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The Biological Management of Australia's Multispecies Tropical Demersal Fisheries: A Review of Problems and some Approaches

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THE BIOLOGICAL MANAGEMENT OF AUSTRALIA'S MULTISPECIES TROPICAL DEMERSAL FISHERIES: A REVIEW OF PROBLEMS AND SOME APPROACHES

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Abstract

Declaration of a 200 n. mile fisheries management zone gave Australia the responsibility to manage the exploitation of demersal fish stocks inhabiting the broad continental shelf of tropical Australia.

Tropical demersal fisheries have three pronounced attributes which lead to difficulty in their biological management; (1) a large number of species are exploited, (2) there are biological interactions between species and (3) the additional mortality imposed by the fishery is not equal for all species and is influenced by fishermen behaviour. The implications of each attribute to biological management of the tropical fisheries are examined.

It is concluded that currently available methods are inadequate to resolve many of the questions arising from management of Australia's tropical demersal fish resources; particularly questions requiring prediction of the species mix under widely differing fishing regimes. Research directions are indicated which would overcome some of these difficulties. In particular an experimental management approach is suggested, utilizing part of the area occupied by the existing fishery, to both empirically test some fishery development options and provide the opportunity of evaluating some assumptions of available multi-species fishery models.

INTRODUCTION

Australia's declaration of a 200 nautical mile fisheries management zone on 1 November 1979 brought a large area of ocean under Australia's control (Fig. 1), stimulating the interests of both foreign and local fishing industries.

Many requests to fish the Australian fishing zone (AFZ) resulted, some involving the deployment of fleets with substantial fishing poer, highlighting the management responsibility implicit in the declaration of an extended fishing zone (Lauterpacht 1978). Generally the continental shelf around Australia is narrow (Fig. 1) and productivity is low (Tranter 1962), so that the opportunity for a greatly increased demersal fishery is limited. In addition the demersal stocks (those on or near the seabed) on most of Australia's continental shelf are already substantially utilized by the Australian fishing industry (Allen 1978), and so new operations are mostly restricted to previously underexploited pelagic fish, squid and deep (>200m) demersal resources.

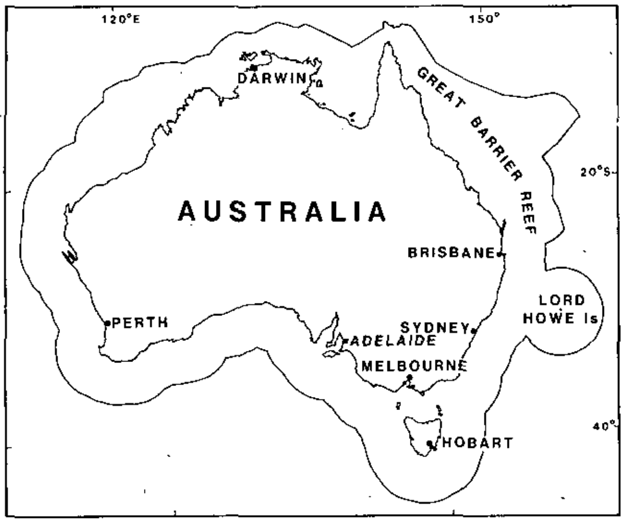

Figure 1.

The extent of the Australian Fishing Zone declared on 1 November 1979. The 200 m depth contour indicates the approximate extent of the continental shelf.

An exception to these general statements, however, is provided by the northern coastline of Australia. In this region the continental shelf is wide (over 300 n. miles in some places, Fig. 1), the waters are productive (Kabanova 1968; Motoda *et al.* 1978) and except for the prawn fishery there has been little fishing by Australians. There has, however, been a significant Taiwanese fishery in the region (Liu *et al.* 1978), which has yielded an average of 53 531 tonnes per year between 1972 and 1978. (The average annual Australian catch of trawl fish throughout the country during the same period was 59 490 tonnes.) Under the new legislation this and any additional fishing operations must be managed by Australia.

There are several fishing operations which could occur on Australia's tropical demersal stocks, ranging from fully foreign operations, *through various forms of joint* arrangement, to a fully Australian operation. Determining what types of operation are economically viable and the option resulting in greatest overall benefit to Australia is a complex task involving many factors. Management should also try to ensure that current fishing activities do not compromise future resource use options.

Examination of these questions and subsequent management of whatever option is judged desirable requires that reliable predictions can be made concerning the exploited fish community. Fundamental among these is prediction of the catch and catch rate of the major species of the community under different fishing regimes. This in turn requires *prediction of the effects of fishing* on species abundance.

Answering these questions poses many theoretical and practical problems, due mainly to the multispecies nature of the resource. The aim of this article is to (i) outline some of the characteristics of tropical demersal fisheries and the problems they introduce to analysis and management, and (ii) indicate research activities CSIRO could initiate in an attempt to derive a suitable strategy for the management of Australia's tropical trawl fisheries.

Charactertistics of tropical demersal fisheries

Tropical demersal fisheries have three important charactertistics, not entirely distinct, which lead to difficulty in their biological management. These are

(1) a large number of species are being exploited,
(2) biological interactions *e.g.* ecology and population parameters (rates of growth, death and birth) of any given species are influenced by other species in the community, and
(3) technological interactions *e.g.* fishing effort simultaneously imposes an additional, and not necessarily equal, mortality on many species which may vary as the fleet alters its activities.

These features are not unique to tropical systems: they occur to some degree in virtually all demersal trawl fisheries. Rather, each is encountered in a more extreme form in tropical systems. The Indo-Pacific fish fauna is the most diverse in the world, comprising six to seven thousand species (Carcasson 1977). It is suggested that biological processes play a larger role in the regulation of tropical communities than temperate ones (*e.g.* Sanders 1969). The fish apparently exist in schools which are small relative to those formed by most temperate demersal fish, so that, despite attempts at targeting, many species are caught each trawl.

Examining each feature in turn:

(1) The large number of species

The fishery operates on an extremly diverse fauna whose field identification is often very difficult. Because of the difficulty of identification and the sheer number of species involved (CSIRO surveys on the North West Shelf of Australia have resulted in over 70 fish species per one hour trawl) commercial operators cannot identify all the species in the catch and so cannot provide species specific information in their fishing logs. This leads to extensive 'lumping' of species in the fisheries statistics, resulting in an absence of data on one of the basic items required for analysis of a fishery by currently available techniques - the quantity of each species removed from its population. If the commercial catch statistics are available for species groups rather than for species the problem facing management and research immediately departs from that dealt with by 'classical' fisheries dynamics in which the individual species is the basic unit to which model structure and parameter definitions relate.

The often urgent need for management guidelines has, however, resulted in models designed for single species being applied to species groups, and even to the exploited community as a whole (*e.g.* Gulland 1968; Liu *et al.* 1978). The validity of the assumptions and concepts of the models has not been closely examined with respect to this new role, and even the interpretation of estimated parameter values is unclear (see Horwood 1976). The application of single species models in such circumstances must be regarded as an empirical use of essentially arbitrary equations. In particular the models lose any predictive value in extrapolation which they may have had.

A further key implication of combined species catch data is that the resulting time series cannot be used in future to test any models of the biological system involving the behaviour of components defined at a lower taxonomic level than those used to generate the data set. With our current understanding of community dynamics, this may well be one of the most valuable uses for such data, so every effort must be made to provide detailed catch data, even though the effort required may be great.

The high diversity of tropical demersal communities may have other implications, fundamental from an ecologist's point of view, for the yield characteristics of tropical fisheries and the response of the community to exploitation. The questions of how and why tropical communities exhibit and maintain a high species diversity have yet to be satisfactorily resolved, but the answers are important to management. Suggested reasons for this high diversity include (i) high levels of ability of predators to preferentially reduce prey population which start to become large ('prey suitability') and might otherwise exclude competitor species (Paine 1966; Glasser 1979;

Teranoto *et al.* 1979); (ii) intense biological competition (Dobzhansky 1950; MacArthur and Levins 1967) and the form this competition takes (Roughgarden 1974; Glasser 1978, 1979); (iii) a comparatively high predictability in the physical environment (Sandars 1968; Slobodkin and Sanders 1969); (iv) a high rate of productivity (Connell and Orias 1964); (v) the length of time available for the evolution of complex communities (Simpson 1964); and (vi) spatial and/or temporal heterogeneity preventing the achievement of 'global' equilibrium (Whittaker and Levin 1977; Sale 1978). Some of the suggestions are mutually compatible, while others appear contradictory. None is unanimously accepted by ecologists as the complete answer.

Besides being of ecological interest, the mechanism invoked has great bearing on the form of species interaction models, and different hypotheses generate quite different management implications. This may be illustrated by elaborating on suggestions (i) and (ii) above for two trophic levels (predators and prey). In an unfished community under (i) predators are food limited and exert a high predation pressure (with prey switching) on prey populations. This results in low competition for resources (*e.g.* food or space) between prey species because the population of each prey species is kept below the limit set by prey resource availability, leaving a surplus of resources. Under (ii) predator population are again food limited but competition between prey is intense and provides the major limitation on prey size. Both possibilities can imply narrow ecological niches for prey species in the unfished situation, the first through optimal foraging considerations (Pyke *et al.* 1977) and the second through the competition exclusion hypothesis (see Levin 1968, Chapter 5). With low environmental variability and sufficient time it appears that either could result in high species diversities (see Glasser 1979 and Sanders 1968, respectively). Systems operating under the two conditions would respond quite differently to fishing, particularly, as is often the case, if predators are harvested preferentially. In the first situation the prey populations could escape predator control and reach resource limitation, at which point competition could generate considerable alteration of community structure. The second case would be largely unaffected by predator removal. It remains to put these hypotheses, or some implications of them, into a form which is testable using data which can be collected from a fish community living on a continental shelf. To date this difficulty has not been resolved.

(2) Biological interations

There are several instances of the influence of biological interactions on the management of fisheries. Perhaps one of the best known is that of the Californian sardine and northern anchovy (Murphy 1977) in which the anchovy population increased and apparently utlized most of the resources formerly used by the sardine population as the sardine population was reduced by the fishery. The situation has not yet reverted to its initial state despite a considerably reduced catch of sardine.

Another illustration may be taken from the Peruvian anchovy, this time involving predators rather than competitors (Murphy 1972, 1977). Indeed, this example indicates that the conceptual basis for one of the most commonly used models in fisheries management is inappropriate to prey species. The model may be summarized as follows. The stock-production model of Schaefer (1954) predicts a parabolic relationship between catch and fishing effort on the assumption that the rate of increase of population biomass is related to the current population biomass by a parabolic curve. Rate of increase of biomass is zero for a zero population and at the unexploited equilibrium population level, and is maximal at a biomass half way between. It is held that a fishery yield is obtained by reducing the population biomass from its unexploited level, thereby increasing production which provides the steady-state harvest (sustainable yield). This is simply described as:

$$\frac{1}{P}\frac{dP}{dt} = a - bP - qE \qquad (1)$$

where P is the biomass of the species, E is the fishing effort, a and b determine (empirically) the stock-production characteristics of the species and q is the catchability coefficient (the proportion of the population removed by a unit of fishing effort). Steady-state conditions occur at $\frac{dP}{dt} = 0$, and at that equilibrium biomass (P^*) for a given level of fishing effort (E^*), the catch is given by qE^*P^*. Returning to the example of Peruvian anchovy, both the yield to the fishery alone and the total quantity of anchovy removed by combined fishing and natural predation are shown in Fig. 2. The total withdrawals curve indicates that in the unfished situation the species was already providing close to its maximum sustainable yield to predator populations, and with the addition of a fishery the stock was taken well below the point of maximum production.

Interestingly, the 'stock-production' relationship based on the fishery data alone followed the expected pattern during this time (total catch increasing asymtotically with increasing effort, somewhat like the left hand limb of a parabola) and

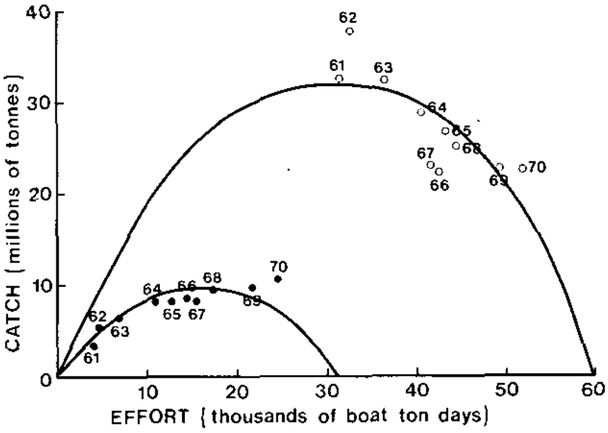

Figure 2.

The stock-production curves for Peruvian anchovy. The closed circles show fishery removals alone, while the open circles include the yield of anchovy to the fishery and any other predators (birds and fish). (After Murphy 1972).

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suggested that catches were in the region of the maximum sustainable yield (Fig. 2). The fishery data gave no indication that the total production of the stock was declining along the relatively unstable right hand limb of the curve, indicated by the total withdrawls data of Fig. 2 and in 1971 the anchovy population abruptly collapsed. The catch-effort relationship for the fishery data shown in Fig. 2 clearly did not originate solely from the stock-production relationship central to Schaefer's model (although that relationship, or at least one limb of it, is broadly indicated by the total withdrawls curve of Fig. 2). Rather, it is likely that the fishery yield-effort relationship largely reflects the dynamics of various anchovy predators as they are displaced by the fishery and move toward new equilibria. Other interpretations are possible, but behaviour of the type described is to be expected whenever a prey species is harvested, or a predator and its prey are harvested simultaneously, and is well illustrated in the whale-krill fishery model provided by May *et al.* (1979).

Examination of the composition of the demersal fish community of the Gulf of Thailand during development of the fishery there (Pope 1979; Pauly 1979) indicates that different groups of fish have declined at different rates, and that the abundance of some (notably squid) have actually increased with fishing pressure. Pauly's (1979) analysis indicates that the rate of reduction is correlated with the broad trophic level of the species in question with small, shortlived 'prey species' showing the greatest rate of reduction, at least over the period covered by the data. Unambiguous interpretation of these changes cannot be made without data on the activities of the fishery during the period, since those groups showing a faster decline may have simply been subject to more fishing pressure. However, one of a number of possibilities is that biological interactions such as altered predation pressure or intensity of competition at the reduced population densities generated the different responses.

Optimal management of the resource depends upon the ability to predict alterations in species composition and yields under different possible management strategies, so that a strategy may be chosen which will maintain the exploited community at a satisfactory level of fish density with the desired mix of species. This goal is still distant however, and the guidelines emerging from examination of current, very simple models of species interactions are tentative.

Probably the simpliest approach to modelling interacting speices is given by an extension of the Schaefer model mentioned earlier to give

$$\frac{1}{P}\frac{dP}{dt} = a_1 - b_1P - c_1Q - q_1E$$
$$\frac{1}{Q}\frac{dQ}{dt} = a_2 - b_2Q - c_2P - q_2E \qquad (2)$$

where P and Q are the population sizes of two interacting species. The b's measure intraspecific competition, while the c's measure interspecific competition, and any number of species may be included, with additional c terms relating each species pair. If both c_1 and c_2 are positive the two species are competitors, while if c_1 and c_2 are of opposite sign, one species (that with a negative c) is a predator of the other. While the difficulty of parameter estimation greatly reduces the utility of this model in any practical example involving several species, the equation set has been used to obtain a general idea of possible system behaviour. For example it can be shown (Pope 1979; Anon 1978) that provided the catchability of each stock does not alter (so that whatever the fishing effort, fishing mortalities on the various species remain in the same proportion) and the structure of the system is maintained (*i.e.* no species disappear or appear and all interactions remain quantitatively the same over time and population density, ensuring that the constants in the equation do in fact remain constant) then the yield curve for the whole community is parabolic with its maximum at half the virgin community density. Under the above assumptions this occurs when the sum of the catch per unit effort of all species is half that obtained from the virgin community. However, the observed maximum will be the maximum possible yield from the system only for a particular set of species catchabilities, and for other sets a different yield parabola will be traversed which will provide an under-estimate of the 'global' maximum sustainable yield. It also follows from this equation set that the strategy of reducing the stock size of each species to about half of its virgin level (irrespective of the relationship between catchabilities by providing all interactions remain quantitatively the same through time) will often result in close to the global maximum yield (Pope 1979). This argument is most reliable when interactions are weak, becoming less reliable as interactions become stronger and is least satisfactory when dealing with predator-prey systems. Examination of this simple interaction model also indicates that the yield obtainable from interacting stocks would be less than that which could be obtained if they did not interact.

These results may provide useful guidelines for management, and are somewhat comforting in that they suggest the simple strategy of fishing to the level of about half the virgin community biomass will provide close to the maximum yield. This is consistent with the 'half community biomass rule' of Gulland (1968) in that the maximum yield is approximately where predicted, but leaves unanswered questions on the magnitude and species composition of the yield. The yield obtainable from a group of species exhibiting even the simple form of interaction indicated by (2) is highly dependent upon the signs and sizes of the various coefficients and gives no indication that Gulland's (1968) approximation, maximum sustainable yield $\simeq \frac{1}{2} MB_o$ (M = an 'overall' natural mortality rate, B_o = virgin community biomass), is necessarily valid.

Further difficulty lies with the validity of the interaction model given by Eq. 2. For example competition coefficients (the c terms in Eq. 2) are known to vary with the physical environment and the size of the various interacting populations (Levins 1968). Prey switching, threshold responses, time lags and prey refuges are certainly a part of predator-prey systems in nature, and their presence is known to alter the behaviour of the system from that predicted by the simple equation set (Holling 1959, 1973; Steele 1974; Rozenzweig 1977; Glasser 1979; Teranoto *et al.* 1979). Since such effects have been suggested as possible causes of the high species diversity observed in the tropics, it is likely that the simple species interaction model ignores whole classes of mechanisms which play an important role in the dynamics of the community.

Shirakirhara and Tanaka (1978) have examined the behaviour of a model involving higher level interactions (*i.e.* more than the simple cross products of Eq. 2), chosen to broadly represent competition between the Japanese mackerel (*Scomber japonicus*) and the Pacific saury (*Cololabis saira*). The model exhibits multiple stable states, each at a different relative abundance of species and indicates that transition from one equilibrium state to another under the influence of a fishery may be very abrupt. The yield characteristics of their model illustrate another potential difficulty in the management of stocks with complex interactions. The yield contours (yield as a function of fishing mortality on each of the two species) for species exhibiting the simple interactions of Eq. 2 are eliptical around the maximum yield (Pope 1979) and for a wide range of catchability ratios between species the catch will decrease as a boundary of the mixed fishery region (beyond which one of the species will collapse) is approached, so affording some warning. In the model examined by Shirakihara and Tanaka (1978) yield contours are no longer eliptical and catches can increase with increasing effort right up to the point of abrupt collapse of one species and movement of the system to another equilibrium state. That natural communities have multiple stable states is generally accepted in ecology (Sutherland 1974; Holling 1973) which implies that the simple cross product interaction model of Eq. 2, which does not exhibit this feature, is substantially incomplete.

(3) Technological interactions

Tropical demersal fish are apparently highly dispersed across their habitat. On the North West Shelf of Australia this is implied by the large number of species caught in single trawl samples and a simultaneous rarity of demersal school signals on echosounder traces, and borne out by a recent survey using underwater closed-circuit television. Consequently the fishery is to a large extent indiscriminate, simultaneously applying a fishing mortality on many members of the community; predators, prey and competitors alike. This suggests the need for a multispecies approach to management, even if only a few species are of commercial interest.

However, the various species are distributed differently in that they have different preferences for water depth, bottom types etc., so that fishermen can and do alter their catch rates of the different species by altering the area and time of operation and the details of their fishing gear. Some of the management implications of species interactions given in the previous section (particularly those regarding behaviour of a system following Eq.2) assumed a constant catchability through time for each species. While this assumption may be acceptable in some cases it must also be recognized that relatively subtle alterations in the commercial fishery can generate changing relationships of fishing mortality and apparent abundance (as measured by catch per unit effort). That this has occurred on the North West Shelf of Australia can be seen from examination of the Taiwanese catch data for certain species groups. These data, relating to lethrinids, nemipterids and small shark (mainly *Loxodon, Rhizoprion* and small *Carcharhinus* species) in particular, show marked changes in catch rate (which under the assumption of constant catchability is proportional to population size) over a period of one to three years, despite the fact that most of these fish have a much longer life span than this. It is likely that these data reflect alterations in fishing activities, resulting in changing catchability coefficients and fishing mortalities. If fishery data alone are available, these apparent changes in abundance are indistinguishable from those caused by real changes in the community's composition. It is only sudden and biologically unlikely changes in catch rate which arouse suspicion, although the same influences may be present to a significant degree in apparently 'well behaved' data. For example the approximate effect of the North West Shelf fishery changing its area of operation from 80-120m depth to 40-80m on the fishing mortalities exerted on lethrinids and nemipterids may be examined. The deep depth range contains about 0.5 of the lethrinid and 0.1 of the nemipterid fishable populations, while the shallower ground contains about 0.5 of the lethrinid and 0.8 of the nemipterid population (Sainsbury 1979). If vulnerability to the fishing gear remains constant and is equal for the two species groups then the relative fishing mortality is given by the ratios of these population proportions. In the shallow zone any fishing mortality in nemipterids is about 1.5 times that on lethrinids, while in the deeper zone the fishing mortality on lethrinids is five times that on nemipterids. There is obviously the potential in just this one factor to generate quite large changes in the relative mortality and catch rate of different stocks from quite small changes in depth allocation of fishing effort.

Access to commercial data only is unsatisfactory for the detection of changes in community composition or of biological interactions because changes in catchability can generate patterns similar to those being searched for which cannot be isolated using that data set alone. The problem compounds if several types of fishing operation are simultaneously exploiting the same fish community. Research survey data, collected on a strict sampling basis, can measure changes in species abundance. However analysis of research survey data alone for the influence of biological interactions may also be quite misleading, in that the effects of biological interactions cannot be distinguished from the effects of changes in fishing mortality (as for example in Pauly's (1979) analysis of the Gulf of Thailand data). Progress can be made only if both types of data, commercial and research survey, are available. Even with the concentration of biological research mounted in the North Sea over past decades multispecies analysis is severly restricted by a lack of appropriate data, particularly fishing mortalities and relative stock sizes for species when they were not specific fishery targets (see Anderson and Ursin 1978; Hempel 1978). The combination of commercial catch data, including adequate knowledge of the composition of the discarded component, and of research data is an essential first step in overcoming these problems. At the very least these data would allow the assumption of constant catchability to be examined.

Research Directions

Current models of biological systems are inadequate in that they cannot be used with confidence to guide management of an exploited fish community. This is particularly true of Australia's tropical marine resources, where management questions concern more than just the total biomass which may be removed, irrespective of species composition (an aim implicit in the yield calculations of Liu *et al.* (1978) for tropical Australian waters). Selection and subsequent management of the exploitation strategy providing most benefit to Australia requires knowledge of the abundances and catch rates of the various species under different fishing regimes. This is the area of greatest weakness of currently available models.

In approaching the problem, four main areas of difficulty emerge:

(1) Collection of reliable data on the species composition of the community and of the commercial catch.

(2) Development of a reasonable understanding of the biology of the species involved.

(3) Quick and reliable formulation of advice on some of the most pressing management questions (*e.g.* is a fully or part Australian operation likely to be viable?).

(4) Critical evaluation of currently available community models, and development of more appropriate models if necessary.

The first two problems are reasonably familiar from the 'single species' approach to fisheries study, although their difficulty is increased when dealing with tropical systems, and work under these headings is already in progress.

In terms of the data from the commercial fisheries, the total fishing effort and catch by broad commercial category (basically along family lines) from all vessels is being collected using a logbook system. In addition observers will periodically be placed on the vessels to obtain, on a sampling basis, a species breakdown for each of the commercial categories and the discarded ('trash') component of the catch. This is an exacting task, requiring well trained and highly mobile observers. It is crucial that accurate fishery withdrawals data be available, as biased methods of reporting and calculating landings can generate apparently meaningful, but quite misleading, trends.

The intensity of research vessel sampling required to provide reasonably precise estimates of population abundances at any point in time is considerable. Data from the North West Shelf indicate that about 200 trawl samples would allow estimation of most population abundances to within ±30%. In addition to a regular annual survey of at least this intensity, many of the parallel biological studies would require more frequent sampling. Much of the scientific value of the collected data lies in its use as a time series, and this places great demands upon consistency of research vessel operation. Considerable care would be necessary to ensure that avoidable alterations in sampling procedure do not compromise this usage. In addition to ensuring (as far as possible) that the catchability coefficients for the research vessel remain constant, it is highly desirable that the value of this coefficient be estimated by separate experiments.

Concurrent with collection of this species abundance data, studies must rectify an alarming lack of knowledge concerning the biology of tropical Australian continental shelf fishes. At present many cannot even be identified consistently. Basic items in need of attention include taxonomy, life history descriptions and estimates of the current population parameters (rates of reproduction, growth and mortality), for at least the more abundant species.

Problems 3 and 4 are more difficult, but interestingly seem to necessitate very similar action, at least initially. Both require a form of large scale experimentation. Problem 3 is the need for management guidance on a more immediate time scale than that imposed by ecological research. Management of the existing fishery should develop by (a) cautious application of the existing models (with the inclusion of large safety factors), and (b) implementation of an experimental fishery management policy to provide empirical data on the commercially important features of the fish communities response to a changed fishing regime. To evaluate the fully foreign, part Australian and fully Australian fishery options mentioned earlier, the information needed includes the species composition and catch rate obtained under different intensities of exploitation. Fishing intensity is a key variable because the Australian market would be most interested in the larger, older fish which become rare as fishing intensity increases. The sequence from a fully foreign to a fully Australian fishing operation implies a progressive decrease in the fishing intensity which can be applied to the community and still yield the desired types of fish economically.

A suitable experimental management policy to examine these questions on the North West Shelf of Australia would be to close part of the Shelf to the existing fishery for about four years, while allowing intensive fishing on the remaining area of Shelf. Provided that the two areas (fished and unfished) were large and interchange of fish between them was not great, this could provide a direct comparison of the effects of exploitation at slightly differing fishing intensities. The fully foreign, intensive style of operation would then be compared with the lower intensity, more selective fully or part Australian option to examine viability and determine which gives most benefit to Australia.

This management experiment would also provide empirical data on the feasibility of a rotational or strip harvesting approach to management of tropical fisheries. For rotational harvesting the fishing ground is divided into a number of areas, with each area fished for a time and then allowed to recover. This could be expected to provide a higher catch per unit effort than that obtained from an open fishery, because each year the fishery begins operation on recovered grounds. This gain in catch rate is at the expense of the total annual catch from the whole fishery, but this may be unimportant if catch rate is the principle determinant of an economic fishery. (This would be particularly relevant to an Australian fishery targeting the larger, older fish in the community).

A further gain which may arise from rotational harvesting is protection of fish habitat. It is possible that some fish species of particular commercial interest (notably some *Lutjanus* and *Lethrinus* species), would be displaced from the fishing grounds by destruction of their habitat (soft corals, hard corals, sponges etc.) during trawling operations. Other possible results of the widespread destruction of bottom fauna and substrate include loss of juvenile fish habitat and reduction of diversity and/or abundance of prey eaten by commercial species. Rotational harvesting is well suited to harvesting operations in which the method of exploitation greatly disrupts the regenerative powers of the exploited species. A separate experiment within the closed area would be used to examine at least the short term habitat-fish interactions. Thus the experimental management regime would simultaneously provide a means both of assessing relevance to the fishery of habitat protection, and of empirically evaluating the practicality of rotational harvesting.

Problem 4, evaluation and development of community models, provides considerable difficulty and impinges upon some of the most basic and as yet unresolved aspects of ecology: the means by which populations are limited (both in terms of the number of species and the abundance of each species) through their interactions with the organisms around them and the physical environment. Systematic approach to the problem is confused by a bewildering array of possible interactions, and studies on perturbed systems in which some initially obscure feature played a dominant role in shaping the biological outcome of the perturbation (*e.g.* Kitchell and Kitchell 1980). The seemingly endless permutations of action and reaction are particularly apparent in some well documented cases of changes caused when man has transferred species from one system to another (see Elton 1958).

A reasonable first step is the critical examination of the simple and commonly used Eq. 1, the logistic model assuming no interaction between species. The three major ecological assumptions of this model are; that biological processes (rather than the influence of the physical environment) primarily determine ultimate population sizes and productivities in a given community; that, of all biological processes, those which are intraspecific in their net effects dominate (providing justification for use of a single species mode); and that these intraspecific processes are summarized by a linear function relating per capita productivity and current population size. Although the first two assumptions are of fundamental importance, no practical means of directly testing them is at present apparent. The third is more accessible to examination, but of course failure to negate the linear relationship does not prove it to be correct (it is simply acceptable for the data available), nor does falsification prove that interspecific interactions are involved (a different non-interaction model may be the correct one). It is possible that the non-interaction logistic model provides an adequate description for many species over certain ranges of population density (if only because it is a first order approximation for a class of more complex models) and should be negated over the range of population densities of relevance to the fishery before the need for more complex models is accepted. The model may be found acceptable for some species in a community but not for others, which in itself will serve to direct ecological research toward species comparisons of immediate relevance.

Critical examination of the model's predictive ability requires that two sets of data be available, one from which parameters are estimated and the other on which predictions may be tested. Estimation of parameters requires a time series covering a wide range of population densities and extending over at least three years (the model for n species has 3n parameters with n data points collected per year). This situation is provided by the four-year closed area experiments, although clearly a longer time series would be necessary for the tests to be meaningful. Population density measurements must be made on a strict sampling basis from a consistently operating research vessel, and accurate data of the total withdrawals from each species group in the fished area must be available. Parameter values are estimated from this data and the models predictions compared with a similar data set collected in the years following the experimental closure.

The non-interaction logistic model may be examined by another independent method. The parameters of the model (a and b in Eq. 1) may be expressed in terms of functions describing density dependent natural mortality and birth rate. Hence Eq. 1 may be examined by testing its implications to these rates. For example, if the rate of natural mortality is not influenced by population size over the range of population sizes of relevance to the fishery, then Eq. 1 implies a parabolic relationship between the number of young entering the population and the size of that population. For examination of these implications of the model to mortality and 'birth' rate to be successful, data must be available over a wide range of population sizes, a situation provided by the experimental management regime.

While the initial step should be close scrutiny of the non-interaction logistic model, it is unlikely that a sufficient description of a community is provided simply by arranging several single species models in parallel. The problem of detecting and measuring interspecific interactions must be faced. No solutions to these problems are currently available, but a point to emphasize is that complete and empirical application of interaction models at the species level is impractical in tropical areas because of the excessive data requirements for parameter estimation. (The simple model given by Eq. 2 contains $n^2 + 2n$ parameters for n species, requiring at least n + 2 years of data collection for parameter estimation. So far about 900 species are recognized from trawl survey work on the North West Shelf).

Models of this type could be applied, however, if the species were combined into a more manageable number of ecologically meaningful groups. It is important that each group constitutes a functional unit to ensure biologically meaningful parameters in the 'collapsed model' and avoid construction of a purely empirical and practically untestable formulation (it would still contain a large number of parameters). Details of the behaviour of equation sets such as 2 under successive collapse and the desired biological characteristics of species to be grouped have to be examined in depth, although there is a clear need for such an examination. Uncertainty as to the most appropriate groupings of species emphasizes the need to collect species specific abundance data for the present.

Another approach to examining species interactions is to determine the parameters of the equation set from independent biological observations. Again, however, the data requirements dictate that this could be done for only a few species in the community or at the level of species groupings.

The relationships between competition coefficients (the b's and c's of Eq. 2), community structure and patterns of food resource (assumed to be limiting) usage have been the subject of considerable study since the mid 1960's when several ecologists (*e.g.* Hutchinson 1965; MacArthur and Levins 1967) began examining the concept of the 'ecological niche'. If the community is food limited it is theoretically possible to estimate the parameters of an equation set, such as Eq. 2, from biological data (*e.g.* Schoener 1974). This data includes a knowledge of all species abundances, species and density specific predation rates, nutritive values of the various prey species to each predator, the number of food items eaten by each predator and parameters governing the dynamics of the prey species in the absence of predators. The practical difficulty of gaining the necessary data has so far prevented application of this technique; a situation which is unlikely to change quickly. This general approach seems to be promising, however, and further development could provide some very practical benefits. In particular there is need to reformulate the equations in terms of more readily measurable parameters. Some features of this approach which may be examined using the experimental management opportunity are already identifiable however. These include the relation between predation rates and prey population sizes (a critical relationship strongly influencing both the size of competition coefficients and model structure), the relationship between the range of prey types taken by a predator and overall prey abundance, predicted to increase by optimal foraging theory (Pyke *et al.* 1977) but usually regarded as constant in resource usage models, and the assumption that populations are food limited.

Examination of the assumed food limitation of post-larval fish is particularly critical because this assumption is basic to the structure of several community models suggested for fisheries application, although it is not unanimously supported in the ecological literature (*e.g.* Sainsbury in press) and there are indications that recruitment to some exploited fish populations is strongly influenced by the physical environment (*e.g.* Lasker 1978 a,b). The multispecies model given by Eq. 2 is basic to niche theory (see Sainsbury in press) in which competition for these limiting resources dictates species packing and community structure. Population control in the trophodynamic models of Laevastu and Favorite (1978 a,b) is via a combination of food resource limitation and predation mortality. The community model selected for application depends greatly upon whether food resource limitation among post-larval fish is accepted as an important mechanism limiting population sizes, and testing the validity of this assumption may be regarded as a fundamental step in both assessment of currently available models and development of alternative models. The experimental management regime would result in units within the same population operating at quite different densities because of an applied treatment (fishing); a situation in which the effects of food resource limitation in adult fish, if such exists, should be detectable.

Finally, it is apparent that current moves toward the management of fisheries on a multispecies or community basis is bringing fisheries biology and ecology closer together than has generally been the case over the past few decades. While solutions are clearly distant as yet, fisheries studies with their extensive data gathering facilities and need for predictions on perturbed systems may prove to be an excellent testing ground for some of the ecological hypotheses generated in recent years. This is particularly true if there are opportunities for experimental management; opportunities which will ultimately return the benefits of improved resource usage.

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