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A Diagnostic Tool for Identifying Tag-Related Biases in Mortality Estimates: A Case Study from Kuwait's Shrimp Fishery

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Abstract

Changes in the ratio of tagged shrimp recovered to untagged shrimp caught in the fishery during a release and recapture tagging experiment may be used to identify the occurrence of tag-related mortality in the field. Where the ratio declines, it is likely that tag-related mortality occurs, that estimates of total mortality are biased and that only fishing mortality estimates will be reliable. The theory and assumptions underlying the method are discussed and applied to Kuwait tagging data, which show that tag-related mortality occurred in the field, contrary to results of laboratory observations. The method may be applied to old tagging data on fish or shrimp for which laboratory experiments on tagging mortality are unavailable. The method has the advantage of being able to identify (but not measure) tag-related mortality in the field, which may differ from tag-related mortality determined in laboratory experiments.

Introduction

Extensive tagging experiments carried out in Kuwait (Mohamed et al. 1981; Al-Shoushani et al. 1984) showed that tagged shrimp, *Penaeus semisulcatus* de Haan, usually move less than 10 km from their point of release, although exceptionally they may move as much as 70 km. Tagged shrimp were released in five different fishing grounds covering Kuwait's main fishing areas (Mohamed et al. 1981). El-Musa (1982) reanalyzed the data and

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showed that movements of tagged shrimp occurred between all fishing grounds. It is likely that tagged shrimp mixed into the untagged populations rapidly. Mathews (1982) also concluded that mixing of tagged shrimp into the untagged populations occurred rapidly. Preliminary analysis of the migration pattern within Kuwait waters showed that Kuwait's shrimp stocks were separate from other stocks in the area and that they could be managed separately. No tagging studies involving shrimp outside Kuwait waters have been carried out, however.

At a series of shrimp fisheries management workshops (FAO 1982; Mathews 1982, 1984a, 1984b, 1986), management strategies were presented and revised annually. These strategies were based on estimates of population parameters which assumed no significant interaction with neighboring stocks. For instance, Jones and van Zalinge (1981) estimated total mortality (Z) using a size-based adaptation of cohort analysis. The estimates obtained were, however, very high (Mathews et al. 1987), 4.85-12.50 per year for male and female *P. semisulcatus* and 33.33-36.44 per year for male and female *Metapenaeus affinis* (these two species combined usually comprise over 90% of commercial landings in Kuwait). Estimates of Z based on analyses of tag returns from two independent tagging experiments for *P. semisulcatus* were also suspiciously high, 26.5-31.5 per year (Mohamed et al. 1981). Both sets of results differed from estimates of Z based on catch curves, Z=2.6-6.3 (mean 4.4 per year) for female and Z=2.9-6.5 (mean 4.7 per year) for male *P. semisulcatus* (Mathews et al. 1987). Farmer and Al-Attar (1982a) also reported high total mortality estimates from tag returns (up to 28.5 using floy tags, attaching tags and anchor tags). They used a much smaller sample than Mohamed et al. (1981).

Mohamed et al. (1981) carried out a simple laboratory experiment to determine tag-related mortality and concluded after a short initial period of low tag-related mortality (<10%) lasting less than two weeks, that tag-related mortality was reduced to zero. In Ricker's (1975) terminology, type A mortality (causing immediate reduction in number of tagged shrimp) was <10% and type B mortality (increasing the natural mortality coefficient M) was zero for the duration of the laboratory experiment. The Mohamed et al. (1981) experiment was carried out in 1-m^3 tanks of seawater, without a substratum, with shrimp fed ad libitum. In later laboratory observations, it was noted that tagged *P. semisulcatus* may bury themselves in sand with tags being visible at the surface (A.S.D. Farmer, pers. comm.). It is possible that tag-related mortality of shrimp in the field may differ from that observed in the laboratory, for instance because fish predation in shrimp may be enhanced if shrimp carry tags. Tagged shrimp were released from special cages which were not opened before they touched sea bottom to eliminate predation mortality prior to release. However, no attempt was made to evaluate predation or other type B-related mortalities upon tagged shrimp once they were released (Farmer and Al-Attar 1982b). Tag-related mortality could have been high (Cody and Avent 1980; Howe and Hoyt 1982).

The object of this study was to determine whether the ratio of tagged to untagged shrimp catches during a tagging experiment could be used as a criterion to determine whether or not tag-related mortality occurs in shrimp at sea. Such ratios may be calculated directly from the number of shrimp recaptured and from available data on commercial landings. Therefore, analysis of the ratio of tagged to untagged shrimp in the landings may provide an easily applicable diagnostic test to demonstrate the presence of biases in estimates of Z from field experiments.

Methods

Algebraic formulae

Let Z = instantaneous total mortality coefficient
E = instantaneous emigration coefficient
I = instantaneous immigration coefficient
N = number of shrimp at the beginning of the tagging experiment
U_i = number of untagged shrimp caught during ith period
T_i = number of tagged shrimp caught during ith period

Subscripts u or t indicate that a parameter refers to untagged or tagged shrimp, respectively. In the following analysis, Z, E and I were assumed to be constant throughout the period considered. The two populations on the first day of the ith month will be:

$$N_t \cdot e^{-(Z_t+E_t)(i-1)} \quad \text{tagged shrimp and}$$

$N_u \cdot e^{-(Z_u+E_u-I)\cdot(i-1)}$ untagged shrimp.

Therefore, assuming F is the same for both populations (see text), the catch of tagged shrimp during the ith month is:

$$T_i = \frac{F}{Z_t} \cdot \left[N_t \cdot e^{-(Z_t+E_t)\cdot(i-1)}\right] \cdot \left[1 - e^{-(Z_t+E_t)}\right] \qquad \text{...1)}$$

and for untagged shrimp is:

$$U_i = \frac{F}{Z_u} \cdot \left[N_u \cdot e^{-(Z_u+E_u-I)\cdot(i-1)}\right] \cdot \left[1 - e^{-(Z_u+E_u-I)}\right] \qquad \text{...2)}$$

The ratio of the catches of tagged (T_i) to untagged shrimp (U_i) in the ith month is therefore obtained by dividing equation (1) by equation (2); thus

$$\frac{T_i}{U_i} = \frac{Z_u}{Z_t} \cdot \left[\frac{N_t}{N_u \cdot e^{(I+E_t-E_u+Z_t-Z_u)\cdot(i-1)}}\right] \cdot \left[\frac{1-e^{-(Z_t+E_t)}}{1-e^{-(Z_u+E_u-I)}}\right] \qquad \text{...3)}$$

Therefore,

$$I + E_t - E_u + Z_t - Z_u \neq 0 \qquad \text{...4)}$$

is the condition for a change of T_i/U_i with increasing i. Z_t-Z_u is unlikely to be negative.

Six cases exist which need to be considered. The first three are based on the assumption that immigration of untagged shrimp to the population occurs, i.e., that $I > 0$:

(i) Let $E_t = E_u$ then $e^{(I+E_t-E_u+Z_t-Z_u)\cdot(i-1)} = e^{(I+Z_t-Z_u)\cdot(i-1)}$

Therefore, as i increases, $e^{(I+Z_t-Z_u)\cdot(i-1)}$ increases, so that T_i/U_i will decrease with time.

(ii) Let $E_t > E_u$, then T_i/U_i will decrease with time as in (i) above.

(iii) Let $E_t < E_u$, then T_i/U_i will either decrease or increase, depending on the magnitude of the difference between E_t and E_u.

The other three cases are based on the assumption that immigration of untagged shrimp into the study area is zero, i.e., that I = 0:

(iv) Let E_t=E_u, then T_i/U_i is either constant (when Z_t=Z_u) or will decrease (when Z_t>Z_u) with time.

(v) Let E_t>E_u, then T_i/U_i will decrease with time.

(vi) Let E_t<E_u, then T_i/U_i will increase or decrease with time depending on the magnitude of (E_t-E_u), which is negative.

i.e.

If (E_u-E_t)>(Z_t-Z_u), T_i/U_i will increase with time and
if (E_u- E_t)<(Z_t-Z_u), T_i/U_i will decrease with time.

Therefore, T_i/U_i will decrease with time when I = 0, if

a) E_t=E_u and Z_t>Z_u ...(case iv)

or

b) E_t>E_u and Z_t=Z_u or Z_t>Z_u ...(case v)

or

c) E_t<E_u and Z_t>Z_u and (E_u-E_t)<(Z_t-Z_u) ...(case vi)

The inverse of the ratio T_i/U_i (equation 3) can be used to estimate population size. Assuming that Z_u=Z_t, E_u=E_t and I=0, equation 3 can be reformulated for i=l as:

$$N_u = \frac{N_t \cdot U_1}{T_1} \qquad \text{...5)}$$

This equation is, in fact, a simple formulation of the Petersen method (Ricker 1975) for estimating the size of the untagged population; data must be characterized by the restrictions mentioned above, however, for it to be applicable.

Tagging and recovery

Shrimp tagged with orange plastic Floy Streamer tags were held in tanks on board RV Oloum-l for one hour prior to release, to separate shrimp in bad condition which were unlikely to survive (Al-Shoushani et al. 1984). Large specimens of *Sepia vulgaris* were often taken in trawls with the shrimp, and frequently expelled ink. It was observed that shrimp covered with the ink were narcotized and showed a poor survival rate. Shrimp with ink marks were therefore excluded from the tagging experiment. The size range of tagged shrimp, 20-46 mm CL (carapace length), was similar to that of the untagged population. Shrimp were tagged randomly with respect to size. Returns were collected by commercial fishers and the rewards per returned shrimp varied from about US$3.50 to $14.00. Returns were obtained in significant numbers over 3-4 months after the initial release; there were two releases, in February and July 1979. A full description of the methodology used is given by Mohamed et al. (1981).

The number of tagged shrimp returns was known for each month of the tagging experiment. The numbers of untagged shrimp were then calculated from data on the number of *P. semisulcatus* per commercial pack of each size category together with the number of commercial packs landed each month provided by courtesy of the shrimp fishing companies, and from landings of artisanal boats and the size composition of these landings, which were sampled directly.

Monthly size-frequency distributions of *P. semisulcatus* for 1978- 1984 were analyzed by FAO (1982), Mathews (1982) and Mathews and Abdul-Ghaffar (1986) who concluded that two easily distinguishable cohorts occur each year, with recruitment of small shrimp (14-20 mm CL) occurring in May and June and in October and November. Recruitment of shrimp above 20 mm CL does not occur before July or December in substantial numbers. Therefore, shrimp recruiting to the fishery were smaller than tagged shrimp and recruitment of *P. semisulcatus* above 20 mm CL was negligible during the tagging experiment periods referred to in Table 1. Because only sizes above 20 mm CL were considered from untagged shrimp landings, it is unlikely that recruitment of small shrimp

Table 1. Ratio of tagged to untagged shrimp in the fishery, February-September 1979. Shrimp less than 20 mm CL are excluded from the analysis.

Month	Tag returns (T) (unadjusted, sexes combined)	Total (U) landings (numbers of shrimp)	$\left(\frac{T_i}{U_i}\right)\cdot 10^5$	$\frac{T_i/U_i}{T_{i+1}/U_{i+1}}$
February	501*	2,145,991	23.35	
March	580*	4,688,543	12.37	1.9
April	168*	5,570,342	3.02	4.1
May	033*	6,014,835	0.54	5.6
June	030*	2,258,083	0.13	4.2
July	-	-	-	
August	189**	1,546,239	12.22	
September	036**	3,184,337	1.13	10.8

T = tagged; U = untagged; * tagged in February; ** tagged in July caused any immigration (I) during the study period. Therefore, it is reasonable to assume that I=0 during the study period.

Shrimp were tagged from randomly selected stations on each fishing ground. Tagged shrimp mixed with untagged shrimp fairly quickly (El-Musa 1982) and were probably randomly distributed within less than 2-3 weeks after release. It is, therefore, unlikely that biases occurred because of nonrandom mixing of shrimp on the grounds where they were released.

Results and Discussion

Use of the ratio of tagged to untagged shrimp to diagnose biases in total mortality estimates

The ratio T_i/U_i decreased from 23.35 to 0.13 from February to June 1979 during the major tagging experiment when 9,800 shrimp were released in February; and from 12.22 to 1.13 during a less important tagging experiment conducted from August to September 1979 based on releases in July 1979, when only 3,510 tags were released in Kuwait waters (Table 1). After the first two months, the ratio of T_i/U_i in successive months, i.e., $(T_i/U_i)/(T_{i+1}/U_{i+1})$, stabilized within a range of 4.1 to 5.6 for the February release (Table 1). This suggests that mortality rates and migration rates are steady during the experiments, which validates the assumptions made in formulating the model. The low value in February-March (Table 1) could be due to sampling problems.

Because I is assumed to be zero during the study period, the marked decrease in the ratio T_i/U_i shown in Table 1 must fall into one of the cases (iv)-(vi) above. Cases (iv) and (vi) indicate that $Z_t > Z_u$, while case (v) shows that either $Z_t = Z_u$ or $Z_t > Z_u$. The combination of $E_t > E_u$ and $Z_t = Z_u$ in case (v) indicate that tagged shrimp must be likelier to emigrate than untagged shrimp which, although possible, is unlikely to be true. Hence, total mortality of tagged shrimp is likely to be higher than that of untagged shrimp.

Let $Z_t = M_t + F$ and $Z_u = M_u + F$, where M_t and M_u are the instantaneous natural mortality rates of tagged and untagged shrimp, respectively, while F is the instantaneous fishing mortality coefficient and is assumed to be equal for both tagged and untagged shrimp. This will only be true if untagged and tagged shrimp of the same size are equally likely to be caught by fishing gear and are mixed randomly throughout the fishing area. Presently there is no evidence to the contrary. Therefore, the decreasing ratio of T_i/U_i as i increases suggests that either systematic tag-related mortality occurs in nature (case iv) but not in the laboratory (Mohamed et al. 1981), or that tagged shrimp migrate more readily (case v), i.e., they behave more actively than untagged shrimp with respect to migration, or that both of these phenomena occur simultaneously (case v); or that tagged shrimp are less likely to migrate and tag-related mortality occurs (case vi; this may be possible). It is provisionally concluded that the decrease in the ratio of tagged to untagged shrimp caught provides evidence that tag-related mortality occurs in nature.

In general, it may be concluded that where T_i/U_i decreases, mortality estimates are biased, either because $Z_t>Z_u$ or because $E_t>E_u$ or both. Where either is the case, estimates of total untagged population size (equation 5) are impossible. In fact, where the ratio of T_i/U_i declines it is probable that only fishing mortality can be estimated with any likelihood of obtaining a realistic value.

Changes in the ratio T_i/U_i may easily be detected during shrimp tagging experiments where the number of shrimp are easily estimated from the commercial fishery, so that this ratio may be used to determine the likelihood that tag-related mortality occurs in nature. It is suggested that this technique in its broader sense (considering appropriate cases) may be applied to other shrimp and fish stocks. It may also be applied to old data for which no laboratory experiments to determine the possibility of tag-related mortality have been conducted, and where laboratory experiments may not be feasible.

Estimates of total mortality (Z)

The mean monthly ratio of T_i/U_i from March to June is reasonably stable (Table 1) and gives a mean monthly value of 4.85. Assuming that immigration is zero, the fact that this ratio is roughly constant suggests that $E_t-E_u+Z_t-Z_u=(\ln 4.85)=1.58$.

Since it is unlikely that $E_t>E_u$, there is a great likelihood that $Z_t>Z_u$. As a first approximation, the difference between Z_t and Z_u is estimated to be 19 (i.e., 1.58 x 12) per annum. This value, when deducted from the range of values obtained by Mohamed et al.

(1981) for Z, produces a range of 7.5-12.5 which is comparable with that obtained by Jones and van Zalinge (1981) for *P. semisulcatus*.

Yet these values are higher than the values of Z ≈ 5 accepted for stock assessment purposes (Mathews and Abdul-Ghaffar 1986; Siddeek and Abdul-Ghaffar, in press) on the basis of seasonally adjusted growth curves and catch curve analysis.

Since $Z_t > Z_u$, equation 5 is not applicable in this case to estimate the population size.

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