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Key elements of the IMARPE/GTZ/NMFS/ICLARM study of the Peruvian anchoveta and its upwelling ecosystem as an example of multidisciplinary research in oceanography[a]

by

Daniel Pauly[b]

Abstract

Some arguments are presented to support the thesis that research on marine (fisheries) resource s shoul d generally be conducted i n multidisciplinary fashion. A multidisciplinary study, involving staff from the Instituto del Mar del Perú, the German Agency for Technical Cooperation, the U.S. National Marine Fisheries Service and the International Center for Living Aquatic Resources Management is presented in the form of 19 abstracts reprinted from the book which contained the key results of that study. Suggestions are made concerning the possibility of conducting a similar investigation in the Philippines.

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Oceanography spans a vast number of disciplines - in fact, any science applied to the marine environment and/or to the organisms that inhabit it become *ipso facto* a subdiscipline of physical/chemical oceanography or of biological oceanography, respectively.

For those who want to explain e.g. the biomass fluctuation of exploited stocks of marine fishes, this implies covering an enormous ground, far more than a single scientist can usually master.

For this and other reasons, studies aimed at elucidating questions such as in the above example must be multidisciplinary, i.e., involve practitioners of a number of key oceanographic disciplines. Reports of various multidisciplinary studies exist, e.g. of the Indian Ocean Expedition, conducted in the 1960s, or of various Antarctic expeditions of the 1970s.

Close reading of these reports usually reveals, however, that the various scientists of different disciplines did not share their hypotheses or aims. Often, they could not even agree on sampling physical and biological parameters at the same stations!

We have recently completed the first phase of a multidisciplinary study of the biology of the Peruvian anchoveta *Engraulis ringens* (Pisces, Fam: Engraulidae), and of the upwelling system that supports it.

This study covers the stretch of the Peruvian coasts and adjacent offshore area from 4 to 14°S, from January 1953 to the mid 1980s, and was aimed at identifying the key factor(s) which determined the biomass levels of anchoveta. This was deemed important because: (1) at its peak in the late 1960s, the Peruvian anchoveta supported, with an annual catch of over 15 million tonnes, the largest single-species fishery in the world; and (2) ecosystems similar to the Peruvian upwelling system, and species similar to *E. ringens*, occur throughout the world.

The importance attached to this study is reflected in the all-out support it received from the Instituto del Mar del Peru (IMARPE), the institution whose staff collected over the years the bulk of the data used in this study, from the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), the bilateral agency of the Federal Republic of Germany, which had supported a project at IMARPE and whose staff contributed crucial analyses to the study, from the U.S. National Marine

Fisheries Service, whose participant staff contributed, among other things, key oceanographic papers (based on data held in the U.S.A. and to which Peruvian scientists previously had no access), and from ICLARM, where a team of four contributed several papers on the dynamics of anchoveta and from where this author coordinated the project as a whole.

The results of this study are difficult to briefly summarize. Therefore, I shall give instead the title and abstract of the various contributions included in the book which contains the results of the first part of this study (Pauly and I. Tsukuyama (eds.) 1987. The Peruvian Upwelling Ecosystem: Three Decades of Change. ICLARM Studies and Reviews 15, 351 p. Instituto del Mar del Peru (IMARPE), Callao, Peru; Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), GmbH, Eschborn, Fed. Rep. of Germany and International Center for Living Aquatic Resources Management (ICLARM), Manila, Philippines):

1. On the implementation of management-oriented fishery research: the case of the Peruvian anchoveta, p. 1-13 (D. Pauly and I. Tsukuyama).

Abstract. Some features of previous oceanographic and fishery research in the Peruvian upwelling system are presented and contrasted, with emphasis on the need for biologists to retrieve and standardize historic data and to present and analyze longer time series than commonly done to date. The genesis and aims of an international multidisciplinary project between IMARPE, GTZ and ICLARM and aiming at deriving and analyzing monthly time series on the Peruvian current system for the period 1953 to 1982 and beyond are discussed, and the key hypothesis that gives its structure to the present book is presented.Brief discussions, with copious references, are given of various important species of the Peruvian upwelling ecosystem not discussed in the book of which this contribution forms the introducttion.

2. Seasonal and interannual subsurface temperature variability off Peru, 1952 to 1984, p. 14-45 (R.E. Brainard and D.R. Mclain).

Abstract. Time series of monthly means of subsurface ocean temperature data along the Peru coast are developed for the period 1952 to 1984 for historical studies of anchoveta populations. Monthly mean values of sea surface temperature (SST), depth of the 14°C isotherm, and thickness and heat content of the surface layer were computed from all available subsurface temperature profiles. Means of these four parameters were computed for five areas along the Peru coast from 1 to 17°S, extending approximately 300 km offshore. Intra-annual (seasonal) and interannual variations of the four parameters are described and plotted as contour isograms. Time series of the four parameters are presented for the region from 4-14°S, as are monthly means of the Southern Oscillation Index and SST and sea level at Talara and La Punta (Callao), Peru.

3. Monthly variability in the ocean habitat off Peru as deduced from maritime observations, 1953 to 1984, p. 46-74 (A. Bakun).

Abstract. Monthly time series, generated from summaries of maritime reports from the region off Peru, are presented for the period 1953 to 1984. These included sea surface temperature, cloud cover, atmospheric pressure, "wind-cubed" index of rate of addition ofturbulent mixing energy to the ocean by the wind, wind stress components, solar radiation, long-wave back radiation, evaporative heat loss and net atmospheric-ocean heat exchange. All series are found to undergo interrelated nonseasonal variations at multiyear periods. El Niño episodes are characterized by intense turbulent mixing of the ocean by the wind, intense offshore-directed Ekman transport and by low net heat gain to the ocean through the sea surface. Effects of constant versus variable transfer coefficient formulations on the bulk aerodynamic flux estimates are discussed. Certain comments on the utilization of these data in analysis of biological effects are offered.

4. Monthly turbulence and Ekman transport indexes, 1953 to 1985, based on local wind records from Trujillo and Callao, Peru, p. 75-88 (J. Mendo, L. Pizarro and S. Castillo).

Abstract. Mean monthly turbulence and Ekman transport (upwelling) indexes have been computed based on subdaily wind records from Trujillo and Callao airports, Peru, for the period 1953 to 1985. The seasonal and interannual variability of these indexes are discussed, with special references to differences between inshore and offshore winds, the differences between Trujillo and Callao and their relevance to the spawning of pelagic fishes off Peru.

5. Monthly catch and catch composition of Peruvian anchoveta (*Engraulis ringens*) (Northern-Central Stock, 4-14°S), 1953 to 1982, p. 89-108 (I. Tsukayama and M.L.D. Palomares).

Abstract. This paper presents an uninterrupted time series of monthly catch data on Peruvian anchoveta (*Engraulis ringens*) covering the northern/central stock (4-14°S) and the period from January 1953 to December 1982. Also presented is a monthly, largely uninterrupted time series, also covering 1953 to 1982, of % length-frequency data representing the catch composition by 1-cm class of the fishery and the anchoveta consumed by major predators such as the guano birds. This paper presents, finally, a time series of monthly "condition factors," i.e., of the multiplicative factor (c.f.) in length-weight relationships of the form $W = (cf/100) \cdot L^3$. These c.f. values can be used to turn the data presented here into monthly catch-at-length data, i.e., absolute numbers of fish caught by length and month, from 1953 to 1982. The methods used to obtain and standardize these data are briefly presented, along with potential source of errors.

6. Estimation of unregistered Peruvian anchoveta (*Engraulis ringens*) in official catch statistics, 1951 to 1982, p. 109-116 (S. Castillo and J. Mendo).

Abstract. The causes of underreporting in the Peruvian fishery fo anchoveta (*Engraulis ringens*) are discussed. Estimates of this underreporting were obtained for each step in the catch-landing-processing chain from standardized interviews of 40 informants with professional experience in that fishery ranging from deckhand to fleet manager, and from worker in processing plant to plant manager. The interviews led to an aggregate figure of over 20% of fish caught in excess of official catch statistics, much more than previously assessed. This figure is confirmed by an analysis of production figures from processing plants which contrasts reported, low reduction coefficients (i.e., fish meal/fish processed) with their actual, high values.

7. Growth of Peruvian anchoveta (*Engraulis ringens*), 1953 to 1982, p. 117-141 (M.L. Palomares, P. Muck, J. Mendo, E. Chuman, O. Gomez and D. Pauly).

Abstract. Growth parameters were estimated, using the ELEFAN I method of D. Pauly and N. David, from length-frequency data covering the years 1953 to 1982 and pertaining to the northern/central stock (4-14°S) of the Peruvian anchoveta (*Engraulis ringens*) and, for larvae and young juveniles, from daily otolith rings. Growth was found to oscillate seasonally with an annual minimum in August when temperatures are usually lowest. The dynamics of "condition" and fat content are discussed with emphasis to their relation to water temperature. A marked increase in the 30-year period covered of anchoveta maximum length and growth performance is documented along with a simulation model used to identify some density-dependent factors capable of explaining the changes in growth that have occurred.

8. VPA estimates of the monthly population length composition, recruitment, mortality, biomass and related statistics of Peruvian anchoveta, 1953 to 1981, p. 142-166 (D. Pauly, M.L. Palomares and F.C. Gayanilo).

Abstract. A recently developed version of length-structured Virtual Population Analysis, implemented in the form of a graphic-oriented microcomputer program (ELEFAN III) was used to estimate, on a monthly basis, the population in number and weight by 1 cm length class of the Peruvian anchoveta (*Engraulis ringens*, northern/central stock). The analyses were performed with predation (by three species of guano birds, by bonito and two species of seals) accounted explicitly, and with estimates of (residual) natural mortality obtained by back calibration with independent acoustic estimates of biomass. The estimated biomasses rather faithfully reflect environmental perturbations (El Niño events) and human interventions (fishing and overfishing). Likely sources of errors involved in the analysis are discussed.

9. Monthly spawning stock and egg production of Peruvian anchoveta (*Engraulis ringens*), 1953 to 1982, p. 167-178 (D. Pauly and M. Soriano).

Abstract. Available data on the reproductive biology of the Peruvian anchoveta (*Engraulis ringens*, northern/central stock, 4-14°S) are reviewed and used to estimate monthly spawning size and egg production from January 1953 to December 1982. Basic information used are: (a) monthly biomass by length class (4 to 20 cm), (b) a model relating the shape and position of the maturation ogive to sea surface temperature, (c) seasonal patterns of maturity, (d) batch fecundity estimates of female anchoveta, and (e) various ancillary information woven into a coherent whole. Potential uses of the time series derived are discussed along with sources of errors and ways of reducing these.

10. Relationship between anchoveta egg standing stock and parent biomass off Peru, 4-14°S, p. 179-207 (H. Santander).

Abstract. A planimetric analysis of ninety maps of anchoveta egg distribution, covering the Peruvian coast from 4-14°S, based on egg surveys conducted from 1964 to 1985 , was performed and the standing stock of eggs corresponding to each map estimated. The estimates for 1964 to 1981, divided by temperature-related egg development times were plotted against independent estimates of anchoveta parent stock. A dome-shaped curve emerged, suggestive of a strong effect of parental cannibalism on anchoveta egg standing stocks.

11. Monthly population size of three guano bird species off Peru, 1953 to 1982, 208-218 (H. Tovar, V. Guillen and M.E. Nakama).

Abstract. Monthly population size estimates of three species of fish eating, guano-producing birds (cormorant: *Phalacrocorax bougainvillii;* booby: *Sula variegata* and pelican *Pelacanus thagus*) were obtained, based on planimetric analyses of over 10,000 maps of their distribution on guano islands and points along the coast of Peru, for the years 1953 to 1982. These data allow for a much more detailed description of the interactions between the bird populations and their environment than had hitherto been the case and a preliminary discussion of such interactions is given, with emphasis on the combined effects of the anchoveta fishery off Peru and successive El Niño events.

12. Monthly anchoveta consumption of guano birds, 1953 to 1982, p. 219-233 (P. Muck and D. Pauly).

Abstract. Anchoveta consumption by Peruvian guano birds (*Phalacrocorax bougainvillii, Sula variegata, Pelecanus thagus*) was estimated for the period 1953 to 1982 for the area 4-14°S latitude using an analytical consumption model and monthly seabird population estimates based on field counts. Highest estimates were obtained for 1955-1956 with about 2 million metric tonnes (t) per year of anchoveta being consumed by the guano birds.

Due to the continuous decline of the guano bird populations, their anchoveta consumption dropped to values of less than 20,000 t at the beginning of the 1970s and an average of around 30,000 t between 1970 and 1982. Population decline of guano birds is most probably caused by reduced anchovy availability, a consequence of the combined effects of the heavy anchovy fishery and El Niño-related periods of low food vulnerability.

13. Sea lion and fur seal predation on the Peruvian anchoveta, 1953 to 1982, p. 234-247 (P. Muck and H. Fuentes).

Abstract. The importance of the predation of the fur seal (*Arctocephalus australis*) and sea lion (*Otaria flavescens*) on fish, particularly on anchoveta (*Engraulis ringens* J.) from 1953-1982 for the area from 4-14°S along the Peruvian coast was examined. Based on a population growth and consumption model, both pinniped species were estimated to have a maximum annual total consumption of fish of about 35,000-59,000 tonnes (t) in 1982. At its peak in 1967, annual pinniped anchoveta consumption was 10,000-17,000 t and only 3,000-5,000 t between 1968 and 1982. These values are negligible compared with the impact of the guano birds and of the fishery. The population growth of Peruvian pinnipeds did not seem to have been affected by the breakdown of an anchoveta biomass in the early 1970s.

14. Population dynamics and estimated anchoveta consumption of bonito (*Sarda chiliensis*) off Peru, 1953 to 1982, p. 248-267 (D. Pauly, A. Ch. del Vildoso, J. Mejia, M. Samamé).

Abstract. The population dynamics of bonito (*Sarda chiliensis*) off Peru is reviewed, with emphasis on its growth, mortality and biomass. A food consumption model is derived, based on actual data on *S. chiliensis* and other scombrids. Daily rations in % body weight were estimated as ranging from 2.23 (at 14°C) to 7.04 (at 24°C), and used, along with food composition data, to estimate monthly anchoveta (*Engraulis ringens*) consumption by bonito off Peru, between 4 and 14°S, from 1953 to 1982. These estimates ranged from a maximum of 86,000 tonnes (t) in May 1953 to 400 t, first reached in June 1975. Overall, bonito appears to have a modest impact on the anchoveta stock.

15. Abundance of sardine, mackerel and horse mackerel eggs and larvae and their relationship to temperature, tu rbulence and anchoveta biomass off Peru, p. 268-275 (P. Muck, O.S. de Castillo and S. Carrasco).

Abstract. Data from 81 egg and larval surveys conducted from 1964 to 1986 off Peru were analyzed with emphasis on the interrelationships between sardine eggs, larvae of mackerel and horse mackerel, sea surface temperature (SST) and SST anomaly, turbulence and anchoveta biomass. A significant negative correlation was found between anchoveta biomass and sardine eggs, while a significant positive correlation was found to occur between SST and the abundance of mackerel and horse mackerel larvae. Some biological implications of these findings are provided.

16. The importance of mackerel and horse mackerel predation for the Peruvian anchoveta stock (a population and feeding model), p. 276-293 (P. Muck and G. Sanchez).

Abstract. Mackerel (*Scomber japonicus*) and horse mackerel (*Trachurus murphyi*) predation on the Peruvian anchoveta (*Engraulis ringens*) was estimated, on a monthly basis, for the period 1953-1982. A key element of the model used to derive the estimate is the simulation of the temperature-induced inshore-offshore migrations of mackerel and horse mackerel, their relationship to El Niño events, and the resulting changes in the overlap anchoveta and mackerel/horse mackerel distributions. Model parameters were estimated from a variety of sources, including ichthyoplankton and echo-acoustic surveys, catch statistics and miscellaneous field data, covering the years 1964 to 1986 on the growth, mortality, diet composition and anchoveta consumption of mackerel and horse mackerel. Overall, results indicate that these two fishes, especially mackerel, are far more important anchoveta predators than the guano birds, bonito or marine mammals, and that their anchoveta consumption, except for the 1961-1971 period, either exceeds or is similar to the fishery catches. The implications for research are pointed out.

17. Exploratory analysis of anchoveta recruitment off Peru and related environmental series, p. 294-306 (R. Mendelsohn and J. Mendo).

Abstract. An exploratory analysis of monthly anchoveta (*Engraulis ringens*) recruitment estimates and associated biological and environmental series for the years 1953 to 1981 was performed with the aim of investigating the possibility of forecasting anchoveta recruitment three months ahead of time. While the high degree of autocorrelation in the monthly recruitment series prevented the identification of causal models, yearly models combining pairs of adjacent months were identified which appear promising as a means of forecast future trends in anchoveta recruitment. These, models, however, do not appear to conform to any of the conventional hypotheses provided mechanisms to explain recruitment fluctuations.

18. A bioeconomic model of the Peruvian pelagic fishery, p. 307-324 (M. Aguero).

Abstract. This paper presents an overview of the evolution of the Peruvian fisheries from an economic point of view. The consequences of El Niño phenomena on Peruvian fleet and processing overcapacity, fluctuations on landings and fish meal production and the need for tools to assess economic consequences of alternative conditions in the fishery system are outlined. A mathematical, conditional programming model structured in terms of a constrained optimization problem is presented. A Fisheries Net Benefit Function (FNBF) is proposed which expresses all activities implying costs and revenues. Assumed functional relationships are based on data data obtained from secondary sources and extrapolation from similar fisheries. Results from the base model representing conditions similar to those prevailing in 1982 show that the Peruvian purse seine fishery for small pelagics is capable of generating a net benefit of approximately US$371 million, of which US$300 million could

consist of export revenues. However, costs are approximately US$200. The fleet required to harvest this amount is estimated as 364 vessels operating under normal conditions and an average excess capacity of about 37%. A sensitivity analysis of the model is presented.

19. Managing the Peruvian upwelling ecosystem: A synthesis, p. 325-342 (D. Pauly).

Abstract. A brief review is given of the interrelationships and implications of the findings reported in the contributions included in this volume. Emphasis is given to some questions that now appear crucial, e.g. the cannibalization of anchoveta eggs and biannual cycles in anchoveta recruitment and their possible cause(s). Some suggestions are made for future research on various elements of the Peruvian upwelling ecosystem. Steps are indicated toward an integration of what is now known on the dynamics of the fishes off Peru into a large-scale simulation model that could be used to help formulate a comprehensive fishery management plan for that system.

What could the implication be, for the Philippines, of a study of this type?

One, obviously, is that it would be nice to see a multidisciplinary study of this type be performed for one or several of the major exploited fish resources.

Problems that come to mind, however, are: (i) none of the fish species exploited in the Philippines has a biomass comparable to that of the Peruvian anchoveta and hence, none of those species might justify such massive research effort; and (ii) such massive amount of data as compiled and analyzed for this study is not available from any of the Philippine fishing grounds and/or fisheries.

Both of these problems may apply (in part, at least). However, oceanographic and meteorological data such as analyzed e.g. by A. Bakun and J. Mendo, et al., respectively (see above for references), als o exist for the Philippines and are available through oceanographic databases and local weather stations, respectively.

As for important resources, perhaps the anchovies or "dilis" (Fam. Engraulidae) and/or roundscads or "galunggong" (*Decapterus* spp, Fam. Carangidae) could be studied in the Philippines with the same emphasis as the anchoveta in Peru.