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# An attempt to estimate the stock-recruitment relationship of Gulf of Thailand penaeid shrimps.

by

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Abstract: A procedure is proposed by means of which recruit number and parental biomass of shrimp (or fish) stocks can be derived, given a series of catch/effort data and estimates of a few ancillary parameters.

The method is applied to the stock of shrimps exploited by the Gulf of Thailand Demersal Trawl Fishery. The demonstration is made that recruitment decreased with parental biomass, but increased with decreasing fish standing stock. The net result of these counteracting effects was an overall increase in recruitment, attributable to a greatly reduced pre-recruit mortality.

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## 1. Introduction

Although shrimp stocks throughout the world support highly profitable fisheries, much too little is known of the biology and population dynamics of the various species which support these fisheries.

This is particularly true in the case of tropical and subtropical penaeid shrimps which, on the other hand, so greatly contribute to the economy of many developing countries.

Of the various factors which determine the yield of a fishery, recruitment certainly is the most evasive. Marr (1976, p. 41) wrote for example that "it is almost impossible to obtain informations on the stock and recruitment relationships. Indeed, this is one of the most perplexing problems of fishery biology." This statement, which was meant to apply for fishes applies even more in the case of shrimps, the stock-recruitment relationships of which - to my knowledge at least - hardly ever have been established.

The present contribution is an attempt to identify the stock-recruitment relationship of a commercially exploited stock of the penaeid shrimp, and is based mainly on catch/effort data from the Gulf of Thailand Demersal Trawl Fishery.

The analysis is very preliminary and relies heavily on a set of what may be thought to be questionable assumptions. These assumptions, however, had to be made in order to extract any information from the crude data presently available.

## 2. Material and Methods

### 2.1 Data for the whole demersal trawl fishery

The mean catch/effort of the Thai Research trawler R/V Pramong, the total effort exerted by the commercial fleet and the fishing mortality for the Gulf of Thailand inshore waters ($\geq 50$ m depth) are summarized in Table 1. The catch per effort (c/f) and the effort figures (f) are taken from Ritragsa (1976) and Boonyubol & Hongskul (1978), respectively. The estimates of fishing mortality (F) were estimated recently (Pauly, in press) on the basis of mean length data given in Boonyubol & Hongskul (1978) and growth and mortality parameter values whose estimation was discussed in Pauly (in press). The yield (Y) through the relationship

$$Y = c/f \cdot f \qquad \ldots 1)$$

Table 1. Basic data on the Gulf of Thailand demersal trawl fishery[1)]

| | Virgin Stock | 1963 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 |
|---|---|---|---|---|---|---|---|---|---|
| Catch per effort (in kg/h) | - | 248 | 131 | 115 | 106 | 103 | 97.4 | 66.3 | 63.1 |
| Effort, in million trawling hours | 0 | 0.698 | 2.078 | 2.800 | 3.500 | 3.600 | 3.800 | 6.200 | 7.188 |
| F (annual) | 0 | 0.22 | 0.64 | 0.87 | 1.09 | 1.12 | 1.18 | 1.92 | 2.23 |
| Total standing stock[2)] (in tons x 10 ) | 1978 | 1264 | 681 | 592 | 545 | 530 | 502 | 343 | 325 |

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1) From Pauly (in press), based on data in Ritragsa (1976) and Boonyubol & Hongskul (1978).

2) There is a difference between the catch per effort figures for the research and commercial trawlers which accounts for the difference that would be found by using the data in this Table to estimate total standing stock straightforwardly (see Pauly, in press).

Table 2. Estimation of a mean relative fecundity value in penaeid shrimps[1)]

| | Length/Fecundity relationship | | Lenght/Weight relationship | | Absolute fecundity | relative fecundity |
|---|---|---|---|---|---|---|
| | intercept (for LT, mm) | slope | intercept (for LT, mm) | slope | (of a 5g ♀, in thousand) | eggs x $10^3$/gram |
| Penaeus setiferus | (-0.7721) | (3) | -5.14 | 3.075 | 99.5 | 19.9 |
| Metapenaeus dobsoni | -0.7175 | 2.847 | (-5.10) | (3) | 61.1 | 12.2 |
| Parapenaeopsis stylifera | -1.575 | 3.344 | (-5.10) | (3) | 77.4 | 15.5 |
| | | | | | mean relative fecundity | 15.9 |

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1) Based on data in Lindner & Cook (1970), George (1970) and Vedayasa Rao (1970).

and the yield values so obtained were subsequently multiplied by a factor of 1.6 to account for the different mesh sizes used by the research and commercial trawlers (4 and 2 cm streched mesh, respectively, see Boonyubol & Hongskul, 1978). The yield estimates were then used to obtain estimates of mean annual standing stock (B) through the relationship

$$B = \frac{Y}{F} \qquad \ldots 2)$$

The values of standing stock so obtained are given in Table 1. These overall demersal standing stock figures will be used in the subsequent analysis as an indicator of the biomass of all potential shrimp predators and competitors, as it consists overwhelmingly of fishes and other animals which, at some their life history feed on some stages of shrimps, or on food items also consumed by shrimps.

## 2.2 Data on the reproduction, growth and natural mortality of shrimps.

### 2.21 Relative fecundity and size at first maturity

To estimate the egg potential of a shrimp population, an estimate is needed of the relative fecundity of shrimps (eggs produced per gram of female body weight). The relative fecundity was here estimated by calculating, using literature data for different species, the number of eggs (per gram body weight) contained in a mature female of average size. The results are given on Table 2 which provide a mean value for the relative fecundity of penaeid shrimps of 15.9 eggs per gram of female body weight.

Assuming a mean value of about 2/3 for the ratio between length at first maturity ($L_m$) and asymptotic length ($L_\infty$) (Beverton & Holt, 1959 Fig. 8) allowed for the estimation of a value of length at first maturity of 6 cm, which corresponds to an age at first maturity of $t_m = 0.3$ years when the growth parameters estimated in the next section are used for the conversion.

### 2.22 Growth and natural mortality of shrimps

Published growth and natural mortality parameter values are quite scarce as far as shrimp are concerned. In fact, I was able to locate only two stocks in which natural mortality had been estimated along with the growth parameters. These values, which in the case of the growth parameters, distinguish between females and males have been summarized in Table 3. This Table contains data for both a relatively small-sized shrimp (Penaeus plebejus) as well as for a relatively large shrimp (P. duorarum). I have, therefore, averaged the lot and constructed a hypothetical mean shrimp whose asymptotic length ($L_\infty = 9.1$) may roughly corresponds to the average maximum size of Gulf of Thailand shrimps. The growth and mortality parameter values of this hypothetical average shrimp are given in Table 3 and used for all further calculations.

Table 3. Growth and mortality parameters in two stocks of shrimps, and derivation of mean values.[1]

| | $LT_\infty$(cm) | $W_\infty$(g) | K(year) | $t_0$(year) | M(year) |
|---|---|---|---|---|---|
| Penaeus plebejus | | | | | |
| females | 4.9 | 0.9 | 5.2 | +0.10 | 2.67 |
| males | 4.0 | 0.5 | 5.2 | +0.13 | 2.67 |
| Penaeus duorarum | | | | | |
| females | 21.7 | 80. | 2.04 | -0.23 | 1.86 |
| males | 16.1 | 33 | 3.36 | -0.26 | 1.86 |
| "Geometric Mean Shrimp" | 9.1 | 6. | 3.69 | ≈0 | 2.23 |

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1) Based on data in Lucas (1974) and Garcia (1975 a, b)

2.3 Combining the biological data on shrimps with data from the shrimp fishery.

Ritragsa (1976) gives shrimp catch/effort data obtained by R/V Pramong 2 in 1963, and 1966 through 1972 in the Gulf of Thailand. These data, which are summarized in Table 4 cannot directly be used the commercial catch (through multiplication with effort, as suggested in equation 1) because the commercial trawlers use smaller meshes than R/V Pramong 2 (see above).

A formula, therefore, was devised which converts the catch rates obtained by using a given mesh size to those catch rates which would be made - on the average - by using another mesh size, given the growth coefficient K, the total mortality Z, and the mean ages at first capture corresponding to the two mesh sizes under consideration.

The formula has the form:

$$c = \frac{\frac{1}{Z} - \frac{3\ \exp(-Kr_1)}{Z + K} + \frac{3\ \exp(-2Kr_1)}{Z + 2K} - \frac{\exp(-3Kr_1)}{Z + 3K}}{\exp(-Zr_3)\cdot\left\{\frac{1}{Z} - \frac{3\exp(-Kr_2)}{Z + K} + \frac{3\exp(-3Kr_2)}{Z + 3K} - \frac{\exp(-3Kr_2)}{Z + 3K}\right\}} \qquad \ldots 3)$$

where c is a multiplicative factor which converts the catch rates made with the larger meshes to the catch rates that are made with the smaller meshes, and

where $r_1 = (t_{c2} - t_o)$

$r_2 = (t_{c4} - t_o)$

$r_3 = (t_{c4} - t_{c2})$

and $Z = M + F$

The growth parameters of the mean shrimp (Table 3) suggest values of $t_{c2} = 0.11$ and $t_{c4} = 0.29$, when a value for the selection factor of 1.5 is used. This, combined with the value of $K = 3.69$ (quite a high value, incidentally) and the F value for each year allowed for the calculation of the correction factors c given in Table 4.

The estimated commercial catch/effort and the total effort figures now allow for an estimate of catch to be obtained by means of equation 1, these estimates of catch then being used, in conjunction with equation 2 to estimate the average standing stock (B) of shrimps (Table 4).

Using the growth parameters of Table 3 in conjunction with the F - values of Table 1 allow for the calculation of yield-per-recruit (Y/R) by means of the relationship

$$Y/R = F\cdot W_\infty \cdot \left\{\frac{1}{Z} - \frac{3\cdot\exp(-Kr_1)}{Z + K} + \frac{3\cdot\exp(-2Kr_1)}{Z + 2K} - \frac{\exp(-3Kr_1)}{2 + 3K}\right\} \qquad \ldots 4)$$

where $Z = F + M$ and $r_1 = t_{c2} - t_o$, the model itself being the simplified version presented by Jones (1957) of the yield equation of Beverton & Holt (1957).

The number of recruits produced annually can then be estimated from the relationship

$$\text{recruits} = \frac{\text{annual yield}}{\text{yield-per-recruit}} \qquad \ldots 5)$$

The results are given for each year in Table 4, along with the Y/R values computed from equation 4.

Table 4. Data for the identification of a stock recruitment relationship in Gulf of Thailand shrimp stocks.

| | Virgin stock | 1963 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 |
|---|---|---|---|---|---|---|---|---|---|
| Research catch/effort (kg/h)1) | - | 0.567 | 0.269 | 0.116 | 0.090 | 0.112 | 0.147 | 0.260 | 0.218 |
| conversion factor "c" | 1.100 | 1.115 | 1.145 | 1.163 | 1.181 | 1.184 | 1.189 | 1.258 | 1.291 |
| Commercial catch/effort (kg/h) | - | 0.632 | 0.308 | 0.135 | 0.106 | 0.133 | 0.175 | 0.327 | 0.281 |
| catch (tons) | - | 441 | 640 | 378 | 371 | 479 | 665 | 2027 | 2020 |
| yield per recruit (gram) | - | 0.259 | 0.585 | 0.702 | 0.785 | 0.794 | 0.812 | 0.945 | 0.968 |
| recruits (millions) | (≈2000)2) | 1702 | 1094 | 538 | 472 | 603 | 818 | 2145 | 2087 |
| shrimp standing stock (tons) | (≈2887)3) | 2005 | 1000 | 434 | 340 | 428 | 564 | 1056 | 906 |
| conversion factor "m" | 0.900 | 0.887 | 0.862 | 0.848 | 0.833 | 0.831 | 0.828 | 0.778 | 0.757 |
| shrimp parent stock (tons) | 2598 | 1778 | 862 | 368 | 283 | 356 | 467 | 822 | 686 |
| egg production (billions) | 41.3 | 28.3 | 13.7 | 5.85 | 4.50 | 5.66 | 7.43 | 13.1 | 10.9 |
| daily death (%) of prerecruits | 7.3 | 6.8 | 6.1 | 5.8 | 5.5 | 5.4 | 5.3 | 4.4 | 4.0 |

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1) recalculated from Tables 5-13 in Ritragsa (1976)

2) estimated from figure 2.

3) estimated by extrapolating to $F = 0$ the natural logarithm of the 1963 ($F = 0.22$) and 1966 ($F = 0.64$) standing stock values plotted on fishing mortality.

To obtain a stock-recruitment relationship, estimated recruit number must be faced with an estimate of the parental biomass, or better, with an estimate of the number of eggs produced annually by all spawning females of the stock.

To obtain an estimate of parental biomass, one can simply reduce the total shrimp standing stock, by means of a multiplicative factor "m" (analogous to the factor "c" above) expressing the proportion of shrimp in the total shrimp standing stock whose age is equal or higher than the mean age at first maturity ($t_m$, see above). The value of the multiplicative factor m is given through

$$m = \frac{\exp(-Zr_3) \cdot \left\{ \frac{1}{Z} - \frac{3\exp(-Kr_2)}{Z + K} + \frac{3\exp(-2Kr_2)}{Z + 2K} - \frac{\exp(-3K_2)}{Z + 3K} \right\}}{\frac{1}{Z} - \frac{3\exp(-Kr_1)}{Z + K} + \frac{3\exp(-2K_1)}{Z + 2K} - \frac{\exp(-3K_1)}{Z + 3K}} \qquad \ldots 6)$$

where $r_1 = (t_{c2} - t_o)$

$r_2 = (t_m - t_o)$

$r_3 = (t_m - t_{c2})$

and $Z = M + F$

The values of m computed by means of equation 6 are given in Table 4, along with the estimates of parental biomass obtained by multiplying the overall shrimp standing stock, for each year with its corresponding value of m.

Annual egg production was then obtained by directly multiplying the parental biomass by the mean relative fecundity obtained in Table 2, under the assumption that the females make one-half of the shrimp parental biomass and that they spawn twice a year.

The mortality, in % per day, of the shrimp pre-recruits, finally, was estimated from the relationship.

$$\text{percent mortality} = 1 - \exp \frac{\ln\left\{\frac{\text{recruits}}{\text{eggs}}\right\}}{t_{c2}} \qquad \ldots 7)$$

Where $t_{c2}$ is the mean age at first capture with 2 cm meshes (= 0.11 year or 40.15 days). The percentage mortality value so obtained may be found in Table 4, along with the estimated annual egg production.

## 3. Results

On the basis of the data of Tables 1 and 4 (or 5), the following exploratory plots were drawn and/or estimated:

1) shrimp recruitment on parent biomass which is proportional to egg production (Fig. 1);

2) shrimp recruitment on total demersal standing stock; (Graph similar to Fig. 1, not shown here.)

3) $\log_{10}$ of shrimp recruitment on $\log_{10}$ egg production and $\log_{10}$ total demersal standing stock (see data of Table 5).

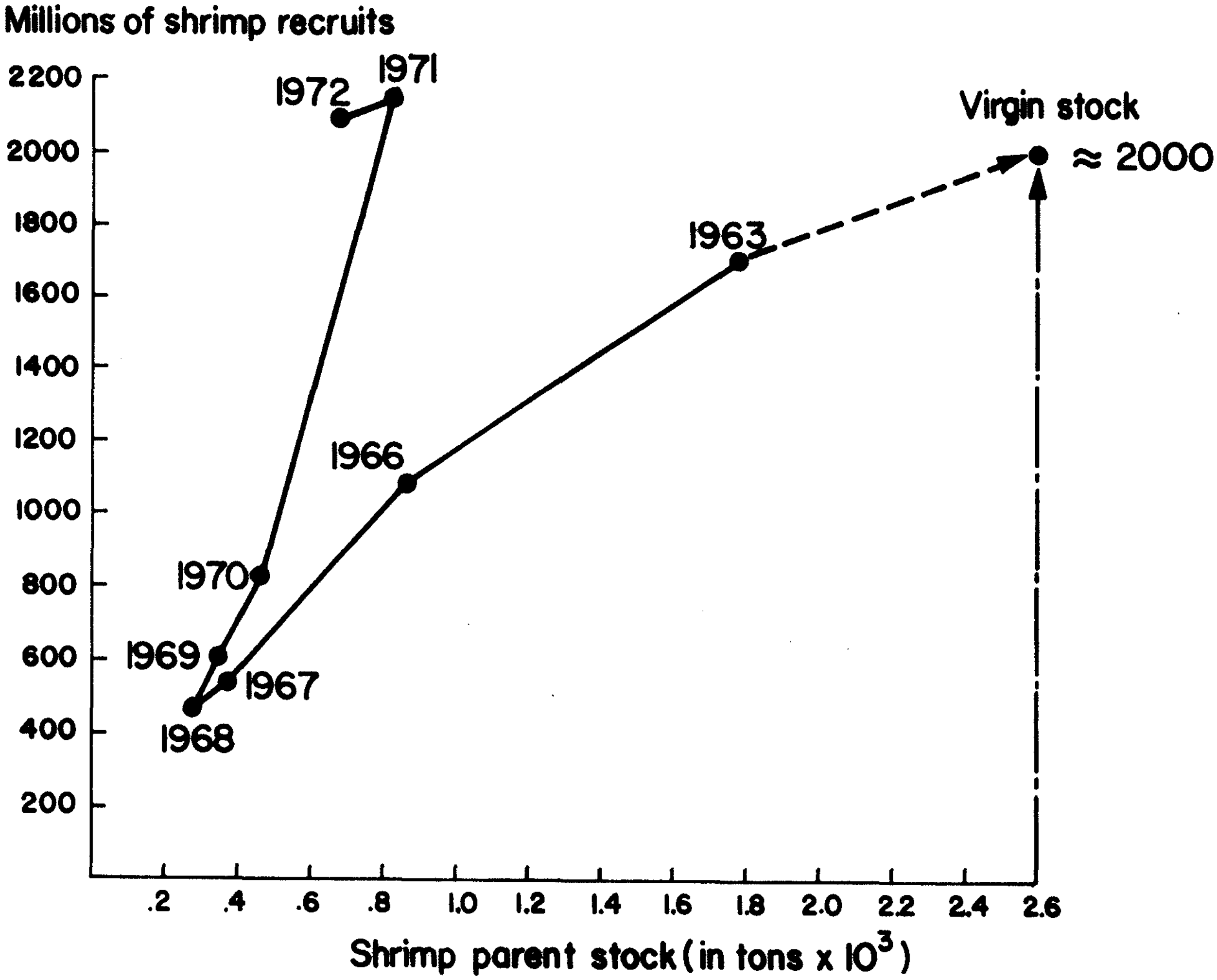

Fig. 1. Stock-recruitment relationship of penaeid shrimps in the Gulf of Thailand. Note increase of recruitment from 1968 onward, probably due to reduction of total demersal stock biomass. Virgin stock recruitment ($2000 \cdot 10^6$ recruits) in an extrapolation.

Table 5. Relationship between shrimp egg production, potential predation and shrimp recruitment. (R = 0.991)

| date | shrimp egg production[1)] | biomass of predators & competitors[2)] | shrimp recruitment[3)] | estimated recruitment[4)] | % deviation |
|---|---|---|---|---|---|
| Virgin stock | 41.3 | 1978 | 2000 | 1840 | - 8.0 |
| 1963 | 28.3 | 1264 | 1702 | 1750 | + 2.8 |
| 1966 | 13.7 | 681 | 1094 | 1297 | -18.6 |
| 1967 | 5.85 | 592 | 538 | 556 | + 3.3 |
| 1968 | 4.50 | 545 | 472 | 443 | - 6.1 |
| 1969 | 5.66 | 530 | 603 | 588 | - 2.5 |
| 1970 | 7.43 | 502 | 818 | 839 | + 2.6 |
| 1971 | 13.1 | 343 | 2145 | 2200 | + 2.6 |
| 1972 | 10.9 | 325 | 2087 | 1869 | -10.4 |

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1) from Table 4

2) from Table 1

3) from Table 4

4) from equation 9

5) from figure 1

The last of these plots corresponds to a multiple regression of the form

$$\log Z = a + b \log X + c \log Y \qquad ...8)$$

with Z being the shrimp recruitment
X the annual shrimp egg production
and Y the total demersal standing stock.
The data of Table 5 provided the empirical relationship

$$\log Z = 4.218 + 1.133 \log X - 0.845 \log Y \qquad ...9)$$

which has a multiple correlation coefficient of R = 0.991, while a value of 0.886 is sufficient for significance (with 6 dF, P = 0.01). The data on the pre-recruit mortality (Table 4), finally, were plotted against the total demersal standing stock figures of Table 1.

The resulting plot (Fig. 2) shows quite unequivocally that pre-recruit mortality was drastically reduced (almost halved) when the total demersal standing stock declined to its 1972 level; this can be interpreted easily by assuming that a sizeable part of the fishes and other organisms that were removed from the total demersal stock had been feeding on shrimp pre-recruits. This reduction of mortality at low levels of demersal stock sizes (in 1971 and 1972 especially) would then account for the greatly increased recruitment in 1971 and 1972 (see Fig. 1).

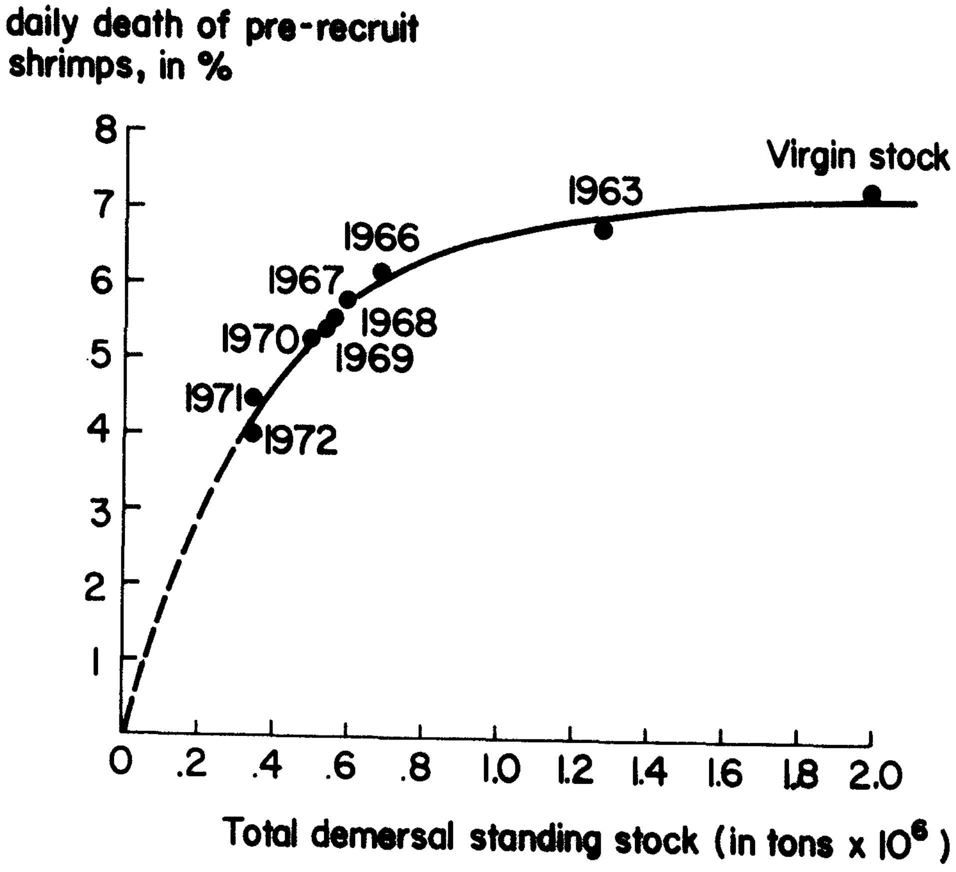

Fig. 2 Relationship between pre-recruit mortality in penaeid shrimps and the size of the total demersal standing stock exploited by the Gulf of Thailand Trawl Fishery.

## 4. Discussion

The method outlined here to derive stock recruitment relationships from catch/effort data, estimates of F and growth and natural mortality parameters is still tentative, although it appears to generate, among other things, a classical "Ricker curve" when used in combination with appropriate data (e.g., in the case of Lactarius lactarius from the Gulf of Thailand, see Pauly, in press), while another type of stock recruitment relationship - a dependence of recruitment on predator biomass only - was generated by applying the method to data on the flatfish Psettodes erumei, also in the Gulf of Thailand. (Pauly in press). Thus, in fact the method has generated hitherto three different types of stock-recruitment relationships possibly corresponding to three different ecological strategies (Table 6).

This would suggest that the method would not tend to always generate the same type of stock recruitment relationship, e.g., due to some inherent bias.

Still, more work will have to be done with this type of approach in order to assess its overall applicability.

A drawback of the method - when taxa larger than species are considered - is the need to "construct" average organisms with "average" growth and mortality parameter values. Clearly, since such average organisms do not exist, all estimates of yield-per-recruit, recruit numbers, egg production, etc., will be biased to an unknown extant.

I have, therefore, chosen to perform all calculations with values for the parameters as realistic as possible, such as to be able to assess the reasonableness of some numerical results. Thus, for example, the values of about 4 to 7% death per day for shrimp pre-recruits appear reasonable (see Fig. 2) as it is close to the mortality values reported from fish larvae in different areas of the world (Dahlberg, 1979).

This is recomforting in the light of the fact that two of the parameter values used for the computation were particularly shaky. This applies both to the value of K = 3.69 which seems quite high and which, in connection with the other growth parameters generates among other things a mean age at first maturity of less than 4 months, and to the value of the selection factor (S.F.) which I have set at 1.5 because S.F. values in penaeid shrimps seem to range from 0.4 (Aoyama, 1973) to 3.5 (Simpson & Perez, 1975), and because value of about 1.5 corresponds to the S.F. of the bulkiest fishes of the South China Sea area (Sinoda et al., 1979, Fig. 1)

Table 6. Biological predictors of recruitment in selected tropical fish and crustacean stocks.

| Predictor variable(s) | Examples | Remarks |
|---|---|---|
| Parental stock size | *Lactarius lactarius*1) (Pisces, Lactariidae) | corresponds to a typical Ricker curve (see Ricker 1975) |
| Parental stock size and biomass of predators | penaeid shrimps2) (Crustacea, Penaeidae) | intertidal vegetation area may be considered as an additional predictor of shrimp recuitment. (see Turner, 1977, or Martosubroto and Naamin, 1977) |
| Biomass of predators | *Psettodes erumei*1) (Pisces, Psettodidae) | the relationship, obviously, does not hold for extremely low levels of parent stock. |

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1) Pauly, in press
2) present paper

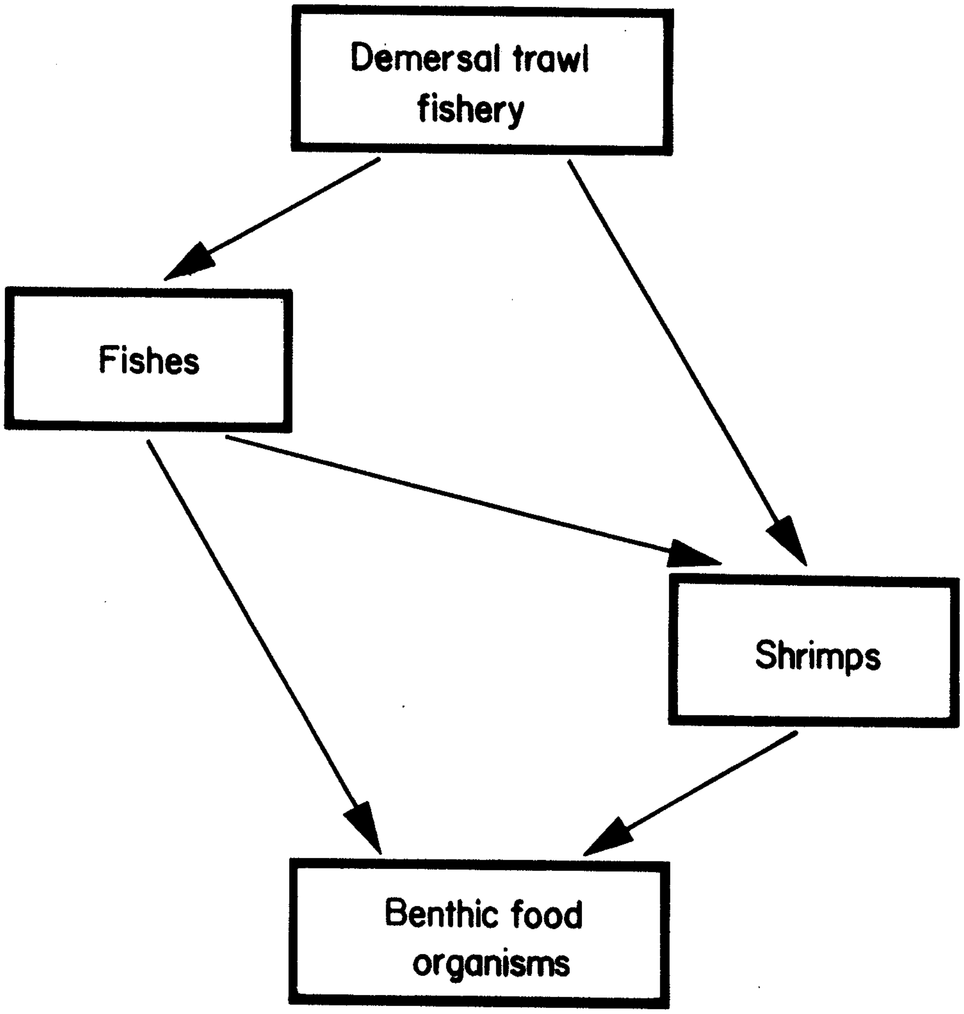

Fig. 3 Basic interrelationships between shrimps, fishes and a demersal trawl fishery. Note that fishes are both the competitor and the predator of shrimps, while the fishery is both a competitor and predator of fish. Based on the concept of a food web "in triangles" of Rodney Jones (pers. comm.).

The drawbacks of the methods, and the shakiness of some of the assumptions do not prevent the results from being essentially easy to interpret.

We do know that fishes eat shrimps, and that many fishes feed on organisms also consumed by shrimps (c.f. data in Tiews _et al._, 1968a with data on Tiews _et al._, 1968b). Thus, generally speaking, fishes are both the predators and the competitor of shrimps, while both fishes and shrimps are prey of a demersal fishery (Fig. 3).

The demersal fishery, by offsetting the natural balance between shrimps and fishes can therefore indirectly increase the survival of shrimps by removing their predators and competitors (Fig. 2). This is probably what happened in the Gulf of Thailand where the biomass of shrimps, along with that of other invertebrates (crabs, squids, cuttle-fish) and fishes (conger eel, flatfish) increased as the total standing stock decreased (Pauly, 1979).

This would explain why plotting shrimp recruitment on egg production and on the total demersal standing stock should remove such a large percentage (> 98%) of the variance in recruitment.

This high value of $R^2$, incidentally, suggest that recruitment, in the Gulf of Thailand shrimp stocks is determined solely by biological or/and by fishery-induced changes in stock biomass and composition and not, as in temperate waters, by fluctuations in the abiotic environment.

Baranov (1927), cited in Ricker (1975 p 309) stated that "a fishery, by thinning out a fish population, itself creates the production by which it is maintained".

As it appears, "thinning out of a fish population" also has the effect of reducing the predation and the food competition affecting the shrimp stock associated with these fishes. This can result, eventually, in an increase of the shrimp component in the catch, granted that the parental (shrimp) population is itself not too badly reduced.

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