Multiple Environmental States Affecting Penaeid Shrimp Production in Peru

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Abstract

A modification of the Schaefer surplus-production model was used to account for environmental induced variations of shrimp catch in northern Peru. Based on time series of catch, effort, river discharge and sea surface temperature, fluctuations in catch of shrimps are explained and discussed with respect to multiple level of carrying capacity and hence different maximum "sustainable" yields.

Introduction

The Peruvian shrimp fishery started in the 1950s as a traditional activity in northern Peru (Fig. 1) and became a commercial fishery in the 1960s. The exploited shrimps belong mainly to the species *Penaeus vannamei*, exported mainly to USA and thus an important activity for the development of northern Peru. In 1990, the exports of shrimps reached around 3,000 t, which yielded $16 million (APOYO 1992).

The region where the fishery takes place, is characterized by the discharge of the Tumbes River, which apparently affects the production of penaeid shrimps in this area, as suggested by Machii and Rodriguez (1990).

Surplus production models, such as the Schaefer Model (Schaefer 1954, 1957) have been widely used to estimate maximum sustainable yield of shrimps (Boerema 1969; Garcia and Lhomme 1977; Marcille 1978). This model has been also applied to the Peruvian shrimp fishery by Machii and Rodriguez (1990), assuming equilibrium conditions

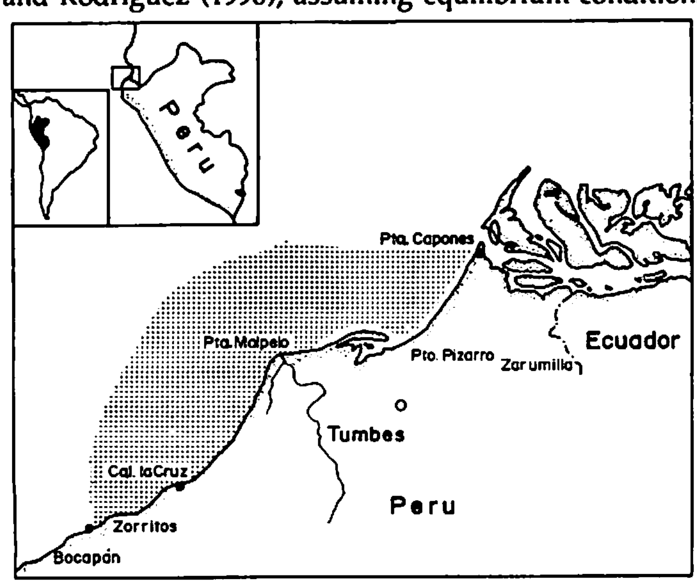

Fig. 1. *Fishing grounds (shaded) of the commercial shrimper fleet off northern Peru.*

in spite of the knowledge that the carrying capacity and hence production of shrimps may vary with climate (Garcia and Le Reste 1987). Fréon (1991) has pointed out that conventional surplus production models are not suitable when stocks (especially short-lived species as shrimps) are not under equilibrium. He suggested the incorporation of one or more environmental variables in such models, in order to improve their accuracy.

The present paper intends to: i) demonstrate that the carrying capacity of penaeid shrimp in Peru is not constant through time and hence, ii) estimate maximum sustainable yields according to different environmental states and using a climatic variable.

Materials and Methods

The shrimp fishing ground in Peru extends from Pta. Capones (3°23'S) to Bocapán (3°40'S). The data series of the commercial fisheries at Caleta la Cruz used in this paper were extracted from Rodriguez (1983). They consisted of monthly series of effort (f, horsepower x day = hp-day), catch (C, kg), and Tumbes River discharge (D, millions of cubic meters) collected from 1961 to 1981, a period which includes El Niño conditions during the years 1965, 1969, 1972 and 1976.

Sea surface temperature series for Tumbes (T) was calculated from Talara series (T') reported by Muck et al. (1989), using a significant relationship ($r^2 = 0.633$; $P<0.001$) calculated with available Tumbes data (1983 to 1992) supplied by the Instituto del Mar del Perú (IMARPE):

$$T = 16.174 + 0.518\,T' \qquad ...1)$$

Basic time series data (C, f, C/f, D and T) were plotted using three-month running averages to smooth out monthly variations.

In order to show the relationship between C/f and environmental variables, the raw data were restructured to emphasize clear peaks irrespective of their temporal trend. The restructuring process consisted in subtracting 1 from the ratio between the original data and their 12-month running average (R).

The correlations between C/f and environmental variables were estimated using monthly averages for the whole time series.

Maximum sustainable yield (MSY) was estimated in two ways. The first approach was to use the conventional Schaefer model, which assumes that if the stock is in equilibrium, the biomass increment is zero. This model includes carrying capacity (B_∞), the rate of population increase (r_m) and the catchability coefficient (q):

$$C/f = B_\infty q + B_\infty q^2/r_m\ f \qquad ...2)$$

where: $a=B_\infty q$, $b=B_\infty q^2/r_m$, $MSY = -a^2/4b$, and $f_{opt} = -a/2b$

The second approach was to modify the conventional Schaefer model by inserting an environmental variable (V) as proposed by Fréon (1991). In this case, it is assumed that the carrying capacity is a variable, i.e., a linear function of V ($B_\infty = c + dV$) in the first term of the right side of equation (2), and that the slope is constant, i.e., $h=B_\infty/r_m$ in the second term of the right side of equation (2). Thus we obtain:

$$C/f = (c + dV)q + q^2f/h \text{ or}$$
$$C/f = cq + dqV + q^2f/h \text{ or}$$
$$C/f = p_1 + p_2V + p_3f \qquad ...3)$$

where: $MSY = -(p_1 + p_2V)/2p_3$, and $f_{opt} = -(p_1 + p_2V)^2/4p_3$. It must be mentioned that V may not only affect abundance, but also catchability.

Annual C/f and effort values used for the two approaches were obtained by cumulating monthly values from April to March, such as to incorporate the peaks of the series for each year.

Results and Discussion

Brief description of data time series

Fig. 2A shows the catch and effort time series, which indicates low levels of effort and catch until 1966, after which both the magnitude and the variability of the series increased. The high variability of effort reflects the opportunistic nature of the fleet, whose effort fluctuates according to the changes in resource abundance due to environmental variations. From 1974 onwards, the increment in effort was not accompanied by an increment in catch, which is reflected in a negative trend of the C/f time series (Fig. 2B). This suggests a decrease in shrimp abundance.

However, this does not necessarily mean that overall effort has surpassed the level needed to reach maximum sustainable yield (MSY), as suggested by Machii and Rodriguez (1990), due to the existence of other possible levels of MSY related to multiple environmental states.

The temporal variation of sea surface temperature in Tumbes and Tumbes river discharge values are shown in Fig. 2C. Both time series present interannual fluctuations, with higher values during years with El Niño events: 1965, 1969, 1972 and 1976.

C/f, river discharge and sea surface temperature relationship

A highly significant correlation between C/f (-ln C/f) and river discharge (ln D) was obtained ($r = -0.919$; $P<0.001$). River discharge is assumed to carry nutrients, decrease the salinity and thus increase the habitable area for shrimps at sea, thus also reducing intraspecific competition (Garcia and Le Reste 1987). The power relationship obtained arises from the fact that the C/f first increases rapidly at low values of discharge and thereafter the C/f increases slowly. This suggests that C/f is regulated by factors other than nutrients or salinity.

A similar high correlation was found between C/f and temperature ($r = 0.928$; $P<0.001$). Temperature is believed to accelerate growth and reproduction (Garcia and Le Reste 1987), thus increasing shrimp biomass.

River discharge and temperature were also correlated ($r = 0.974$, $P<0.001$). Temperature explained 95% of river discharge variation. However, collinearity prevents the simultaneous use of both variables to estimate C/f values.

The above relationships demonstrate that shrimp carrying capacity is not constant through time, and depends on environmental variables such as river discharge and temperature.

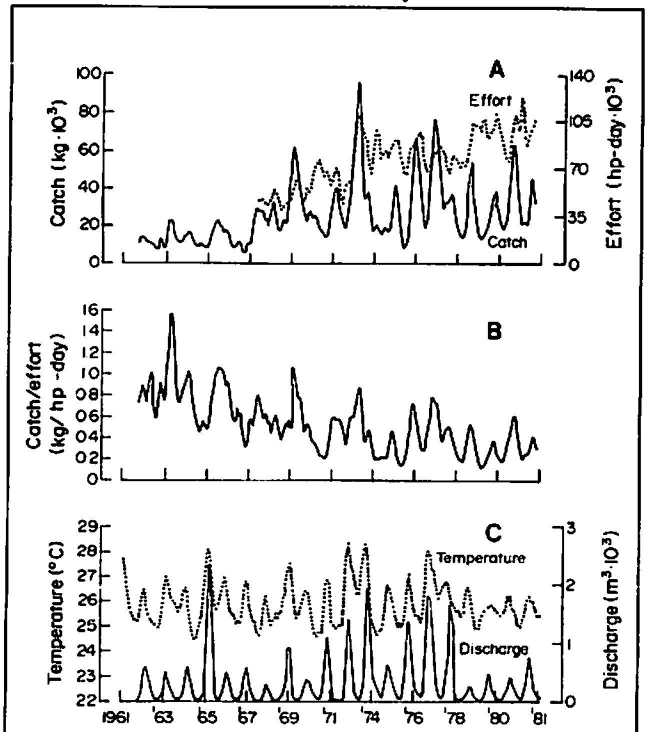

Fig. 2. *Times series of catch and effort (A), catch/effort (B) and environmental variables (C) for the shrimp fishery off northern Peru, 1961 to 1981 (all series smoothed using a three-month running average).*

MSY estimation for two environmental states using the Schaefer model

In view of the higher values of C/f, river discharge and temperature observed during El Niño years, a first approach to define multiple environmental states would be to select those years affected by El Niño events (1965, 1969, 1972 and 1976) and calculate MSY for the two sets of years. The year 1963, at low values of effort, showed a high value of C/f similar to 1965 and thus was not included in the regression for El Niño years.

The results are shown in Table 1. It may be noted that the MSY for El Niño years approximately duplicates the value estimated for the other years and hence the optimum effort is also higher. Figs. 3A and 3B show the Schaefer model for this approach. It may be seen that the slopes are very

Table 1. MSY values calculated for two sets of years using the conventional Schaefer model.

Parameter/ function	Years with El Niño	Years without El Niño
Schaefer model	$C/f = 1.035 - 4.11 \times 10^{-7} f$	$C/f = 0.795 - 4.96 \times 10^{-7} f$
r^2	0.984	0.661
MSY (kg·year^{-1})	651,643.3	337,266.3
f_{opt} (hp-day)	1,259,387	848,433.7
n	4	15

similar, as assumed for the second approach.

A second approach to get estimates of MSY is to explicitly incorporate the environmental variables described above into the Schaefer production model. Taking into account that sea surface temperature (T) is easier to measure than river discharge and that it presents a better correlation with C/f, temperature was included in the model assuming a linear relationship with resource abundance. The model takes the form as:

$$C/f = 5.552 + 0.248T - 4.83 \times 10^{-7}$$
$$(r^2 = 0.802; n = 19$$

and the results obtained are summarized in Table 2.

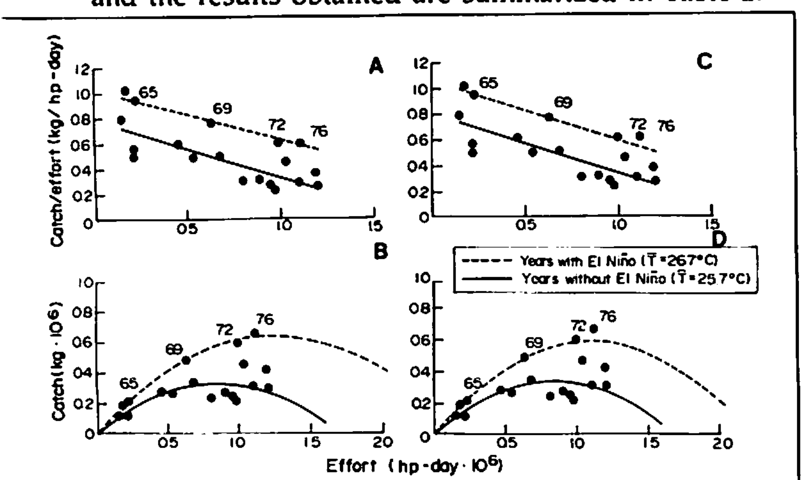

Fig. 3. *Production models for the shrimp fishery off Northern Peru: A; B: conventional Schaefer model C; D: production model incorporating temperature.*

Table 2. MSY estimates for two sets of years using the Schaefer model modified by the incorporation of sea surface temperature.

Parameter/ function	Years with El Niño	Years without El Niño
Average T(°C)	26.8	25.7
MSY (kg·year^{-1})	586,124	341,222.5
f_{opt} (hp-day)	1,101,565	840,493

Similar values of MSY were obtained using both approaches, and in both cases the data set with El Niño years almost duplicates the value obtained for the other data set. Machii and Rodriguez (1990) using the conventional Schaefer production model for all years estimated MSY as 414,000 kg·year^{-1} for an optimal effort of 796,000 hp-day and suggested that fishing effort in 1978 had to be reduced to 53% to reach MSY. Our results indicate that a reduction of 45% of fishing effort in 1978 was necessary

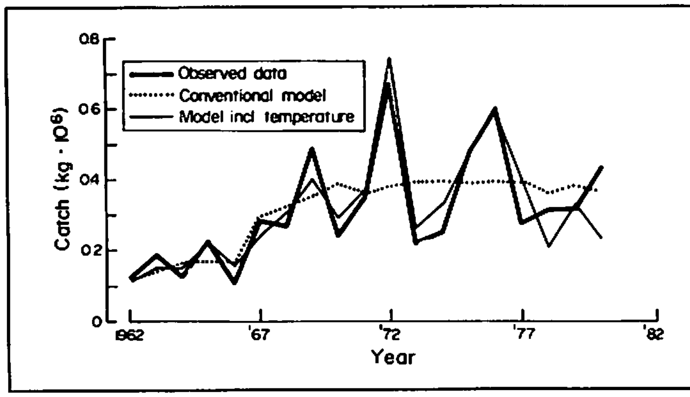

Fig. 4. *Time series of observed and predicted catch, given a conventional Schaefer model, and a production model incorporating temperature. Note good fit of the latter to observed data.*

to obtain the MSY. For 1972, an El Niño year, the conventional model suggests an effort reduction of 30%, while our results suggest an increase of 5% to reach MSY. Thus, optimal management strategies should incorporate estimates of different MSYs for each environmental equilibrium state instead of fixing a unique "optimum" level of catch and effort.

To validate the modified Schaefer model, observed and estimated catch values were compared in Fig. 4, and they show a very good agreement. On the other hand, the values estimated by the conventional Schaefer model do not explain much of the variation in catch.

A family of yield curves was estimated for different environmental conditions to construct a yield isopleth diagram based on different temperatures and effort levels (Fig. 5), which could be used for management purposes. As might be seen, fishing effort exceeded optimum levels during years without El Niño events, but they should have been higher during the warmer years. This emphasizes the importance in management of environmental considerations such as presented here.

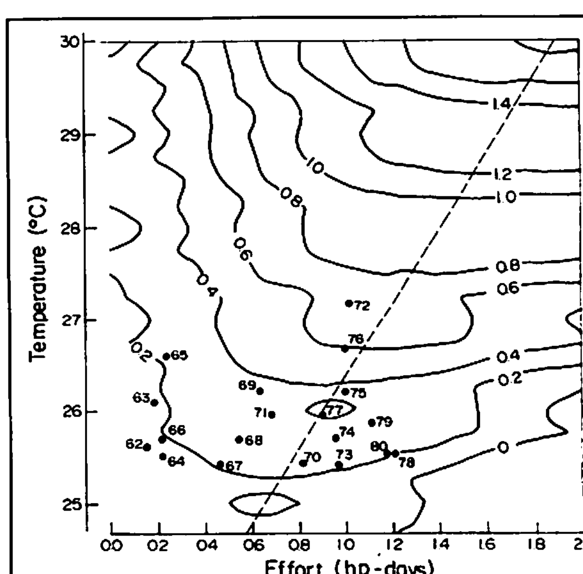

Fig. 5. *Yield isopleths (= lines of equal catch in kg·10⁶·year⁻¹) for different levels of environmental temperatures and effort levels (broken lines indicate optimum level of effort, given the temperature).*

Acknowledgements

We wish to thank Ing. E. Llata from IMARPE for Tumbes temperature data, and to Dr. D. Pauly from ICLARM for the review and valuable comments on the manuscript.

References

APOYO. 1992. Situación económica y proyecciones, Junio - 1992. Informe APOYO S.A. Lima, Perú. 47 p.

Boerema, L.K. 1969. The shrimp resources in the Gulf between Iran and the Arabian peninsula. FAO Fish. Circ. 310, 29 p.

Fréon, P. 1991. L'introduction d'une variable climatique dans les modèles globaux de production, p. 395-424. *In* P. Cury and C. Roy (eds.) Pêcheries ouest-africaines. Editions de l'ORSTOM, Paris. 525 p.

Garcia, S. and L. Le Reste. 1987. Ciclos vitales, dinámica, explotación y ordenación de las poblaciones de camarones peneidos costeros. FAO Docum. Tecn. Pesca (203):180.

Garcia, S. and F. Lhomme. 1977. Le crevette rose, *Penaeus duorarum notialis*, de la côte ouest africaine: évaluation des potentialités de capture. FAO Circ. Pêches 703, 28 p.

Machii, T. and E. Rodriguez. 1990. Stock assessment of penaeid shrimps in Peru and the influence of river discharge on the shrimp resource. J. Tokyo Univ. Fish. 77(1):9-19.

Marcille, J. 1978. Dynamique des populations de crevettes pénaidés exploitées à Madagascar. Trav. Doc. ORSTOM 92, 197 p.

Muck, P., I. Tsukayama and E. Ferrandis. 1989. Temperaturas superficiales del mar a lo largo de la costa peruana para el período 1950-1988. Informe Inst. Mar Perú-Callao (95):1-26.

Rodriguez, E. 1983. Análisis de la evolución de la captura de langostinos en la costa del departamento de Tumbes para el período setiembre 1961 - agosto 1981. Universidad Nacional Agraria La Molina, Lima, Perú. 67 p. Tesis.

Schaefer, M.B. 1954. Some aspects of the dynamics of populations, important to the management of the commercial marine fisheries. Bull. I-ATTC-Bol. CIAT 1(2):56 p.

Schaefer, M.B. 1957. A study of the dynamics of the fishery for yellowfin tuna in the eastern Pacific Ocean. Bull. I-ATTC-Bol. CIAT 2(6):245-285.

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News Items

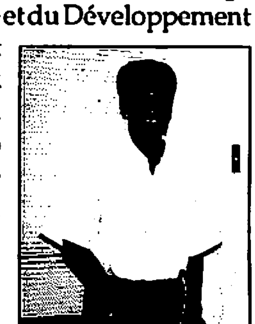
News About NTFS Members

Ulf Löwenberg (c/o GTZ, B.P. 5217, Nouakchott, Mauritania) has worked since 1 March 1993 as a consultant of the Ministère des Pêches et l'Economie Maritime (MPEM), in a project financed by the GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit). The aim of the project is to support the effective utilization and the protection of the fish resources of the Mauritanian EEZ. Mr. Löwenberg's task is coordination within the Ministry, and between the Ministry and governmental and nongovernmental fisheries organizations. This aims at an improvement of the exchange of information, of the quality of the data and, ultimately, of the management of the stocks.

Jun Ohtomi completed his doctoral thesis entitled "Studies on the stock management of the Mantis shrimp *Oratosquilla oratoria* in Tokyo Bay" at the University of Tokyo in March 1991. He is now assistant professor at the Faculty of Fisheries, Kagoshima University and works on the ecology of some crustacean species from deep waters, with emphasis on *Plesionika martia* and *Solenocera melantho*. Having found very little information about the biology of these species, he would be interested in obtaining any publication related to these. You may write to him at the Faculty of Fisheries, Kagoshima University, 4-50-20 Shimoarata, Kagoshima 890, Japan (Tel./Fax (0992)-864152/864015).

Fish Stock Assessment Training at ICLARM

Mr. Ahmed Darar Djibril from the Direction de l'élevage et des Pêches, Ministère de l'Agriculture et du Développement Rural, Republic of Djibouti, was taught computer-based methods for fish stock assessment from 19 March to 21 April. His stage, sponsored by GTZ, led to his completion of a contribution on the fisheries of Djibouti, to be published in a next issue of *Fishbyte*.



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Squid determination using statoliths

Contents

Ochumba, P.B.O. and J.O. Manyala. 1992. Distribution of fishes along the Sondu-Miriu River of Lake Victoria, Kenya with special reference to upstream migration, biology and yield. Aquacult. Fish. Manage. 23:701-719.

Patterson, K.R. 1992. An improved method for studying the condition of fish, with an example using Pacific sardine *Sardinops sagax* (Jenyns). J. Fish Biol. 40:821-831.