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THE RELATIONSHIP BETWEEN SHRIMP YIELDS AND INTERTIDAL VEGETATION (MANGROVE) AREAS: A REASSESSMENT*

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ABSTRACT: Three data sets (one from a worldwide survey, one from Indonesia and one using Philippine data) are combined to derive a single relationship linking penaeid shrimp yield, intertidal vegetation area (mainly mangrove) and latitude. This relationship, being logarithmic, cannot be used to compute precise estimates of shrimp fishery losses, given destruction or reclamation of a given surface area of intertidal vegetation. It gives support, however, to the widely held perception that intertidal vegetation plays a major role in penaeid shrimp recruitment.

RESUMEN: Tres juegos de datos (uno de investigaciones a nivel mundial, otro de Indonesia y otro usando datos de Filipinas) son combinados para derivar una relación simple vinculando capturas de camarones peneidos, áreas de vegetación intermareal (principalmente manglares) y la latitud. Estas relaciones, siendo logarítmicas, no pueden ser usadas para computar estimaciones precisas de pérdidas de capturas pesqueras, por destrucciones o usos alternativos de áreas de vegetación intermareal dadas. Sin embargo, justifica la noción ampliamente aceptada de que la vegetación intermareal juega un papel principal en el reclutamiento de camarones peneidos.

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1. INTRODUCTION

Mangrove and other forms of intertidal vegetation have greatly increased in status in recent years. Once viewed as "wasteland", the sole raison d'être of which was to be drained, filled, defoliated, burned or otherwise brought into the folds of "development", they are now seen as a resource of their own, and the habitat of a variety of aquatic animals, especially the larvae and juveniles of commercially exploited stocks (Kutkuhn, 1966).

Among the stocks which wholly depend on intertidal vegetation for their recruitment are various species of penaeid shrimps (Garcia & Le Reste 1981). The requirement of such commercially important species as *Penaeus duorarum* in the Atlantic and *P. monodon* and *P. indicus* in the Indo-Pacific for sheltered, estuarine conditions - *e.g.* as occur in mangrove swamps - has prompted several researchers to postulate, and later to demonstrate the existence, for various areas, of a correlation between penaeid shrimp yields and area of intertidal vegetation (MacNae, 1974; Turner, 1977; Martosubroto & Naamin, 1977).

The purpose of this paper is to expand on these earlier approaches, and more specifically:

- to demonstrate that earlier data (those of Turner 1977 and Martosubroto & Naamin 1977) can be combined into a single relationship,
- to show that data now available from various regions of the Philippines can also be incorporated into this single relationship,
- to show that the correlation between penaeid shrimp yields and intertidal vegetation can be increased by the inclusion of latitude as an explanatory variable, and
- to discuss some of the computational problems associated with both our and earlier approaches, notably with the use of logarithmic relationships.

2. MATERIALS AND METHODS

2.1 Materials

Three sets of data on penaeid shrimp yields and intertidal vegetation area were used in the present study:

2.1.1 Data compiled by Turner (1977)

The data set consists of 24 pairs of estimated maximum sustainable yield (MSY) of penaeid shrimps and intertidal vegetation areas from 3 continents, together with the latitude corresponding to each area. All MSY estimates consist of the average landings in years with high, stabilized effort (see Turner, 1977). Turner's estimate of MSY were turned from "head off" to "head on" values through multiplication by a factor of 1.6 (Kutkuhn, 1962) to make them comparable with the "head on" values from Indonesia and the Philippines.

The surface areas of intertidal vegetation (salt marsh macrophytes, *Spartina* spp., *Juncus* spp., mangrove) were estimated by Turner (1977, Table 1, numbers 1-14) mainly by planimetry from high-scale maps. These data are reproduced in Table 1, numbers 15-24 and numbers 25-38. Turner's estimates for Indonesia and the Philippines (one data triplet each) have been omitted, much more detailed data being available from these two countries (see below).

2.1.2 Data compiled by Martosubroto & Naamin (1977)

The data set consists of 7 pairs of penaeid MSY and intertidal vegetation area (i.e. mangrove in this case). Both MSY and mangrove area were estimates as in Turner (1977) except for South Java where MSY was estimated from a plot of catch per effort on effort (Zalinge & Naamin, 1978). The Indonesian data are reproduced in Table 1 (#1-7), with latitudes added.

2.1.3 Original data from the Philippines

The data consist of 7 pairs of values of shrimp MSY and mangrove area from seven administrative Regions of the Philippines (Table 3). We used the same definition of MSY as Turner (1977). We have discounted shrimp landings from Region III (Manila Bay and adjacent waters and from Region IX to XII (Southern Philippines) for fear of over-reporting and under-reporting, respectively. The MSY estimates were obtained for each region by adding to the average "commercial" landings of the year 1974 to 1978 the average "municipal" (=artisanal) landings for the years 1977 and 1978 (Table 2). Gaps in the Philippine Fisheries Statistics prevented a more consistent approach.

The surface areas of intertidal vegetation are taken from Anon. (1979). They refer to mangrove areas as obtained using LANDSAT imagery, and differentiate between more or less untouched or "virgin" mangrove and logged-over or "exploited" mangrove (see Table 3). The summary data for the Philippines are given in Table 1 (#8-14).

2.2 Methods

Three approaches were used in the analysis of the data of Table 1.

- Plotting $\log_{10}$MSY/area on $\log_{10}$ intertidal vegetation area, and plotting $\log_{10}$MSY/surface area on latitude, to demonstrate the effects of intertidal vegetation area and latitude on shrimp MSY.

- Plotting $\log_{10}$MSY on $\log_{10}$ intertidal vegetation area and latitude by means of a multiple regression, and comparing the results with those obtained without taking logarithms, to demonstrate that the relationship between MSY and intertidal vegetation area is not linear.

- Calculating the residuals of the best fitting multiple regression and ranking these residuals (= differences between actual and predicted values) to identify outlyers.

3. RESULTS

The relationship between $\log_{10}$MSY/ha and $\log_{10}$ intertidal vegetation in km^2 can be described by the equation

$$\log_{10}\text{MSY/area} = 2.761 - 0.24194\log_{10}\text{intert.veg.} \qquad ...1)$$

with $R = 0.508$, which is significant ($P < 0.01$). The relationship between MSY/area and latitude (° N or S) is, similarly:

$$\log_{10}\text{MSY/area} = 2.158 - 0.01539 \text{ lat.} \qquad ...2)$$

with $R = 0.327$, which is significant ($P < 0.05$).

Table 1. Data on penaeid shrimp yield (MSY) and its relationship to intertidal vegetation (mainly mangrove) and latitude.[a]

Nr	Area	Latitude	Intertidal vegetation $km^2 \times 10^3$	Shrimp MSY $t \times 10^3$	MSY per area[b] kg/ha
	Indonesian Waters				
1	Northern Sumatra	2°N	1.29	9.57	74.2
2	Southern Sumatra	2°S	5.26	14.9	28.3
3	N-E Java Coast	6.5°S	0.587	5.21	88.8
4	South Java Coast	8°S	0.262	4.31	165
5	Kalimantan	0°	6.97	11.9	17.1
6	Sulawesi	3°S	0.962	5.24	54.5
7	Western New Guinean and Moluccan Waters	5°S	9.69	15.4	15.9
	Philippine Waters[c]				
8	Region I	16.5°N	0.010	0.340	344
9	Region II	18°N	0.0268	0.721	270
10	Region IV	15°N	0.406	5.29	130
11	Region V	13.5°N	0.163	4.75	291
12	Region VI	10.5°N	0.0972	3.40	350
13	Region VII	10°N	0.103	2.88	278
14	Region VIII	11°N	0.184	2.45	133
	Misc. Asian Waters				
15	Sri Lanka	7°N	0.370	1.01	273
16	West Bengal	21°N	41.6	17.4	41.8
17	Malaysia	4°N	30.0	97.0	323
18	Pakistan	24°N	32.0	30.4	95.0
19	Thailand[d]	10°N	16.4	124[d]	756[d]
20	Cambodia	10°N	2.15	1.38	64.2
21	South Vietnam	10°N	4.74	88.8	187
	African Waters				
22	Madagascar	17°S	3.20	7.84	24.5
23	South Africa	18°S	1.35	0.845	62.6
24	Mozambique	15°S	8.58	5.28	61.6
	American Waters				
25	Ecuador and Peru	2°S	4.00	9.98	250
26	Venezuela (Lake) Macaraibo	10°N	12.0	12.9	108
27	Trinidad	10.5°N	1.41	0.870	61.7
28	Nicaragua (Pacific Coast)	12.5°N	1.50	2.30	153
29	Nicaragua (Atlantic Coast)	12.5°N	21.2	7.97	37.6
30	El Salvador	13.5°N	6.5	5.76	88.6
31	Costa Rica (Pacific Coast)	9°N	3.85	3.81	99
32	Guatemala (Pacific Coast)	14.5°N	1.83	3.39	185
33	Louisiana to Texas (USA)	29°N	122	65.7	53.7
34	West Florida to Mississippi (USA)	29°N	4.05	22.4	55.3
35	East Florida (USA)	28°N	6.15	2.21	35.9
36	Georgia (USA)	31.5°N	14.8	3.08	20.8
37	South Carolina (USA)	33°N	17.6	2.22	12.6
38	North Carolina (USA)	35.5°N	6.43	2.03	31.6

[a]See text for sources of data.
[b]To convert kg/ha to tonnes/km^2, multiply kg/ha by 10.
[c]See also Tables 2 and 3.
[d]Probably includes shrimp caught outside Thailand, as is also known to occur with "Thai" fish landings.

The linear plot of MSY (in tonnes) on intertidal vegetation area (in km^2) and latitude in (° N or S) is described by the equation

$$MSY = 19.9 + 0.1334 \text{ int. veg.} - 0.8292° \text{lat.} \qquad ...3)$$

with R = 0.510, which is significant ($P < 0.01$). Using logarithms, i.e. plotting $\log_{10}$MSY on $\log_{10}$ intert. veg. and latitude, leads however to the equation

$$\log_{10} MSY = 2.41 + 0.4875 \log_{10} \text{int.veg.} - 0.0212° \text{lat.} \qquad ...4)$$

and a much improved fit (R = 0.726), explaining 53% of the variance in the dependent variable (MSY).

Table 2. Data on shrimp landings by regions of commercial and artisanal fisheries for 1974-1978.

	Commercial fishing vessels ($t \times 10^3$)						Artisanal fisheries ($t \times 10^3$)			Commercial and artisanal ($t \times 10^3$)
	1974	1975	1976	1977	1978	Mean (1974-1978)	1977	1978	Mean (1977-1978)	Annual mean (1974-1978)
Region										
I	0.055	0.0641	0.0827	0.058	0.051	0.0622	0.389	0.167	0.278	0.340
II	–	–	–	–	–	–	0.695	0.747	0.721	0.721
IV	2.29	4.06	1.73	0.941	1.10	2.03	3.89	2.62	3.26	5.29
V	4.22	4.59	4.42	2.91	0.633	3.36	1.37	1.41	1.39	4.75
VI	3.01	2.7	2.59	1.68	1.08	2.21	1.21	1.17	1.19	3.40
VII	2.71	2.18	2.32	1.32	3.74	2.44	0.585	0.296	0.439	2.88
VIII	0.527	0.686	0.713	0.667	0.236	0.565	2.20	1.56	1.88	2.45

Table 3. Data on mangrove areas of the Philippines by regions (adapted from Anon. 1979).

Region	Virgin mangrove km^2	Exploited mangrove[a] km^2	Total mangrove area km^2
I	–	9.89	9.89
II	6.47	20.3	26.8
IV	346.00	59.6	406.00
V	101.00	61.6	163.00
VI	39.00	58.2	97.2
VII	72.1	31.3	103
VIII	139.00	45.3	184

[a]Exploited mangrove consists of logged-over areas and low density areas.

4. DISCUSSION

Our results suggest that the data sets of Turner (1977), that of Martosubroto & Naamin (1977) and the one we present here from the Philippines are, as a whole, mutually compatible and can be incorporated into a single relationship. The analysis of the residuals suggest that the values of MSY and/or mangrove areas for Thailand and possibly Malaysia may be erroneous (MSY too high).

The residuals for the Philippine data all have negative signs, *i.e.*, the actual MSY values are lower than predicted by equation (4). Possible reasons for this may be found in the fact that we have not differentiated between virgin and exploited mangrove, that reported shrimp landings were underestimated, or both. The frequency distribution of all residuals is normally distributed ($P < 0.01$), as assessed through a Kolmogorov-Smirnov test (Siegel,1956). This justifies the use of the statistical model implied in equation (4). (See Blalock 1972, p. 464 footnote).

The problem with a relationship such as (4) is however that as a logarithmic relationship, it cannot be used in a predictive mode, as is illustrated in the example below:

Let's assume a country, located at 0°latitude had 3 shrimping grounds, each with associated mangroves as follows:

area A	300000 km^2
area B	100000 km^2
area C	50000 km^2
	450000 km^2

Equation (4) provides estimates of $\log_{10}$ shrimp MSY of 5.08, 4.85 and 4.70 for areas A, B, and C respectively; the sum of their antilogs (241000 t) is much more than the value of 147000 t that would have been obtained, had the total area of 450000 km^2 been inserted into equation (4).

This dilemma cannot be avoided: it is due to the fact that large areas of intertidal vegetation have, on a per area basis, a smaller impact on fish yields than small areas, a fact reflected by the improved fit of equation (4) over equation (3). When reviewing aspects of this shrimp/mangrove relationship, the Standing Committee on Resource Research and Management of the Indo-Pacific Fisheries Commission (Anon. 1980 p. 6) wrote about this:

> "there appears to be a logarithmic relationship between the recruitment of shrimps in a given stock and the area of mangrove. [...]. If the logarithmic relationship holds, the impact of a given reduction of mangrove area on shrimp production will become greater as the remaining area is reduced".

We have demonstrated that the logarithmic relationship holds (even if it cannot be used directly for predictive purposes) and that, therefore destroying intertidal vegetation will affect shrimp fisheries, especially in those areas that have little of such vegetation.

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