transported by the tidal currents back, through the passes, into the lagoon, i.e., into their nursery areas in very shallow waters dominated by turtle grasses and mangrove. Here, they remain until they become late juveniles, at which point they return to deeper waters. Cross (1978) stated that his sampling results showed migration into deeper waters at a length of around 11-12 cm and first sexual maturity of females at a length of 22 cm and of males at 19 cm. Considering this suggests that the samples in Table 1 will not provide a true representation of the natural population but only of the juveniles.

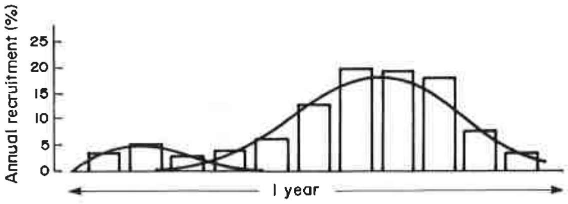

Fig. 3. Recruitment pattern of *Gerres oyena* at Tarawa, Kiribati. Note the separation of two unequal pulses by a period of about 6 months.

Thus, if one were to use these data as if the above-mentioned migrations did not occur, one would (i) underestimate L_∞; (ii) overestimate K and consequently (iii) overestimate Z and M[c].

On the other hand, these data, pertaining exclusively to young fishes, are well-suited to identify the seasonality of recruitment of *G. oyena* in Tarawa Lagoon. Fig. 3 presents the recruitment pattern thus obtained.

As might be seen, this suggests that *G. oyena* recruits in two annual pulses of unequal strength - which is similar to what other tropical species appear to do.

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[c]Editor's note: Since the work reported upon here was conducted, a paper was published which may present reliable growth parameter estimates for the common silverbiddy. Its reference is: El-Agamy, A.E. 1988. Age determination and growth studies of *Gerres oyena* (Forsk.) in the Arabian Gulf waters. Mahasagar 21(1):23-34.

Estimating Natural Mortality of Kuwait's *Penaeus semisulcatus* Using a New Tag-Recapture Data Analysis Method

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Abstract

A novel method was used to estimate natural mortality (M) of Kuwaiti *Penaeus semisulcatus* using tagging data. The new M estimator is based on two tagging experiments with similar products of initial survival after tagging times reporting rate, but with different total mortality (Z) values. The best M-estimate for males was 2.4 $year^{-1}$; the data on the female were, however, inadequate for use by this method. The new method is likely to produce reasonable estimates of M if accurate Z-values are used.

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Introduction

Natural mortality (M) is an important parameter in all analytical models of fish and shellfish stock dynamics. This article describes a novel method employed to estimate M for the heavily exploited phase of the *P. semisulcatus* stock, using tag-recapture data.

Materials and Methods

The following notation is used:

N_o = number of tagged and released shrimps; n_i = number of recaptures during i^{th} time period; Z_i = instantaneous total mortality coefficient during i^{th} time period; F_i = instantaneous fishing mortality coefficient during i^{th} time period; X = instantaneous natural mortality coefficient of tagged shrimp during i^{th} period; SB = product of initial survival rate (due to initial tagging death, nonsystematic tag loss and emigration) and reporting rate of recoveries (i.e., Ricker's (1975) Type A error); and t = last period for which tagging data were considered.

The following four assumptions were made:

i) M is constant;
ii) SB is constant;
iii) Numerous releases are made in each experiment to conform to deterministic mortality processes and to minimize dependence between successive recaptures;
iv) At least two experiments with different magnitudes of Z are performed.

The product SB was estimated using Pope's (1972) formula (1.5) for initial population estimation from incomplete recoveries. Thus,

$$SB = 1/N_o\,[n_1 \exp(X/2.1) + n_2 \exp(X + X/2.1) + .. + n_i \exp[(i-1)X + X/2.1] + ... + [n_t \exp((t-1)X + X/2.1)]/[1 - \exp(-F_t)]] \quad ...1)$$

The approximation factor 2.1 used in equation (1) fitted well the observed range of Z from the two tagging experiments, with less than 0.25% error (as compared with Gulland's (1965) VPA formula).

When two tagging experiments with similar SB values but different Z value are analyzed (i.e., with different F_t values), a unique X value based on the method of Silliman (1943) can be determined using equation (1). F_t values can be selected by trial and error to satisfy $Z = F_t + X$, where Z values are slopes of the regressions (equation 2, below) of the two experiments and X is the result, for a particular pair of the F_t values, that produced the least difference between the two SB-estimates.

A FORTRAN program was written for this purpose, incorporating a simple grid-search method. In this program, F_{t1} (F_t in the experiment with the lower Z-value, say Z_1) was varied from O to Z_1 by an arbitrary small step size. At each step, the X-value was determined which satisfied $Z_1 = F_{t1} + X$. This X-value was then used to evaluate F_{t2} from $Z_2 = F_{t2} + X$, where Z_2 and F_{t2} were the corresponding mortality parameters of the second experiment. It was assumed that $X \leq Z_1$. Using the above F_{t1}, F_{t2} and X-values in equation (1), SB-values for the two experiments were determined. The square of the difference between these two SB-values was then evaluated for minimization.

Tagging Experiments

The 1982 to 1983 experiments considered in this analysis were of subadult and adult *Penaeus semisulcatus* (20.5-49.7 mm CL) tagged with vinyl streamer tags and released in the southern fishing grounds, dominated by this species. Most recaptures were reported from the southern fishing grounds by Kuwaiti trawlers. The releases were grouped into major experiments separately for each sex with respect to area and time of release. Recapture rates for these experiments varied between 5.4 and 15.6% for females and 8.5 and 17.3% for males. They were grouped into 20-day periods (Table 1). Because most recoveries were reported within four to five months of release, only recoveries up to 140 days were considered.

Table 1. Tagged *Penaeus semisulcatus* recovered off southern Kuwait, grouped by 20-day time periods.

Expt. no.	Release date	Number released	Recaptures (%)	Time period (days) 1-20	21-40	41-60	61-80	81-100	101-120	121-140	141[a]
Female											
1	12-14 Sep 82	1,189	5.4	18	16	8	6	11	2	0	3
2	13-16 Jun 82	1,026	11.7	4	40	34	18	3	9	5	7
3	20-22 Jun 83	907	15.6	12	30	45	16	14	6	7	11
Male											
1	12-14 Sep 82	1,298	8.5	19	37	27	14	5	4	1	3
2	13-16 Jun 82	932	14.3	2	53	24	21	5	10	10	8
3	20-22 Jun 83	1,089	17.3	9	36	57	14	24	17	7	24

[a]All recoveries whose recapture time periods exceeded 140 days were pooled.

The Z-value for each experiment was determined using the following equation:

$$\ln (n_{i+1}) = \ln \{(FN_0SB/Z)[1-\exp(-Z)]\} - iZ \qquad \text{...2)}$$

This Z-value was used to select a pair of X- and F_t-values to estimate SB for each experiment. Only the males from experiment 2 and 3 (Table 1) produced close SB-values for a range of X- and F_t-values. Thus, these two experiments were considered for optimization.

Results and Discussion

The grid search was initiated with Z-values from equation (2). The optimum X-value was 0.1314/20 day (i.e., 2.4 $year^{-1}$); the optimum SB value was 0.30. The optimization was repeated with Z-values varied by 5%, which produced results differing by 11-12% from the optimum (Table 2). Thus, the results appear fairly sensitive to variation in Z-estimate, highlighting the need to obtain a fairly accurate Z-value to select the best F_t for each experiment.

The optimum X-value (2.4 $year^{-1}$) will be an overestimate if Ricker's (1975) Type B errors - systematic tagging mortality, tag losses and emigration - occur. Previous tagging experiments in Kuwait water have shown restricted movements of tagged shrimp (Mohammed et al. 1981). Thus, systematic migrations were assumed not to occur. Because of the short time span of tag recoveries (140 days), systematic tagging mortality and tag losses were also assumed to be low. Thus, the estimate of X could be taken as close to the true M.

Because very young and old shrimp were excluded from the experiments, assumption (i) (constant M) was largely satisfied by the tagged population. Assumption (ii) (constant SB) was satisfied by the males of the two experiments considered here, thus enabling estimation of X. Assumption (iii) (numerous releases) was satisfied by the males and females of both experiments, where releases exceeded 900. Assumption (iv) (two experiments with different Z values) was also met.

The new X estimator appears well suited in a situation where effective fishing intensity is unknown, the tagged population suffered a variable fishing mortality, and initial tagging mortality and nonreporting of tags occur.

The major drawback of this method is the necessity for at least a pair of experiments having similar SB but different Z-values. If a number of tagging experiments are conducted under similar conditions (i.e., during the same season and using the same tagging methods), the probability will be high, however, that a pair of suitable experiments with suitable properties can be found, thus making M estimable using the method proposed here.

Table 2. Optimized results from cohort formula with male *P. semisulcatus* tagging experiment Nos. 2 and 3 with Z-values of 0.3543 and 0.3222, respectively.[a]

Regression method		Optimized results				
F_{t2}	F_{t3}	X	SB_2	SB_3	Square of SB difference	Remarks
0.2229	0.1908	0.1314	0.3000	0.3001	0.1584×10^{-7}	Inputs from regression Z-estimate
0.2195	0.1890	0.1171	0.2838	0.2839	0.5500×10^{-8}	Inputs from 5% less than the regression Z-value
0.2245	0.1908	0.1475	0.3209	0.3207	0.1638×10^{-7}	Inputs from 5% more than the regression Z-value

[a]Z, F_t and X values are given for 20-day period; F_{t2}, F_{t3}, SB_2 and SB_3 refer to F_t and SB values of experiment nos. 2 and 3, respectively.

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