

## Software Tools for Management of Tropical Aquatic Resources<sup>1</sup>

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**Abstract.** — Major software to support research towards the management of living aquatic resources in tropical developing countries, notably the ELEFAN system, ECOPATH II, and FishBase, are presented (and some lesser programs as well) along with their conceptual background and details on their dissemination and use. The paper concludes with a discussion of some problems arising when a research institution disseminates and attempts to maintain complex software packages.

Work on the software presented in this contribution began in the late 1970s, at a time when sophisticated programmable calculators were beginning to put into the hands of fisheries scientists some of the computing power then exclusively available to those with access to mainframe computers. Later came personal computers, which made mainframes largely obsolete for fisheries scientists and made it possible for fisheries scientists working in tropical developing countries to store and analyze data using computers, as did their colleagues in developed countries.

The opportunity that these developments created was seized, and an early result was a set of integrated software packages for programmable calculators incorporating most of the stock assessment models then available (Pauly 1981a, 1981b, 1984; Vakily et al. 1986; Palomares and Pauly 1987). However, despite their initial success, this software and the hardware it depended on began to become obsolete by the mid-1980s with the widespread availability of personal computers.

### The Growth of ELEFAN (1980 –1992)

The best known of the products to be discussed here is the ELEFAN I program for the estimation of growth parameters from length-frequency data.

Initially, ELEFAN I was a relatively simple computer program, implemented on an impressive 16K(!) microcomputer fed via cassette tapes. In spite of its limitation, the ELEFAN I program caught on, for a number of reasons:

— it was straightforward and easy to understand;

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- it was better than the subjective paper-and-pencil methods then predominantly used;
- it required length-frequency data, of which immense quantities had already been gathered for decades in many laboratories throughout the world (Figure 1); and/or which can be straightforwardly and cheaply obtained (Morgan 1983; Mathews 1987).

The adoption of ELEFAN I and its gradual transition into a standard method did not proceed smoothly. Many colleagues, for example, those involved in teaching

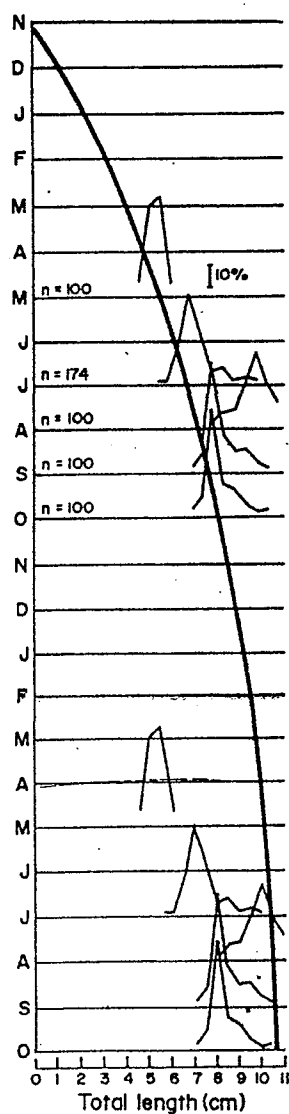


FIGURE 1.— The first published graph illustrating the ELEFAN I program, showing a set of length-frequency samples sequentially arranged in time, with growth curve fitted by the program. The curve, which pertains to slipmouths (*Leiognathus bindus*) caught off Calicut, India, has the parameters  $L_{\infty} = 12.2$  cm and  $K = 1.3/\text{year}$ , and is based on data originally published by Balan (1967).

fisheries biology, had to be convinced that this approach would not mislead its users, or even prevent them from doing their own "thinking" (Pauly 1987).

A major step in overcoming these fears was an international conference held in February 1985 in Mazarra del Vallo, Sicily, which was co-sponsored by the International Center for Living Aquatic Resources Management (ICLARM), the Kuwait Institute of Scientific Research (KISR), the Food and Agriculture Organization of the United Nations (FAO), and the Italian Consiglio Nazionale delle Recherche (ICNR). Several contributions presented at this conference and subsequently included in the proceedings (Pauly and Morgan 1987) dealt explicitly with the ELEFAN I program. They helped define the conditions under which ELEFAN I can be expected to produce reliable results and, conversely, identify data sets to which this method should *not* be applied, thus reducing the risk of misuse (see also Isaac 1990).

Also, a number of approaches for preliminary data treatment and supporting routines were identified that improved the estimation of parameters using ELEFAN I, for example, the Wetherall plot for independent estimation of the asymptotic length of fishes (Wetherall 1986; Wetherall et al. 1987) and the (partial) correction of data for selection effects. Following this conference, two software packages were developed that incorporated these findings:

- the one-diskette "Kiel version" of ELEFAN for either Apple II (CP/M) or IBM PC and their compatibles (Brey et al. 1988);
- the 12-diskette "Compleat ELEFAN" for the IBM XT and their compatibles (Gayanilo et al. 1987).

Both the Kiel version and the Compleat ELEFAN are rather popular throughout the world (Figure 2) with, to date, over 150 sets distributed of the former package, and over 300 sets of the latter, not accounting for unregistered copies. The reasons could be: (1) the programs are user-friendly and (2) they not only lead to the estimation of growth parameters, but also allow one to "dig deeper" into the available length-frequency data once the growth analysis is complete, and to estimate from them parameter values for a number of processes (e.g., seasonal growth oscillations, mortality and gear selection). These are parameters fishery biologists and aquatic ecologists are interested in but, more often than not, would not know how to estimate from length-frequency data, especially in tropical contexts.

The Compleat ELEFAN also includes straightforward routines for: (1) estimating total, natural, and fishing mortalities; (2) identifying and describing seasonal pulses of recruitment; and (3) performing standard and non-standard stock assessments such as yield-per-recruit analyses, or age- and length-structured virtual population analyses.

The FAO, through its DANIDA-funded Training Courses in Tropical Fish Stock Assessment, also developed a software package for analysis of length-frequency data—the LFSA package (Sparre 1987). Participants of numerous courses held in Asia, Africa, South America, and Europe were introduced to both LFSA and the Compleat ELEFAN, although they overlapped in well over half of their routines (Venema et al. 1988).

In 1989, a reassessment of this duplication led the Marine Resource Services of FAO and ICLARM to sign a Letter of Agreement involving the merging of these two softwares into a new software called FISAT (Pauly and Sparre 1990), to be released in the first half of 1994. Although the ELEFAN I routine for estimation of growth parameters is part of FISAT, this development means the discontinuation of the

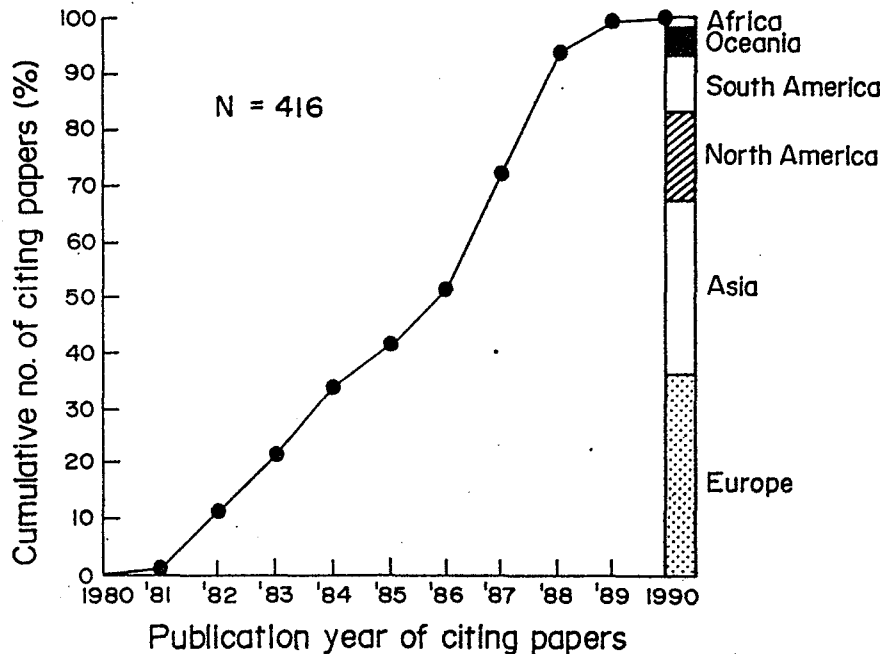


FIGURE 2. — By early 1990, the publications referring to the ELEFAN programs had been cited at least 846 times in at least 416 citing papers, reports, theses, etc. This impact is illustrated here as a temporal trend, and by major regions of the world (from Pauly and Gayanilo 1990).

integrated ELEFAN packages. However, FiSAT keeps the “feel” of the Compleat ELEFAN, i.e., it includes high-resolution interactive graphics, and text-rich, self-documenting menus.

The release of the new software is seen as a milestone for establishing length-based assessment as a major component of quantitative fisheries science. Also of importance is that this calls for support and information of its practitioners. To supply this information the Network of Tropical Fisheries Scientists (NTFS) was established a decade ago and it has by now expanded to include 1,300 members in more than 80 countries, connected through *Fishbyte*, formerly an independent newsletter, now a section of *Naga, the ICLARM Quarterly*. Graduates working on tropical fisheries are encouraged to join the NTFS (c/o ICLARM).

#### ECOPATH II—A Software for Construction of Ecosystem Models and Food Web Analysis

The ECOPATH II approach and software were developed from the ECOPATH model of Polovina (1984), and were designed to facilitate the construction and parametrization of trophic ecosystem models. The software includes routines for balancing of flows in an ecosystem and for estimating indices for ecosystem characterization (ascendency, cycling, efficiencies, etc.), primarily estimated from network analysis based on the theory developed by Ulanowicz (1986).

Basically, the ECOPATH approach is to model an ecosystem using a set of simultaneous linear equations, one for each group (i) in the system (Christensen and Pauly 1992a), i.e., production by (i) – all predation on (i) – non-predation

losses of (i) – export of (i) = 0, for all (i) thus assuming mass balance. This can also be put as

$$P_i - B_i M2_i - P_i(1 - EE_i) - EX_i = 0 \quad (1)$$

Where  $B_i$  is the biomass of (i),  
 $P_i$  is the production of (i),  
 $M2_i$  is the predation mortality of (i),  
 $EE_i$  is the ecotrophic efficiency of (i),  
 $(1 - EE_i)$  is the “other mortality”, and  
 $EX_i$  is the export of (i).

In this equation, the  $M2$  term links the components of the ecosystem—predators with prey. Knowledge of the diet and consumption rates of predators can then be used to estimate how much the prey groups must produce to meet the predators’ requirements. As all important trophic flows are to be included in the analysis, this linking makes it possible to estimate a “missing” parameter for all groups in an analysis, one of the most noteworthy features of analyses performed with ECOPATH II (see Figure 3).

Indeed, the main reason for using an approach like the ECOPATH is that it forces the user to describe all the important components of an ecosystem, how these interact, and how much each of them produces and consumes. However, the data required to do this are basically those that fisheries biologists usually gather or can easily find in the literature. The ECOPATH analysis puts these data into a rigid network and points to, for example,

- areas where more information is needed;
- the compatibility of existing data;
- the ways in which different groups of a system impact each other, and thus the relative trophic importance of the different groups; and
- the efficiency of the energy transfers in a system.

ECOPATH modeling should therefore be considered a first and necessary step in ecosystem modeling. It creates an overview of a system. Existing data are assembled, analyzed, and evaluated and, most importantly, the system leads the way toward more sophisticated management methods (which invariably turn out to require the same data as ECOPATH, plus a great deal more).

Partly for this reason, and partly because of its simplicity, the ECOPATH II system has been applied to a large number of ecosystems worldwide, and some 50 system descriptions have been published, mostly in “Trophic Models of Aquatic Ecosystems”, the proceedings of a Theme Session of the International Council for the Exploration of the Sea, held in October 1990 (Christensen and Pauly 1993).

User’s manuals for this public domain system are available in English, French, and Spanish (Christensen and Pauly 1992b, 1992c, 1992d), and a Portuguese version is under preparation. ECOPATH II has been distributed to some 350 scientists or groups of scientists worldwide.

#### FishBase as a Computerized Encyclopedia

FishBase is a joint project between ICLARM, FAO, and a large number of collaborating institutions and individual scientists. The project’s long-term aims are



to create and widely distribute a large relational database of published information on all known fish species in the world (Froese 1990; Pauly and Froese 1991).

FishBase was created with the help of a relational database management program (DataEase 4.5) that permits quick and easy development of applications by project staff. Through the resulting preprogrammed forms, users can communicate with the database through a "query by example" process. Thus, fairly complex searches can be performed by the users without knowledge of any programming language. This important feature will be maintained when FishBase is transferred to another, WINDOWS-compatible database program.

The bulk of the information incorporated in FishBase is entered either from multiple choice fields or as numerical data (Figure 4). However, the forms were designed so that some qualitative data can also be entered in the form of free text.

The structure of FishBase covers all aspects of ichthyology, notably:

- a) systematics: valid scientific names as established in close cooperation with the FAO Species Identification and Data Programme (Fischer 1976) and with reference to the California Academy of Science's "Recent Genera of Fishes" (Eschmeyer 1990), now also a component of FishBase;
- b) common names in English, French, and Spanish as standardized by FAO and the American Fisheries Society (Robins et al. 1991);
- c) distribution: by FAO fisheries area, by country, by habitat type and by latitude and longitude for occurrence records in museums, or from other sources, such as the *R/V Dr. Fridtjof Nansen* survey project (Strømme 1992);
- d) commercial importance: as target or bait species in industrial, small-scale, or sport fisheries, in aquaculture, or in the aquarium trade;
- e) morphology: morphometric and meristic characters of larvae and adults (with digitized black-and-white or colored fish pictures); features of eggs, gill surface area, striking features, etc.;
- f) physiology: oxygen and food consumption of various life stages, swimming speed, and related items;
- g) ecology: relative abundance, ecological niches of larvae and adults, behavior, reproduction and life history (including data on egg development times), diet composition, predators, competitors;
- h) population dynamics: growth parameters, natural mortality rates, length-weight relationships, and related items;
- i) genetics (allele frequencies, cellular DNA contents, etc.) and aquaculture systems (including genetic features of the strains used therein);
- j) pathology: diseases and their symptoms, parasites, etc.;
- k) species introductions between countries (from Welcomme 1988 and other sources); and
- l) the annotated, language-indexed bibliographic references documenting all information in FishBase.

A  $\beta$ -release version of FishBase on diskettes, covering 8,000 fish species, i.e., a third of all fish species in the world, has been released and documented (Froese et al 1992).

The next product will be a database on a low-cost CD-ROM (laser) disk for IBM and compatible personal computers, building FishBase with other software presented in this contribution, and distributed in annual updates, starting in late 1994. This disk will mainly be used by scientists (fisheries biologists, environmentalists, etc.) but will also be of use to managers, libraries, and educators of all levels.

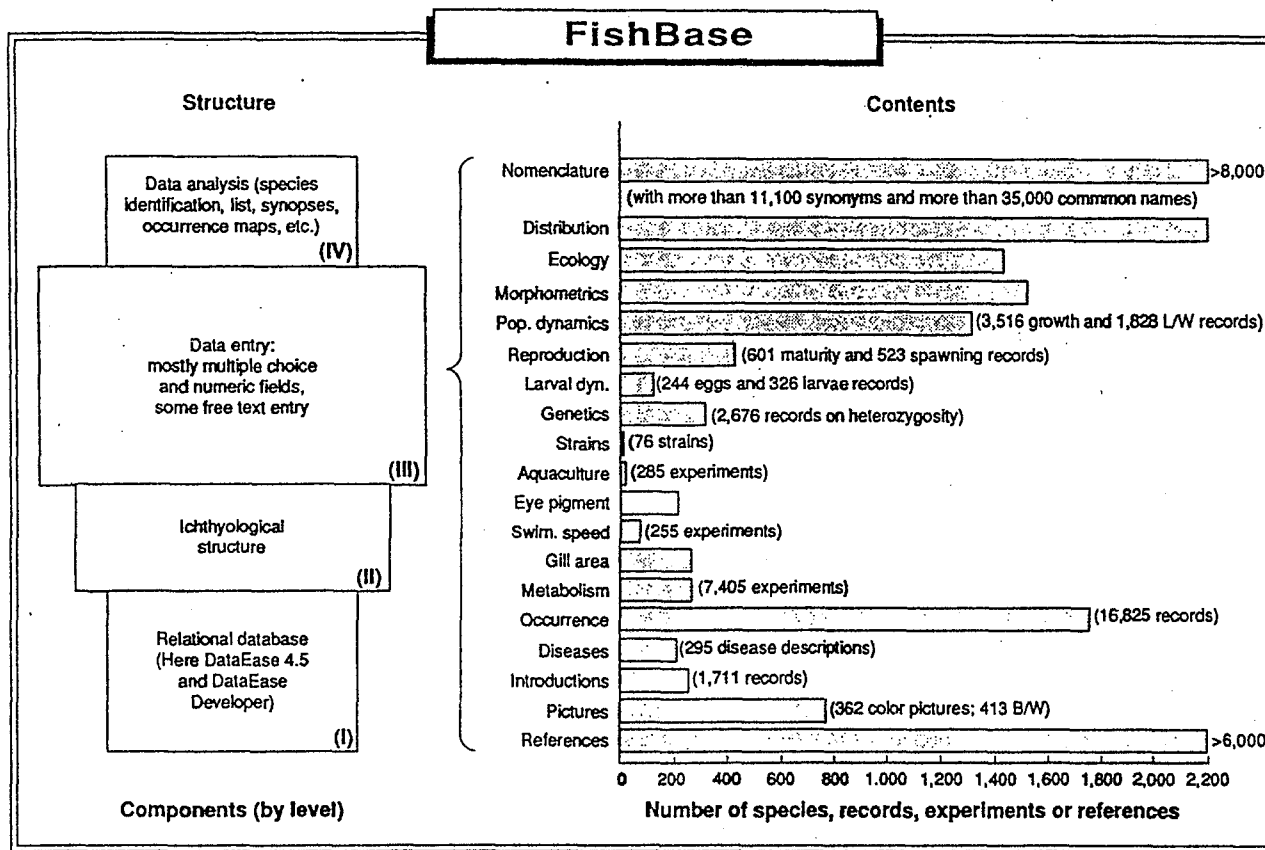


FIGURE 4.— Structure and contents of FishBase:

- Left: Level I is represented by a commercial database, which can produce executable files that can be distributed royalty-free; Level II is the ichthyological structure, created in cooperation with various specialists throughout the world; Level III consists of the entries themselves, of which only a small fraction—the free text entries—will require translation when preparing versions of FishBase for languages other than English. Level IV consists of various graphical and statistical routines for the presentation and comparative analysis of the quantitative and categorical data entered into FishBase, including MAPPER for georeferenced data.
- Right: Information incorporated in FishBase as of late 1993. Note that the bars refer to the number of species (except for references). Numbers in parentheses indicate the number of records entered. There can be several records for one species.

### Miscellaneous Other Softwares

Besides the major software presented above, a number of smaller programs were developed as part of the ICLARM Software Project to support tropical fisheries (including aquaculture) research:

- a spreadsheet program for estimating growth parameters from growth increment data, with emphasis on aquaculture situations (Vakily 1988);
- a program called MAXIMS for the estimation of ration, stomach evacuation rate, and related parameters from a 24 hour cycle of stomach contents data (Jarre et al. 1990, modified from Sainsbury (1986) and further documented in Jarre et al. 1991).
- a program called GOTCHA for the construction of catch curves (for estimation of total mortality) from length data *when growth is seasonal* (Gayanilo 1991, based on Pauly 1990)—a problem not considered in earlier softwares (and whose solution is also incorporated in FiSAT);
- CDS-Assistant, a program facilitating the use and expanding the capability of the CDS-ISIS bibliographic software released by UNESCO (Gayanilo 1990).

Other programs of potentially wide usefulness are presently being developed, notably in conjunction with the Level IV (analytic) routines of FishBase (Figure 4), as well as "Low-Level" Geographic Information Systems (LL-GIS), for displaying spatially structured information stored on standard spreadsheets. The former include MAPPER, a LL-GIS for displaying the geo-referenced data in FishBase (Coronado and Froese 1993). Three realizations of the latter approach are available:

- SIGMAP (Sistema de Information Geographico del Mar Peruano), for displaying (1) the results of a simulation model of the pelagic fish resources of the Peruvian Upwelling Ecosystem (Jarre et al. 1991) and (2) the spatially structured components of a large data set describing that system (see below);
- B:RUN, a program for display of geographic information on the shelf and fisheries resources of Brunei Darussalam, Southeast Asia, which incorporates a spatially based bioeconomic simulation of trawling off Brunei;
- SIERRA, same as the B:RUN, but for Sierra Leone, West Africa (Vakily 1992).

Finally, various databases were assembled for dissemination in diskette form. These include: bibliographies (Jarre et al. 1989; Gervis 1991) a training and education directory (Carigma and Morales 1989); the results of the aquaculture experiments documented in Prein et al. (1993); and a 15 diskette data set on the Peruvian upwelling ecosystem, covering the over 30 years' worth of meteorological, oceanographic, biological and fisheries-related time series (Palomares et al. 1989) forming the basis of the contributions included in the books edited by Pauly and Tsukayama (1987) and Pauly et al. (1989).

### Discussion

The very existence at a research institution of a software project for fisheries scientists raises a fundamental question: should fisheries scientists even use software (for fisheries management) of which they do not know all the constructional and computational aspects? Some suggest, rather strongly, that fisheries scientists should not. For example, Hilborn and Walters (1992) write: "Don't use someone else's package—build your own. We believe that if you cannot write your own computer

program to do an analysis, that you should very likely not be doing the analysis because there is a good chance you will misinterpret the results.”

We are, however, of a different opinion. The software packages that have dominated fisheries science in the past decades and which generally ran on mainframe computers have usually been mathematically advanced but had primitive interfaces. Their main disadvantages were inaccessibility, complexity, inflexibility, and underutilization of graphics, not to speak of lack of documentation. This has led to irreproducibility of results being the rule rather than the exception, very much in conflict with the basic principles of science (Pauly 1993).

We don't find the “Do-It-Yourself” option realistic at all. The tools available for software development are indeed much more advanced and powerful than they were a software generation (i.e., a few years) ago. But our understanding of what is needed to identify and quantify management options has also developed. Thus, while a table of numbers and perhaps a scatterplot were sufficient in the 1970s, this would not do much in the 1990s to convince managers that a job has been well done. For this, we need sophisticated, graphically oriented software such as can be developed only by persons with special skills. It is no longer necessary to be a giant software company to do it or even a professional programmer, but still, it should not be a requirement for all fisheries biologists.

The programming of ELEFAN and ECOPATH was begun by scientists using BASIC, the programming language that was easiest to use and to date comes with every personal computer. Later, professional programmers took over the software development and the disadvantages of BASIC became more evident, namely the lack of an inherent language structure favoring the famous “spaghetti code”, slow program execution, and a lack of preprogrammed functions (libraries) for the creation of menus, graphics, or data management systems. Libraries also reduce the problem of tracing programming errors (“bugs”) since their functionality has already been tested by many users.

This, in 1990, led to the decision to write new software (e.g., MAPPER, see below) in C ++, a highly structured (object-oriented) programming language used by professionals because of its speed and because of the many available libraries for all kinds of purposes. However, while the libraries indeed allowed one to produce software with sophisticated mouse-driven interfaces and stunning graphics, the simultaneous use of libraries from different suppliers led to redundancies and compatibility problems, and to a largely inflated source code with subsequent memory problems under DOS.

As of 1993 the environment for software development has again changed. Microsoft WINDOWS has become a *de facto* standard and comes pre-installed with most new personal computers. WINDOWS effectively handles the interactions between a software on the one side and the hardware (printer, screen, mouse) and the user on the other side. Recent programming languages (e.g., Visual BASIC and Visual C ++ ) make intensive use of the standardized WINDOWS interface and allow the development of software through a menu-driven, interactive process that drastically reduces the need to write and debug source code. In the light of these developments it was decided to gradually phase out the development of DOS software and to switch to the WINDOWS platform: the new graphical version of ECOPATH will be developed in Visual C++ or Visual BASIC.

Turning to FishBase, the key lesson learned during its development is that the decision to use a relational database instead of an expert system or a text system

with arbitrary links between paragraphs and words (e.g., Hypercard) was justified. This is evidenced by our ability to navigate with ease in a system containing, as of late 1993, more than 350,000 records structured in about 60 interlinked tables with over 1,200 fields. The 1989 decision to use the relatively unknown DataEase package instead of PARADOX or dBase was justified as well: it was the only software on the market that allowed development of a complex system in a prototyping fashion, i.e., without writing any source code. This allowed concentration on the data and on the design rather than on writing and debugging an ever increasing source code. DataEase's native query language (DQL) was only used for pre-programmed reports that drew on several tables and presented the result in a special format.

One of the aims of the FishBase project is to disseminate not only information previously available in printed form, but also other existing computer databases. Although FishBase could easily have replaced a number of such databases, many collaborators did not want to give up what they had developed over the years. For such cases, FishBase acts as a "host" of subsequent versions of databases which continue to be used and updated by their developers. This solution also made it much easier to maintain the integrity of FishBase: simultaneous data entry into separate copies of a database poses major logistic problems in preventing double entries and concurrent updates of existing records.

The key to encouraging people to contribute their valuable information was not only to convince them of the usefulness of the FishBase approach, but also to give visible credit on screen, in reports, and in publications derived from FishBase.

Software and data can be made available in a variety of ways, some of them being more nominal than real. For example, a software that runs only on certain workstations and requires a library of mathematical functions to operate is actually not "available" to most users, even if they hold its diskette(s) in their hands; neither are online databases available to students or to researchers in most developing countries, due to high connection costs.

Thus, for software and data to be available to and used by a targeted group, it has to be bundled in low-priced package consisting of a user-friendly software, a well-written user manual, a textbook explaining the scientific background, the hardware needed to run the software, a training course to help the members of target group understand and use the software, and a follow-up system for subsequent queries and the resolution of problems. We plan to put the software mentioned in this article on a CD-ROM disk and we are negotiating with donors to obtain the funds needed to distribute this disk together with notebook computers, textbooks, and training courses to fisheries resource scientists and managers in developing countries.

In summary, we argue that software that is to be useful for resource management in tropical developing countries must have the following features:

- the product must include methods that can be used, and for which data *are* available, or *can* readily be collected;
- the software intended for distribution *must* run on widely available, low-cost platforms, and *not* exclusively on sophisticated workstations;
- the software must be user-friendly—as determined by the intended users, *not* by its developers;
- the software should generally be introduced to its prospective users through training courses, not solely as a result of a purchase;
- the software must be free, or very cheap, and one must accept that it will be "pirated";

— the institution that produces the software in question must be willing and capable to handle the maintenance of this software, and to respond to users' inquiries and feedback.

In this spirit, we are willing to entertain queries concerning the software presented in this contribution. Please just write to any of us.

#### Acknowledgments

This contribution could not have been produced had it not been for our interactions with the hundred of colleagues using our software. To all: many thanks. We also thank the Danish Development Agency (DANIDA) for support of the ECOPATH II project, the Commission of European Communities (CEC) for support of FishBase, and FAO for good cooperation.

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