Pauly, D. 1981. Consultant Report (25 November-12 December 1981) Programma Cooperativo Peruano-Aleman de Investigacion Pesquera Instituo del Mar del Callao, Peru, 22p.

PROGRAMA COOPERATIVO PERUANO-ALEMAN
DE INVESTIGACION PESQUERA
(PROCOPA)
Instituto del Mar del Perú
Esquina Gamarra y General Valle s/n.
CALLAO – PERU

Consultant Report

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Duration of consultancy: 24 November to 13 December 1981

Terms of reference:

"1) Verification of the applicability of classical models in fishery biology with regards to the former and actual situation of multispecies fish stocks off Peru, and design of potential alternatives in fishing strategy,

2) Assistance in the application of new, simplified methods for the estimation of fishery biological parameters, especially in the field of growth and mortality."

Narrative

As suggested in the terms of reference, my task while at PROCOPA* was essentially to apply to Peruvian data, particularily to those obtained by PROCOPA, methods and approaches such as those I developed for use in Southeast Asia.

However, is appeared that much of the fishery data available at PROCOPA for analysis are data pertaining to hake (merluza) and which can be analyzed using convential, age- - based Virtual Population Analysis (see consultant reports of W. Hall, and of D. Armstrong).

On the other hand, it appeared that there are at IMARPE** a large amount of unanalyzed length-frequency data, notably of such important pelagic fishes as anchoveta, but also of numerous demersal fishes. It was recognized that the detailed analysis of these data could greatly contribute to an understanding of growth and mortality processes in the marine fishes of Peru.

One PROCOPA staff is at present actively involved with simulation modelling of the stock off Peru, emphasis being given to a "translation" to Peruvian conditions of the "Danish Model" of Andersen and Ursin.

I feel that this modelling effort is not well focused, and I do not think that it is perceived as useful by IMARPE scientists.

This possibly is due to the fact that no attempt was made to first construct one (or several) simpler model(s) of the ecosystem off Peru such that the usefulness of modelling could be made evident to colleagues not accustomed to such techniques.

For these reasons, I have, during this consultancy, stressed the need to summarize what is known of the system off Peru in the form of a preliminary, static "box model", which could be used as a stepping stone toward a more complex, dynamic model, and which would have the advantage that - unlike a simulation model - it could be communicated straightforwardly (i.e. in the form of a graph such as for example in Appendix 3.3).

On the basis of all these previous considerations, a program of work was proposed to Dr. R. Jordán, Scientific Director of IMARPE and Co-Director of PROCOPA, by Dr. Arntz and myself, which covered the following items:

1) Setting up a small working group in charge of adapting my ELEFAN programs for the analysis such that the programs can be run on IMARPE's HP 1000.

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2) Advising IMARPE staff on various technical matters, especially concerning the analysis of length-frequency data, and questions of growth and metabolism.

3) Presentation of a simple methodology with the help of which "box models" of exploited ecosystems can be quickly constructed and verified.

4) Giving a series of lectures on fish population dynamics and stock assessment to IMARPE staff, emphasis being given to methods and approaches likely to be useful in a Peruvian context (see Appendices).

Item (1) has resulted in the ELEFAN I program being now partly adapted to the IMARPE computer; the interest that this program has arisen among IMARPE scientists suggests this effort will continue after my departure, and lead to this program being operative in the very near future. Dr. P. Muck and Dr. U. Damm will assist, as the need arises, the programmer involved in this effort (Ms. María Antonietta Alvarez, of IMARPE's Pelagic Fish Division).

It is planned that the whole series of ELEFAN programs (I, II and III) will be implemented, and I have agreed to send listings and user's instruction for ELEFAN III as soon as these become available (in early 1982).

Item 2). Several Peruvian scientists showed me length-frequency data they were trying to interpret using subjective "paper and pencil" methods. Although I could help with some of the details pertaining to the presentation of such data, it appeared that they could not be reliably interpreted without the computer-based methods mentioned above. This gives emphasis to the need to ensure that these ELEFAN programs be made operational as soon as possible.

Item (3) was implemented mainly in discussion with the PROCOPA staff concerned, and by means of the lectures listed below, one of which explicitely adressed the topic of multispecies fisheries.

Item (4) resulted in 5 lectures of 1 hour + each.The lectures were well attended, and led to interesting questions and discussion with IMARPE scientists. Care was taken to prepare, for each lecture a short written introduction which summarized the main items of the lecture, and which, along with the excellent translations by Drs. Damm and Arntz greatly contributed to the success of these lectures.

I left with several PROCOPA and IMARPE staff a number of reprints of publication, and will remain in contact with several colleagues who have asked me to correspond with them. Also, Dr. Damm and I have identified a research topic (a certain method for the analysis of length-frequency data with the help of programmable calculators) which will result in a scientific publication which we will co-author.

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* This lecture was also given the 11 Dec. at the Universidad Nacional Mayor de San Marcos (Dept. Biol. Sciences), Lima.

** Lecture 5 covered topics that were first planned to be presented in two separate lectures (see Appendix 1).

Sugerencias para la consultoría a desarrollarse por el Dr. Daniel Pauly (ICLARM, Manila - Filipinas) durante su estadía en el IMARPE (30.11.-12.12.1981).

1) Métodos para el análisis detallado de datos longitud-frecuencia

ELEFAN

I - Adaptación del programa de crecimento ELEFAN (I, II, III) a la computadora HP 1000

- Cálculo de parámetros de crecimento incl. oscilaciones estacionales

II - Estimación de la mortalidad total (Z) por medio de curvas de captura deducidas de datos de frecuencias por longitudes

- Estimación de la mortalidad por pesca (F) por sustracción de valores empíricos de M de la mortalidad total

- Estimación del patrón de reclutamiento por estaciones

III - Análisis de población virtual con datos de longitudes para determinar

la mortalidad por pesca por grupo de tamaño
el tamaño poblacional
y el impacto de cambios en F y el tamaño de mallas.

2) El uso de métodos simples para la descripción de stocks multiespecíficos

3) Consultoría en cualquier otro asunto

4) Ciclo de conferencias:

- 1° de Diciembre: On the detailed analysis of length-frequency data
- 3 de Diciembre: The estimation of mortalities (Z, F, M) and biomass in exploited fish populations
- 4 de Diciembre: The biological basis of fish growth
- 9 de Diciembre: Problems of multispecies stocks and fisheries
-10 de Diciembre: Fisheries research in the developing world: Methods and challenges
-11 de Diciembre: Basic concepts in fishery management and fishery economics.

Todas las conferencias se dictarán en ingles despacio en la Sala de Conferencia, IMARPE, de las 14.00 - 15.00 horas.

LECTURE 1 : ON THE DETAILED ANALYSIS OF LENGTH-FREQUENCY DATA

Starting in 1892 with Petersen, length-frequency data have been often used to obtain information on the growth of fish.

This method is nowadays of limited value in temperate waters, especially because it is intrinsically unreliable when fish are investigated which can become very old.

In tropical and subtropical waters, fishery biologists generally have relied on the analysis of length-frequency data to obtein data on the growth of fish, often for lack of better alternatives.

The major problem with the estimation of growth based on length-frequency data is one of subjectivity, i.e. results obtained by a worker with a given set of data generally cannot be duplicated by another worker.

Another feature of analyses based on length-frequency data is that the data are generally nor fully analyzed i.e. information on items other than growth are rarely extracted from a length frequency data set . Examples of additional informations which can be extracted from a length-frequency data set are:

- information of total mortality (Z) or estimation of the parameter Z/K through construction of length-converted catch curves,
- information or mean length in the catch, from which Z or Z/K can also be estimated,
- information on the pattern of mesh selection prevailing in the fishery from which the data were obtained,
- information on the seasonal pattern of recruitment into a fishery
- information on catches by dividing the weight of representative length-frequency samples into e.g. monthly bulk catches, and
- information on the biology of investigated fishes e.g. on the relationship between seasonality of growth and "master factors" such as environmental temperature.

This lecture will illustrate some of the methods available to extract such information from length-frequency data, emphasis being given to a series of three computer programs called ELEFAN (for Electronic Length Frequency ANalysis) which will be available at IMARPE shortly.

This lecture will be based predominantly on:

D. Pauly, J. Ingles and R. Neal (1981) Aplication to shrimp stocks of objective methods for the estimation of growth, mortality and recruitment related from length-frequency data. Paper prepared for the NOAA/FAO "Workshop on the Scientific Basis of the Management of Penaeid Shrimps, photocopies of which are available from PROCOPA.

LECTURE 2 : THE ESTIMATION OF MORTALITIES (Z, F, M) AND BIOMASS IN EXPLOITED FISH POPULATIONS

A convenient way of summarizing those factors that determine biomass in exploited fish population is by means of Russel's Axiom :

$$\text{Biomass at time } t_2 = (\text{Biomass at time } t_1) + (\text{Recruitment}) + (\text{Growth}) - (\text{Losses through Predation}) - (\text{Catch})$$

The axiom may be also seen as a program of work for anybody involved in fish population dynamics and stock assessment, since it states that the future basis of a fishery, i.e. the biomass at any time t_2 is a function of quantities that are (at least in part) affected by that very fishery.

Mortality estimations

Estimating total mortality((Z), the sum of mortality due to fishing(F) and that due to natural mortality, (M)) is rather straight forward, and an number of methods for obtaining estimates of total mortality will be reviewed, emphasis being given on length-structured methods.

Separating (Z) into its component (F) and (M) is more difficult, and a significant part of fish population dynamics consists of methods to achieve this. Appropriate methods will be briefly reviewed; it will shown that generally, it is F which is estimated, with M being obtained by substraction from Z .

However, since the classic paper published by Beverton and Holt in 1959 on this subject, comparative studies have shown that the values of M of fishes strongly correlate with their growth parameters. Using data from Beverton and Holt and others I have shown* that reasonable estimates of M can be obtained from:

$$\log_{10} M = -0.0066 - 0.279 \log_{10} L_\infty + 0.6543 \log_{10} K + 0.4634 \log_{10} T$$

Where L_∞ is expressed in cm, K put on a yearly basis (L_∞ and K are parameters of the von Bertalanffy equation) and where T is the mean annual temperature, in °C. This equation allows for the indirect estimation of F by substraction of M from Z, which might often be quite helpful.

Biomass (B) and fishing mortality are linked with each other by the catch, as expressed by the equation:

$$\text{Catch} = F \cdot \overline{B}$$

And thus, given catch data, it is always possible when estimating F to also estimate biomass (or vice versa). Methods will be reviewed that make use of this, notably cohort analysis-type methods, and the new production model of J.Csirke and J.Caddy (FAO).

Miscellaneous methods for estimating biomass will be briefly reviewed emphasis being given to their close link to methods for the estimation of fishing mortality.

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* Pauly, D. 1980 On the interrelationships between mortality, growth parameters and mean environmental temperature in 175 fish stocks. J. du Conseil. 39 (3) : 175 - 192.

LECTURE 3 : THE BIOLOGICAL BASIS OF FISH GROWTH

Fish, as all other animals, need in order to grow both FOOD and OXYGEN. All biologists are **aware** that food is needed for growth but few are aware of the important role of oxygen. Food alone, without an adequate supply of oxygen does not result in growth (see Fig. 1)

Fish extract oxygen through their gills, and the amount of oxygen extracted per unit time is closely proportional to the surface area of their gills. However, gills being a surface cannot grow as fast as the volume (the fish body) they have to supply. Thus, with increasing body size, fish obtain per unit weight a decreasing supply of oxygen. This results in a number of effects, some of which will be discussed during this lecture:

- growth declines with increasing size,
- food conversion efficiency declines with increasing size,
- increasing environmental temperature, by increasing maintenance metabolism, decrease the O_2 supply available for growth,
- there exist a direct relationship between the gill size and the growth performance of fishes,
- increasing oxygen concentration of the water in which fish live results in faster growth for the same food supply,
- size at first maturity and maximum size match each other very closely and react in same fashion to environmental factors, etc.

The connection between these effects and von Bertalanffy theory of growth will be pointed out, and a growth formula presented which explicitely considers the role of oxygen in the biology of fish.

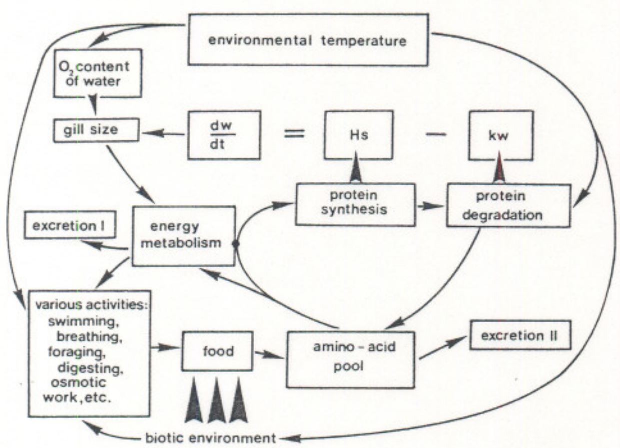

Fig. 1. Simplified model of fish growth, with emphasis on the role and supply of oxygen (see text)

This lecture is adapted from: D. Pauly (1981) the relationship between gill surface area and growth performance in fish: a generalization of von Bertalanffy's theory of growth. Meeresforschung 28 (4) : 251 - 282.

LECTURE 4 : PROBLEMS OF MULTISPECIES STOCKS AND FISHERIES*

Generally, the models used in fish population dynamics and stock assessments are single species models, the assumption being that such things as growth, mortality and recruitment of a given stock are little affected by what happens to other stocks.

This approach is not appropriate in most tropical demersal fisheries, where no single species is singled out.

This lecture aims at reviewing some concepts used in stock assessment in the light of their usefulness when dealing with multispecies stocks.

Concepts that will be reviewed are:

- the by-catch problem
- technological vs biological interactions
- effects of interactions on maximum sustainable yields
- growth/recruitment overfishing
- ecosystem overfishing

Various multispecies models will be discussed, starting with simple two-species interaction models (Lotka-Volterra Pope), and leading to more complex simulation models.

Models intermediate in complexity, i.e. "box-models", will be presented in some details, and their usefulness for research in multispecies stocks will be assessed.

* Footnote

This lecture is based mainly on:D. Pauly (1981) the Nature, Investigation and management of Tropical Multispecies Fisheries. Lecture Notes prepared for the Joint FAO Regional Training Course on Fishery stock Assessment and Fishery Statistics. Thailand Sept.Oct. 1981.

This paper is on file at PROCOPA.

LECTURE 5 : ON MANAGEMENT-ORIENTED FISHERIES RESEARCH

Fisheries biology emerged as a scientific discipline of its own when in Northern Europe and North America, near the end of the last century first signs became apparent of what was later to be called "overfishing". This feature should suffice for characterizing fishery biology as a discipline which links the scientific study of aquatic organisms (and of their habitat) with a fishery, conducted by people to attain certain goals which generally have little to do with the welfare of the animal populations that are exploited.

Three basic motives may be distinguished why people may fish:

1) to obtain food
2) to make money
3) "because they are fishermen"

Each of these reasons may be itself subdivided into different aspects, e.g. "making money" can mean "gainful employment" (returns to labour) or "investment opportunity" (returns to capital).

The last item, "people fish because they are fishermen" adresses the concept of "mobility", i.e. the availability, and suitability of alternative employment.

A simple Schaefer-type model, with costs of fishing added, can be used to show that, given an "open-access fishery" (and/or a "common property resource") equilibrium will be reached at a point beyond Maximum Economic Yield (MSY) and beyond Maximum Sustainable Yield (MSY).

Such model suggests that for most purposes, fishery management is equivalent with attempts to decrease or limit fishing effort.

The role of fishing biologists, in this context, is to suggest options to fishery management in which the role of different groups of resources users (e.g. artisanal vs commercial fishermen) are considered.

When working in a developing country, fishery biologist find it generally difficult to formulate realistic options for fishery management, for two major reasons:

- the data base is often too limited to infer on the state of the stock, and on the impact of any fishery,
- the social realities are such that decisions based on advice given by biologists cannot be implemented, or even considered.

An attempt will be made to define the role of fishery biologists working under such conditions.

COMPUTATION AND USE OF POWER FACTORS

Power Factors (P.F.) allow for the comparision of catch per effort (c/f) data obtained by different vessels, and thus allow for the construction of time series of (adjusted) c/f data in places where continous surveys, using standard vessels and gears, have been not been conducted.

Usually, PF's relate miscellaneous vessels to a "standard" vessel, which is chosen as the one providing the most reliable data, over the longest period of time, and/or the widest area (In the case of the Peruvian data, the Paita vessels might well serve as standard) P.F's are obtained by comparing the catch rates of different vessels (say A, B, C, D and E) that have fished at the "same time" and the "same place", i.e. exploiting the same stock. The definition of "same time" and "same place" should be narrow enough to account for seasonal, annual and depth-related differences in stock sizes, but wide enough to allow at least about 10 hauls (for each vessel) to be included in the computation of the average c/f used in the estimation of each P.F.

The computation of P.F.'s for a number of vessels <u>does</u> <u>not</u> require that all vessels have fished at the same time and place. Rather a P.F. can be calculated between say vessels A and E, which can then be used to establish another P.F. between say A and D, etc. until all vessels (A to E) are interconnected by a series of P.F's. A wise procedure is then to plot these first estimates of P.F. against quantifyable vessel and gear characteristics (eg. horsepower, length, tonnage, and headrope length, area of net opening, respectively). Such plots will allow for:

a) the identification of outright erroneous PF.estimates,

b) the estimation of average P.F. based on both c/f <u>and</u> vessel/ gears comparison, and

c) The estimation of P.F. values (based solely on vessels and gear characteristics) for vessels from which a P.F. could not be estimated using comparisons of c/f.

The P.F. values thus obtained are used, as discussed above to convert catch rates from different vessels to "standard" catch rates, and thus to make a better use of available data.

THE DETAILED ANALYSIS OF LENGTH-FREQUENCY DATA

At IMARPE (as in most other fishery research laboratories of the world) a great mass of length-frequency data has been obtained which has remained largely unalyzed.

These data if properly processed could greatly contribute to the achievement by PROCOPA of its stated aim of assessing the demersal stocks off the Peruvian Coast. Length-frequency data can be used to obtain the following information on a stock:

- Growth parameters (L_∞ and K of the von Bertalanffy Growth Formula, or VBGF), as needed for most stock assessment models,

- Seasonality of growth (i.e. information on the intensity of growth oscillations and on the times of the year when growth is showest and fastest) as needed to assess the impact on growth of seasonally oscillating environmental factors,

- Total mortality (Z), either from length-converted catch curves or from the mean length (above some selection length) in the catch,

- Patterns of mesh selection, i.e. information on the mean selection length and on the selection range (as well as estimates of selection factors when the mesh size is known),

- Patterns of recruitments, i.e. information on the seasonal oscillations of the recruitment into the stock under investigation, and

- Population sizes and fishing mortality by length classes, using e.g. the length-structured cohort analysis approach suggested by R. Jones (Aberdeen).

The techniques generally used to extract these informations from sets of length-frequency data area generally "paper and pencil" methods which are both very tedious and very subjective. This latter point is the reason why many fishery biologists tend to underestimate the usefulness of length-frequency data.

The author has therefore, in the last years worked intensively on approaches to remove subjective inputs from method for the analysis of length-frequency data, and produced, in cooperation with various colleagues a series of computer programs (in BASIC) called ELEFAN I, II and III which could easily be implemented on the Hewlett Packard 1000 Minicomputer at IMARPE.

The use of these programs by PROCOPA staff would amoung other things ensure that full use is made of the long time series of length-frequency data available for merluza (and sciaenids); which go back to the late sixties (hence earlier than the otolith samples).

The estimates of Z obtained from such data could then be used in conjunction with the recent production of Csirke and Caddy (FAO) in which catch is plotted as a parabolic function of Z (rather than of effort).

Considering the time constraints imposed on the project, it seems indeed that this approach is more likely than any alternative to allow for an assessment of the merluza stock.

These programs specifically do the following:

ELEFAN I : extract growth parameters from length-frequency data set, including in cases where growth oscillates seasonally,

ELEFAN II : extract estimates of Z from a length-converted catch curve, provide an estimate of mean length (from which other estimates of Z can be obtained), output data for the drawing of a "selection pattern" (analogous to a mesh selection ogive), as well as data for the drawing of a "recruitment pattern", from which inferences can be drawn on the seasonality of spawning in the stock in question,

ELEFAN III: converts length-frequency data and matching bulk catch data into estimates of catch-at-length for use in two type of length-structured virtual population analysis; also allows for assessing the effects of changes of effort and mesh size on catch level and composition.

These programs, all of which are thoroughly tested and documented are fully interactive and can be used by biologists and technicians having no previous experience in the use of computer-based methods.

Their implementation on the HP1000 at IMARPE would not only facilitate and accelerate the work of PROCOPA, but also represent a real asset to the IMARPE staff working on fish stocks in general.

The methodology briefly outlined obove is presented in greater detail in the following publications,copies of which have been left with PROCOPA:

Pauly, D. 1980. A selection of simple methods for the assessment of tropical fish stocks FAO Fish.Circ. N°729.54p.

Pauly, D. and N. David 1981. ELEFAN I, a BASIC Program for the objective extraction of growth parameters from length-frequency data. Meeresforsch. 28 (4) : 205-211.

Pauly, D., J. Inglés and R. Neal 1981. Applications to shrimp stocks of objective methods for the estimation of growth, mortality and recruitment-related parameters from length-frequency data. Paper prepared for the NOAA/FAO Workshop on the Management of Penaeid Shrimps, Florida, November 1981, 36 p. (in press).

Other reports, especially User's instruction and full program listings will be sent to PROCOPA upon my return to Manila.

CONSTRUCTION OF "BOX-MODELS" of ecosystems[a)]

While the construction of simulation models such as the "Danish Model" [b)] may be helpful to identify the basic structure of ecosystems and gaps in the knowledge of such systems, it will be most offen impossible, in the frame of a fishery development project such as PROCOPA, to construct and run a realistic [c)] simulation model such that useful information might be gained from the exercise.

The most modest aim of constructing what might be called a "quantified box model" (see e.g. Fig. 1), on the other hand, is easily achievable; such model can serve as well as a computer-based simulation model to understand the basic interaction within an ecosystem, to assess the impact of changes in the biomass of the various components of a system (as caused by a fishery or by environmental factors), and identify gaps in the knowledge of a given system.

Quantitative box models consist of four elements, the first two of them structural, the others quantitative.
Those elements are:

a) the taxa included in each box,

b) the energy links between each box (i.e., the direction of the arrows linking the boxes with each other),

c) the average biomass represented in each box, and

d) the average energy transfer between boxes (i.e., the quantities represented by the arrows). (See Fig.1)

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a) This note is condensed and adapted from: Pauly, D.1981. The Nature, Investigation and Management of Tropical Multispecies Fisheries. Joint FAO Training Course in Fishery Stock assessment and Fishery Statistics, Thailand,Sept. Oct.1981 (PROCOPA files).

b) See lecture notes by Dr. Ursin (PROCOPA files)

c) There is no point here to elaborate on whether a simulation model can be "realistic".

Identifying the taxa to be included in the various boxes (a) involves criteria relating to the size of the animals, to their distribution and to their feeding habits. Generally, it will be possible to identify groups separated by all three criteria, e.g.

- apex predators e.g. mammals and birds, or tuna (which occur further offshore and feed on smaller fish),
- small, demersal, forage fish, e.g., croakers (which are small and occur in relatively shallow waters)
- anchoveta, or
- miscellaneous pelagics ...etc.

and thus to place the animals concerned in the appropriate boxes. When detailed food and feeding habits cannot be determined for all species concerned, exhaustive use should be made of the available literature and of generalizations relating the morphology of fishes to their feeding habits.

Examples of such generalizations are:

- large fish with strong, pointed teeth (sharks, conger eels, barracuda) are piscivorous,
- piscivorous fish tend to eat fish about one-quarter to one-fifth of their length,
- fish with long, coiled guts (longer than 3-4 times their body length) are generally detritivorous,
- fish with an extremely small mouth are generally zooplanktivorous,

- generalist-type fish (e.g., such as snappers) are omnivorous.

- the size of the spaces between the gill-rakers of pelagics gives a direct indication of their favorite food, etc.

This list is not exhaustive but indicates some of the methods which can be used to group fish into feeding niches and hence into the various boxes of a model. When detailed data are available on food and feeding habits, ecological similarity ($\approx$ niche overlap) indices can be computed to quantify objectively the similarity in the diet of different fishes to assist grouping.

Obviously, grouping fish (and invertebrates) into boxes on the basis of their food and feeding habits makes the drawing of the arrows which link the various boxes quite easy, such that task (b) above becomes part of task (a).

Putting numbers into the boxes and along the arrows is a little more complicated.

The first step is to obtain the mean standing stock in each box (or at least in most of them). The most staightforward method to obtain standing stock estimates is to conduct a surveys, i.e.trawling in the case of demersal stocks, or acoustic surveys, in the case of pelagic stocks. In both cases, tagging-recapture experiments (or egg surveys) can also be conducted from which (spawning) biomass and a number of other important parameters can be estimated.

When neither these methods, nor catch-based (cohort analysis type) methods can be used to estimate standing stocks, another method can be used - at least as a first approach-which uses mortality estimates.

It will be recalled that in fishery biology, mortalities are generally ecpressed as exponential rates, i.e.

$$N_t = N_o \cdot e^{-Zt}$$

which states that the number of fishes (N_t) left after a certain time (t) is a function of N_o, the original number of fish, and Z, the total mortality rate. Z is defined as

$$Z = F + M$$

where M is the natural mortality rate.

Methods to estimate Z from the mean length of the fish in the catch, or from length-converted catch curves are discussed in a variety of papers.

Methods to obtain reasonable estimates of F are the swept-area method in the case of demersal fisheries and the subtraction from Z of an independent estimate of M, e.g., as obtained from empirical equations. (See Table 1 for a hypothetical data set).

TABLE 1. Hypothetical example of data from a multispecies fishery for use in the construction of a quantitative box model.

Tropic groups	Catch (Y) (arbitrary units)	Mortalities *		
		Z	M	F
Large predators	3	0.5	0.2	0.3
Intermediate predators	30	1.1	0.5	0.6
Zooplanktivorous fish	120	2.7	1.5	1.2
Zoobenthivorous fish	300	2.4	1.2	1.2
Detritivores (fish & shrimps)	105	5.5	2.0	3.5

* pertaining to representative species within each group.

The interesting thing about the values of F is that they can be used to estimate, in conjunction with the yield data, the mean standing stock, or biomass ($\bar{B}$) via the equation

$$Y/F = \bar{B}$$

which can be used to put numbers into the boxes. It will generally not be possible to obtain estimates of $\bar{B}$ for all fishes included in each box; as a first approximation, however, all the fishes in a given box may be assumed to have the same fishing mortality (they will have similar sizes and occur at similar places, so it's not a completely unreasonable assumption). Putting numbers along the arrows linking boxes with each other is now relatively simple:

- for the arrow linking fishes with the fishery, one uses the yield data themselves, i.e.,

  $$Y = F \cdot \bar{B}$$

- for the arrows linking predators and their prey one uses

  $$Q = M \cdot \bar{B}$$

  where M is the natural mortality of the prey and their biomass and Q is the wet weight of prey consumed by the predators,

- when a predation arrow goes to two or more predators, the value of Q is divided up in proportion of the biomass of each predator box (see Fig. 1).

From a box model quantified such as in Fig. 1, the following quantities may be estimated:

a) food consumption per day and unit of weight of the animals in each box. Divide the amount ($\sum Q$) going into a box by $\bar{B}$, then by 365,

b) the conversion rate within each box (or by trophic level if appropriate adjustments are made), calculated by dividing all matter leaving a box ($\sum Y + \sum Q$) by all matter entering it.

The values of a) generally should fall between 3% and 6% day, and those of b) 5% to 25%. These ranges can also be used to quantify certain arrows in the model, when values of Y and F are unobtainable, e.g., for zooplankton (see Fig. 1).

Quantitative box models, constructed along principles such as outlined here can serve the following purposes:

- summarizing the data available on a multispecies system
- allowing for an integration of fishery-related data with ecological data
- identifying those parts of the system where gaps in knowledge occur
- assessing the possible impact of exploiting one stock or the other.

The data available at IMARPE - especially those concerning pelagic fishes, and those available at PROCOPA on the demersal stocks probably allow for the construction of two box models, one pertaining to the Peruvian shelf system prior to the collapse of the anchovy stocks, one pertaining to the present situation (i.e. 1970 vs 1980). These two box models would match those presented by Walsh (1981)[a], and in fact, come of the data presented in the latter paper could by used (after appropiate conversion) for the construction of the two PROCOPA box models suggested here.

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a) Walsh. J.J. 1981. A carbon budget for overfishing off Peru. Nature 290 (5804) : 300-304

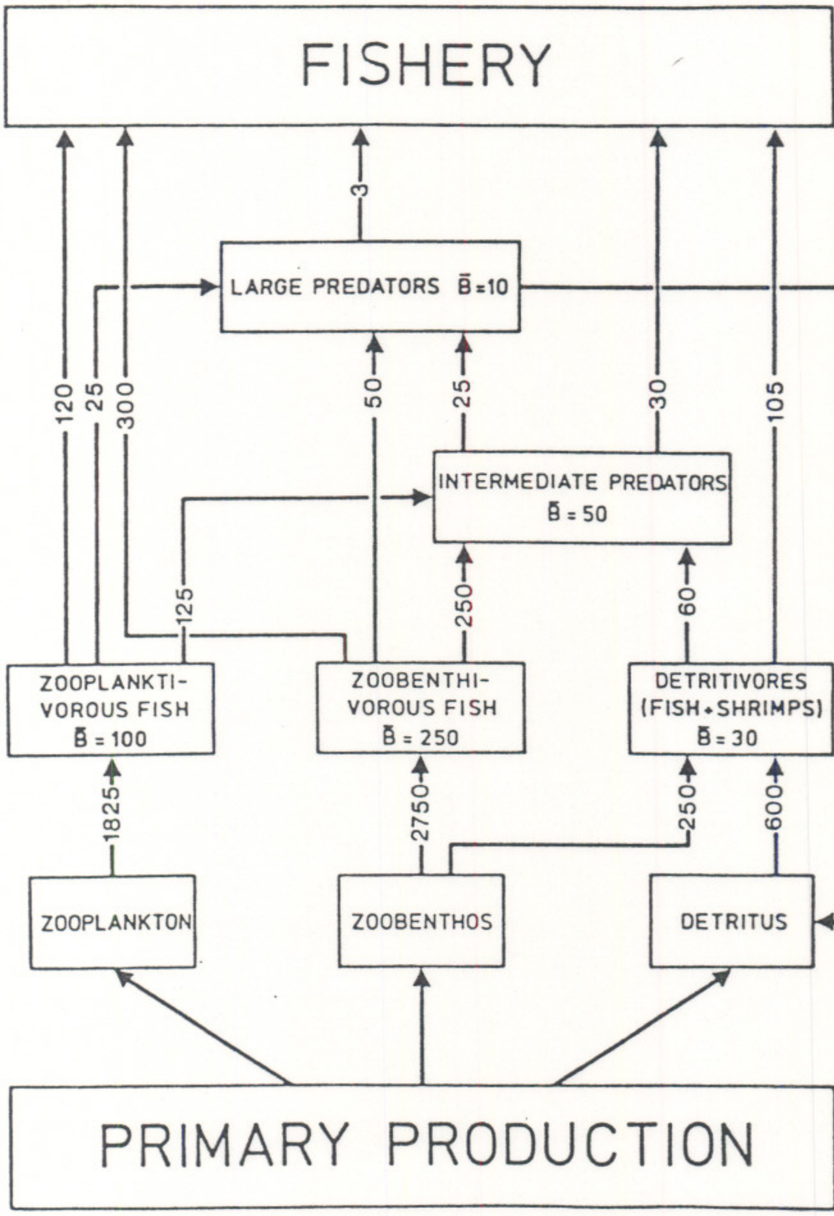

Fig. 1: A "box model" of a fishery, showing the major exploited group and their interrelationships.