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Stock assessment packages for programmable calculators and microcomputers: two examples, with a discussion of their potential usefulness in developing countries.

by

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Abstract

Early computer applications in temperate stock assessment are briefly reviewed, along with some properties of present lines of programmable calculators and microcomputers.

Differences and similarities between temperate and tropical fish stocks are also reviewed, emphasis being given to implications for stock assessment.

Based on the properties of the machines, the tropical fish stocks and the end-user, two packages for use in the tropics, one for HP67/97 programmable calculators, and one for the detailed analysis of length-frequency data using microcomputers, are discussed in some detail.

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Introduction

Fishery biology, particularly its applied aspect of stock assessment, became a truly quantitative science in the mid-1950s, when Beverton and Holt (1957) and Schaefer (1954, 1957) published their papers on what became the "workhorse" models for stock assessment.

The computations involved in using these models, and their variants and successors, are generally quite tedious, and early attempts were made to provide to the "user in the field" with simplified versions which could be handled with a minimum of calculations (e.g. Jones, 1957; Willimovski and Wicklund, 1963; Beverton and Holt, 1966).

In the 1960s and early 1970s, the availability of large computers led various authors to expand on the available models, adding a variable here, a species there (e.g. Paulik and Gales, 1964; Silliman, 1969; Clayden, 1972; Paulik et al, 1967, and see Paulik, 1969, for a review of the earlier literature). However, the use of large computers as a research tool in fisheries remained, as a whole, limited to a few centers of excellence, and many of the earlier leads were not followed through. One reason for this might be that these attempts were premature, as were the suggestions that exploited fish species act upon each other, for which stock assessments must account.

Another reason might be that the software used in these early ventures usually remained undocumented, unavailable, or if documented, unintelligible to other users and computers, as illustrated by the fact that none of these earlier programs are included in recent catalogues (Firestone, 1976; J. Caddy, unpublished data).

In the mid-1970s, new types of hardware became available which have changed that situation: microcomputers and programmable calculators.

Microcomputers

In spite of a wide range of available brands and models, the present types of microcomputers are essentially similar, with most capacities ranging from 2 to about 60 kilobytes, and prices ranging from about 500 to 5,000 US$. The relative uniformity of performance of the major models on the market is based on the fact that they tend to be built around the same micro-processors; more importantly (for the users) the overwhelming majority of microcomputers are programmable in easy-to-learn BASIC language.

Manufacturer-supplied software for microcomputers is generally limited to business applications and bloodthirsty "games"; scientific programs are generally standard statistical packages which can be performed with almost equal ease on programmable calculators.

Programmable calculators

Most programmable calculators are produced by two firms (Texas Instruments and Hewlett-Packard). This situation has led to a wide range of software being available to the users, both in terms of manufacturers' and users' contributed programs. This software, which covers the fields of statistics and the engineering sciences quite well, is very limited in fishery applications.

The reasons for this unfortunate state of affair are not obvious; I know of many colleagues with excellent programs for stock-assessment which could be extremely helpful if well-documented and widely accessible. As of now, published calculator programs for fishery science are the exception (but see Doubleday, 1975, 1977, or Pauly and Gaschütz, 1979) while integrated program packages are simply unavailable - at least to my knowledge.

Stock assessment in tropical waters

In addition to the well-documented institutional constraints such as lack of sufficient numbers of well-trained scientists, lack of support for these scientists, immensity of problems to handle, etc., two equally erroneous notions have almost succeeded in totally paralyzing fisheries research in the predominantly tropical waters of developing countries:

- the notion that the good old methods developed for the North Sea can be applied to tropical waters, things being essentially the same everywhere.
- the notion that the good old methods developed for the North Sea cannot be applied to tropical waters, things being essentially different in the tropics.

There are differences. Most tropical fish are small with extremely short life-spans; the bulk of the demersal fishes of the Sunda Shelf (Southeast Asia), for example, do not live beyond two or three years.

These small fish are further characterized by extremely high rates of natural mortality ($M = 2$ or beyond in many species). Consequently, they can be exploited on a sustainable basis with rates of fishing mortality that would be devastating in any temperate fishery. Because of the short life-span involved and the relative constancy of major environmental parameters, visible "annuli" are generally not formed on the otoliths or scales of most species.

The properties listed above thus result in three major features by which tropical fish differ from temperate fish:

- the scale of sizes is smaller
- the scale of time is faster
- the intensity of seasonal phenomena is reduced.

Coping with these features represents a major problem for any fishery biologist trained on the basis of temperate concepts.

This problem, however, can be tackled on the basis of the assumption that life processess are essentially intelligible (see Darwin, 1859), that accounting for the differences between tropical and temperate systems is basically a question of adjusting one's scales, and that the "trick" with tropical fish is to turn what appears to be a liability (i.e., the fact that they do not depict properties possessed by temperate fishes) into an asset.

For example, the feature that many demersal stocks in tropical waters consist of annual fishes, while preventing aging by means of annuli, allows one to follow the growth and decay of a cohort within a period of 12 months. When there are well-defined spawning seasons (as is often the case), one can then:

- determine growth from length-frequency data without encountering any of the problems of applying this method to long-lived temperate fishes (see below)
- neglect time-lag effects when fitting Schaefer-type models to catch and effort data

- estimate absolute recruit numbers from a division of yield-per-recruit into the catch
- estimate the age, in days, of individual fish

and other nice things which can't be done when working with cods.

Also, the extremely large number of species often encountered in the tropics (especially in demersal fisheries), which many authors have generally considered a major problem, may 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 (Pauly, 1979a, 1980a).

How does all this link up with the electronic gadgetry discussed above? Tentative answers follow showing how the gadgetry could help.

Programmable calculators in tropical stock assessment

From the above, a package of programs for calculators suitable for use in the tropics would have to address both common and different features of temperate and tropical fishes.

The potential user of a tropical stock assessment program package, neglecting expatriate experts and consultants, is generally young, rather inexperienced, trained in description rather than analysis, underpaid (and therefore often unmotivated) and most often, overwhelmed by the responsibilities (qualified, highly skilled scientists in developing countries are quickly promoted out of their research jobs - an acute case of Peter's Principle). Finally, our typical, potential user has no back-up library to speak of, and no mathematically-oriented friend to consult. Therefore:

- the package must pertain directly to tropical conditions The user cannot be expected to "translate" North Sea concepts
- the package must be versatile because the user cannot be expected to modify or adapt it
- the package must be self-explanatory and fully documented because the user cannot be expected to have access to the literature beyond few old copies of the California Fish and Game
- because of the biological properties of tropical fishes, (relative ease in using length-frequency data, difficulties with routine aging), the program package should include as many length-structured models as possible.

I have attempted to write a program package for programmable calculators with all these things in mind, and the result is a series of programs, implemented on HP67/97 calculators, which can be easily implemented also on HP 41C, or TI 59. (see Table 1). A fully documented manual for their use is in the making now (Pauly in press a).

Microcomputers in tropical stock assessment

The relatively low prices and ease of handling of microcomputers are major reasons why they could become widely used for stock assessment in tropical countries.

To make the most out of such microcomputers, however, the following should be considered:

Table 1. Contents of HP 67/97 presented in Pauly (in press a) and discussed in the text.

Code	Program name	No. of progr. steps and of ½ cards	Main equation(s) used	Inputs, data requirements	Output(s) and remarks	Author(s) of basic equations
FB 1	Length-weight relationships	167, 2	$W = a \cdot L^b$; $W = cf/100\ L^3$	Length and weight data, grouped or not	a, b and r^2, or condition factor (c.f.), length for weight and weight for length	see Ricker (1975)
FB 2	Trawl mesh selection	36, 1	$L_c = L_{n+1} - \Sigma y_i$	Number caught per cm class in cod-end and cover of trawl	Mean length at first capture (L_c)	see Gulland (1969)
FB 3	von Bertalanffy Plot*	199, 2	$\ln\left[1 - \left(\frac{L_t}{L_\infty}\right)\right] = Kt_o - Kt$, and similarly for weights	Size-at-age (L or W) data, grouped or not and preliminary value of asymptotic size	Values of K and t_o, and value of r^2 to use for improving L_∞ or W_∞	Bertalanffy (1934, 1938)
FB 4	Ford-Walford Plot*	130, 2	$L_{t+1} = a + bL_t$, and similarly for weights	Size at age data at equal time intervals	L_∞ (or W_∞), K and r^2. Estimate based on a geometric mean regression	see Ricker (1975)
FB 5	Gulland and Holt Plot*	167, 2	$\frac{L_2 - L_1}{t_2 - t_1} = a + b \cdot \frac{L_1 + L_2}{2}$, with $K \approx -b$ and $L_\infty \approx a/b$ and similarly for weights	Growth increments (L_1 to L_2) in time (t_1 to t_2) and similarly for weights	K and L_∞, with possibility to force L_∞ (or W_∞) through a preset value	Gulland and Holt (1959)
FB 6	Munro Plot*	108, 108, 1	$\ln(L_\infty - L_1) - \ln(L_\infty - L_2) = K(t_2 - t_1)$ and similarly for weights	Same as above, plus a preset value for asymptotic size	Values of K and their coefficient of variation, which should be low for best L_∞ (or W_∞)	Munro (unpubl. MS), in Thompson and Munro (1978)
FB 7	Fitting seasonally oscillating growth data*	448, 4	$L_t = L_\infty(1 - \exp - [K(t - t_o) + C\frac{K}{2\pi} \sin 2\pi(t - t_s)]$	Length-at-age data that oscillate seasonally and initial value of L_∞	R^2, K, t_o, t_s and C (a measure of oscillation intensity). R^2 is used to improve L_∞	Pauly and Gaschütz (1979)
FB 8	Estimating d, D and t_o*	53, 1	Empirical equations to obtain rough estimates of t_o or of parameters of generalized VBGF	See user's instruction	d and D are parameters of generalized VBGF, not discussed here	Pauly (1979b)
FB 9	Generalized VBGF and derivatives: solutions*	186, 2	$L_t^D = L_\infty^D(1 - \exp - KD(t - t_o))$ and similarly for weight; VBGF = Von Bertalanffy Growth Formula	$t \to L_t$; $L_t \to t$; $t \to W_t$, $W_t \to t$, $L_t \to dl/dt$; $W_t \to dw/dt$; etc.	Program gives quick solutions e.g., for drawing growth curves, based on generalized VBGF	Pauly (1979b, 1981)
FB 10	Total mortality from mean size I	224, 2	p. 66 and 107 in Gulland (1969)	$\bar{w}$, t_c, t_o, W_∞ and K ; $\bar{L}$, L', L_∞ and K	Z, based on mean weight (iterative solution) or on mean length	see Gulland (1969)
FB 11	Total mortality from mean size II*	106, 1	Several equations in Ssentengo and Larkin (1973)	Mean weight, length or age in catch, sample size	Z and its standard deviation	Ssentengo and Larkin (1973)
FB 12	Data for catch curves*	109, 1	VBGF for converting size to age, and other equation for correcting for bias in this conversion	Numbers at size (e.g., length-frequency samples) and growth parameters	Data points for a catch curve which can be used for estimating Z	Pauly (1980a)
FB 13	Independent estimates of M	100, 1	Empirical equation linking M to growth parameters and mean environ. temp.	L_∞, K and T or W_∞, K and T with temperature ranging between −2 to 30°C	Reasonable estimate of M usable for stock assessment purposes	Pauly (1980b)
FB 14	F & M from tagging-recapture data	83, 1	$\ln N_r = a + br$; $F = \exp. a \cdot Z/N_o (1 - \exp - Z)$	Number of recoveries per coded time interval (N_r), initial number released (N_o)	Fishing and natural mortality estimate	see Gulland (1969)
FB 15	Population sizes (Petersen's method)	146, 2	$N = Tn/m$; var $N = T^2n(n - m)/m^3$, with three variants for each of the two basic equations	T = number of fish tagged, n = total number recaptured, m = number of tagged animals recaptured	Population size (N) and its variance	see Jones (1977, Table 1)
FB 16	Leslie's equation	72, 1	$C_t/f_t = q N_o - q\Sigma t$	Catch (C_t) and corresponding effort (f_t) for a short period of time, with intensive fishing	Original population size (N_o), catchability coefficient (q)	see Ricker (1975)
FB 17	VPA and cohort analysis	124, 2	$\frac{N_{i+1}}{C_i} = \frac{(F_i + M) \cdot \exp\{-F_i + M\}}{F_i(1 - \exp\{-(F_i + M)\})}$	Catch-at-age data, terminal F, tolerance limit for error in Virtual Population Analysis (iterative solution)	Population sizes and fishing mortality based on either VPA or cohort analysis	see Pope (1972)
FB 18	Jones length cohort analysis*	89, 1	$N_1 = N_{1+\Delta t} \cdot \exp M\Delta t + C_{1-2}^{M\Delta t/2}$	Catch-at-length data for a certain period of time (e.g., one year), growth parameters	Population size and fishing mortality, by length class	Jones (1974, 1981)
FB 19	VPA with catch-at-length data*	126, 2	Similar to VPA, but generalized for use with length data.	Same as above	Same as above, except that results are exact rather than approximate	Pauly (in press b)
FB 20	Yield-per-recruit (special VBGF)	220, 2	Program uses 3 versions of basic model: Beverton and Holt (1957), Jones (1957) and Beverton and Holt (1966)	In version 1: W_∞, K, M, t_o, t_c, t_r, t_{max} & F in version 2: same except t_{max}; version 3 uses c, M/K and E	Yield-per-recruit (version 1 and 2) relative yield-per-recruit (version 3)	Beverton and Holt (1957) Jones (1957), Beverton and Holt (1966)
FB 21	Yield-per-recruit via incomplete β function*	185, 2	See Jones (1957), Wilimovsky and Wicklund (1963) or Ricker (1975)	W_∞, K, M, t_o, t_c, t_r, and F, with length weight exponent having values = 3 or ≠3,	Yield-per-recruit with allometric weight growth	Jones (1957)
FB 22	Conversion factor "k"	111, 1	Equation 17 in Pauly (1980c); with m = k	t_o, t_c, t_k, M, K and F	fraction (k) of the biomass of a fish population above age t_k.	Pauly (1980c), but see also Hempel and Sarhage (1959)
FB 23	Stock-recruitment curve of Beverton and Holt	107, 1	$R = 1/(\alpha + \beta/P)$	Parent stock sizes (P) and estimate of recruitment (R).	α, β, r^2 ; $P \to R_{HM}$ and R_{AM}	see Ricker (1975)
FB 24	Ricker's stock-recruitment curves	171, 2	$R = \alpha P \exp - \beta P$: $R = P \exp a(1 - P/P_r)$	Same as above	α, β, r^2 or a and P_r ; $P \to R_{GM}$ and R_{AM}	Ricker (1975)
FB 25	Schaefer and Fox's models	192, 2	$Y = af - bf^2$; $y = f(\exp a) \cdot \exp - bf$	Catch and effort data (both models are fitted with one entry of data)	r^2, a and b, MSY and f_{opt} for both models. Also Y for f.	see Ricker (1975) for both models
FB 26	Logistic growth curve	102, 2	$B_t = B_\infty/1 + \exp - r_m(t - t_i)$ (program also estimates r_m from empirical equation)	Biomass or number at time, and estimate of carrying capacity	r_m, t_i and r^2 ; rough estimates of r_m also estimated from adult body weights	see Ricker (1975) and Blueweiss et al. (1978) for r_m
FB 27	Yields from two interacting species	162, 2	$Y_T = aF_P - bF_P^2 + c_1F_PF_Q + dF_Q - eF_Q^2 + c_2F_PF_Q$	Constants a, b, d, e and interaction terms c_1 and c_2. Values of F_P and F_Q	Total yield (Y_T) and partial yields Y_P and Y_Q are estimated, along with MSY of system (program can be used only to simulate multispecies system, not to fit empirical data)	see (Pope (1979)
Complete Fishery Biology Package:		3923.44				

*Note: Programs with an asterisk can be used in conjunction with both the special and the generalized VBGF, as defined in Pauly (1981).

- there is no point purchasing and programming a microcomputer to perform tasks which can be handled as well by programmable calculators
- software must be available which is designed for performing jobs likely to be important when tropical fishes and fisheries are considered.

Hence, standard statistical and most stock assessment procedures like those in Table 1 are not useful.

There are, on the other hand, a number of applications in which the special abilities of a computer can be put to good use in areas important for tropical stock assessment. Examples of such areas are:

- the detailed analysis of length-frequency data
- the analysis of trawl survey data
- the simulation of multispecies systems.

Analysis of length-frequency data

As mentioned above, length-frequency data and their analysis are extremely important in tropical fishery biology; a vast proportion of information on the biology of tropical fishes was obtained by the careful analysis of such data.

However, the methods used are essentially refinements of the approach pioneered in 1892 by Petersen. Recently, a radical departure from the classical methods (which often involved the use of sophisticated programs, e.g., NORMSEP or ENORMSEP, for the separation of multi-peaked, length-frequency samples into normally distributed sets) was proposed (Pauly and David, 1980, 1981), which led to a package of 3 ELEFAN (for Electronic LEngth Frequency ANalysis) programs, all of which extract different information from length-frequency samples:

ELEFAN I : Extracts growth parameter values from a (set of) length-frequency sample(s). The parameters estimated are L_∞, K, C and WP, the last two parameters referring to a seasonally oscillating version of the von Bertalanffy growth formula, where the dimensionless parameter C expresses the intensity of the growth oscillations and generally ranges from about zero (in tropical waters) to 1 (in temperate waters), while WP (Winter Point) is the time of the year where growth is slowest (Fig. 1).

Important properties of the approach used in ELEFAN I are that no assumptions are made concerning the age-structure (e.g., the number of year classes) of the data set investigated, and that the goodness of fit is estimated by means of a parameter analogous to a coefficient of determination.

ELEFAN II : Derives a catch curve from length-frequency data and a set of growth parameter values (L_∞ and K), estimates Z from this catch curve, and subtracts from this estimate a value of M obtained from the empirical equation of Pauly (1980c) to obtain F.

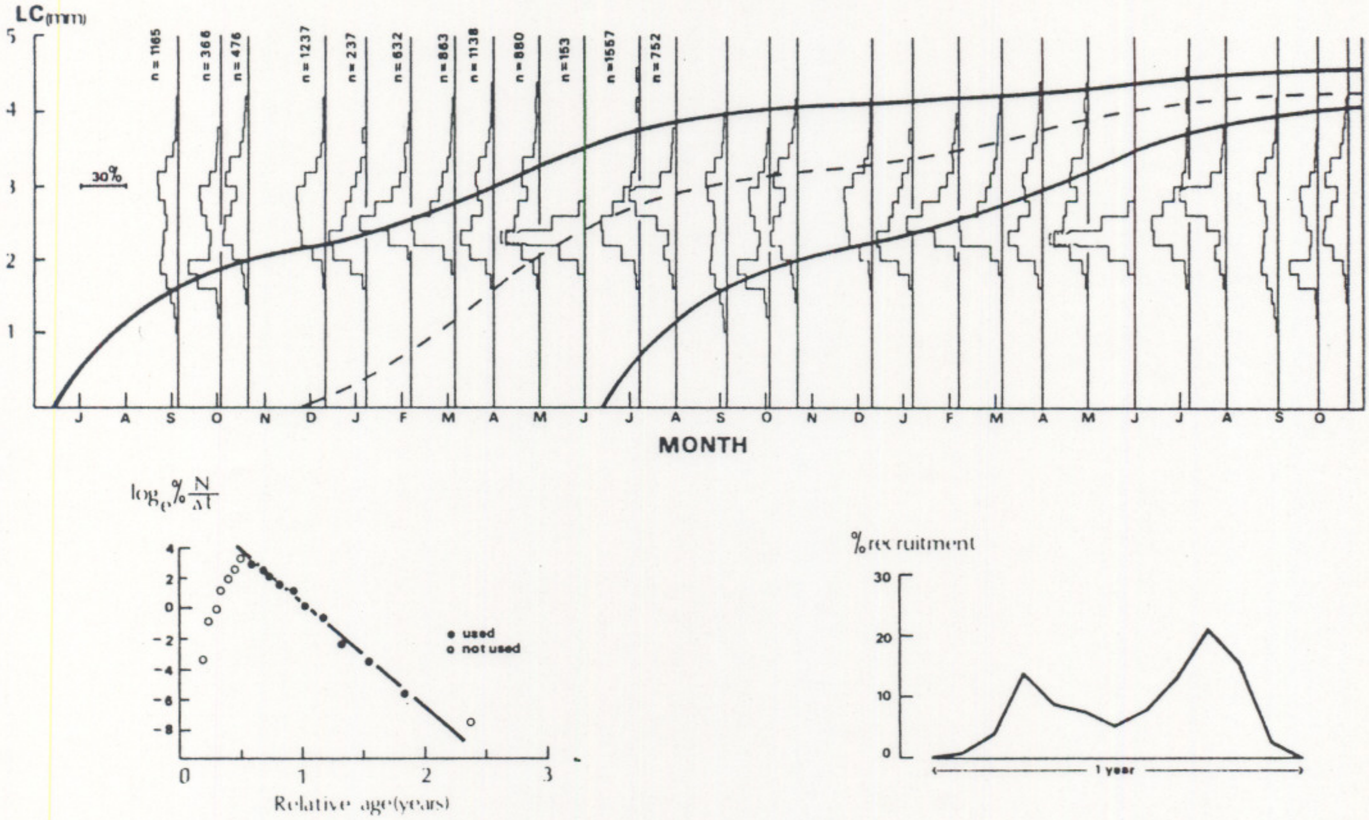

Fig. 1. Example of the use of the ELEFAN I and II programs.

Above: Length-frequency data of Penaeus duorarum (♂) off Tortugas, Florida (adapted from Iversen et al, 1960), with growth curves fitted by ELEFAN I. The main growth curve has the parameter $L_\infty = 47$ mm (carapace length), K = 1.45, C = 0.60 (the parameter C express the intensity of seasonal growth oscillations and takes value usually ranging between 0 and 1) and Winter Point = 0.93 (this parameter expresses the fraction of the year when growth is slowest, here December); the main growth curve and the set of length-frequency samples are drawn twice for better visualization of the growth pattern. The dotted line has the parameter $L_\infty = 47$ mm, K = 1.2, C = 0.54 and WP = 0.87. It is emphasized that the growth curves were fitted to the length-frequency data without any assumption as to the number of age classes represented in the samples or the age corresponding to the various peaks. The goodness of fit for the main line is ESP/ASP = 0.35 and ESP/ASP = 0.26 for the dotted line; hence, 61% of the peaks available in the samples are explained by the curves.

Below left: Length-converted catch curve for P. duorarum, based on the length-frequency data presented above and the growth parameters estimated by ELEFAN I. The curve, as output by ELEFAN II corrects for the non-linearity of length growth in shrimps, and allows for an estimate of Z = 7.07, with $r^2 = 0.991$.

Below right: Recruitment pattern for the P. duorarum stock in question, as estimated by ELEFAN II. Note demonstration of two major recruitment peaks, corresponding to the two growth lines above.

The program also derives a newly defined "recruitment pattern" which depicts the seasonality of recruitment in the length-frequency sample(s) at hand (Fig. 1). Seasonality of growth must be taken into account when deriving recruitment patterns and this part of the program is therefore best implemented following the use of ELEFAN I.

ELEFAN III : This program, which was developed in cooperation with J. Pope of Lowestoft (U.K.), uses a length-weight relationship, length-frequency data, and matching catch data in weight to estimate catches in number by length class, then runs two different Virtual Population Analyses on the catch-at-length data. Results are estimates of population sizes, estimates of absolute recruitment and an F-matrix.

Documentation and program listings are available for ELEFAN I and II; the documentation for ELEFAN III is presently being prepared. The programs are in Radio Shack's BASIC II and have been implemented on Tandy's TRS 80 (Model 1, 16K); no peripheral accessories except cassette drives are needed for running these programs.

I believe that the three programs combine properties which make them ideal for use in developing countries:

- they are implementable on some of the cheapest microcomputers available
- they are fully interactive, i.e., they prompt inputs (including corrections of inputs)

- they make use of length-frequency data, which are the data most readily available in developing countries and which are easiest and cheapest to obtain
- they perform tasks which cannot be performed by paper-and-pencil methods (unless one is willing to spend months on them) or by programmable calculators
- they estimate parameters which are crucial to fishery management (e.g. growth and total, natural and fishing mortalities).

Analysis of trawl survey data

The late 1950s and early 1960s saw the onset of trawling on a large scale in Southeast Asia, first in the Philippines and the Gulf of Thailand, then in the neighboring countries, e.g., Malaysia and Indonesia. The development of these trawl fisheries was in several cases paralleled by extensive series of research trawl surveys, particularly in the Gulf of Thailand, the results of which have been used to assess the impact of the fishery on the stocks.

However, most models presently used in tropical stock assessment simply cannot utilize the large amount of data gathered during such surveys. Also, most research laboratories have no data-processing capability.

Attempts are presently being made in two Southeast Asian countries to remedy this situation by storing the accumulated data of earlier surveys into large computers outside the research laboratories involved.

Possibly, the best approach is to use microcomputers for storing and analyzing such data, major reasons being:

- <u>costs</u>: once a microcomputer has been bought, it costs almost nothing to run
- <u>training effects</u>: a fishery biologist who has no opportunity of "playing" her- or himself with the data (because they are analyzed at a distant computer center) is very unlikely to learn much from the analysis.

Because of these favorable properties of microcomputers, ICLARM has recently commissioned a program package for the filing and analysis of trawl survey data, to be implemented on a microcomputer (diskette) system. Major properties of this system will be:

- storage and manipulation of detailed catch and oceanographic data by interactive promptings
- computation of mean standardized catch rates, by species, species groups and strata
- manipulation of length-frequency samples to obtain overall samples by strata, and output of length-frequency data for use by the ELEFAN package
- computation from the standardized catch-per-effort data of diversity and other indices such as are used in theoretical ecology
- cluster analysis to identify communities (based on similarities in catch composition).

The last two points, I believe, are extremely important because they offer a solution to the problem that there is at present virtually no use for the detailed c/f data by species (in weight and numbers) available from scientific surveys and which generally cannot be used in the crude models available (e.g. total biomass Schaefer model, or "$P_y = 1/2\ M \cdot B_o$").

Simulation of multispecies systems

Microcomputer-based programs can also be used to simulate the behaviour of tropical multispecies stocks under exploitation. This was demonstrated quite elegantly by Larkin and Gazey (in press) who wrote a simulation model of the Gulf of Thailand trawl fishery based on a description by Pauly (1979a) and used it to test the validity of the latter and that in Pope (1979) of the interactions occurring between stocks in the Gulf of Thailand. As Larkin and Gazey (in press) suggest, this approach may be helpful even when the data base is scanty (data are then replaced by "outrageous" assumptions) because it allows detection of gaps both in the data sets and in our understanding of the system in question.

Summary

- The early phase of computer-based research in stock assessment, although it contributed to increasing our understanding of the stocks in question did not lead to a body of well-documented widely available standardized software.
- Programmable calculators can handle most of the stock assessment and standard statistics commonly used by fishery biologist, and there is, therefore, little need to clog-up computer systems with such software.
- Stock assessment in the tropics must take peculiarities of tropical fishes into account; this should imply, among other things, the development and use of more length-structured models.

- Stock assessment packages for programmable calculators and microcomputers should be written such that the potential end-user can use them. This implies, among other things, versatility of the programs and their full documentation.
- Among the jobs relevant to tropical stock assessment that are easily handled by microcomputers are the detailed analysis of length-frequency data, the analysis of scientific survey data and the simulation of multispecies fisheries.

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Notes:

Table 1. Contents of HP 67/97 presented in Pauly (in press a) and discussed in the text.

Code	Program name	No. of progr. steps and of ½ cards	Main equation(s) used	Inputs, data requirements	Output(s) and remarks	Author(s) of basic equations
FB 1	Length-weight relationships	167, 2	$W = a \cdot L^b$; $W = cf/100\ L^3$	Length and weight data, grouped or not	a, b and r^2, or condition factor (c.f.), length for weight and weight for length	see Ricker (1975)
FB 2	Trawl mesh selection	36, 1	$L_c = L_{n+1} - \Sigma y_i$	Number caught per cm class in cod-end and cover of trawl	Mean length at first capture (L_c)	see Gulland (1969)
FB 3	von Bertalanffy Plot*	199, 2	$\ln\ [1 - (\frac{L_t}{L_\infty})] = Kt_o - Kt$, and similarly for weights	Size-at-age (L or W) data, grouped or not and preliminary value of asymptotic size	Values of K and t_o, and value of r^2 to use for improving L_∞ or W_∞	Bertalanffy (1934, 1938)
FB 4	Ford-Walford Plot*	130, 2	$L_{t+1} = a + bL_t$, and similarly for weights	Size at age data at equal time intervals	L_∞ (or W_∞), K and r^2. Estimate based on a geometric mean regression	see Ricker (1975)
FB 5	Gulland and Holt Plot*	167, 2	$\frac{L_2 - L_1}{t_2 - t_1} = a + b \cdot \frac{L_1 + L_2}{2}$, with $K \approx -b$ and $L_\infty \approx a/b$ and similarly for weights	Growth increments (L_1 to L_2) in time (t_1 to t_2) and similarly for weights	K and L_∞, with possibility to force L_∞ (or W_∞) through a preset value	Gulland and Holt (1959)
FB 6	Munro Plot*	108, 108, 1	$\ln\ (L_\infty - L_1) - \ln\ (L_\infty - L_2) = K\ (t_2 - t_1)$ and similarly for weights	Same as above, plus a preset value for asymptotic size	Values of K and their coefficient of variation, which should be low for best L_∞ (or W_∞)	Munro (unpubl. MS), in Thompson and Munro (1978)
FB 7	Fitting seasonally oscillating growth data*	448, 4	$L_t = L_\infty(1 - \exp - [K\ (t - t_o) + C\frac{K}{2\pi} \sin 2\pi\ (t - t_s)]$	Length-at-age data that oscillate seasonally and initial value of L_∞	R^2, K, t_o, t_s and C (a measure of oscillation intensity). R^2 is used to improve L_∞	Pauly and Gaschütz (1979)
FB 8	Estimating d, D and t_o*	53, 1	Empirical equations to obtain rough estimates of t_o or of parameters of generalized VBGF	See user's instruction	d and D are parameters of generalized VBGF, not discussed here	Pauly (1979b)
FB 9	Generalized VBGF and derivatives: solutions*	186, 2	$L_t^D = L_\infty^D (1 - \exp - KD\ (t - t_o))$ and similarly for weight; VBGF = Von Bertalanffy Growth Formula	$t \to L_t$; $L_t \to t$; $t \to W_t$, $W_t \to t$, $L_t \to dl/dt$; $W_t \to dw/dt$; etc.	Program gives quick solutions e.g., for drawing growth curves, based on generalized VBGF	Pauly (1979b, 1981)
FB 10	Total mortality from mean size I	224, 2	p. 66 and 107 in Gulland (1969)	$\bar{w}$, t_c, t_o, W_∞ and K; $\bar{L}$, L', L_∞ and K	Z, based on mean weight (iterative solution) or on mean length	see Gulland (1969)
FB 11	Total mortality from mean size II*	106, 1	Several equations in Ssentengo and Larkin (1973)	Mean weight, length or age in catch, sample size	Z and its standard deviation	Ssentengo and Larkin (1973)
FB 12	Data for catch curves*	109, 1	VBGF for converting size to age, and other equation for correcting for bias in this conversion	Numbers at size (e.g., length-frequency samples) and growth parameters	Data points for a catch curve which can be used for estimating Z	Pauly (1980a)
FB 13	Independent estimates of M	100, 1	Empirical equation linking M to growth parameters and mean environ. temp.	L_∞, K and T or W_∞, K and T with temperature ranging between −2 to 30°C	Reasonable estimate of M usable for stock assessment purposes	Pauly (1980b)
FB 14	F & M from tagging-recapture data	83, 1	$\ln N_r = a + br$; $F = \exp. a \cdot Z/N_o (1 - \exp - Z)$	Number of recoveries per coded time interval (N_r), initial number released (N_o)	Fishing and natural mortality estimate	see Gulland (1969)
FB 15	Population sizes (Petersen's method)	146, 2	$N = Tn/m$; $\text{var } N = T^2 n\ (n - m)/m^3$, with three variants for each of the two basic equations	T = number of fish tagged, n = total number recaptured, m = number of tagged animals recaptured	Population size (N) and its variance	see Jones (1977, Table 1)
FB 16	Leslie's equation	72, 1	$C_t/f_t = q\ N_o - q\Sigma t$	Catch (C_t) and corresponding effort (f_t) for a short period of time, with intensive fishing	Original population size (N_o), catchability coefficient (q)	see Ricker (1975)
FB 17	VPA and cohort analysis	124, 2	$\frac{N_{i+1}}{C_i} = \frac{(F_i + M) \cdot \exp \{-F_i + M\}}{F_i(1 - \exp \{-(F_i + M)\}}$	Catch-at-age data, terminal F, tolerance limit for error in Virtual Population Analysis (iterative solution)	Population sizes and fishing mortality based on either VPA or cohort analysis	see Pope (1972)
FB 18	Jones length cohort analysis*	89, 1	$N_1 = N_{1+\Delta t} \cdot \exp M\Delta t + C_{1-2}^{M\Delta t/2}$	Catch-at-length data for a certain period of time (e.g., one year), growth parameters	Population size and fishing mortality, by length class	Jones (1974, 1981)
FB 19	VPA with catch-at-length data*	126, 2	Similar to VPA, but generalized for use with length data.	Same as above	Same as above, except that results are exact rather than approximate	Pauly (in press b)
FB 20	Yield-per-recruit (special VBGF)	220, 2	Program uses 3 versions of basic model: Beverton and Holt (1957), Jones (1957) and Beverton and Holt (1966)	In version 1: W_∞, K, M, t_o, t_c, t_r, t_{max} & F in version 2: same except t_{max}; version 3 uses c, M/K and E	Yield-per-recruit (version 1 and 2). relative yield-per-recruit (version 3)	Beverton and Holt (1957), Jones (1957), Beverton and Holt (1966)
FB 21	Yield-per-recruit via incomplete β function*	185, 2	See Jones (1957), Wilimovsky and Wicklund (1963) or Ricker (1975)	W_∞, K, M, t_o, t_c, t_r, and F, with length weight exponent having values = 3 or ≠3,	Yield-per-recruit with allometric weight growth	Jones (1957)
FB 22	Conversion factor "k"	111, 1	Equation 17 in Pauly (1980c); with m = k	t_o, t_c, t_k, M, K and F	fraction (k) of the biomass of a fish population above age t_k.	Pauly (1980c), but see also Hempel and Sarhage (1959)
FB 23	Stock-recruitment curve of Beverton and Holt	107, 1	$R = 1/(\alpha + \beta/P)$	Parent stock sizes (P) and estimate of recruitment (R).	α, β, r^2; $P \to R_{HM}$ and R_{AM}	see Ricker (1975)
FB 24	Ricker's stock-recruitment curves	171, 2	$R = \alpha P \exp - \beta P$: $R = P \exp a\ (1 - P/P_r)$	Same as above	α, β, r^2 or a and P_r; $P \to R_{GM}$ and R_{AM}	Ricker (1975)
FB 25	Schaefer and Fox's models	192, 2	$Y = af - bf^2$; $y = f\ (\exp a) \cdot \exp - bf$	Catch and effort data (both models are fitted with one entry of data)	r^2, a and b, MSY and f_{opt} for both models. Also Y for f.	see Ricker (1975) for both models
FB 26	Logistic growth curve	102, 2	$B_t = B_\infty/1 + \exp - r_m\ (t - t_i)$ (program also estimates r_m from empirical equation)	Biomass or number at time, and estimate of carrying capacity	r_m, t_i and r^2; rough estimates of r_m also estimated from adult body weights	see Ricker (1975) and Blueweiss et al. (1978) for r_m
FB 27	Yields from two interacting species	162, 2	$Y_T = aF_P - bF_P^2 + c_1F_PF_Q + dF_Q - eF_Q^2 + c_2F_PF_Q$	Constants a, b, d, e and interaction terms c_1 and c_2. Values of F_P and F_Q	Total yield (Y_T) and partial yields Y_P and Y_Q are estimated, along with MSY of system (program can be used only to simulate multispecies system, not to fit empirical data)	see (Pope (1979)
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