Management-Oriented Research and Assessment of Reef Fish Stocks: Problems and Approaches

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The interaction of unique biological and ecological characteristics of reef fish communities with socioeconomic conditions associated with fishing produces a particularly challenging set of circumstances for stock assessment of living reef resources. Bohnsack (1979; 1983), Bohnsack and Talbot (1980), Goldman and Talbot (1976), Ogden (1982), Sale (1977; 1977a; 1978b; 1980a; 1980b), and Smith (1978) review various aspects of the biology and ecology of coral reef fish communities. Munro (1980; 1982), and Powers and Crow (1982) discuss some of the implications for stock assessment.

Proper assessment is hampered by both practical problems with collecting appropriate data and theoretical problems posed by biological complexities of reef ecosystems. Often, data are collected without a clear idea of the exact questions they will be used to answer, much less what analyses will be performed in an attempt to answer these questions. As a result, the process is not cost-effective and commonly produces information of limited utility for stock assessment. When this approach co-occurs with limited data collection, labor and budgets, the status of exploited populations may well remain unknown until it is too late to exert proper management.

The objectives of this paper are to (1) clearly define the questions that stock assessments seek to answer, (2) describe the practical and theoretical problems that pose obstacles to answering these questions, (3) propose approaches appropriate to their solution and (4) devise a preference schedule for data collection based on the questions and analyses required for management of exploited resources. The goal is to provide for those charged with responsibility of collecting data from diffuse, artisanal reef fisheries, with severe budget and labor constraints, the knowledge necessary to optimize available resources by collecting information most critical to the appropriate analyses on a priority basis.

Management Questions

We will limit ourselves to the most fundamental question for management: what is the biological status of the exploited population? In order to answer this question, we would ideally like to have three categories of information about the population: (1) age structure, (2) prevailing natural and fishing mortality rates and individual growth rates and (3) distribution and abundance.

This information is often more difficult to collect for reef fish systems relative to ecologically simpler systems. Biological characteristics of reef fish species and communities underlie the practical and theoretical obstacles to obtaining this information.

GENERAL CHARACTERISTICS OF REEF FISH SYSTEMS AND THEIR CONSEQUENCES

Numerous authors have discussed ecological characteristics of reef fish communities. Four main characteristics are particularly important for managers to consider: (1) high diversity, (2) trophic complexity, (3) tight energetic cycling and (4) rare and patchily distributed habitat.

High diversity implies that high sustained yield of one or several species is not possible, particularly when the exploited species occupy higher trophic levels. This is the case for many commercially important reef fish, for example lutjanids and serranids.

Reef fish communities characteristically support a large proportion of fairly generalized, opportunistic predators (Gladfelter et al. 1980; Bohnsack 1982), resulting in a highly complex trophic web with a large number of energetic pathways. This community structure is thought to be more resilient to perturbation than a community dominated by highly specialized feeders (Wilson and Bossert 1971). Bohnsack (1983) provides empirical evidence for resiliency of reef fish systems.

Despite high standing crop and high gross production, reef fish systems have low net or surplus production due to high expenditure of energy for maintenance, which is associated with extremely efficient recycling of energy between system components. Tight energetic cycling allows highly productive reef areas in relatively nutrient-poor oceans, but reduces yield available for human consumption.

The level and distribution of reef fish production is strongly habitat-dependent, a characteristic associated with the importance of spatial requirements for many reef species (Smith and Tyler 1972; Sale 1975; Ogden and Ehrlich 1977). Coral reefs are relatively rare, patchily distributed, and fixed in space, which limits total reef fish production and influences the distribution of fishing effort and the potential for overexploitation.

Characteristics of commercially important species within reef fish communities, typically upper level carnivores, are also important to consider for management. Generally, such species exhibit: (1) relatively low natural mortality, (2) slow growth, (3) long lifespan, (4) protracted spawning activity, (5) limited home range and, in some instances, (6) alternative life history strategies (most importantly, protogynous hermaphroditism, where individuals begin life as females and transform to males).

The consequences of these species characteristics include: (1) maximum yields result from low fishing mortality rates and high age liable to capture (minimum size), (2) difficulties in determining age using hard parts or length frequencies, (3) ease of overexploitation through overfishing of fixed, easily-located areas and (4) potential damage to the reproductive capacity of the population due to differential mortality by sex, for example through intense exploitation of spawning aggregations.

Practical Problems

A number of practical obstacles to stock assessment result directly from the preceding biological qualities of reef fish systems. Fisheries for reef fish have the following general attributes: (1) many species enter the catch, (2) fishing effort is diffuse, unevenly distributed and often artisanal, employing a variety of gears and (3) catch is often landed at many small ports.

These general attributes in turn lead to typical limitations in data from reef fisheries: (1) data on catch and effort, when they exist, are incomplete by geographical area, (2) data on effort are particularly difficult, both to collect and to quantify by gear type and (3) several or more species are often combined in general categories. These limitations thwart efforts to assess the biological status of the exploited population.

Theoretical Problems

Two biological characteristics of reef fish systems pose problems for theoretical aspects of stock assessment: (1) interspecific interaction and (2) life history strategy. Perturbation of one or several species may have positive or negative impacts on populations of ecologically related species, and hermaphroditic populations may be expected to respond differently to perturbation than gonochoristic populations (those in which the sexes are separate).

APPROACHES TO THEORETICAL AND PRACTICAL PROBLEMS

General Approach

Three major analytical techniques are most often applied to the assessment of fish stocks: (1) production models, (2) yield per recruit analysis and (3) cohort or virtual population analysis (VPA). The first two techniques are often termed standard yield models; VPA is an advanced population estimation technique. These approaches were largely developed in the 1950's and 60's for application to single species, gonochoristic populations. Although some theoretical work has been done to incorporate rudimentary inter- and intra-specific competition, mixing populations, protandrous hermaphroditic populations and interactions of multiple gears, the effects of the overwhelmingly complex suite of characteristics typical of most reef fisheries remain largely uninvestigated. Furthermore, data necessary for the application, however inappropriate, of even these existing models are seldom available. At the same time there is a perception by fishermen and other individuals involved in reef fish fisheries of declining resources in the Caribbean and elsewhere, lending a sense of urgency to the situation.

The general approach to these difficulties should be two-fold: (1) immediate, cost-effective data collection and analysis using existing tools and (2) investigation of the limitations of those tools and development of new methodology.

Investigation of Assessment Model Limitations

Two general requirements for fully investigating model limitations are: (1) a single, complete data set from a typical reef area that could be used as a generic example and (2) a population simulator program capable of producing reasonably realistic data. These two requirements have been or are being fulfilled for the first time by (1) detailed catch and effort data from Bermuda's Department of Agriculture and Fisheries resulting from a mandatory system of fisherman log books and (2) conversion of simulator program (GXPOPS) developed by Fox (1972; 1973) for protandrous hermaphropitic pandalid shrimp to a protogynous hermaphroditic life history.

A brief outline of the proposed investigation includes: (1) standard yield model analysis, (2) Markov modelling of landings over time and (3) simulation of hermaphroditic populations. Production models and yield per recruit analysis of the data from Bermuda will provide "unadjusted" on "standard" results. System stability and interspecific interactions will be investigated by Markov models of the catch data time series from Bermuda, an approach first proposed by Saila and Parrish (1972) and further developed by Saila (1982). Simulation of biological and production data for protogynous hermaphrodites, followed up by production and yield per recruit analysis to determine the effects of life history strategy on the stability of the results, will complement the Markov approach. The life history investigation follows the approach of Fox (1972). The results of both simulation and Markov modeling will be used to assess the efficacy and robustness of standard yield models when applied to reef fish populations.

A Preference Schedule for Data Collection

While work to improve analytical methods continues, the immediate practical problems faced by data collection agencies can be addressed directly by devising cost-effective collection based on the specific questions and analyses relevant to management. It may be useful to begin by considering the two extremes.

First, one might envision an "analyst's dream data set" consisting of: (1) Total catch - by species, age, sex, length, depth, area and gear; (2) Total standardized effort - by species, depth, area and gear; (3) Fishery-independent estimates of abundance of both adult stock and recruits - for example, from direct visual census or from experimental traps or other gear. If these data were available in relatively small time increments, for example in months, over the entire year, for 10 or more years, complete estimation of each existing "standard" assessment technique would be possible, as well as comprehensive analysis of their shortcomings when applied to components of reef fish systems.

The other extreme is simply no data. One could still approach the problem of assessment through yield per recruit analysis using age, growth, and mortality estimates from the literature for related genera inhabiting similar environments, or through empirically derived equations (Pauly 1980a; 1980b; 1981).

Most data sets lie somewhere between these two extremes in terms of the useful information they contain. The essential question facing the fishery officer or other person responsible for data collection is one of allocation. One objective should be to maximize the amount of information relevant to stock assessment gained per expenditure of limited monetary resource. Virtually no nation or territory can afford to collect an "analyst's dream data set," so the process becomes one of getting the most out of whatever monetary and manpower resources are available, through optimal allocation of these resources to the appropriate activities.

Figure 1 is a generalized preference schedule designed to guide this optimization process. Items 1 through 6 in the figure represent categories of information that could, with enough effort, be collected from most fisheries. They are listed in approximate order of increasing difficulty and cost of procurement per amount of useful information gained, i.e., useful relative to stock assessment. The brackets to the left of the list, labeled by letters, group these data items into larger categories which are needed to employ various techniques to assess the biological status of the exploited population. These groups will be discussed in more detail below. Two fishery-independent estimations are listed separately from the preference schedule; these provide a valuable complement to any or all of the six fishery-dependent items and should be carried out, if at all possible, even if on a limited scale.

Item 1, length frequency distributions, constitutes the bare minimum requirement for an approximate fishery-specific yield per recruit analysis, denoted in Figure 1 as level of analysis A. Other useful assessment information, for example, age structure of the population, can also be derived from item 1. Since only a representative sample is required, this item produces the most information per unit sampling effort. Everhart and Youngs (1981) provide a basic treatment of population parameter estimates possible from length frequency data. Ricker (1975) is more comprehensive, and Pauly and David (1981) is the first of a series of microcomputer programs designed for rapid extraction of population parameter estimates from length-frequency data.

If it is possible to extract and preserve hard parts (otoliths, for example) from subsamples of the catch, perhaps during the course of length frequency sampling, anatomical aging studies may be possible (item 2). Aging by hard parts provides a valuable complement to length frequency information on growth patterns. When the two are combined, a more reliable yield per recruit analysis can be performed (level B) than one based on item 1 alone. Panella (1974), Mathews (1974), Brothers (1982) and Manooch (1982) are a good review of anatomical aging of reef fishes, while example studies are provided by Manooch and Huntsman (1977) and Johnson (1983).

At this point it should be emphasized that every attempt possible should be made to separate all data by species. Lumping species into categories, for example, parrotfishes, snappers, grunts or groupers, vastly reduces the possibility for meaningful stock assessment.

Item 3 in Figure 1 represents a quantum leap in cost and effort of procurement. Annual total catch in numbers and total annual effort are extremely difficult to obtain from most reef fisheries for reasons previously discussed. This item does constitute the minimum data requirement for a production model if the time series is 10 or so years long (level C). Item 3 would also allow more accurate estimation of population mortality rates than items 1 and 2, which would in turn allow a still more accurate yield per recruit analysis when combined with these items (level D).

Item 4, frequency distributions of catch per unit effort over time (for example, distribution of catch per fisherman - day, catch per fleet - day, etc.), is less difficult and expensive to collect than item 3, but does not by itself support a stock assessment technique. It provides a useful complement to various analyses, particularly in combination with fishery independent estimates of fish abundance (Bannerot and Austin 1983). Important applications of this item, as well as the information contained in item 5, include the estimation of non-linearities in the catchability coefficient of production functions (resulting in a more accurate production model analysis, level E) and more accurate standardization of effort (probably the most complete production model analysis, level F). Item 5, however, is another difficult category of information to collect for reef fisheries. Fox (1974) reviews techniques,, assumptions and requirements of production modeling. Fox (1975) provides a widely used program to execute the approach. Schnute (1977) and Csirke and Caddy (1983) add refinements and extensions to applying production models to stock assessment problems.

Total annual catch by length, or preferably by age, (item 6), often requires the largest allocation of data collection effort of the six fishery-dependent information categories. A 10-year time series, particularly when combined with fishery-dependent abundance estimates, would likely fulfill data requirements for virtual population analysis (level G). VPA is a technique in which back calculation of population abundances is done based on historical catch data, natural mortality rate(s) and present fishing mortality rates. Development of VPA or cohort analysis methods are generally attributed to Gulland (1965). A number of papers have followed. Several important examples are Pope (1972), Ulltang (1977), Jones (1981) and Cooke and Beddington (1982).

When fishery-independent estimates of adult stock and annual

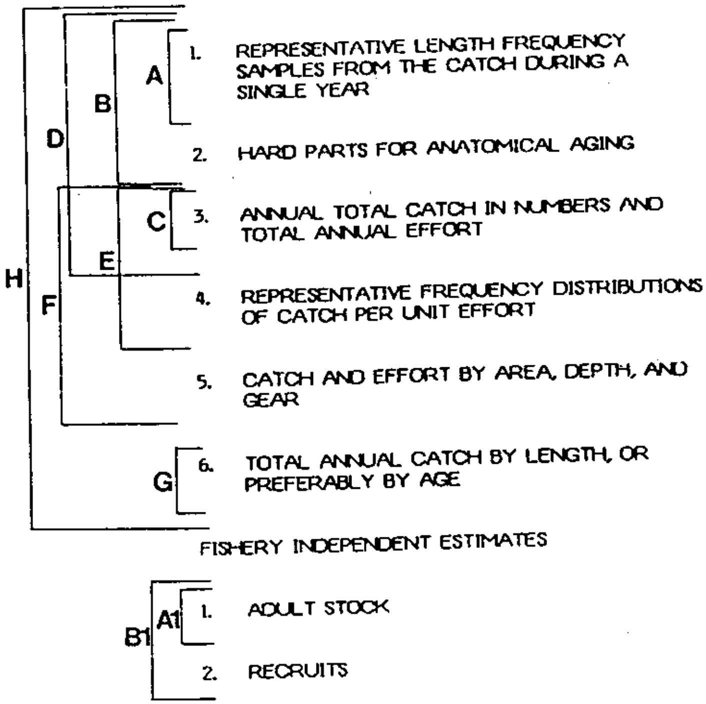

Figure 1. A preference schedule for data collection providing reef fish stock assessment information. Brackets on the left group these data items into categories needed to employ various levels of analysis. These groupings are discussed in detail in the text.

recruitment are combined with fishery-dependent data (level H, in Fig. 1), then we have the previously described "analyst's dream data set." This situation would allow application of the three major existing assessment techniques and investigation of their shortcomings when applied to reef fish systems. Fishery-independent estimates of adult stock size are usually somewhat more accessible than estimates of recruitment. The former, as mentioned before, provides a means of calibrating the analyses described in levels A through H (this calibration is labeled A1 in Fig. 1). If estimates of recruitment are available, the combination of fishery-independent items 1 and 2 could allow estimation of a stock-recruitment relationship (level B1). These models theoretically provide a means for predicting annual recruitment based on the number of adults in the population (Cushing 1973, Ricker 1975 and Cushing and Horwood 1977).

CONCLUSIONS

The interaction of biological and socioeconomic characteristics in fisheries for living reef resources poses numerous practical and theoretical problems for stock assessment and subsequent management.

Even with limited information, rudimentary stock assessment analyses using existing tools may be performed.

Results of current research activities are needed to remove some theoretical obstacles to more accurate assessment of reef stocks.

Data collection efforts can be made more efficient in terms of minimizing costs and maximizing information derived, by designing survey plans accordinig to a simple preference schedule. This preference schedule is based on having a clear, *a priori* assessment objective for which the data are needed and the analysis to be performed to meet that objective.

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LITERATURE CITED

Bannerot, S.P. and C.B. Austin 1983. Using frequency distributions of catch per unit effort to measure fish-stock abundance. Trans. Amer. Fish. Soc. 112:608-617.

Bohnsack, J.A. 1979. The ecology of reef fishes on isolated coral heads: An experimental approach with emphasis on island biogeographic theory. Ph.D. dissertation, University of Miami, Coral Gables, Florida.

_______ 1982. Effects of piscivorous predator removal on coral reef fish community structure. Pages 258-267 *in* G.M. Caillet and C.A. Simenstad, eds. Gutshop '81: Fish food habits studies. Washington Sea Grant Publication, University of Washington, Seattle, Washington.

_______ 1983. Resiliency of reef fish communities in the Florida Keys following a January 1977 hypothermal fish kill. Env. Biol. Fish. 9:14-53.

_______ and F.H. Talbot 1980. Species-packing by reef fishes on Australian and Caribbean reefs: An experimental approach. Bull. Mar. Sci. 30:710-723.

Brothers, E.B. 1982. Aging reef fishes. Pages 3-23 *in* G.R. Huntsman, W.R. Nicholson and W.W. Fox, Jr., eds. The biological bases for reef fishery management. NOAA Tech. Mem. NMFS-SEFC-80.

Cook, J.G. and J.R. Beddington 1982. Further development of an assessment technique for male sperm whales based on length data from the catches. Rep. Int. Whal. Commn. 32.

Csirke, J. and J.F. Caddy 1983. Production modelling using mortality estimates. Can. J. Fish. Aquat. Sci. 40:43-51.

Cushing, D.H. 1973. Dependence of recruitment on parent stock. J. Fish. Res. Bd. Canada 30:1965-1976.

_______ and J.W. Horwood 1977. Development of a model of stock and recruitment. Pages 21-35 in J.H. Steele, ed. Fisheries mathematics. Academic Press, London.

Everhart, W.H. and W.D. Youngs 1981. Principles of fishery science. Cornell University Press, Ithaca, New York.

Fox, W.W. Jr. 1972. Dynamics of exploited pandalid shrimps and an evaluation of management models. Ph.D. dissertation, University of Washington, Seattle, Washington.

_______ 1973. A general life history exploited population simulator with pandalid shrimp as an example. Fish. Bull. U.S. 71:1019-1028.

_______ 1974. An overview of production modelling. U.S. Natl. Mar. Fish. Serv., Southwest Fish. Center, Admin. Rep. LF-74-10, La Jolla, California. 27pp.

_______ 1975. Fitting the generalized stock production model by least-squares and equilibrium approximation. Fish. Bull. U.S. 73:23-37.

Gladfelter, W.B., J.C. Ogden and E.H. Gladfelter 1980. Similarity and diversity among coral reef fish communities: A comparison between tropical western Atlantic (Virgin Islands) and tropical central Pacific (Marshall Islands) patch reef ecology 61:1156-1168.

Goldman, B. and F.H. Talbot 1976. Aspects of the ecology of coral reef fishes. Pages 125-154 in O.A. Jones and R. Endean, eds. Biology and geology of coral reefs, Vol. 3, Biol. 2. Academic Press, New York.

Gulland, J.A. 1965. Estimation of mortality rates. Annex to Arctic Fisheries Working Group Report, ICES, C.M. 1965, Doc. No. 3. 9pp.

Johnson, A.G. 1983. Age and growth of yellowtail snapper from south Florida. Trans. Amer. Fish. Soc. 112:173-177.

Jones, R. 1981. The use of length composition data in fish stock assessment (with notes on VPA and cohort analysis). FAO Fish. Circ. 734. 55pp.

Manooch, C.S. 1982. Aging reef fishes in the Southeast Fisheries Center. Pages 24-43 in G.R. Huntsman, W.R. Nicholson and W.W. Fox, Jr., eds. The biological bases for reef fishery management. NOAA Tech. Mem. NMFS-SEFC-80.

_______ and G.R. Huntsman 1977. Age, growth, and mortality of the red porgy, *Pagrus pagrus*. Trans. Amer. Fish. Soc. 106:26-33.

Mathews, C.P. 1974. An account of some methods of overcoming errors in ageing tropical and subtropical fish populations when the hard tissue growth marrings are unreliable and the data sparse. Pages 158-166 in T.B. Bagenal, ed. Proceedings of an international symposium on the ageing of fish. Unwin Bros. Ltd., Surrey, England.

Munro, J.L. 1980. Stock assessment models: Applicability and utility in tropical small-scale fisheries. Pages 35-47 in S.B. Saila and P.M. Roedel, eds. Stock assessment for tropical small-scale fisheries. Int. Center Mar. Res. Dev., University of Rhode Island, Kingston.

_______ 1982. Some advances and developments in coral reef fisheries research: 1973-1982. Proc. Gulf Carib. Fish. Inst. 35:161-178.

Ogden, J.C. 1982. Fisheries management and the structure of coral reef fish communities. Pages 147-159 in G.R. Huntsman, W.R. Nicholson, and W.W. Fox, Jr., eds. The biological bases for reef fishery management. NOAA Tech. Mem. NMFS-SEFC-80.

_______ and P.R. Ehrlich 1977. The behavior of heterotypic resting schools of juvenile grunts (Pomadasyidae). Mar. Biol. 42:273-280.

Pannella, G. 1974. Otolith growth patterns: An aid in age determination in temperate and tropical fishes. Pages 28-39 in T.B. Bagenal, ed. Proceedings of an international symposium on the ageing of fish. Unwin Bros. Ltd., Surrey, England.

Pauly, D. 1980a. On the relationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer. 39:175-192.

_______ 1980b. A new methodology for rapidly acquiring basic information on tropical fish stocks: Growth, mortality and stock recruitment relationships. Pages 154-172 in S.B. Saila and P.M. Roedel, eds. Stock assessment for tropical small-scale fisheries. Int. Center for Mar. Res. Dev., University of Rhode Island, Kingston.

_______ 1981. The relationships between gill surface area and growth performance in fish: A generalization of von Bertalanffy's theory of growth. Meeresforsch. 28:251-282.

_______ and N. David 1981. ELEFAN I, a BASIC program for the objective extraction of growth parameters from length-frequency data. Meeresforsch. 28:205-211.

Pope, J.G. 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. ICNAF Res. Bull. 9:65-74.

Powers, J.E. and M.E. Crow 1982. Towards models of reef fish exploitation. Pages 185-201 in G.R. Huntsman, W.R Nicholson and W.W. Fox, Jr., eds. The biological bases for reef fishery management. NOAA Tech. Mem. NMFS-SEFS-80.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191. 382 pp.

Saila, S.B. 1982. Markov models in fish community studies - some basic concepts and suggested applications. Pages 202-210 in G.R. Huntsman, W.R. Nicholson and W.W. Fox, Jr. eds. The biological bases for reef fishery management. NOAA Tech. Mem. NMFS-SEFC-80.

_______ and J.D. Parrish 1972. Exploitation effects upon interspecific relationships in marine ecosystems. Fish. Bull. U.S. 70:383-393.

Sale P.F. 1975. Patterns of use of space in a guild of territorial reef fishes. Mar. Biol. 29:89-97.

_______ 1977. Patterns of use of space in a guild of territorial reef fishes. Mar. Biol. 29:89-97.

_______ 1978a. Coexistence of coral reef fishes - A lottery for living space. Env. Biol. Fish. 3:85-102.

_______ 1978b. Patterns of demog raphic change in populations of territorial fish in coral rubble patches at Heron Reef. J. Exp. Mar. Biol. Ecol. 34:233-243.

_______ 1980a. The ecology of fishes on coral reefs. Oceanogr. Mar. Biol. Ann. Rev. 18:367-421.

_______ 1980b. Assemblages of fish on patch reefs - predictable or unpredictable? Env. Biol. Fish. 5:243-249.

Schnute, J. 1977. Improved estimates from the Schaefer production model: theoretical considerations. J. Fish. Res. Board Can. 34:583-603.

Smith, C.L. 1978. Coral reef communities: a compromise view. Env. Biol. Fish. 3:109-128.

_______ and J.C. Tyler 1972. Space resource sharing in a coral reef fish community Los Angeles Co. Natur. Hist. Mus. Sci. Bull. 14:125-170.

Wilson, E.O. and W.H. Bossert 1971. A primer of population biology. Sinauer Associates, Inc., Sunderland, Massachusetts. 192 pp.