner, stock can be ideally defined, where genotype is known, as a population of fish maintaining and sustaining Castle-Hardy Weinberg equilibrium. Where no genetic basis is available for characterising a stock, then phenotypic definitions need to be recognised so that a population of fish would maintain these characteristics and therefore could be called a stock.” The latter case is the one generally applied today. Booke also emphasises the need to recognise stock genetic variability in management, given the guardianship implication of fishery management.

Probably more familiar to the usual stock assessment community is the assignment of stock labels by convention, based on fishing gear, geography, i.e. ocean hemisphere, or simple species designations, i.e. South Atlantic albacore, Baltic herring, etc. The numerous very tenuous stock structure hypotheses for most fish species have tended toward hemispheric or large regional approach to stock definition.

As a starting point in delineating “stocks” it should be obvious that the geographic location of reproduction is an important criterion, but that species may have variable geographic and temporally stratified reproduction, sustaining more complex rather than simple panmictic populations within any geographic context. These complex age-structures imply complex temporal and spatial patterns of reproduction.

The recent advances in thinking regarding marine teleost larval fish requirements have provided considerable basis for changing the usual premises applied to fish reproductive success. The concept of a “survival window” in time and space, arising from studies of the critical energetic requirements of larval fishes and the processes which promote them, is a key to better understanding the multiple cohorts of recruits entering most fisheries. This suggests that complex genetic composition might be a confounding issue, and that more definitive studies are needed.

Table 5 gives a synopsis of methods and data useful for population discrimination.

Methods based on characteristics of populations which are considered to be relatively sensitive, hence definitive, but which are quite discrete and can be categorised as being useful for both differentiation and consolidation of identities are: protein or enzyme characteristics, mitochondrial DNA comparisons, and immunological reactions. Methods based on chromosomal comparisons, colour patterns, and numerical or metrification studies are fraught with subjectivity and are integrative, hence less definitive, except for differentiation, where they are adequate inferential tools.

Table 5. Methods, Utility and Data Sampling Characteristics for Population Discrimination (from Sharp, 1983)

TECHNIQUE		METHOD	RELATIVE UNIT COST	DATA TYPE	DETERMINATION OF POPULATION CHARACTERISTICS	DEFINITIVE OR NOT IN DISCRIMINATION	1. WEAKNESSES & 2. STRENGTHS
A1	Protein characterisation	a. electrophoresis	low	non-parametric	sample size dependent	yes	1. sampling difficult 2. genetic basis
		b. electrofocusing	high	non-parametric	sample size dependent	yes	1. procedure slow highest 2. resolution
		c. purification and functional	very high	parametric	sample size dependent	can be	1. technique difficult great 2. sensitivity
A2	Chromosomal comparisons	a. karyotyping	low	subjective	can be useful	can be	1. requires big differences 2. genetic basis
		b. banding studies	moderate	subjective	can be useful	yes	1. requires large chromosomes 2. genetic basis
A3	Mitochondrial DNA	a. isolation and fractionation	moderate	non-parametric	sample size dependent	can be for familial studies or differentiation by area	1. tedious procedures 2. maternally inherited
A4	Colour patterns	a. pigmentation patterns	low	non-parametric	can be useful	can be	1. basis needs determining i.e. ontogenetic or hereditary 2. usually genetic basis
A5	Immunology	a. tissue typing, i.e. blood	low	non-parametric	sample size dependent	yes	1. sensitive to ambient 2. genetic basis
		b. microcomplement	moderate	non-	too sensitive	yes	1. very sensitive

		fixation		parametric			2. level tool
A6	Numerical or metrification studies	a. hard part dimensions	low	parametric	can be useful	yes	1. basis needs determining samples must have common expectation usually regionally 2. specific, often genetic basis
		b. morphometrics of body dimensions	low	parametric	can be useful	can be	1. basis needs determining samples must have common expectation usually regionally 2. specific, often genetic basis
B1	Growth and life history parameters	a. age-growth by 1. annual ring on hard parts	can be high	parametric	often useful	corroborative	1. subjective ease of 2. collection
		2. daily growth rate	high	parametric	definitive	can be useful	1. needs calibration 2. gives rates on short-term basis
		3. tagging-recovery	high	estimation	not usually	corroborative	1. usually biases in release and capture 2. tagging changes natural patterns on short-term
		b. onset of maturity	low	parametric	useful	corroborative	1. differences can be induced by environmental changes 2. helpful in assessing changes
		c. fecundity	moderate	parametric	useful	corroborative	1. difficult to evaluate true number of eggs produced or hatched

							often less important than 2. the knowledge of where eggs are successful
B2	Distribution studies	a. mark and recapture					1. needs substantive support data of A type
		1. tags and markers	high	point A to B	can be useful	corroborative	
		2. hooks	low	point A to B	can be useful	corroborative	2. fraught with estim. errors but useful for assessing movements
B3	Natural tags	a. parasites	moderate	non-parametric	can be useful	corroborative	1. can be lost or 2. transferred area/host specific
		b. chemical/hard parts	high	parametric	can be useful	corroborative	1. can be transferred or source can be spuriously distributed i.e. currents high information if source specifically located 2.
B4	Meristic counts	a. gillrakers or vertebrae	moderate	parametric	not useful in tunas	no	1. highly variable in some species due to ambient can indicate some 2. species' differences

Table 6. Comparison and Evaluation of Methods for Monitoring Abundance

METHOD	BIOLOGICAL CONSIDERATIONS	ENVIRONMENTAL CONSIDERATIONS	SPECIES SPECIFICITY
Catch-per-unit effort (CPUE)	Sensitive to behaviour: school size, distribution, availability, mixed species. Difficult to define "effort"	Sensitive to physical influences on distribution and availability	Fair to Good
Cohort analysis (VPA)	Needs accurate ages, estimate of natural mortality. May be sensitive to population structure, mixing, non-constant natural mortality	Changes in natural mortality rate	Good
Cooperative "Eureka" fishing vessel surveys	Depends on survey method	Depends on survey method	Depends on survey method
Acoustic surveys	Sensitive to behaviour: depth, diurnal movement, mixed species, schooling density, evasion	May be sensitive to thermal structure of water column, sea state	Poor to good (unresolved)
Aerial surveys (or logbooks)	Sensitive to behaviour fraction of population visible at surface, diurnal migration, mixed species	Sensitive to thermal structure, bioluminescence, atmospheric and aquatic visibility, sea state, moon phase	Poor to good
Experimental Fishing	Gear avoidance, selectivity	Thermal structure, sea state, bioluminescence, moon phase	Good
Egg/larva Census	Diurnal distribution and evasion, patchiness, compensatory changes in vital processes, patchiness	Temperature, light, sea state	Good
Egg production method	Seasonality, patchiness reproductive behaviour and segregation of maturity stages	Temperature, sea state	Good, if eggs are identifiable
Tagging	Dispension, tagging mortality, anomalous		Good

	behaviour, recapture efficiency and intensity		
Predator indices	Sensitive to behaviour mixed prey species diet specificity and switching	Environmental influences on predators, rainfall on guano	Poor to good

APPROPRIATE USE	COST CAPITAL/ /HUMAN (Equipment)	TIMELINESS	IMPROVEMENTS NEEDED
Exploited segment, economics; bad for schooling, easily detected species, better for some demersals	Low/low to medium	One fishing season	Understand biases, definition of nominal efforts
Historical analysis - not current. Good for calibrating other indices	(Cost of data)/low	Several years late	Input (assumed) parameters, robustness needs examination
Regularly scheduled surveys, fishermen participate constructively	Low/low to medium		Calibration, coordination, navigation
Long time series best single fish and mid-water species. Unproven utility, especially in short-term surveys	High/medium	Synoptic	Calibration, species identification, avoidance
Rapid assessment of surface fishes	Low to medium/low	Synoptic to one fishing season (logbooks)	Fraction visible, calibration, species identification
Often use together with other methods, provides age structures, etc. unexploited resources	High/medium	Synoptic	Sampling design, avoidance, selectivity
Index of spawning biomass	High/high	6 or more months	Calibration, automation, understand biases
Estimate of spawning or total biomass, easily sampled and abundant Ichthyoplankton, also good for localized spawning areas	High/high	4 or more months	Knowledge of spawning behaviour, dispersal and predation

Not recommended for estimation of abundance	Low to medium/high	One fishing season to lifespan of fish	Reduce and estimate tagging mortality, understand behaviour
Supplementary and pre-fishery index of abundance	Low/low	Variable	Understand behaviour, needs more examples

Other useful methods for population discrimination are: growth and life history parameters, distribution studies through mark and recapture, natural tags, and meristic counts. These methods permit various levels of inference to be made but alone cannot be considered definitive. Unless far more data are collected or spawning populations and/or heritability are known and studied extensively, their uses are primarily for estimation. All population structure conclusions based only on these data are tenuous.

6. ABUNDANCE ESTIMATION

Fishery analysis and management usually requires knowledge of the abundance of fish. Sustainable yields tend to be closely related to absolute abundance, and the impact of harvest is mostly clearly monitored by relative changes in abundance. In most cases, development, calibration and monitoring of an abundance index should be given high priority. Due to the uncertainties associated with all methods of abundance estimation, it is generally undesirable to rely on a single method. Comparison and evaluation of methods for monitoring abundance are given in Table 6.

Commonly a fishery will provide information useful for calculation of CPUE indices and/or virtual population analysis (VPA) estimates. The former requires monitoring of nominal fishing effort and respective catches by a representative segment of the fishery, whereas the latter requires estimates of catches by age of fish for all segments of the fishery. In some cases fishery operations may also provide an index of abundance based on aerial scouting to locate fish. Due to the nature of fish behaviour and fishery operations, CPUE indices tend to underestimate changes in abundance, and therefore entail some risk in underestimating the magnitude of declines. VPA cannot provide reliable current estimates of abundance, since population estimates are reconstructed from subsequent catches. VPA estimates are typically about 3 years out of date.

Due to the shortcomings of these fishery-based abundance indices, fishery-independent estimates are desirable. Unfortunately, they also tend to be expensive. One method of reducing cost is cooperative synoptic surveys using vessels from the fishing fleet. This method has been used for 20 years in Peru, where it is called a “Eureka” survey. The utility and reliability of such a survey depends on coordination, navigation and calibration. The information obtained from calibration may also be useful in documenting changes in fishing power or catchability coefficient due to gear change and improvement, and may be a useful adjunct to normal CPUE monitoring. Frequently a cooperative “Eureka” survey will use the vessels' acoustic equipment. Since a large number of vessels can be mobilised, such a survey can cover the entire range of the stock. Also, the method can give the fishermen a sense of participation in management, and may help to reduce the alienation commonly existing between fishermen and managers.

Acoustic methods are still in a process of development, and have not achieved the promise envisioned over the last decade. The relation between biomass and acoustic properties is still uncertain in many cases, and species identification generally requires direct biological sampling, usually with nets. Acoustic surveys are useful when used in a long-term monitoring programme, but may be misleading when employed as a one-time estimate of absolute biomass. Different vessels and equipment can give different acoustic measurements, and cross-calibration is necessary for comparing survey results.

Systematic aerial surveys have been used for some surface-schooling pelagic species. Species composition and estimation of the visible fraction of the stock are problems that usually are solved by coordinating the survey with a research vessel. Generally, the research vessel is able to provide biological samples for age composition, stock identification, etc. in addition to its contribution to the abundance estimate. For some species, experimental fishing is a useful method in its own right.

Egg and larva surveys have been used widely, and are generally very species-specific. Major problems with larva census (standing crop) estimates are: 1) calibration difficulty, 2) variable fecundity and age of maturity, and 3) variable larva mortality rate. The last two problems act in a compensatory way, and will cause larva census estimate to be insensitive to changes in stock abundance. Thus results from larva census may be similar to CPUE, although for different reasons. A recently developed method called the "egg production method" (Parker, 1980; Alheit *et al.*, 1983) solves most of the problems with the larva census. The method is based on estimated daily production of eggs (avoiding the standing stock problem), and uses histological examination of adult gonads to determine spawning rate and fecundity per unit biomass. The two sources of information are combined to give a direct estimate of spawning biomass, with statistical confidence limits. The egg production method is especially suited to multiple, serial spawners with easily sampled eggs or larvae and spawning adults. A variant of this method has been used to estimate size of local stocks of herring in the North Sea. In this case, herring are single-batch spawners, and fecundity is determined directly.

Tagging or mark-recapture methods have been attempted for neritic fishes, but tend to be unsuccessful as estimates of abundance. There are many unsolved problems with tag-related mortality, non-random behaviour, and the volume of marked fish necessary to achieve a useful marked-to-unmarked ratio. Tagging seems to have more useful application in studies of growth and/or migration.

In some areas it may be possible to develop "predator indices" of prey abundance. For example, guano production by seabirds in South Africa seems to be related to the biomass of surface schooling pelagic fishes such as anchovy and sardine. There are presently no cases where predator indices are sufficiently precise for direct use in fishery management. However, they are inexpensive and can provide useful information on relative abundance, migration, and ecological relationships. Further study of the predator species is necessary to interpret the predator index, particularly with regard to behavioural and environmental sources of variability.

7. RECRUITMENT FORECASTS

Both the nature of recruitment forecasts and their usefulness depend on the management objectives of the fishery (i.e. the nature of optimality). The more clearly defined the objectives are, the better we can evaluate the utility of a recruitment forecast. The recruitment forecast can take several forms, each associated with costs and levels of precision. The best form and associated cost and precision will depend on the management objectives. Three useful forms are:

<u>Continuous form</u>. Here recruitment is estimated as a continuous variable, generally with statistical confidence limits. The estimate may be either an index (relative recruitment), or if the proportionality can be determined, it may be an estimate of absolute recruitment.

<u>Discrete form</u>. Recruitment may be forecast as falling into one of several categories. A relative estimate may be "above-, about-, or below-normal", and an absolute estimate may be "greater than R_2, between R_1 and R_2, and less than R_1". The probability of falling in the wrong category may be estimated, and will be high as we approach the divisions between categories. On the other hand, the sampling effort and associated cost may be much lower than for the continuous form of forecast.

<u>Decision form</u>. This is a variant of the discrete form and may be best suited for the objective of catastrophe prevention. Recruitment would be classified as above or below a critical value, and

can be statistically treated by a hypothesis test. Without getting too deeply into statistical theory, it is important to discuss the types of errors that can occur. Consider the following possibilities

		Decision	
		R is below critical	R is safe
Actual condition	R is below critical	Correct	Wrong (Type I error)
	R is safe	Wrong (Type II error)	Correct

When we treat “R is below critical” as the null hypothesis, we can make two kinds of errors. In one case we may let the fishery continue without necessary preventative action (Type I error), and in the other case we may take preventative action when it actually is not necessary (Type II error). If we choose criteria making one type of error unlikely, we increase the probability of making the other type of error, given the same sampling intensity (i.e. precision). The manager must decide on the relative seriousness of the two types of errors; however, the objective of catastrophe prevention argues that the probability of making a Type I error is kept small.

While it is desirable to develop a recruitment forecast based only on causative or correlated environmental variables, few (if any) known empirical relationships are precise enough to use in this manner. Presently the best possibilities for a useful recruitment forecast are direct or indirect sampling of young fish (pre-recruits). Nets can be used, but young fish are highly evasive, and there is a need for improved sampling gear and techniques. Indirect sampling includes acoustic surveys which may use swim-bladder resonance to identify species and size. In some cases a pre-recruit survey could concentrate on indicator areas where these fish are known to concentrate.

In general, the younger the age at entry to the fishery, the more difficult it is to obtain a timely, useful, recruitment forecast. Ironically, it tends to be these short-lived, early recruiting species that are most in need of recruitment forecasts.

Early fishery indications of recruitment strength, such as catch rates of young-of-the-year, may be combined with the recruitment forecast to update the estimate. Here, increased precision is purchased by a delay in time; however, management may easily incorporate a two-step progressive response as the recruitment estimate gains precision.

Bayesian statistical methods may provide increased precision and reduced risk at little cost if a stock-recruitment relationship (including the extent of natural variabiity) has been developed for the resource. The stock-recruitment relationship provides an *a priori* probability distribution for recruitment, and the recruitment which has been forecast may be assumed to be a sample from this *a priori* distribution. Another attractive feature of this approach is that a risk function (defining the seriousness of various errors) may be introduced to the recruitment estimator, so that sensitivity to catastrophic recruitment failure (or other conditions) can be explicitly incorporated.

Recruitment strength is often positively serially correlated, that is successive recruitments tend to be somewhat similar. This is due to the stock-recruitment relationship (stock itself being serially correlated due to persistence of year-classes), and also to the tendency for environmental conditions to persist over more than one year. A high serial correlation argues that response to unusual recruitment strength should be somewhat disproportionate, because the next year is likely to produce similar conditions.

8. ECOSYSTEM CONSIDERATIONS

Recent years have seen many calls for "multispecies" and "ecosystem" approaches to fishery analysis and management. While the theoretical wisdom of such approaches is clear, our practical knowledge tends to fall far short of the level necessary for successful implementation. In fact, our knowledge of single-species dynamics is often only marginally sufficient for single-species fishery management, and is wholly inadequate as a foundation for multispecies models.

For example, small "forage" species such as anchovies contribute to the diets of larger fishes as well as seabirds and marine mammals. Multispecies management would require recognition of the trophic value of unharvested anchovies as well as the value of the harvested fish. However, being planktivores, the anchovy undoubtedly consumes eggs and larvae of larger predatory fishes, and may have a negative value in that respect. The balance between these aspects could be investigated by multispecies modelling, but the information required to implement such a model would require an expensive programme of fishery-independent investigation.

8.1 Habitats and fishery characteristics

There are a wide variety of neritic ecosystems. These vary with latitude as well as with habitat. Table 7 (a), (b) and (c) examines the relationships of neritic habitats to their fisheries in tropical, sub-tropical and temperate zones.

Table 7a. Habitats and Fishery Characteristics in Tropical Zone (Surface Temperature in the 23–29°C Range)

	ESTUARINE - DIVERSE	HARD BOTTOMS, REEFS	SOFT BOTTOMS, RIVER DELTAS	COASTAL UPWELLING PELAGIC	REEF OR ISLAND ASSOCIATED PREDATORS
Resource base	Shrimps, juvenile marine fishes, reproductive adults, freshwater spp.	Herbivorous and piscivorous spp.	Numerous species from all trophic levels	One to three main species and predators	Tuna,, Billfishes, large Jacks
Main taxa exploited	Penaeids, Mugilids, Perciformes, Selacians	Perciformes	Perciformes	Clupeoids, Scombrids, Carangids	Thunnus, Katsuwonus, Istiophoridae, Perciformes, Carangids, Serranids
Stock density at virgin state	Variable, medium, seasonal	High, apparently stable	Medium to high	Extra-variable low to high	Low to medium
Main gears employed	Seines and artisanal gear	Traps, hand lines, some distructive gears	Demersal trawl and artisanal	Seines	Trolling, pole and line, handlines and artisanal
Depth strata exploited	Top to bottom	To about 100 m	Top and bottom ≃100 m	Mixed layer	Top to bottom depending on species
Significant artisanal fisheries	Yes	Yes	Yes	Some	Yes
Catch used for	Food and export	Food, photos	Food and export	Food and reduction	Food and export
Quality and value of products/kg	Usually good medium	Usually very high	Varies with treatment	Usually poor low	High, but marketing problems

Year class patterns	Fairly stable	Possibly unstable at species level, stable at community level	Little information but appears to be variable on small scale	Unstable but can be high for a long period	Continuous recruitment, some seasonal availability
Knowledge of biology of resource	Good	Reef fishes not well known as resources	Poor	Good	Variable
Stocks exploited by	Local fishermen	Local fishermen, tourism	Local and some distant water fleets	Local and often distant water fleets	Mainly local fishermen
Major Perturbations	Man-made changes in environment as well as biological-ocean ones	Reef destructions some reef predators e.g. crown-of-thorns	Fishery induced and localised biology	Climatic trends, weather events	?
Scope of expansion	Little	Little	Usually not but some areas could have	Varies with resource flux	Not great
Seasonal limitations	Flooding	Little	Monsoon or tropical storms	High winds or tropical storms	Monsoon or tropical storms

Table 7b. Habitats and Fishery Characteristics in Sub-Tropical Transition Zone: Eastern Boundary Currents(Surface Temperature in the 15–23°C Range)

	COASTAL/LAGOONS	SHELF-ISLAND AGGREGATIONS	PELAGICS	SUB-SURFACE LAYERS
Resource base	Small pelagics, small predators, young marine fishes	Jacks, Bonitos, Tunas, Squids, Spanish Mackerel	Anchovy, Sardines, Mackerels, Jack Mackerels, Bonito	Adult Jack Mackerels, Hake, Redfish, Bonitos
Main taxa exploited	Engraulis, Opistonema, Sphyraenidae, Caranx, Serranidae	Seriola, Sarda, Thunnus, Loligo, Scomberomorus, Acanthocybium	Engraulis, Sardinops, Scomber, Trachurus, Sarda, Sardina, Sardinella	Trachurus, Merluccius, Sebastes, etc.
Stock density at virgin state	Variable to high	Seasonally high	Variable to high	High
Main gears employed	Seines, artisanal	Trolling, hand line, seining	Seines	Trawls
Depth strata exploited	Top to bottom	Surface and bottom	Surface	Mid to deep, i.e. 25–1000 m
Significant artisanal fisheries	Yes	Yes	Not usually	No
Catch used for	Food	Food and export	Food, reduction, export	Export
Quality and value of products/kg	Mostly low	High	Mostly low to medium	Medium
Year class patterns	Highly variable	Variable	Eruptions and failures	Eruptions and failures
Knowledge of biology of resource	Poor	Poor to fair	Some very good	Fair
Stocks exploited by	Local fishermen	Local and foreign fishermen	Local and foreign fishermen in some areas	Often foreign fishermen

Major perturbation	Cyclic or epochal shifts in ecosystem, i.e. birds and predators	Long-term population cycles due to climate-ocean events	Sporadic and epochal trends apparently change system, i.e. El Niño and Sahel cycles	Sporadic and epochal trends apparently change system, i.e. El Niño and Sahel cycles
Scope for expansion	Nil	In some areas, very high	Usually not	In some areas, very high
Seasonal limitations	Cyclic changes in tropical/temperate influences	Migration and distribution associated with changes in location of transition zone	Few	Few

Table 7c. Habitats and Fishery Characteristics in Temperate to Boreal Zones (Surface Temperature in the 4–15°C Range)

	PELAGIC	SUB-SURFACE LAYERS	ISLAND OR PLATEAU ASSOCIATED
Resource base	Capelin, Herrings, Sprats, Mackerels, Sardines, Osmerids	Pollock, Codlike fishes, Flatfishes, Hakes, Redfishes, large Jack Mackerel	Codfishes, Hakes, Herrings Pollock, Flatfishes
Main taxa exploited	Clupea, Sprattus, Scomber, Sardinops, Mallotus	Theragra, Gadoids, Merluccius, Sebastes, Trachurus, Pleuronectids	Gadoids, Merluccius, Clupea, Theragra, Pleuronectids
Stock density at virgin state	Variable to high	Generally high	Variable to high
Main gears employed	Seines	Trawls, gillnets, setlines	Trawls, setlines, seines
Depth strata exploited	Mixed layer	Mid to deep	Top to bottom
Significant artisanal fisheries	No	No	No
Catch used for	Food and export	Food and export	Food and export
Quality and value of products/kg	Medium - high	Medium - high	Medium - high
Year class failures	Common	Occasional	Common
Knowledge of biology of resources	Good	Usually good	Usually good
Stock exploited by	Local and foreign fishermen	Local and foreign fishermen	Local and foreign fishermen
Major perturbations	Climatic shifts	Ice and climatic trends	Climatic trends
Scope for expansion	Varies with resource abundance	Not in northern hemisphere	Not usually
Seasonal limitations	Migratory and reproduction cycle	Migrations and storms	Migrations and storms

8.2 Interaction between pelagic planktivores and their physical environment

Dramatic changes in the physical environment and the abundance of neritic fishes provide a dynamic environment for major neritic fisheries. Understanding and predicting some of the fishes' responses to the physical changes, and the ecosystems' responses to the changes in abundance of the fishes, may assist in formulation of management recommendations.

First, the physical changes, such as El Niño, are characterised by major displacements of water masses. The boundaries between water masses change geographic position. Many of the neritic fishes, such as anchovies, sardines, mackerels, etc., are pelagic and are expected to respond as volitional nektonic organisms by redistributing geographically in respect to the temperature and other characteristics of the water. Fishes have well-defined preferences that direct these movements in oceanic gradients. Laboratory estimates of temperature and other preferences, along with synoptic information on physical oceanography, may help explain north-south displacements of warmer-or-cooler-living fishes, restrictions in the total area of preferred environments, and replacements in a single geographic location of one species by another. In addition fishes generally have the highest growth rates at the preferred temperature if food is abundant. If food is less abundant there is some evidence that they can and do maximise growth by moving to cooler temperatures. A hypothesis on how fishes distribute in an environment which is spatially heterogeneous in respect to food and temperature is developed in Crowder and Magnuson (1983).

Second, the large changes in abundance of certain neritic fishes such as anchovies and sardines cannot occur without these fishes having an influence on their ecosystem. The most direct way that consumers modify their environment, especially when at high densities is by the consumption of their prey organisms. Consumers can reduce the abundance of their prey, and if they tend to select larger zooplankton, for example, they can alter the size distribution of their prey. When the larger planktors become rare it has been observed that fishes grow rapidly to a given size and then have marked reductions in growth rate. They reach a plateau at this size because larger particles on which they can feed with lower energetic costs are no longer available. Thus the increased cost of preying on small organisms reduces their net energy intake and growth slows or stops. The changes induced in the plankton can alter the suitability of the prey size spectra for other zooplanktivores and can cause decreases in abundance of other species. When the dominant zooplanktivore decreases in abundance, these pressures are removed and other species may then do better. Egg predation may also be a more critical factor during periods of high fish abundance when zooplankton particle size distribution is modified.

Other changes induced by a consumer include altered consumption rates by their prey species on organisms further down the trophic structure, and altered patterns of remineralization of nutrients, i.e. nitrogenous compounds may be concentrated or retained in near-surface waters. Also, primary production can be altered by fish-induced concentrations in nitrogenous compounds and by altered biomass of the phytoplankton owing to consumption of phytoplankton by the fish or by the prey organisms of fish. These consumer effects have been observed and documented in pelagic ecosystems of lakes, and some have been observed in marine environments (Stroud and Clepper, 1979).

8.3 Diet overlap of anchovies and sardines

There has long been speculation about possible feeding competition between adult sardines and anchovies as an explanation for replacement within this species pair; however, no evidence has yet been presented which proves feeding competition between both species. One reason for this fundamental lack of knowledge is that it is notoriously difficult to quantify the food habits of many planktivorous fish species because of the high taxonomic diversity of their food items. Furthermore, both sardines and anchovies can change their feeding mode from filtering to biting, depending on prey size. Secondly, even if it were shown that the food spectra of both genera overlap to a high degree, it would not mean that they were competing for food. If the carrying capacity of the environment is high (in this case, if plankton is highly abundant), both species could occupy exactly the same feeding niche without competing at all. This would be "feeding co-existence" in the sense of Jones (1982). Nevertheless, although sound evidence on feeding competition between sardines and anchovies has never been presented, some scientists ignore the weakness of existing data and report feeding competition to be one mechanism to cause replacement within this species pair. A careful study of the habits of both species in the same environment together with a parallel analysis of their food source and energetics is needed to clarify the relationship between these two fishes and to end the long record of speculation on this subject.

The same study could also examine the effects of predation and cannibalism on eggs and larvae. This phenomen has already been documented (e.g. Santander et al., 1983), and its influence on anchovy-sardine relationships is similar to that expected from competition, although the mechanism is rather different.

8.4 Species interaction modelling in fisheries

It should be borne in mind that a model is no more than a rational formulation of the modeller's ideas. The model when applied, shows whether available information is consistent with these ideas. When it is found to be, the output from the model often indicates what further information might put the ideas to another and more rigorous test.

Biological interaction models may be entirely empirical (e.g. based on polynomial expressions), or may be based on more familiar fishery models of the Schaefer production model (Lotka-Volterra) type, or the more detailed Beverton-Holt type. The latter category includes multispecies cohort analysis models being used to analyse mixed catches in the North Sea. The production model approach seems to disclose too little biological information, although some sound reasoning can be based on their concepts and assumptions.

Generally multispecies models tend to be either simple and unrealistic, or difficult to handle and definitely no tempting tool for beginners in the art of modelling. An interesting exception is perhaps the approach by Larkin and Gazey (1982) to modelling the development of the fisheries of the Gulf of Thailand by means of a simple biomass model. It can be handled by a small personal computer and requires relatively little programming expertise. It models a closed system, but should be easily adaptible to an open system like a zone of coastal upwelling by adding migration terms.

It might be an interesting exercise to formulate the Peruvian system as conceived by Walsh (1981) in terms of the Larkin and Gazey approach. Walsh adds to the common knowledge of Peruvian anchoveta history the observation that sedimentation of organic matter increased when the anchoveta stock collapsed. This may provide the necessary information for beginning to understand the interactions within this highly variable system.

A system such as that off Peru presents a challenge to the ecosystem modeller. The greater the perturbations to be described, the better the model must be. It is no problem to model a system in a steady state, but such a model is likely to prove unsatisfactory when a perturbation occurs, and it is unlikely to contain the necessary mechanisms to respond realistically to a perturbation not experienced before.

9. EQUIPMENT AND FACILITIES

9.1 Equipment

As in most other fields of natural science, fishery science is more limited by human creativity and resourcefulness than by the sophistication of its equipment. In most cases adequate fishery research requires only a few basic items of research equipment (although sophisticated equipment may be required for particular investigations). Computing facilities are quickly becoming essential to processing and analysis of large data collections and development of complicated models.

However, a large computer is seldom necessary for this purpose; small and inexpensive desktop computers with appropriate data storage devices are often sufficient and do not require expensive maintenance.

9.2 Research vessels

It is often financially inadvisable to acquire a large research vessel. Sometimes large vessels are required due to long-range or heavy weather operations, but in other cases large vessels are thought to be associated with increased agency prestige. In either case, the reason for acquiring a large vessel (often at nominal cost) must be balanced against the reals costs of operating the vessel. In most cases the operating cost is the decisive factor in the success of a seagoing research programme. Also, the vessel should be designed to use equipment (engines, hydraulics, electronics, etc.) for which spare parts and service are readily available in the country of use (as opposed to the country of construction); otherwise, equipment repairs may be very expensive and take many months, with associated losses of programme funds and time.

9.3 Fishing gears

A great deal of money and effort is often wasted because inappropriate gear is purchased for a research vessel, particularly when this involves purse seines and trawls. Account should be taken of the type of fish and the quantity required as well as the capabilities of the vessel and its crew. If expert advice is not readily available, judicious recourse should be made to consultants.

10. BIAS IN FISHERY SCIENCE

Fishery scientists have a professional and ethical responsibility for acquiring, improving and evaluating their tools ("tools" include analytical techniques, models, unifying concepts, etc.). Of these three activities, evaluation is the most difficult and the most necessary. A brief review of assorted biases in fishery information and analysis suggests a very important and disturbing conclusion: the preponderance of errors in fishery science are conducive to overexploitation.

This bias does not seem to stem from the theoretical basis of fishery science. Rather, it is mainly associated with methods of application and measurement which are strongly influenced by circumstances. The following examples may help clarify the nature of the problem.

10.1 Estimated change in abundance

If the method of estimating abundance is insensitive to changes in true abundance, fishery analysis may underestimate the true degree of impact on a resource. The associated yield models will tend to overestimate optimal harvesting intensity.

<u>Catch-per-unit-effort</u>. This popular index is often insensitive to changes in true abundance, particularly in pelagic surface (e.g. clupeoid) fisheries. Both fishing and fish are distributed non-randomly. As the resource declines, school size may remain unchanged, and the range of the resource may contract while abundance at the center remains relatively constant. Fishermen respond to decrease in abundance by adaptive gear changes and attrition of less effective vessels, keeping catch per nominal unit of effort high. In multispecies fisheries nominal effort directed towards a given species is often defined as the effort which resulted in catching that species. This results in an insensitive CPUE.

<u>Developing fisheries</u>. A period of learning often occurs when a fishery is initiated. The early fishery working inefficiently on high abundance will later become an efficient fishery working on decreased abundance. During the transition catch per nominal effort will not decline, giving the appearance of a resilient resource. Also, as the geographic range of a developing fishery expands, the fishery may progressively exploit virgin segments of the stock for a prolonged period.

Ichthyoplankton surveys. Compensatory changes in fecundity, age of maturity and egg or larval mortality will cause these surveys to underestimate changes in stock abundance.

Acoustic surveys. At high densities fish in the center of schools may not be detected quantitatively, whereas at lower densities detection improves.

10.2 Fishery information

Catch. Non-reporting of catch can cause inadvertent overexploitation. Quotas enacted to protect the resource may result in increased non-reporting or misidentification of species.

Progressive improvement. Progressive improvement in monitoring may give a false impression of stability while catches are actually declining.

10.3 Models and statistical procedures

Functional regression. Use of the standard "Y on X" regression rather than a functional regression (recognising observation error in the independent variables) will underestimate the absolute value of the slope of the regression. In production models this often produces overestimates of MSY and optimal effort. In stock-recruitment relationships this produces an erroneous impression that recruitment is independent of stock size. Functional regressions have not yet been developed for non-linear application, so this bias is presently unavoidable in estimating non-linear regression models.

Random variability. Random variability and serial correlation of recruitment are factors which cause realisable yields to be less than deterministic maximum sustainable yield (MSY). Nonetheless, deterministic MSY is often used as the criterion of a fully developed fishery.

Potential yield. The popular Alverson-Pereyra-Gulland potential yield estimate ($Y = 0.5 MB_{\infty}$) tends to overestimate realisable sustainable yields. Fisheries are often initially developed on abnormally high-resource abundances, giving an overestimate of virgin abundance B_{∞}. The formula also implies that recruitment at MSY is equal to virgin recruitment, which is seldom the case. For highly fluctuating resources potential yield may not be appropriate to lower levels of abundance cycles. Unfortunately the potential yield estimate tends to be adhered to long after improved fishery information becomes available.

Model formulation. Most fishery models are formulated in deterministic equilibrium-oriented terms with smooth transitions among states. These models will overestimate resource stability if the true behaviour is sustained disequilibrium, with catastrophes or multiple stable states. It may be attractive to assume a constant multispecies productivity, but experience shows that total productivity may be low for several years during transitions (if this concept is valid at all).

10.4 Wishful thinking

Fishery scientists and managers, as well as fishermen, want to see a healthy, productive resource. There may be an unconscious tendency to overestimate productivity or abundance (this has been observed in other sciences, e.g. Gould, 1978). For example, a suspected bias toward overestimation of true abundance is generally tolerated whereas a suspected bias toward underestimation is viewed with more severe criticism.

10.5 A prescription

This dangerous and pervasive direction of bias can be avoided to a large extent, but the prescription is not easy:

- Scientists and managers must be aware of the tendency toward inadvertent overexploitation, and the various ways this can happen.
- Methods and analyses should be subject to periodic critical review to detect these kinds of errors.
- Appropriate methods are important. This often means a more lengthy and detailed analysis. Short-cut methods are often dangerous if treated as a final product.
- More robust methods and models need to be developed. Also, the inherent biases of existing methods need to be investigated and better understood.

11. SUMMARY

Fishery science requires working criteria of knowledge, responsibility, timeliness, appropriateness, and a situational viewpoint (consideration of context).

Variability of physical, biological and human subsystems of fisheries occurs at all time scales, and their interactions are important to management.

Changes in abundance may be due to intraspecific dynamics, competition, predation, fishing, or environmental causes. Variability in fishery and resource data elucidate these causes.

Various symptoms of adverse changes in resource status fall into three main categories: decreases in abundance or recruitment, and high relative fishing intensity. These symptoms must be considered in a fishery context, from which reference levels can be established.

A variety of topics on monitoring of fishery operations and biological sampling are discussed. A historical narrative or journal should be maintained in addition to such data as catch and effort. Sampling should recognise multispecies aspects of catches.

An extensive survey of comparative catch-per-unit-effort abundance indices would be useful in evaluating the performance of that index and in helping define best available measures of nominal fishing effort.

Many standard procedures (age-length keys, maturity criteria, fecundity determination) should be reviewed in light of recent developments in technology and advances in understanding.

Stock identification continues to be an important but difficult task. Methods continue to be developed, but many require sophisticated technology.

Various methods of abundance estimation are compared, with no single method showing superiority. It is advisable to monitor abundance by more than one method.

Recruitment forecasting is still at a primitive stage of development. The nature of the forecast depends on the way it is used in fishery management; for most purposes, a qualitative “above-, about-, or below-normal” may suffice.

Recent calls for multispecies and/or ecosystem management are unsupported by current knowledge. This area provides the greatest challenge for research and modelling.

Progress in fishery science is seldom limited by equipment or facilities. Acquisition of large research vessels is often inadvisable due to prohibitive operating cost.

Fishery scientists must evaluate the biases in their methods and analyses. A brief review suggests that the preponderance of errors in fishery science are conducive to over-exploitation.

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