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A framework for identifying fisheries management problems associated with the influence of environmental factors on the distribution, movements and migration of marine species

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INTRODUCTION

The Scientific Council, at its Annual Meeting in September 1983, reconfirmed its interest in relating environmental factors to the dynamics of exploited fish populations. The Council recognized the value of having specific goals to focus research efforts on important problem areas. It chose to concentrate its work "on the influence of environmental factors on the distribution, movements and migrations of marine species in the Northwest Atlantic" (NAFO, 1983). While this narrows the field of consideration substantially we are still left with a broad subject area with which to deal. The purpose of this paper is to provide a framework within which the nature of the problems can be considered, and their importance to the work of the Council can be evaluated.

A definition of "importance" is perhaps the first task. The Council has a broad mandate but its primary practical task is to provide advice on the management of fisheries. We propose to look at the question of environmental effects on distribution, movements and migration of marine species in relation to the practical problems encountered in fish stock assessment, control of fisheries exploitation, and longer-term prognosis.

The next job is to circumscribe "environment". Our intent, as much as to focus attention on practical problems, is to identify problems of common interest to physical oceanographers and fisheries biologists. Thus, we define environment for present purposes as physical oceanographic conditions.

While on the topic of definitions, clarity in our use of the words "movements" and "migration" will be of value. We consider movement to be a characteristic of individual fish and to be of a haphazard nature. Migration is considered to be a stock characteristic and a term used to describe systematic seasonal movements.

In choosing distribution, movements and migration as the subjects for consideration, the Council deliberately excluded the effects of environment on fish production. The influence of environment on recruitment, through study of population dynamics at egg and larval stages, has been the subject of other recent initiatives by the Council (i.e. Flemish Cap, and Georges Bank herring projects) but has proved to be an intractable problem. The effect of environment on population parameters at later life history stages which affect production has, however, received less attention. A number of recent studies have considered large-scale relationships (in a geographic sense) between fish production and environmental parameters (Sutcliffe et al. 1976, 1977, 1983). If these highly integrated views of the effects of environmental factors are looked at from the perspective of explaining the geographic distribution of production, they would become relevant to the present topic.

To provide further structure to our considerations, we view environmental effects at different levels of organization - the level of individual fish or groups of fish, nominally called the population level; the level of stocks in the context of reproductively self-sustaining population units; and the species level. Within this framework, then, we consider the nature of the effects on distribution, movements and migration of physical oceanographic factors which are of practical importance to fisheries management.

DEFINITION OF PROBLEM AREAS

Environment affects the behaviour of individual fish, and in discussing the effects of environmental factors at stock or species level we are addressing the net effects of environment on many individual fish. In other words, what we are classifying here is the nature of the problems we wish to discuss.

Population Level

Movements and migrations modify distribution and we choose to discuss most problems under the title of distribution. Indeed it is difficult to conceive of practical problems in the present context which can conveniently be thought of under the title of "movements" or "migrations".

In the sense of movement as "activity", degree of activity in relation to environment, say temperature, could have significant impact on catchability, particularly to fixed gears such as traps in invertebrate fisheries and to hook and line finfish fisheries. This is not, however, a common type of problem in the NAFO context.

Migration patterns, as stated above, are considered to be characteristic of stocks, resulting in systematic seasonal changes in distribution of the various life history stages. Variation in migration patterns are reflected in the distributional characteristics of fish aggregations. Aspects of migration which perhaps deserve separate treatment relate to the direction and speed of migration. The success of localized, particularly coastal fixed-gear, fisheries is sensitive to fluctuations in precise location of migration routes. Examples can be found in components of important species fisheries e.g. herring, mackerel, haddock and cod. It can be hypothesised that transit times are also likely to be instrumental in causing such variations. Ability to predict such variations may have practical value in relation to inshore fixed gear fisheries and the ability to explain them may provide a useful basis for interpretation of events and for longer-term fisheries management planning.

The fundamental distribution-related issue, at this level, is aggregation as it relates to catchability. The location, timing and degree of aggregation have major impacts on the practice of commercial fisheries, fisheries management, conduct of research, and interpretation of results. Improved understanding of variation in aggregation resulting from variation in environmental factors would be of substantial practical import.

Variation in aggregation has a major impact on fishing success and hence on the profitability of fisheries over short time scales. This has, at times, stimulated interest in, or demand for, forcasting services as an aid to fleet deployment. This is not, however, a class of problem, i.e. promoting increased fleet efficiency, which has merited much attention in the scientific community in the last two decades, effort being directed toward control of exploitation rates. It is the secondary effects of such variations on fishing success which have had substantial impacts on fisheries management, both on the general managerial process and on stock assessment *per se*.

In terms of managerial planning, catch quota management and then extensions of fisheries jurisdictions introduced an era of increasingly detailed fisheries controls. Integrated fleet planning is based on a static concept centered around "average" conditions, and variations disrupt such detailed fishing plans. Closure area/seasons illustrate the nature of this class of problem. The Scotian Shelf small mesh gear line (SMGL) provides a good example. The defined season and area is designed to allow satisfactory conduct of directed fisheries (with small mesh gear) for silver hake and squid while preventing significant bycatches of other species, particularly cod and haddock. Variation in the timing and/or location of aggregation of any of these species will have an impact on the efficacy of this regulation. If haddock are concentrated in deeper water than usual or if these concentrations persist later in the year than usual, bycatch problems could result in fisheries closures. On the other hand, if silver hake disperse over the shelf early, or in greater proportion, fulfilment of allocations may be prevented. The degree, as well as location and timing, of aggregation will also affect fishing success, of course. Decisions on the part of the licensing authority on the amount of fishing effort to licence, and of the fishing nation on the number of ships to deploy and for how long, are predecated on expectations of fishing success. Variations from this will, at least, create inefficiencies and could create difficulties in intergovernmental relations.

In addition to the technical aspects of management, just discussed, there is also an important "philosophical" element to be considered. In particular, if fishing conditions vary greatly from regulatory expectations, the credibility of the regulation, the regulators and the management process comes into question by the fishing industry. Of particular concern to the Council is, of course, the credibility of the stock assessment and advisory process.

From a practical stock assessment viewpoint, interpretation of commercial catch rates plays an integral, sometimes key, role in determination of stock status. A substantial variance around catch rate versus stock size relationships is common. While factors other than environmental ones are no doubt at play, it is likely that a better understanding of the role of environmental factors on aggregation and hence catch rates would aid greatly in data interpretation. Understanding factors affecting (ie. biasing) data for the most recent year is of greatest practical importance.

In the NAFO Area a strong research emphasis has been placed on the development of research vessel surveys, particularly stratified-random bottom trawl surveys, to obtain fishery independent estimates of stock size and to provide quantitative estimates of recruitment (see e.g. Doubleday, 1981). Although relationships between research vessel abundance indices and stock size are less subject to bias than those between commercial catch rates and stock size as a result of the standardized survey design, they are plagued by very high variances. Again variation in environment, while not the only factor at play, is likely to be one of the most important.

In the case of commercial catch rates, the most comprehensive data are acquired from the large vessel mobile fleets. For these fleet sectors, the precise location and timing of aggregation will tend to have a secondary impact on catch rate, while the degree of aggregation (and timing in the sense of duration) is of major impact. For smaller, less mobile, vessels and fixed gears, location of aggregations assumes a greater importance in determining catch rates.

Variation in the degree of aggregation will not introduce the same biases in stratified-random research vessel abundance estimates as in commercial catch rates because of the randomization of research vessel fishing effort. This variation will, however, be reflected in increased statistical variance of abundance estimates. Variation in the time of aggregation, in this context, is confounded with degree of aggregation, as surveys are conducted synoptically. Stratified-random bottom trawl surveys are designed to cover the entire area of significant distribution of a stock but variation in location of aggregations is important knowledge in deciding on stratification schemes, and improved stratification will reduce statistical variance of abundance estimates. Of greater impact in this context are factors which affect vertical distribution, rather than location in a geographic sense. Environmental factors which change the proportion of a fish population within the part of the water column sampled by survey gear, i.e. change the availability of fish to the gear, will have a substantial influence on the level of abundance estimates, but will perhaps have little influence on variance of estimates.

Stock Level

Fisheries management on the basis of TAC limitations by species and management area is a practical recognition of stocks as semi-isolated, self-reproducing, production units. Questions concerning the definition of stocks, and the degree of stock mixing, in relation to the suitability and practicality of management areas for control of exploitation on stocks, can fruitfully be considered in the context of environmental influences.

The concept of reviewing species tolerances to environmental factors such as depth, temperature and salinity in the context of distribution of these environmental factors, and inferring stock separations from these distributions, has largely fallen into disuse. Emphasis has been placed on modern applications of tagging, biochemical and parasitological techniques. The influence of environment during early life-history stages on meristic and morphometric characters does, of course, provide a classic method of stock separation which is also still much in use. While these currently used methods may be more efficacious in describing the stock separations which do occur, they nonetheless do little or nothing to explain why they occur and provide no capacity to predict the consequence of environmental change.

A recent study (Iles and Sinclair, 1982) has indicated that the number of genetically distinct herring stocks is determined by the number of distinct, geographically stable larval retention areas. The authors used the Simpson and Hunter stratification parameter (Simpson and Hunter, 1974) to define temperature fronts demarking the transition between vertically well mixed and stratified waters, and they associated larval distributions with well mixed areas. Their theory allowed hypotheses to be erected concerning not only the location but also the size of herring stocks, as a relationship was proposed between absolute population size and size of retention area. This modern approach to explaining stock formation as a resultant of oceanographic structure, which promises the potential of explanatory and predictive ability, deserves attention.

The above is an example concerning stock formation of one species throughout its range, but there are situations where particular areas appear important in stock formation for several species. One is the Western Bank area in Div. 4W which serves as a primary spawning area for several important gadoids - pollock in winter, cod in early spring, haddock in late spring and silver hake in summer. In presenting the preliminary results of extensive egg and larval surveys in the area, O'Boyle et al. (in press) have implied that larval retention mechanisms in the area may be responsible for the popularity of the location.

Considerations such as this will not directly influence our ability to conduct a particular stock assessment in any specific year. Nonetheless, in developing an understanding of the relationship betwen oceanographic structure and stock formation, we will be providing a basis for explaining distributional and migratory characteristics and their variations. This will allow not only improvement in definition of fisheries management units in the present context but perhaps also the development of new approaches less rigorously tied to the simple unit stock management concept.

Species Level

The study of species distributional characteristics in relation to environmental factors is an aspect of zoogeography which has some important implications to fisheries management. Of primary interest are large scale oceanographic, or "climatic", events which significantly modify the distribution of fishable concentrations of a species through changing the "productive capacity" of an area for that species.

A classic example of the relationship between climatic factors and fish production, the West Greenland cod, is well known to fisheries research workers in the NAFO Area and has most recently been treated by Cushing (1982). The work of Sutcliffe et al. (op. cit.) which hypothesises links between environmental parameters and the distribution of fish production was mentioned in the Introduction. We can add to this that a superficial review of most recent cod stock assessments suggests that more southern stocks have recovered more fully (or even "over-recovered") from the general low of the mid-1970's in relation to historical levels than have more northern stocks, which tend still to be below calculated historical levels. This perception may not withstand detailed scrutiny and even if generally true the event may be attributable to factors other than environmental. Nonetheless, the suggestion of a possible shift in cod production to the south is an intriguing question of obvious practical importance. The points we wish to make here are that there are important practical fisheries issues which need to be addressed through the study of climatic effects on species distributions and that these climatic effects can concern not only boundary conditions but distribution of production through the species range.

So far in this document we have discussed the impact of environmental factors on distribution of marine species, but we wish to end the list by turning the issue on its head and discussing the use of distributional information as an indicator of environmental variation, or "climatic trends". This archaic approach is based on the maxim that species distributional changes will prove to be sensitive indicators of environmental change. Events can then be interpreted in relation to changes observed during direct environmental monitoring. In terms of direct long-term marine environmental monitoring for the purposes of fisheries research, primary questions are what to monitor, where and how often. Changes in species distributions are reflections of the integrated effects of environmental change and systematic monitoring of range variations could provide a cost-effective supplement to an environmental monitoring programme. Potential for success in developing such an approach would be enhanced if indicator species could be identified ie. for which the mechanism of response to environmental factors is known.

PRACTICAL IMPORTANCE OF PROBLEMS

In this section we shall attempt to evaluate the practical importance of the three broad problem areas defined above. Practical importance in the context of this paper is primarily defined as importance to the provision of scientific advice on stock status, the implementation of such advice in the form of TACs, closed areas/seasons, etc., or the conduct of fishing operations (success of fishing). Importance to more general considerations such as social and economic planning are also given some attention, however.

Population Level

(a) Effects on the Stock Assessment and Advisory Process

As stated above, the success of coastal fixed-gear fisheries is critically dependent on the timing of migrations and the location of migration routes of not only the target species but prey species as well. Because of this critical dependence, catches in these fisheries fluctuate widely. An example of this type of fishery is the inshore cod trap fishery along the Newfoundland coast. Catches fluctuate greatly in this fishery from year to year because of annual fluctuations in the availability of cod in the inshore areas, even when total cod populations and inshore fishing effort are similar between years. Factors such as the abundance of capelin, the extent of their inshore migration, and the prevailing environmental conditions, chiefly temperature, all act to produce a high degree of variability in inshore catches. This causes great difficulties for inshore fishermen in planning fishing activities in advance of the season.

If fisheries scientists could understand the mechanisms governing the influence of environmental factors on availability of fish to fixed-gear, at the very least they would be able to explain events occurring in the inshore fishery in a given year and thus, counteract the all too familiar criticism that stock assessments are incorrect because catches are less than implied by the assessments. It is unlikely that knowledge of these underlying mechanisms would allow appropriate changes to be made in the environment to the benefit of the inshore fisheries because of lack of technology to achieve such changes. On the other hand, such knowledge would improve our ability to utilize inshore fishery data in assessing population abundance.

In the case of inshore fisheries, however, there are often other limitations to development of abundance indices from data on fishing success. The 2J3KL inshore cod fishery illustrates well the difficulties of obtaining accurate measures of fishing effort. Year to year variation in effort cannot presently be measured and, although longer-term trends are documented in terms of "catch per man", this index is subject to various sources of bias. Thus, inshore fishing success is not currently used in any statistical calculations on stock status of 2J3KL cod and, indeed, there are very few cases where inshore fisheries data are utilised for this purpose. Thus, utilisation of new knowledge of the effects of environment on availability to inshore fisheries would appear to be contingent on coincident improvement of inshore fishing effort measures.

Variation in aggregation has an obvious impact on commercial fishing success by its effect on the level of catch per standard unit of effort. Less obvious is the effect variation in aggregation has on the process by which stocks are assessed and advice provided to fisheries managers on quantities of fish to be removed. In many instances in the NAFO area, cohort analyses used for stock assessments are tuned using indices of abundance from either commercial or research survey data. One of the underlying assumptions in using such indices is that the catchability of the fish by the gear does not change significantly from year to year. Many factors can affect the catchability of fish not least among which is the degree of aggegation. This in turn is a function of many factors, environmental factors being among the most important. Levels of temperature or patterns of currents for example can cause fish to be lightly or heavily aggregated in a given area. Therefore, in evaluating a regression series, for example CPUE on biomass or research numbers on population numbers, in which the last point is significantly higher or lower than a regression through the earlier points would predict, one is faced with the dilemma of whether the difference represents a real difference in stock abundance or merely a bias due to greater or lesser aggregation of fish in that year. Examples of this can be found in both NAFO (2J3KL cod) and in CAFSAC (4VWX pollock) assessments.

If the latter is the case, then the result would be a biased estimate of stock abundance in the last year, which in turn would lead to scientific advice resulting in sub-optimal yields from the fishery. A knowledge of the manner in which environmental conditions affect the degree of aggregation of fish would likely aid greatly in interpretation of such results. Almost without exception, analytical assessments depend on regressions between commercial or research vessel stock size indices and sequential population analysis (SPA) results. Less frequently, recruitment levels are predicted from regression of RV survey indices vs SPA year-class size estimates. Analysis of historical records on assessment results by Rivard (1981) indicated that current data and analytical methods yield a relative error of 24%, on the average, for estimates of stock size in the current year. Although in his particular analysis using 4TVn cod, Rivard concludes that improved knowledge of factors affecting mean weight at age would improve accuracy of catch projections more than improving research surveys, this stock is a special case. On the one hand, this survey has shown less variation in estimates for cod than that shown by other stratified-random surveys for cod or other species (Koeller 1981), but variation in commercial mean weight-at-age has been greater than that demonstrated for other stocks. Other cases should be analysed to give a more general perception of the importance to the determination of current stock size of correcting abundance estimates for environmental factors. It seems clear enough that the accuracy of catch projections leaves something to be desired and hence there is scope for substantial benefits to be accrued if significant improvement can be effected.

In addition to advice on quantity of fish to be removed, advice is also given on the appropriate distribution of catch and effort to achieve optimum benefits to the fishery as a whole. Such distribution is often achieved by closed areas/closed seasons, which are usually based on average conditions over some historical period and thus are not guaranteed to optimize distribution of catch and effort in any given year. A knowledge of the effect of environmental factors on distribution of fish in a given area would undoubtedly provide advice on closed areas and seasons more appropriate to optimizing benefits from the fishery, or if varability is known to be high, cast doubt on the wisdom of this approach to solving the problem at hand. Conversely, advice to vary closed areas/seasons annually may even be possible.

(b) Effects on Regulation and on Conduct of Fishing.

From the point of view of the fishing fleets, environmental variations can, as is well known, greatly affect fishing success in any particular season. Fishermen are, on the whole, well aware of variations in fishing success on the grounds they frequent and no doubt give this some weight in their fishing strategy, both short and long-term. While they may well wish to know why these variations occur, it is doubtful whether this knowledge would affect their planning, unless it provided them with a predictive ability. Historically, fishing success centred around the ability of fishermen to concentrate on high density aggregrations of fish. While this remains an important element of fishing, comprehensive governmental control of quantities caught has introduced some new elements. For mobile fleets at least, high catch rates increase the speed with which allocations are taken but need not confer a direct benefit in terms of total volume caught. Indeed, there could be disbenefits in terms of reduced fish quality and from the costs of lying idle part of the year when all allocations are taken. Thus for mobile fleets, while foreknowledge is no doubt an advantage, benefits from predicting variability in annual density (other than that arising from stock abundance trends which are predicted through the stock assessment process) are not as clearly obvious as they once appeared to be.

In the case of highly specialised fisheries, particularly fixed gear coastal fisheries, the benefits of predictability are more obvious. If it was known, for example, that the 2J3KL cod trap fishery would be a failure due to adverse hydrographic conditions, important savings could be made by not investing in gear, or by investing in alternate gears such as gillnets or longlines which are more likely to yield economic returns, and associated shore-based processing facilities could direct attention to alternate sources of supply. Coastal fixed gear fisheries are important throughout much of the Convention Area, the primary species being cod followed by herring. Mackerel and haddock fixed gear fisheries are only of relatively local importance. Thus, it would appear that a forecasting service could be of practical importance, particularly for the large scale fixed gear fishery for cod in the northern part of the Area. Feasibility would depend on identifying factors which are relatively inexpensive to monitor while giving predictive ability over a geographic area sufficiently large to encompass a major proportion of the fishery.

The trends toward increasing management intervention over the last 10 years has created another set of problems where the effect of environment on variability in catchability coefficient (q) is important to deciding on management strategies. The basic approach to fisheries management in the NAFO Area has been to control exploitation rate at a fixed "optimal" level. Chosing TAC regulation as the primary control relegates catchability problems to a secondary consideration for, as was pointed out to ICNAF at an early stage (ICNAF, 1973), "The main advantage of catch quotas is that accuracy [in control of fishing mortality] is independent of variations in the catchability coefficient. But the setting of catch quotas is sensitive to fluctuations in recruitment. Fishing effort quotas are not sensitive to fluctuations in recruitment, but they are sensitive to variations in catchability." In that (substantial) part of the NAFO Area controlled by Canada, direct, although crude, fishing effort controls are imposed through the licencing system for both domestic and foreign fleets. In this context, variation in catchability has some importance. The catch allocation process, particularly among fleet sectors which are restricted to area and season of operation, can also exacerbate problems caused by annual variations in the fishing effort versus fishing mortality relationship.

In the case of foreign fleets, Canadian regulatory control uses fishing effort limitation as a failsafe mechanism for the primary control of F through catch limitation. This is dependent for its success, as are national fleet deployment strategies, on low variance in q. The extent to which variation in q presents a problem to the present approach could be quite readily evaluated by retrospective analysis of consistency in catch and effort allocations. The practical importance of such problems could then be assessed and hence the importance of investigating environmental influences on q evaluated.

Fleet sectors restricted as to area and season of operation are typically coastal small boat fleets. These tend to be particularly vulnerable to minor variations in migration routes and locations of fish concentrations. Basically, when the scale of management unit is reduced by sub-allocation to small fishery sectors operating in a localised area in a short season, the importance of annual variability in distribution of stock density is amplified. Success of a "deterministic" approach to resource allocation is dependent on the amount of variance in the system being small. A management approach incorporating more opportunistic elements could prove more effective when working on a regulatory scale which is small in relation to the stock area being managed. This can, however, also be a problem on a large scale, and the 2J3KL inshore cod trap fishery again provides a good example. Management concerns in relation to this kind of allocation problem relate to equity among competing fisheries sectors and to full resource utilization, but in the case of such a large scale problem as 2J3KL cod many other factors become relevent considerations such as seasonal/spatial distribution of supply, product quality, and marketing. These arguements confirm that development of a predictive ability for the effects of environment on availability of cod to inshore gears in the northern part of the Area could be cost-effective.

Other regulatory measures which require consideration are season/area closures. Biological reasons for instituting such closures are to protect juveniles or spawning adults from direct fishing or to reduce by-catch problems. Examples of each are the closure of areas of the Bay of Fundy to purse seiners to reduce their catches of juvenile herring, closures of parts of Browns Bank and Subarea 5 to protect spawning haddock, and the SMGL on the Scotian Shelf to reduce by-catches in small-mesh fisheries. Inevitably such regulations are trade-offs aimed at largely attaining their objectives while not greatly imparing performance of directed fisheries. Presumably, the criterion to be used in establishing such a regulation is that the expected benefits out weigh the immediate costs. To date, closed area/seasons have been fixed from year to year and reflect average distribution patterns. Extreme variations in distribution could make this kind of regulation impractical. In the case where the protected species/life history stage is contained within a relatively small season/area box, there is not likely to be severe impairment of fisheries for other species/life history stages in the much larger area outside it, at least in the context of full resource utilization, although fishing efficiency could be reduced. The question then relates to whether a sufficient proportion of the protected entity occurs within the box sufficiently often to meet objectives. In the case where the box (usually in this case termed the "window") contains the directed fishery, as for the SMGL, emphasis tends to be on impairment of directed fisheries, as relatively small changes in environmental conditions could produce major shifts of biomass into/out of a small geographic area. Conversely, the likelihood of a high proportion of a by-catch species being distributed with the window is not great.

In the present NAFO context, the Scotian Shelf SMGL is the only closed area/season regulation of the "window" type. Although a Canadian regulation, it was inherited from ICNAF and affects the fisheries of several countries and, as well, it has been the subject of cooperative international research since its inception in 1977. It is located adjacent to spawning areas for several major gadoid stocks (e.g. O'Boyle et al., op. cit.) and to a haddock nursery area (McCracken, 1965). The relative importance of problems created for fisheries management by environmentally induced distributional variation could usefully be assessed using the SMGL problems as an example for this class.

Stock Level

The importance of manageing on a unit stock basis is so thoroughly engrained in the fisheries biologists' philosophy that it perhaps receives less thought than it deserves. The importance of conducting assessments on a unit stock basis is a different, although related, question which tends to be more thoroughly examined. When it is realised that the management areas in use today are very largely permutations and combinations of areas defined about 1950 (which bear relation to areas defined as early as 1930), before much of what we now know about stock structures was elucidated, one could perhaps be forgiven for wondering whether exact boundaries are critical for managment purposes. Looked at another way, if the objective were to manage cod, say, at $F_{0.1} = 0.20$ throughout much of the Northwest Atlantic, does it matter if the management boundaries are in the "right" place. Subdivision of this large area distributes fishing over stocks and facilitates allocation but would arbitrary lines serve just as well? Admittedly, the importance of having the "right" boundaries increases when different policies are to be persued for different stocks. If, for example, a stock of low abundance requiring complete protection lies next to one being fished at $F_{0.1}$, both objectives will be more likely to be achieved if the division between them is a good approximation to the stock boundary. Nonetheless, given our investment in data collection amalgamated on the basis of present statistical areas (stock areas, management areas), we are in many regards victims of historical decisions. The fact of the matter is that adoption of new boundary lines for stock assessment and management (other than a reshuffling of existing statistical areas) would only be countenanced if it was clear that management objectives could not be achieved with present boundaries.

For a cod biologist the arguement could, perhaps, stop there. A herring biologist would be less satisfied. The multi-stock composition of herring within management units, concentration of fisheries on mixed-stock aggregations, sometimes with components from separate management units, and the almost uniformly poor response of herring populations to 10 years of management efforts, provide bases for doubt that management is scaled and packaged appropriately in relation to stock structure. A redfish biologist should not be too satisfied either. We have no clear concept of what constitutes a redfish stock. Our managment approach, to the extent that it is more than a convenience, is based on discontinuities in commercial fishery distributions. The same remarks can be made for essentially all deeper-water groundfish and many of the major invertebrate species. It is not obvious that the classic concept of stock distributions and migrations in relation to ocean current patterns is generally applicable.

The point of this extensive dissertation is that understanding the factors responsible for stock formation (or rather, for restrictions in gene flow), which involves the influence of environment on all life-history stages, requires more than the application of present stock separation techniques (tagging, biochemistry, etc.). The result of understanding the causal factors in stock formation may have little practical utility for the well studied cod and haddock around which much of the northwest Atlantic management system has been arranged. It could allow development of new approaches to management of other species for which present arrangements are not producing demonstrably satisfactory results.

In the next section we discuss environment in relation to species distribution. In that context a knowledge of the association between oceanographic systems and stock units would be the basis of predictive ability in relation to climatic change. It is the recruitment process which is most sensitive to environmental change and response to climatic change will be most immediately and obviously reflected in recruitment trends to geographically marginal stocks.

Species Level

Environmental factors affect the distribution and abundance of species at the extremes of their ranges. Species may exist in high (low) abundance at these extremes for varying periods of time but with large scale climatic changes, abundance levels may decline (increase) dramatically for a subsequent period, only to return to former levels with another climatic change. For example, cod were most abundant at West Greenland during the periods 1845-1851, and 1920-mid 1960s but were very scarce during the intervening period. They have been declining from the late 1960s until the present, when they are once again very scarce. Also, some species at the extremes of their range show wide fluctuations in recruitment as a matter of course (e.g. herring in East Newfoundland), with the majority of year-classes being very poor in relation to the occasional large year-class. This, of course, leads to long periods of declining resource abundance followed by sudden upswings. Similarly, squid exhibit marked fluctuations in abundance, periods of high abundance usually followed by periods of low abundance, although exceptions to this do occur. It is highly likely that such fluctuations are influenced by environmental factors and indeed this has been well documented for West Greenland cod (Hansen and Herman, 1965).

An understanding of these changes at the species level and the role of the environment in determining abundance levels at the extremes of areas of distribution may enable fisheries biologists to predict periods of high and low abundance in these areas. Knowledge of the impending decline of a resource in an area due to changing environment may dictate a different fishing strategy than if that resource were declining due to fishing pressure, perhaps leading to a strategy of uncontrolled fishing with the knowledge that environment, not parent stock, is the controlling factor.

So far we have discussed natural environmental factors and their effects on species distributions, but there are man-made influences which also deserve mention. Nutrient flux onto the Labrador Shelf from Hudson Strait has been proposed as a determinant of fish distributions along the Shelf (Sutcliffe et al., 1983). The amount of freshwater outflow from Hudson Bay, through its effect on mixing and the availability of nutrients in surface layers, is suggested as a mechanism controlling production, including fish production. To quote Sutcliffe et al., "The apparent importance of the freshwater discharge indicates possible effects on the fisheries production along the Labrador Shelf by large hydroelectric development schemes on the watersheds adjacent to Hudson Bay."

Runoff regulation for hydro-power in the Gulf of St. Lawrence river system has caused significant changes in the physics and dynamics of waters of the St. Lawrence Estuary and Gulf (Neu, 1976) and the oceanographic effects of variation in runoff have been traced as far as the Gulf of Maine (Sutcliffe et al., 1976). Neu estimates that spring and summer runoff at the entrance to the Gulf of St. Lawrence (of the St. Lawrence river system) has been reduced by between one-third and one-half by hydro-development. Substantial biological effects have been postulated as arising from such variations from the Gulf of St. Lawrence (Sutcliffe, 1973) to as far afield as the Gulf of Maine (Sutcliffe et al., 1977). The effects of freshwater runoff on the marine environment in the Gulf of St. Lawrence has most recently been reviewed by Bugden et al. (1982) and recommendations for further research have been formulated.

The harnessing of tidal power in the Bay of Fundy, which has one of the highest tides in the world, has been under periodic consideration since the 1920s. This has been brought closer to reality with the recent completion of a pilot barrage. Numerical models have predicted that building a barrage across the mouth of the Minas Basin in the upper Bay of Fundy, a likely commercial site, would increase the range of tides at Boston by 30 cm and over Georges Bank by up to 5 cm (Greenberg, 1979). It would thus seem likely that such a construction would affect the oceanography on the scale of the whole Gulf of Maine region and have substantial effects on many of the fisheries resources of the area.

Species distributional changes are, by definition, the result of large-scale climatic or man-made effects. Their impacts are also large-scale. There will be specific practical fisheries assessment and management problems with which knowledge of environmental effects on this scale would aid in dealing. It would aid the assessment of 2J3KL cod if we were aware that our expectations of recruitment should not be the historical long-term average of 500 million fish at age 4 which was used until last year (NAFO Scientific Council Reports). It would have been of benefit to STACRES of ICNAF to have known the role of climate versus fishing in the decline of recruitment to West Greenland cod, and advice may have been more clear-cut. The greatest benefits of this kind of knowledge, however, lie in guidance provided concerning long-term expectations and the use of these in investment decisions. The 2J3KL cod stock, for example, is so large that projections of future yield of cod in the whole Canadian zone are dominated by it. Longer-term expections for this one stock are pivotal in development of Canadian economic and social policy in relation to its Atlantic marine fisheries (Kirby, 1982).

Nothing more need be said about the use of indicator species in environmental monitoring. It is a tool, the value of which can be judged in relation to the importance of the problems which it can be used to address.

CONCLUSIONS

In the above sections, we have concentrated on defining broad problem areas in relation to this general topic and evaluating the practical importance of these problems to fisheries management in the Northwest Atlantic, using examples only to illustrate specific points. We have not attempted to develop an exhaustive list of specific problems within these areas, nor have we attempted to address the tractability of any of the problems discussed, choosing rather to first define such problems which we consider important and address the tractability of such problems at a later stage. In fact, we felt inadequate as biologists in isolation from other disciplines to address either the tractability of the problems or the resource levels necessary to mount programs to solve the tractable problems. We feel this to be a function of the present meeting.

However, at the risk of stating the obvious, we would like to make some general observations. At the one extreme, problems can be critically important but completely intractable while at the other extreme, problems can be easily tractable but completely irrelevant to stated objectives. Between these two extremes are problems with gradients of tractability and relevance. Therefore, it is necessary to rank problems according to their importance, annotate them as tractable or intractable and select the highest priority problems which are considered tractable. This may prevent us from selecting problems which are critically important but which subsequently prove intractable but rather ensure that we select tractable problems which are still of importance. We would suggest that in the past ICNAF (and latterly NAFO) selected undoubtedly the most important problem to fisheries management of this decade in the form of factors affecting year-class size (Flemish Cap Project, Larval Herring Project), but, as the Scientific Council recognised at its September 1983 meeting, this has proven thus far to be intractable. Even though this still remains the overriding problem, we understand the purpose of the present meeting to be selection of a problem which, although perhaps considered less important to the work of the Council, is considered to be tractable. It would still be wise to consider, before going further, the relative importance of the most tractable aspects of the major classes of environmental influence on fish stocks. In other words, some aspects of recruitment problems may still be more attractive research targets than distributional problems.

As a final note, once the Council has selected a problem or problems which are considered important and tractable, has defined the level of resources necessary to solve these problems, and has achieved support among the members of the Council, a commitment to provide these resources for the time frames suggested must be secured in writing from at least the National Laboratory Director level before the field data collection phase of work towards solution of such problems is attempted.

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