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ANNEX 3

On the Development and Dissemination of New Methodologies for Tropical Stock Assessments

by

D. Pauly and J.L. Munro
International Center for Living Aquatic Resources Management
MCC P.O. Box 1501, Makati, Metro Manila, The Philippines

Abstract

The use of length-structured methods for the assessment of fish stocks is reviewed in relation to the present status of tropical fisheries science. It is concluded that these methods, which emerged largely as a result of the development of sophisticated, yet relatively cheap, programmable calculators and microcomputers, will enable significant advances to be made in assessement of tropical stocks.

It is proposed to disseminate the length-structured methods and other methodologies through a management-oriented fisheries-research network which will enhance communication between fisheries scientists who are working on problems of assessment, management and conservation of tropical stocks. The principal mode of communication will be via a newsletter.

1. INTRODUCTION

Fisheries science emerged towards the end of the last century in response to the first signs of what was later to be called "overfishing". As a result of the development of the science, fisheries biologists in temperate regions are now routinely able to respond to requests for scientific advice on the state of various fish stocks and make management recommendations concerning allowable catches, restrictions on effort and closed seasons and areas. The kind of research which leads to the ability to formulate management strategies is called, by ourselves, "management-oriented fisheries research".

In tropical waters there are exceedingly few examples of fisheries which are managed on the basis of options formulated as a result of management-oriented research. For the most part, fisheries are either unmanaged or are "managed" on the basis of ill-founded perceptions of the status and potential productivity of the stocks and undocumented recollections of the history of the fishery. The reasons for this situation are not difficult to discern and relate to the biology of the fishes, the nature of the fisheries and to the institutions responsible for fisheries and management in the tropics.

The biological constraints include the large number of species in the total catch, with few single species important enough to warrant a major research effort, difficulties in ageing fish because of the usual absence of readily discernible periodic growth marks, difficulties in obtaining statistically meaningful samples of individual species and our inadequate understanding of the complex interactions between the species constituting the exploited communities.

These constraints are matched by a set of characteristics pertaining to tropical fisheries, many of which are exploited by a vast number of competing fishermen operating a wide array of gear types and landing their catches at points dispersed over innumerable small beaches adjacent to a variety of fishing grounds. The fishermen are most often illiterate, poverty-stricken, unorganized and suspicious of activities of research workers.

The institutional constraints mostly have a historical basis and include a shortage of adequately educated or trained fisheries scientists, the high cost of imported scientists, poor perception of the practical possibilities of fisheries management by administrators and politicians and thus inadequate financial support for research activities.

However, the greatest constraint of all lies in the scientific personnel attached to fisheries institutions, who are often not well versed in matters relating to fish stock assessment. Apart from the complexities of tropical fisheries which have been previously mentioned, the mathematical aspects of stock assessment are intimidating for most biologists and are often actively avoided. Clearly, dealing with all of the constraints at the same time is almost impossible for any organization. However, partial advances are feasible and this paper discusses a possible approach based on the wide dissemination, through a special "network", of the new methodology that has emerged, since the mid-seventies, for the investigation of tropical stocks. In the following, we review the major features of this new methodology, then present a modus operandi for its dissemination.

2. A NEW METHODOLOGY FOR TROPICAL STOCK ASSESSMENT

Dealing first with the biological properties of tropical stocks, we wish to stress that tropical stocks often fail to exhibit the properties attributed to them or that these properties, far from representing liabilities, can be turned into assets. Thus, for example, the feature that many tropical stocks in South and Southeast Asia consist of very short-lived fishes, allows one to follow the growth and decay of a cohort of fish within a year. If there are also well-defined periods of recruitement (which is often the case, contrary to a widely held assumption), one can often determine growth from length-frequency data without encountering many of the problems occurring when this approach is applied to long-lived temperate fishes and estimate total mortality rate from length-frequency data on an annual basis, i.e., for distinct cohorts.

Additionally, the short life span of many tropical fishes enables one to neglect time-lag effects, for example, when fitting Schaefer-type production models to catch and effort data, when estimating mortalities from catch composition data or when estimating absolute annual recruitment from a division of yield-per-recruit estimates into annual catch.

The large number of species encountered in most tropical fisheries, which most authors have generally considered to represent nothing but a major nuisance, may also be viewed as a beautiful set of replicates from which not only one, but several sets of parameter estimates can be obtained, e.g., to assess the impact of fishing on a multispecies stock (Munro, 1974; Weber and Jothy, 1977; Pauly 1979, 1980a).

The assessment of commercially exploited fish stocks depends heavily upon a sound knowledge of growth, and "natural" and "fishing" mortality rates. In temperate countries routine ageing of large number of samples from the few important species is feasible, and information on growth and mortality is derived from this age data by "age-structured" models. It is also possible to use "length-structured" models to get this information directly from length data. Length-structured methods have become very important to fisheries research in the tropics, and their evolution is briefly reviewed in the following paragraphs and summarized in Table 1. Three phases may be distinguished in the development and evolution of these methods:

(i) a "pioneer" phase around the turn of the century, dominated by the work of C.G. Petersen, T.W. Fulton and T. Edser;

(ii) a "classic" phase in the late 1950s to mid-1960s in which the concepts proposed by R.J.H. Beverton and S.J. Holt were translated into their length-structured equivalents, and

(iii) a "baroque" phase, starting in the mid 1970s, resulting in the development of methods of increasing sophistication and applicability for the estimation of growth and mortalities from length-frequency samples. This phase developed largely as a result of the wider availability of programmable calculators and microcomputers.

Petersen (1982) developed both techniques commonly used for the extraction of growth information from length-frequency samples; these methods may be called the "Petersen method (sensu stricto)" and the "modal class progression analysis". Both techniques, when used with judgment, give reasonable results when applied to representative, well-structured samples; they have become virtually the sole method used more or less routinely in the tropics to obtain growth data. Several refinements to these methods have been proposed, notably their use in conjunction with graphical (Cassie, 1954; Harding, 1949) or computer-based (Hasselblad, 1966; Tomlinson, 1971; Young and Skillman, 1971) techniques for the separation of multi-peaked samples into normally distributed subsets. Still, all of these methods and their variants (e.g., the "integrated method" of Pauly, 1980b), remain essentially subjective, and produce results which are not fully reproducible.

Beverton and Holt's major contribution to the available pool of length-structured methods were the establishment of the relationship between mean length in catch samples and total mortality1/ and the reformulation of their yield-per-recruit model in a form in which the original 7 parameters are collapsed into three parameters, one of which is the ratio of the mean length at first capture to the asymptotic length of fishes (Beverton and Holt, 1964).

The third, "baroque", phase of development of length-structured models has led to the development of a variety of methods for assessing stocks, based almost exclusively upon the length-frequency distribution of catches. Of these methods (listed in Table 1), (6) derives estimates of growth and mortality from length distributions at two time periods, (7) estimates population size and fishing mortality, by size group, from catch-at-size data, obtained by combining length-frequency data with catch statistics while (8) is a modification of length cohort analysis such that the results are independent of the width of the length class used (which affects the accuracy of the results in (7)). Length-converted catch curves (9) and "pseudo catch curves" (10) are methods to obtain estimates of total mortality from representatives length-frequency samples of a population and a set of growth parameters, the former method being the length-structured equivalent of a standard "catch curve", while the latter method (10) uses the interrelationships between depth, abundance and mean length to construct the functional equivalent of a catch curve.

The set of ELEFAN programs are particularly useful in that they allow for the extraction of virtually all the information embedded in a given set of length-frequency data, i.e., growth parameters (including cases where growth oscillates seasonally), total mortality (using several methods), preliminary estimates of natural mortality (and hence, also of fishing mortality), patterns of gear selection and patterns of recruitment into the fishery. Also, when used in conjunction with catch statistics, ELEFAN III can be used to run different types of Virtual Population Analyses (VPA) and thus to estimate recruitment as well as fishing mortality, by length classes and in time (Pope, Pauly and David, in prep.). All ELEFAN programs are in BASIC and run iteratively, with automatic prompting of inputs; also, they do not require any equipment outside of the microcomputer itself.

Of the methods in Table 1, eight (1, 2, 4, 5, 7, 9, 10 and 14) can be implemented either with pencil and paper, or with calculators. Of the remaining methods, (3) produces erroneous results, (6) and (8) can be run with programmable calculators2/, leaving only the three ELEFAN programs (11 to 13) as methods which require (micro) computers for their implementation.

It should be emphasized here that these methods are based on rigorously derived mathematical equivalents of age-structured models. Thus, for the methods (4) to (12) in Table 1, the major assumption that is added in the transformation from the corresponding age-structured

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1/ The equation proposed by Beverton and Holt (1956) has the form $Z = K\,(L_\infty - \bar{L})/(\bar{L} - L')$, where Z is the (exponential) rate of total mortality, L_∞ and K are parameters of the von Bertalanffy growth equation and $\bar{L}$ is the mean length of catch samples, calculated from the smallest size group that is fully selected (L')

2/ Calculator programs (for HP 67/97) incorporating the methods 4-9 and 14 are available from the authors.

model is that the von Bertalanffy growth equation (von Bertalanffy, 1938) adequately describes the growth of the fish in question. This, however, has shown to be the case by a large number of authors (reviews in Pauly, 1978; 1981), despite assertions to the contrary (Knight, 1968; Roff, 1980).

A final point on the usefulness of length-structured models is that very large amounts of length-frequency data are on file at fisheries research stations and laboratories, and in the files of individual scientists, and that these data are virtually unprocessed in the context of the length-structured methodology. Thus, there is the possibility of generating a posteriori extremely useful time series of such important parameters as total mortality, provided it can be established that the data are adequate representations of the length distribution of the catches. In the Philippines, for example, we have been able to locate, document and analyse, using the ELEFAN method, 0.9 million individual measurements of fish (Ingles and Pauly, 1982; in prep.); we also know that similar data sets exist in other countries.

We shall discuss in some detail, in the second part of this paper, some of the constraints which prevent fisheries scientists in developing countries from doing what we have termed "management-oriented fisheries research". Thus, it may suffice to mention here that the methods do exist which can be used for such research, and that all of the methods in Table 1 are available in forms which should allow even moderately well-trained technicians to apply them. Moreover, the costs for hardware needed to support the methods listed in Table 1 are minimal when related to overall expenditures on fishery research. For example, the cost of a fully programmable calculator is perhaps equivalent to 1/2 day in fuel costs for a research vessel or equivalent to the cost of a small navigational error. Similarly, the cost of a microcomputer such as is needed to implement the ELEFAN programmes, or other sophisticated programmes for the detailed analysis of (expensive) data, is perhaps equivalent to 2 days in fuel costs for a research vessel or equivalent to the losses resulting from the use of a sub-optimal cruise track.

3. TRAINING AND ASSISTANCE IN MANAGEMENT-ORIENTED FISHERIES RESEARCH

Despite great efforts by national and international agencies, there has been a remarkable lack of progress in making scientifically sound fish stock assessments in tropical countries. The reasons for the lack of progress in fisheries science are fairly clear. There is a grave shortage of highly skilled manpower in most tropical countries, with internal and external competition for the services of the most skilled and best educated people. Administrative careers emerge as the most attractive avenues for personal development and financial gain. In those countries where there are sufficient biologists to staff fisheries management organizations, those appointed are very frequently faced with heavy administrative responsibilities, have not yet proceeded to undertake graduate work leading to higher degrees and, most often, have received the minimum amount of mathematical training which is consonant with a degree in science.

In many cases, the obvious solution would be to send the individual to a university where suitable graduate training is available but, in many instances, this is impossible for financial, family, or academic reasons. Short-term training courses are a possible means for infusing required items of knowledge but the recipients of such knowledge are not always those most in need of the training and the diverse levels of education and experience of the participants usually ensures that a significant portion are either baffled or bored. A third mechanism which is often pursued is that of "counterpart" training, whereby counterparts are assigned to experienced scientists, most often contracted from abroad by external agencies. However, if this is attended to seriously, it is extremely expensive in terms of man-hours. There is usually an excellent chance of the recipient of any training being deployed elsewhere or moving into a radically different field on completion of the training program. These and other problems have most recently been addressed by ACMRR (1981) and various suggestions put forward for improvements, including improved distribution of FAO manuals.

ICLARM has recently resolved to pursue an alternative strategy for attacking these problems. This will involve the creation of an international network of fisheries scientists who are working on problems of assessment, management and conservation of tropical stocks. To this end, ICLARM will identify scientists who are working in relative isolation in tropical countries and attempt to bring them into contact with fellow scientists with common or similar problems in management-oriented fisheries research. Membership of the network will be on a personal basis and not institutionalized. The principal vehicle for communication will be a newsletter.

ICLARM will provide the following services to the network:

(i) act as a clearing house for information related to assessment and management of tropical fisheries, with particular attention to small-scale, multispecies, multi-gear fisheries;

(ii) provide, at no cost, relevant literature, including "grey" reports, previously unpublished data sets, reprints of papers which are now out of print, and, where possible, act as a distributor for manuals prepared by other organizations;

(iii) provide, in selected cases, assistance in data analysis, including periods spent in Manila by members of the network or visits by ICLARM staff to the institutions concerned to formulate plans and devise appropriate methodologies;

(iv) ICLARM assistance will also include the development of data-acquisition strategies where no data base exists. This is particularly important where inexperienced scientists have difficulties in identifying which data should be collected, when, how and in what quantities. Great expenditures of time and effort quite often prove abortive because the resulting data sets are incomplete.

These services will be available on a long-term and continuing basis, at no cost to the recipients.

The newsletter will contain exchanges of informal notes, news and views on tropical fish stock assessment and management. The emphasis will be on how to make parameter estimates for stock assessments, application and applicability of various stock assessment models and on management decisions based on such assessments. It will contain program descriptions, worked examples applied to tropical stocks and news on developments in appropriate hardware. Additionally it will describe investigations currently in progress and the problems and pitfalls encountered and their solutions. In other words it will attempt to bridge the gap between perception of a fisheries management problem and the production of a set of recommendations to solve that problem.

Initially the newsletter will be distributed only to members of the network. However, if it is successful, bound volumes will be distributed to libraries of fisheries research institutions.

The final phase of development of the network will be the development of Management-oriented Fisheries Research Groups in individual countries. Such groups will only be set up at the request of individual institutions and will consist of a group of scientists from the country concerned working under the guidance of an ICLARM staff member on the analysis of data sets. The ICLARM staff member will be assigned to such a group for a period of up to two years. Basic equipment such as a microcomputer and programmable calculators will be supplied when necessary. Details of such programs will vary by country and be tailored to the needs of the recipient country.

It is also expected that the network will lead to the identification of topics for training workshops. For example, the need for a workshop to further develop and propagate length-structured stock-assessment methods is already evident. The almost uniform incomprehension of mesh-selection phenomena and methods of treating data biased by gear selectivity suggests a second workshop topic. A third workshop could aim at bringing together social scientists and fisheries biologists for further attempts to formulate cohesive management strategies for various fisheries.

The basic argument put forward in support of the program outlined above is that throughout the topics, both in inland and marine fisheries, recently graduated scientists are faced with problems of data and literature acquisition. The relevant literature is sparse, inaccessible and almost invariably not available in remote field stations or even in major national fisheries libraries. In particular, the individuals concerned do not know who is working on what in the tropics, as the lines of communication often run north-south and not equatorially. The proposed network would remedy this to a large degree.

The initial development of the network will be funded by ICLARM, but continuation of the network will require additional funding support from other sources.

To launch the network, ICLARM is presently distributing invitations to a selected list of scientists who are known to be actively engaged in tropical fisheries assessment work. Membership will be increased by inviting Directors of Fisheries Departments to nominate scientists from their organizations to become members. Further increases in membership will be on the basis of nominations by existing members of the network. It is emphasized that membership will be on a personal basis and not institutionalized.

4. CONCLUSIONS

Recent developments in programmable calculators and microcomputers, and the development of length-structured methods for analysis of exploited populations, have put the most sophisticated fish stock assessment techniques within the grasp of almost all fisheries scientists. What is lacking is the confidence and know-how to attempt assessments utilizing these tools. To most tropical fisheries biologists, computers and programmable calculators are intimidating instruments and the exclusive prerogative of scientists of the wealthier nations. This need not be the case and it is ICLARM's intention to further stock-assessment work by attempting to strip some of the aura of mystery from the work of the population dynamicist and demonstrate that useful stock assessments can be based on minimal amounts of data and equipment, even in multispecies, multigear fisheries.

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Table 1

Selected length-structured methods for use in tropical stock assessment[a/]

Phase	No.	Name of method	Originator(s)	Well-documented application(s) to tropical stocks	Remarks
I	1	"Petersen method"	Petersen (1892)	Goeden (1978)	A combination of these two methods into an "integrated method" is given in Pauly (1980b).
I	2	Modal class progression analysis	Petersen (1892)	George and Banerji (1964), Thompson and Munro (1978)	
I	3	"Catch curve"	Edser (1908)	not applicable, method too crude	—
II	4	Z from mean length	Beverton and Holt (1956)	LeGuen (1971), Munro (1974)	Variants of this method have been presented by Ssentengo and Larkin (1973), Marten (1978) and Ebert (1981).
II	5	length-based (relative) yield-per-recruit analysis	Beverton and Holt (1964)	Munro (1977), Sinoda et al. (1979)	No computation necessary when using this method; results are tabled for a wide range of parameter values.
III	6	Z and K from mean lengths	Ebert (1973)	Pauly (in prep.)	—
III	7	Length cohort analysis	Jones (1974, 1979, 1981)	Jones and Van Zalinge (1981)	—
III	8.	Length VPA	Pauly (in prep.)	example in original description	—
III	9	Length-converted catch curve	Pauly (1980a), J.A. Gulland (pers. comm. to Pauly)	example in original description	—
III	10	"Pseudo catch curve"	Pauly (1980c)	example in original description	Method requires further refinements.
III	11	ELEFAN[b] I	Pauly and David (1981)	examples in original description, in Pauly and Ingles (1980) and Pauly et al. (in press)	Most sophisticated approach to date for detailed analysis of length frequency data; incorporate methods 1, 2, 4, 8 and 9.
III	12	ELEFAN II	Pauly et al. (1981 and in press)	same as for ELEFAN I	
III	13	ELEFAN III	Pope et al. (in prep.)	example in original description	—
III	14	Csirke and Caddy's yield model	Csirke and Caddy (in prep)	not yet available	Included here because catch is plotted on Z or Z/K, both of which can be obtained from length-frequency samples

a/ This table includes methods where length replaces age as an explicit parameter, not methods that are inherently length-structured, such as selection curves. Also, methods for the decomposition of length-frequency samples into normally or otherwise distributed subsets are not included (but see text)

b/ Electronic LEngth Frequency ANalysis; a bit contrived, but one remembers it