WF_1305

Application of information on age and growth of fish to fishery management[1]

DANIEL PAULY
INTERNATIONAL CENTER FOR
LIVING AQUATIC RESOURCES MANAGEMENT
MCC P.O. BOX 1501
MAKATI, METRO MANILA
PHILIPPINES

ABSTRACT

Information on the age and growth of fish is usually related to one or several of the following items: construction of age/length keys for direct use in some assessment models (e.g. Virtual Population Analysis); estimation of growth parameters, used as inputs in some other models (e.g., yield-per-recruit); comparative studies of growth performance in different stocks and species (i.e., in studies of environmental factors affecting growth); and studies of the anatomical and physiological mechanisms underlying the growth performance in fish. The relative importance of these aspects is discussed in the context of fisheries management in the Northeast Atlantic, Kuwait and Southeast Asia, which are considered as representative of three major types of situations encountered worldwide in fishery management.

The collection and analysis of age and growth of fish information is a time-consuming activity. It may be a preoccupation of some fishery biologists. This Symposium is certainly not the place to challenge the relevance of this activity. What should be done here, however, is to ask ourselves why knowing about the age and growth of fish is important, and what are the uses to which such knowledge is being put in different parts of the world .

I have not undertaken a formal review; rather, I have chosen a comparative approach, in which the points I want to make are illustrated by the research (and/or routine assessments) conducted in three specific areas of the world: Northeastern Atlantic, Southeast Asia, and Kuwait.

[1]ICLARM Contribution No. 244.

The Age and Growth of Fish, edited by Robert C. Summerfelt and Gordon E. Hall

The first area, the Northeastern Atlantic, corresponds roughly to the jurisdiction of the International Council for the Exploration of the Sea (ICES). Scientists working there operate in developed countries on heavily exploited resources, about which a considerable amount of previous knowledge exists.

Southeast Asia, besides having the world's most diverse marine fauna, is characterized by extremely strong pressures on its natural resources and the lack of conservation of those resources. The fisheries differ in a number of important features from those of high latitudes. Among the differences important to fishery management are the short life-span of the bulk of the organisms (fish, squids, shrimps, etc.) exploited by the fisheries. Also, the resources are concentrated in shallow waters, with commercially exploitable concentrations usually occurring in waters less than 50 m deep within the coastal belt accessible to artisanal fishermen. Fisheries research in Southeast Asia is hampered by a number of factors, the key one probably being the shoestring budgets under which most of the laboratories operate. Factors hampering fishery management are, in the main, governments' inabilities to formulate a science-based fishery policy and to enforce regulations.

Kuwait is a small country with enough oil income to set up and maintain a first-rate research institution, the Kuwait Institute of Scientific Research (KISR); the Fisheries and Aquaculture Division of KISR is in charge of developing the marine resources and supplying government with management advice. The contrast in Kuwait of a sophisticated research institution and partly underexploited, under-investigated tropical resources as the object of its research resembles other situations, namely, those faced by the US National Marine Fisheries Service Laboratory in Hawaii, in charge of resources in the Central Pacific; the French ORSTOM laboratory in Vanuatu, in charge of South Pacific resources; and the CSIRO Marine Laboratory in Cronulla, Australia, in charge of the marine resources on the Northwest Shelf of Australia.

Four aspects of age and growth studies to be considered with respect to these geographic areas are:

1. aging, age-validation and the construction of age-length keys;
2. estimation of growth parameters using data obtained in (1), or other methods (particularly length-based methods);
3. comparative studies of fish growth performance;
4. studies of the anatomical and physiological mechanisms underlying the growth performance of fish.

Only marine fish and fisheries will be discussed.

FISH GROWTH STUDIES VS. FISHERIES MANAGEMENT

The Northeast Atlantic Area

The largely international fisheries of the Northeastern Atlantic area are managed mainly through national quotas (i.e., through allocation of annual TAC's = Total Allowable Catch) within the ICES area, of which a major part overlaps with the waters of the European Community (EC). TAC's are determined through a formal and annually repeated sequence to:

- Establish age-length keys and compilation of quarterly catch-at-length and catch-at-age data for all major exploited species. This work is usually performed in national laboratories;
- Amalgamate several rational data sets into "total international catch-at-age" data for each major species and assessment of these, usually by a form of Virtual Population Analysis (VPA, see Pope 1972). This analysis is usually performed by international working groups, whose members are scientists drawn from the national laboratories of interested countries.
- Review of the working groups' reports and formulation of management advice by the Advisory Committee on Fisheries Management (ACFM), a body of ICES whose members (usually fishery scientists) act as representatives of their countries. The annual ACFM report is then sent to the relevant management authority, usually a department of the EC administration in Brussels;
- Political negotiations over TACs, etc.

Almost all management advice and assessments in the ICES area are based on annually updated catch-at-age data provided by this elaborate and expensive research machinery. Some estimates of the cost of the annual information updates are as high as 80% of all research costs by major laboratories, which have about 20% of their overall budget going to ageing and related studies (see also Casselman et al. 1986).

Important also is that ageing of very old individual fish in the context of VPA-oriented research is not mandatory, because one can create for them a so-called "plus-group" with corresponding catch and biomass (Mesnil 1970; also Beamish and McFarlane 1986).

The fact that the major breakthroughs on the growth of European fishes were achieved at the beginning of this century (see bibliography in Mohr 1927, 1930, 1934) implies that fish ageing has, in the ICES area, ceased to be a major area of research; this contrasts with the Mediterranean area, where age and growth studies are deemed important enough to justify special emphasis by a major funding agency (The European Community, in its guidelines for proposal submission, for the year 1984-1985).

Major insights into the general area of fish growth have been obtained in the ICES area, however, and these concern the relationship between food intake (i.e., predation) and growth performance of individual year-classes. These studies, largely initiated by the landmark study by Daan (1973) and the work of the "Danish school" (Ursin 1967; Andersen and Ursin 1977; Helgason and Gislason 1979; and Sparre 1980), led to a strong awareness of the role played by major predators in exploited marine ecosystems and of the relationship between the food availability and the growth performance of the fishes of a given year-class. Unfortunately, the models used in the North Sea area required a large data base (e.g., over 10^5 stomach contents of North Sea fishes were analyzed in a recent ICES exercise). These models, therefore, do not seem applicable to other areas without empirical data on trophic dynamics. Additionally, most of the models used are based on ages instead of size, even when the latter (e.g., mesh-selection ogives) would be biologically more appropriate.

Although the Northeast Atlantic stocks are presently still managed as single-species stocks, the various multispecies assessments conducted in the North Sea area, have convinced most interested parties of the need to account for species interactions, and of the role of a variable food supply to the growth and maintenance of fish stocks. It can be expected that these insights will gradually percolate to other areas of the world, even if model-building does not evolve to the complex form it has taken in Western Europe.

Southeast Asia

While self-managing artisanal fisheries in Southeast Asia go back to time immemorial, commercial fisheries, particularly bottom trawl fisheries, are quite recent. They started on a grand scale, after relatively unsuccessful pre World War II attempts by the colonial powers, in the 50s in the Philippines, the 60s in Thailand, and the 70s in Indonesia and Malaysia. These new commercial fisheries, bursting as they did onto the national and international scene, faced governments without the institutional apparatus necessary for successfully managing them. As a consequence, major fisheries became overcapitalized a decade after they started (Pauly 1979).

Half-hearted attempts were undertaken by several governments to prevent trawlers from fishing too close inshore, particularly where they were depleting the resources upon which artisanal fishermen depended. These attempts largely failed, as did efforts to increase the mesh size used by these trawlers from the commonly used 20 mm stretched mesh. The only "success story" related to the management of the demersal trawl fisheries in Southeast Asia has been the total ban on trawling in Indonesian waters (Sarjono 1980). Here successful enforcement was put in the hands of the artisanal fishermen who demanded it.

This should not give the impression, however, that fishery biologists based in Southeast Asia have been idle. The life histories, mortality rates, and growth parameters of a number of commercial species have been elucidated or estimated (Simpson 1982; Ingles and Pauly 1984). Thus, it has become possible in principle to provide management advice based not only on the generally used surplus production models, but also on suitable modifications of analytical models such as the yield-per-recruit model of Beverton and Holt (1957). An example of this is the length-structured yield-per-recruit model of Beverton and Holt (1964), which requires estimates of L_∞, of the mean size at first capture (L_c), and of the ratio M/K (expressing natural mortality as related to growth). This model, which provides estimates of relative yield per recruit as a function of exploitation rate ($E = F/Z$), has been extended for use in a multispecies context by Sinoda et al. (1979).

Another model which might turn out to be particularly useful for Southeast Asian stocks is that of Csirke and Caddy (1983), in which annual catch is plotted on corresponding estimates of total mortality (Z) or on the ratio Z/K. These latter quantities can be estimated through length-converted catch curves (sensu Pauly 1982, 1984), or methods proposed by Jones (1984), i.e., combining growth parameter estimates (L_∞ and K) with length-frequency samples.

It appears that estimates of growth parameters in commercial species will become increasingly important in Southeast Asia. Their increased availability would make possible the application of some of the more elaborate management schemes that have been proposed when fishery management institutions and regulatory mechanisms have emerged.

It is my opinion that daily rings, often proposed as a panacea for the ills of those trying to age tropical fish, will not replace length-frequency data as the basic source of age and growth information on Southeast Asian fish. Rather, daily rings will be used to corroborate inferences drawn from length-frequency data (Gjøsaeter and Sousa 1983). An even better approach is to simultaneously estimate growth parameters from length and age data, as is now possible using a method proposed by Morgan (1986).

Kuwait

An interesting intermediate stage between the large-scale, routine ageing activities in the North Atlantic area and the difficult stage in which fishery research finds itself in Southeast Asia is provided in Kuwait. There, management advice is actively sought by both government and industry, and a well-equipped and well-staffed research institute (KISR), is faced with stocks not previously investigated.

Studies on fish stocks in Kuwait began in 1980, and a capability for ageing fish was establishing in 1981. Work at first concentrated on "age-length keys." In 1982, fisheries scientists in Kuwait also began using the ELEFAN I program of Pauly and David (1981), a computer-based objective method for the estimation of the growth parameters L_∞ and K of the von

Bertalanffy growth function from length-frequency data. Also, length-converted catch curves were used for the estimation of total mortality and estimation of mean length at first capture using the ascending, left arm of the curve (Pauly 1984; Morgan 1985).

Of the various species investigated in this fashion, only two Pampus argenteus and Otolithes argenteus are actually short-lived enough for the unmodified ELEFAN I program to be directly applied to them. In these two cases, results were obtained from the length-based analysis which matched closely those obtained from an age-based analysis (Morgan, 1985; Mathews and Samuel 1985).

Encouraged by this, the KISR researchers then attempted to apply the length-based ELEFAN methods to longer-lived fishes (for which the method was not originally designed), notably to Epinephelus tauvina, Lutjanus coccineus (= L. malabaricus) and Acanthopagrus latus. The results of these studies, reported in a number of technical reports, were summarized by Mathews (1986). They suggest that approaches based solely on length data become increasingly more unreliable as the investigated fish become longer-lived. This observation is confirmed by recent Monte-Carlo simulation studies of ELEFAN I (Hampton and Majkowski 1986; Rosenberg and Beddington 1986), which show that growth parameters estimated by ELEFAN I become increasingly biased when the overlap between adjacent length-frequency distributions increases, as occurs in fish with a long life-span and/or a long recruitment season. This bias is in part self-compensatory, with the overestimation of L_∞ partly compensating for the underestimation of K, and the resulting growth curves being very similar to the original curves.

The optimum solution to this problem, however, is the use of additional information on the growth of the fish concerned, either in the form of growth increments, i.e., tagging data (Kirkwood 1983), or, preferably, age-length data pairs obtained by reading otoliths. However, as emphasized by Morgan (1986), the goal, when working with both age- and length-frequency data, should not be for these to be analyzed separately, but to combine the strength of age-based and length-based approaches such that a single set of precise and accurate growth parameter estimates is obtained through simultaneous analysis of both types of data.

Morgan (1986) recently developed a method to perform such combined analysis. The method, a modification of ELEFAN I soon to be made available as "ELEFAN IV," estimates a best set of growth parameters from length-frequency data, age-length pairs obtained from reading of hard parts, and growth-increment data resulting from tagging/marking experiments, or any combinations of the three data types.

Exercises conducted to date with this method (Morgan 1986, and pers. comm.) suggest that it will provide cost-effective estimation of growth parameters in long-lived fishes, because the age information obtained from otoliths (i.e., the information that is usually the most costly to obtain) is not used to determine the shape of a growth curve. Rather it is used to select from the number of local optima on the response surface generated by the analysis of the length-data the one that is most compatible with the available age-length observations.

This precedure requires length-frequency data and only a few age readings to achieve stability of growth-parameter estimates (Fig. 1). This is a feature of particular interest in areas where fish destined for ageing studies must be purchased from fishermen (Morgan 1983), and in which the expertise for otolith reading must be imported (Mathews 1986).

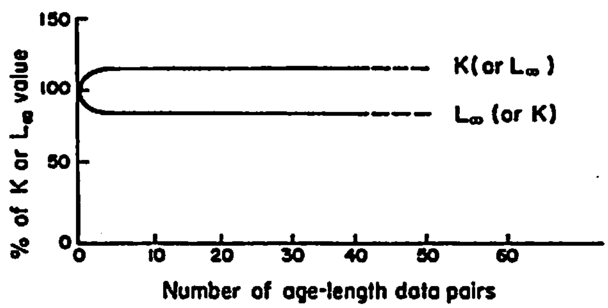

Fig. 1. Schematic representation of the effect of incorporating age-at-length information into an analysis of length-frequency data using ELEFAN V. Number of age-length data pairs in ordinate scale needed to stabilize growth parameter estimate stem from analysis of data on *Lutjanus coccineus* (G. R. Morgan, pers. comm.).

Growth studies of fish are being conducted in Kuwait for stock assessment, and also to identify species suitable for mariculture. In both Europe and Southeast Asia the screening of species for large-scale culture is essentially completed, the pros and cons of the various species, inclusive of their growth performance under culture, being essentially known. Thus, research on sea-going salmonids in Europe and on milkfish *Chanos chanos* in Southeast Asia tends to be oriented toward fine-tuning of long-established production systems, such as genetic improvement of the cultivated animals (Gjedrem 1983), or identification of constraints to intensive production (Chong et al. 1984). In Kuwait, on the other hand, this stage has not been reached, and species suitable for mariculture under Kuwaiti conditions still need to be identified.

It can be expected that fish, which in the wild quickly reach large size, should be anatomically and physiologically equipped to perform well under aquaculture conditions (Pauly 1981). In the present Kuwaiti context, this implies that only those fish for which previous age and growth studies have produced evidence of high growth rates should be screened for their suitability for mariculture. This procedure saves time and resources since it is cheaper and easier to age fish than to obtain live fry from the wild and perform growth experiments with them.

DISCUSSION

In temperate waters, where fish tend to be longer-lived than in the tropics, the use of large computers, the choice of analytic methods (mainly VPA), and the availability of detailed catch data for the major exploited species allow for fishery management to rely predominantly on catch-at-age information. Consequently, vast resources are invested in the annual reestimation of age-length keys. The research leading to ageing methods for the major exploited species was conducted in the first half of the century, and further major advances may not be expected in ageing methods per se; however, because of emphasis on multispecies modelling, further advances can be expected concerning the ecology of fish, particularly the relationships between food intake (i.e., predation) and growth, and hence on the density dependence of growth.

In tropical waters, the specific features of the marine resources and the lack of an adequate infrastructure in the fishery sector render detailed, species-specific investigations and stock assessments less relevant than in other areas. Rather, "gross" assessment methods have to be used, such as treating a species assemblage as if it consisted of a single species. This situation makes comparative studies of the growth performance of various species very useful, especially for the identification of groups of species similar enough for them to be lumped for assessments (Pauly 1979). However, this same situation and the overall scarcity of resources for research make major advances on growth of fish (including further advances based on daily rings in otoliths) unlikely to emerge in the near future from laboratories in the developing countries of the intertropical belt.

The combination of a well-equipped laboratory, with a well-trained staff and little-studied stocks seems to be most conducive to major advances concerning the growth of fish, especially as far as cost-effective, length-based approaches are concerned. Recent work conducted in Northern Australia by K. Sainsbury and associates (Sainsbury 1984, Sainsbury and Whitelaw 1984); in Hawaii by Wetherall et al. (1986); in the South Pacific area by Brouard and Grandperrin (1984); as well as work conducted in Kuwait and discussed above, illustrate this contention.

ACKNOWLEDGMENTS

I wish to thank Drs. Z. Shehadeh, G. Morgan, C. P. Mathews, KISR for their support during several stays in Kuwait. Thanks are also due to Drs. S. Saila, J. A. Gulland and the anonymous reviewers for their editorial suggestions.

REFERENCES

ANDERSEN, K. P., AND E. URSIN. 1977. A multispecies extension to the Beverton and Holt theory of fishing, with accounts of phosphorus circulation and primary production. Meddelelser fra Danmarks Fiskeri-og Havundersogelser (N.S.) 7:319-435.

BEAMISH, R. J., AND G. A. MCFARLANE. 1986. Current trends in age determination methodology. In R. C. Summerfelt and G. E. Hall, editors, Age and growth of fish, Iowa State University Press, Ames, Iowa, USA.

BEVERTON, R. J. H., AND S. J. HOLT. 1957. On the dynamics of exploited fish populations. Fisheries Investigations Series II, Vol. 19.

BEVERTON, R.J.H., AND S.J. HOLT. 1964. Tables of yield function of fishery management. Food and Agricultural Organization of the United Nations (FAO) Fisheries Technical Paper 38, Rome.

BROUARD, F., AND R. GRANDPERRIN. 1984. Les poissons profonds de la pente récifale externe à Vanuatu. Notes et Documents d'Océanographie No. 11, ORSTOM, Vanuatu.

CASSELMAN, J. M., M. POWELL, AND R. BIETTE. 1985. Age and growth determination in fisheries - a review of the science and technology as currently practised. International Symposium on Age and Growth of Fish, Des Moines, Iowa, June 9-12, 1985, Abstract 1-3:33-34.

CHONG, K. C., M. S. LIZARDO, Z. S. DELA CRUZ, C. V. GUERRERO, AND I. R. SMITH. 1984. Milkfish production dualism in the Philippines: a multidisciplinary perspective on continuous low yields and constraints to aquaculture development. International Center for Living Aquatic Resources Management Technical Reports 15, Manila.

CSIRKE, J., AND J. F. CADDY. 1983. Production modelling using mortality estimates. Canadian Journal of Fisheries and Aquatic Science 40:43-51.

DAAN, N. 1973. A quantitative analysis of the food intake of North Sea Cod, Gadus morhua. Netherlands Journal of Sea Research 6:479-517.

GJEDREM, T. 1983. Genetic variation in quantitative traits and selective breeding in fish and shellfish. Aquaculture 33:51-72.

GJØSAETER, J., AND M. I. SOUSA. 1983. Reproduction, age and growth of the Russel's scad, Decapterus russelii (Rüppel, 1828) (Carangidae) from Sofala Bank. (Maputo) Mozambique. Revista de Investigaciones Pesqueria 8:83-107.

HAMPTON, J., AND J. MAJKOWSKI. 1986. An examination of the accuracy of the ELEFAN computer programs for length-based stock assessments. In D. Pauly and G. Morgan, editors, Length-based methods in fisheries research, International Center for Living Aquatic Resources Management Conference Proceedings, Manila, Philippines (in Press).

HELGASON, T., AND H. GISLASON. 1979. VPA-analysis with species interactions due to predation. International Council for the Exploration of the Sea, Council Meetings 1979/G:52.

INGLES, J., AND D. PAULY. 1984. An atlas of the growth, mortality and recruitment of Philippine fishes. International Center for Living Aquatic Resources Management Technical Reports 13, Manila.

JONES, R. 1984. Assessing the effects of changes in exploitation pattern using length composition data. Food and Agricultural Organization of the United Nations (FAO) Fisheries Technical Paper No. 256, Rome.

KIRKWOOD, G. P. 1983. Estimation of von Bertalanffy growth curve parameters using both length-increment and age-length data. Canadian Journal of Fisheries and Aquatic Science 40:1405-1411.

MATHEWS, C. P. 1986. Fisheries management in a tropical country: the most appropriate balance of size and age/length - related methods for practical assessments. In D. Pauly and G. Morgan, editors, Length-based methods in fisheries research, International Center for Living Aquatic Resources Management Conference Proceedings, Manila, Philippines (in Press).

MATHEWS, C. P. AND M. SAMUEL. 1985. Stock assessment of Newaiby, Hamoor and Hamra in Kuwait. Pages 67-115 in C. P. Mathews, editor, Proceedings of the 1984 Shrimp and Fin Fisheries Management Workshop, Kuwait Institute for Scientific Research, Salmiyah, Kuwait.

MESNIL, B. 1980. Théorie et pratique de l'analyse des cohortes. Revue des Travaux de l'Institut des Pêches Maritimes, 44:119-155.

MOHR, E. 1927. Bibliographie des Alters - und Wachstumsbestimmung bei Fischen. Journal du Conseil International pour l'Exploration de la Mer 2:236-258.

MOHR, E. 1930. Bibliographie des Alters-und Wachstumsbestimmung bei Fischen II. Nachträge und Fortsetzung. Journal du Conseil International pour l'Exploration de la Mer 5:88-100.

MOHR, E. 1934. Bibliographie des Alters - und Wachstumsbestimmung bei Fischen III. Nachträge und Fortsetzung. Journal du Conseil International pour l'Exploration de la Mer 9:377-391.

MORGAN, G. R. 1983. Application of length-based stock assessments to Kuwait's fish stocks. International Center for Living Aquatic Resources Management Newsletter 6(4):3-4.

MORGAN, G. R. 1985. Stock assessment of pomfret (*Pampus argenteus*) in Kuwait waters. Journal du Conseil

International pour l'Exploration de la Mer 42(1):3-10.

MORGAN, G. R. 1986. Incorporating age data into length-based stock assessment methods. In D. Pauly and G. Morgan, editors, Length-based methods in fisheries research, International Center for Living Aquatic Resources Management Conference Proceedings, Manila, Philippines (in Press).

PAULY, D. 1979. Theory and management of tropical multispecies stocks: a review, with emphasis on the Southeast Asian demersal fisheries. International Center for Living Aquatic Resources Management Studies and Reviews 1, Manila.

PAULY, D. 1981. The relationship between gill surface area and growth performance in fish: a generalization of von Bertalanffy's theory of growth. Meeresforschung/Reports on Marine Research 28:251-282.

PAULY, D. 1982. Studying single-species dynamics in a multispecies context. Pages 33-70 in D. Pauly and G. I. Murphy, editors, Theory and management of tropical fisheries, International Center for Living Aquatic Resources Management Conference Proceedings 9, Manila.

PAULY, D. 1984. Fish population dynamics in tropical waters: a manual for use with programmable calculators. International Center for Living Aquatic Resources Management Studies and Reviews 8, Manila.

PAULY, D., AND N. DAVID. 1981. ELEFAN I, a BASIC program for the objective extraction of growth parameters from length-frequency data. Meeresforschung/Reports on Marine Research 28:205-211.

POPE, J. G. 1972. An investigation of the accuracy of Virtual Population Analysis. International Commission for the Northwest Atlantic Fisheries Research Bulletin 9:65-74.

ROSENBERG, A. A., AND J. R. BEDDINGTON. 1986. Monte Carlo testing of two methods for estimating growth from length-frequency data, with general conditions for their applicability. In D. Pauly and G. Morgan, editors, Length-based methods in fisheries research, International Center for Living Aquatic Resources Management Conference Proceedings, Manila, Philippines (in Press).

SAINSBURY, K. J. 1984. Optimal mesh size for tropical multispecies trawl fisheries. Journal du Conseil International pour l'Exploration de la Mer 41:129-139.

SAINSBURY, K. J., AND A. W. WHITELAW. 1984. Biology of Peron's threadfin bream, Nemipterus peronii (Valenciennes) from the North West Shelf of Australia. Australian Journal of Marine and Freshwater Research 35:167-185.

SARJONO, I. 1980. Trawlers banned in Indonesia. International Center for Living Aquatic Resources Management Newsletter 3(4):3.

SIMPSON, A. C. 1982. A review of the data base on tropical multispecies stocks in the Southeast Asian Region. Pages 5-32 in D. Pauly and G. I. Murphy, editors, Theory and Management of Tropical Fisheries, International Center for

Living Aquatic Resources Management Conference Proceedings 9, Manila, Philippines.

SINODA, M., S. M. TAN, Y. WATANABE, AND Y. MEEMESKUL. 1979. A method for estimating the best cod-end mesh size in the South China Sea area. Bulletin of the Choshi Marine Laboratory, Chiba Univ. 11:65-80.

SPARRE, P. 1980. A goal function of fisheries (Legion analysis). International Council for the Exploration of the Sea, Council Meetings 1980/G:40.

URSIN, E. 1967. A mathematical model of some aspects of fish growth, respiration and mortality. Journal of the Fisheries Research Board of Canada 13:2355-2453.

WETHERALL, J. A., J. J. POLOVINA, AND S. RALSTON. 1986. Estimating growth and mortality in steady state fish stocks from length frequency data. In D. Pauly and G. Morgan, editors, Length-based methods in fisheries research, International Center for Living Aquatic Resources Management Conference Proceedings, Manila, Philippines (in Press).