Estimation of Fishing Coefficient of Mojako by Tagging Experiments on Drifting Seaweeds -I. Method and an Example

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Rapid increase in catch of mojako (juvenile yellowtail, *Seriola quinqueradiata*) in recent years to meet the demand from the fish culturists has given rise to fears about the effect the intense fishing might have on the adult stock. In 1963, regional fisheries research laboratories of Japanese Fisheries Agency and prefectural fisheries experimental stations commenced a 3-year investigation project on mojako and adult yellowtail along the Pacific coast of Japan.¹⁾ Among the various items of the investigation, tagging of drifting seaweeds was included to obtain information on the rate of exploitation of mojako. Mojako is usually caught by surrounding a cluster of drifting seaweeds with a net and taking it aboard together with fish accompanying it. So, it would be reasonable to assume that recoveries of tagged seaweeds by mojako fishery provide useful information on the rate of exploitation of mojako. General descriptions of the tagging experiments and results along with discussions on the fishing rate have been given elsewhere.^{1), 2)} In this paper, a method for estimating fishing coefficient of drifting seaweeds is presented with a numerical example. The complete results of the estimations will be given in the second paper of this series.

Mathematical Model

Although the progress of tag recoveries varied depending on places and seasons of release, the general pattern of it was as follows. Offshore recoveries by mojako fishery and coastal recoveries in the vicinity of the release points began soon after release but terminated in a short time. Recoveries from distant places especially coastal recoveries followed and lasted for a fairly long time. Some tags were found after having drifted for a considerable distance. Tags attached to the drifting seaweeds were shed as time went on. There were almost no examples of shed tags recovered offshore. In coastal recoveries, many tags were found with seaweeds soon after release but the number of shed tags increased with time, and almost all of recoveries at far distant places after a long time were shed tags.

The frequency distribution of the number of days after release for the offshore recoveries by mojako fishery was characterized by numerous short term recoveries

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Fig. 1. Frequency in logarithmic scale of the number of days after release for tag recoveries by mojako fishery. (1964 and 1965 combined).

Fig. 2. Frequency in logarithmic scale of the number of days after release for coastal tag recoveries with seaweeds. One recovery over 150 days is omitted. (1964 and 1965 combined).

Fig. 3. Frequency of the number of days after release for coastal recoveries of shed tags. (1964 and 1965 combined).

and a sharp decrease of the frequency with increase in the number of days. The frequency shown in logarithmic scale is given in Fig. 1. The trend of decline seems to be in the manner of a geometric progression though scattering of the points is fairly large. The frequency distribution in logarithmic scale for the coastal recoveries of tags with seaweeds is illustrated in Fig. 2. At a glance the type of distribution seemed to be similar to that for the offshore recoveries characterized by high frequency of the short term recoveries, but detailed examination of the data for each experiment suggested a trend of frequency to increase with the number of days upto 10 to 20 days after release. The distribution pattern for the coastal recoveries of shed tags was quite different from the former two (Fig. 3). Starting from rather a low level, the frequency continued to increase upto a certain number of days after release and then turned to gradual decrease. The maximum number of days reached as long as 200.

Considering the above mentioned aspects, a mathematical model on tagging of seaweeds and recovery of tag was set up as stated below.

Offshore recoveries in the area of release

Notation:

- t : time (or the number of days after release).
 N_0 : the total number of released tags.
 N : the number of tags remaining in the area of release at time t , $N = N_T + N_L$.
 N_T : the number of tags being attached to seaweeds.
 N_L : the number of tags shed from seaweeds.
 F : fishing coefficient of seaweeds, constant.
 D : coefficient of decrease due to drifting away from the area of release, constant.
 M : coefficient of shedding of tags from seaweeds, constant.
 c or c_t : the number of reported tag recaptures by mojako fishery at time t .
 α : rate of reporting, $\alpha c' = c$.
 κ : rate of discovery of recaptured tags, $(1 - \kappa)$ of the total recaptures will be returned back to sea.

Basic equations:

$$\frac{dN}{dt} = -(D + \kappa F)N, \quad (1)$$

$$\frac{dN_T}{dt} = -(D + \kappa F + M)N_T. \quad (2)$$

Solving equations (1) and (2),

$$\left. \begin{aligned} N &= N_0 e^{-(D + \kappa F)t} \\ N_T &= N e^{-Mt} = N_0 e^{-(D + \kappa F + M)t}, \quad N_L = N - N_T. \end{aligned} \right\} \quad (3)$$

Coastal recoveries

Notation:

- n : the number of tags drifted away from the area of release but still being drifted, $n = n_T + n_L$.
 n_T : the number of tags being attached to seaweeds.
 n_L : the number of tags shed from seaweeds.
 L : coefficient of complete loss from the study area due to drifting, constant.
 H : coefficient of decrease due to drifting ashore, constant.
 r or r_t : the number of reported coastal tag recoveries at time t .
 β : rate of discovery of tags drifted ashore, $\beta r' = r$.

Basic equations:

$$\frac{dn}{dt} = DN - (H + L)n, \quad (4)$$

$$\frac{dn_T}{dt} = DN_T - (H + L + M)n_T. \quad (5)$$

Substituting (3) into (4) and (5), equations will be solved as

$$n = \frac{DN_0}{H+L-D-\kappa F} \left\{ e^{-(D+\kappa F)t} - e^{-(H+L)t} \right\}, \quad (6)$$

$$n_T = n e^{-Mt} = \frac{DN_0}{H+L-D-\kappa F} \left\{ e^{-(D+\kappa F+M)t} - e^{-(H+L+M)t} \right\}. \quad (7)$$

Estimation of Various Coefficients

As there is almost no chance for the shed tags to be recovered by fishing, the number of reported tags recaptured (will simply be called the number of recoveries, hereafter) will be expressed as

$$c = \alpha c' = \alpha \kappa F N_T = \alpha \kappa F N_0 e^{-(D+\kappa F+M)t}. \quad (8)$$

Since α , κ , F and N_0 are constant as they are defined, the trend of decrease of c at time t represents $e^{-(D+\kappa F+M)t}$. This can also be applied to pooled data from more than one occasion of release by taking the number of days after release for t , provided that all parameters are constant. This means that the type of frequency distribution of the number of days after release obtained from a series of releases is exponential with decreasing coefficient of $(D+\kappa F+M)$. So, the maximum likelihood estimate of $(D+\kappa F+M)$ is given by reciprocal of the mean number of days or,

$$D+\kappa F+M = \sum_i c_i / \sum_i t c_i = 1/\bar{t}_c. \quad (9)$$

The total number of recoveries is

$$C = \int_0^\infty c dt = \frac{\alpha \kappa F N_0}{D+\kappa F+M},$$

and hence, fishing coefficient will be

$$\alpha \kappa F = \frac{C}{N_0} (D+\kappa F+M) = \frac{C}{N_0} \cdot \frac{1}{\bar{t}_c}. \quad (10)$$

Actual F value will not be obtained unless α and κ are known. This formula is essentially the same as the maximum likelihood estimate derived by GULLAND³⁾ from a similar model of release and recapture. This estimate has slight bias and an unbiased estimate is, following CHAPMAN⁴⁾,

$$D+\kappa F+M = \frac{C-1}{C\bar{t}_c}.$$

Other parameters are also possible to be estimated applying data from coastal recoveries. The number of recovered tags being attached to seaweeds on coast is

$$\begin{aligned} r_T &= \beta r_T' = \beta H n_i \\ &= \beta H \frac{DN_0}{H+L-D-\kappa F} \left\{ e^{-(D+\kappa F+M)t} - e^{-(H+L+M)t} \right\}. \end{aligned} \quad (12)$$

As the quantity outside the brackets is constant, r_T represents the variation of the inside terms. The mean number of days after release is

$$\begin{aligned} \sum_t tr_{Ti} / \sum_t r_{Ti} &= \bar{t}_{rT} \\ &= \frac{1}{D+\kappa F+M} + \frac{1}{H+L+M}^* \end{aligned} \quad (13)$$

and hence

$$H+L+M=1/(\bar{t}_{rT}-\bar{t}_e) \quad (14)$$

For estimating the coefficient of shedding of tag M , the relation of

$$n_T = ne^{-Mt}$$

may be applied. This formula suggests that

$$r_{Ti}/r_t = e^{-Mt}$$

and M value will be obtained from the trend of decrease of r_{Ti}/r_t with t .

The total number of recoveries is

$$\begin{aligned} R_T &= \int_0^\infty r_T dt = \beta H \int_0^\infty n_T dt \\ &= \frac{\beta HDN_0}{H+L-D-\kappa F} \left\{ \frac{1}{D+\kappa F+M} - \frac{1}{H+L+M} \right\} \\ &= \frac{\beta HDN_0}{(D+\kappa F+M)(H+L+M)} \end{aligned} \quad (16)$$

and then

$$\beta HD = \frac{R_T}{N_0} (D+\kappa F+M)(H+L+M) = \frac{R_T}{N_0} \frac{1}{\bar{t}_e} \frac{1}{\bar{t}_{rT}-\bar{t}_e} \quad (17)$$

Example

For a numerical example, data for the releases in the water off Tokushima Prefecture, Shikoku in 1964 were taken because relatively many recoveries were made both from the fishery and on coast. A total of 110 tags were released from 3rd to 19th of May. From these, 18 were recovered by the mojako fishery mainly in the water near the release points. The mean number of days after release was $\bar{t}_e=6.28$ days and hence,

* If the type of distribution is e^{-ax} , the mean value of x is

$$m_x = \int_0^\infty x e^{-ax} dx / \int_0^\infty e^{-ax} dx = \frac{1}{a^2} / \frac{1}{a} = \frac{1}{a}$$

and for the type of distribution $(e^{-ax}-e^{-bx})$

$$m_x = \left(\frac{1}{a^2} - \frac{1}{b^2} \right) / \left(\frac{1}{a} - \frac{1}{b} \right) = \frac{1}{a} + \frac{1}{b}$$

$$D + \kappa F + M = 1/6.28 = 0.159/\text{day} ,$$

$$\alpha \kappa F = \frac{18}{110} \cdot 0.159 = 0.026/\text{day} .$$

If it is put $M = 0.02/\text{day}^{1)}$

$$D + \kappa F = 0.159 - 0.02 = 0.139/\text{day}$$

and

$$D < D + \kappa F - \alpha \kappa F = 0.139 - 0.026 = 0.113/\text{day} .$$

When $\alpha = 1$, $<$ sign will be altered to $=$ sign.

Among a total of 10 recoveries in occasions other than mojako fishery, 9 were found being attached to seaweeds. Although 2 of these 9 tags were recovered at sea, the situations were rather similar to that of coastal recoveries, and they were included in the data. The mean number of days is

$$\bar{t}_{rT} = 30.11 \text{ days}$$

and then

$$H + L + M = 1/(30.11 - 6.28) = 1/23.83 = 0.042/\text{day} .$$

Assuming $M = 0.02$,

$$H + L = 0.042 - 0.02 = 0.022/\text{day} .$$

Further,

$$\beta HD = \frac{9}{110} \cdot 0.159 \cdot 0.042 = 0.00055/\text{day}^2 .$$

Substituting $D < 0.113/\text{day}$,

$$\beta H > 0.00055/0.113 = 0.0049/\text{day}$$

As $\beta < 1$,

$$H > 0.0049/\text{day}$$

and finally

$$L = 0.022 - H < 0.022 - 0.0049 = 0.017/\text{day}$$

is obtained. Now, values of all parameters except κ , α and β are estimated.

Discussion and Conclusions

For the purpose of obtaining the rate of exploitation of mojako, estimations of fishing coefficient F and other coefficients such as D and H for drifting seaweeds were tried by tagging of seaweeds. Estimating formulae for various parameters are presented in this paper. However, there may be a number of problems concerning the formulae. The first is the problem on validity of the model. Particularly for the estimates of H and L , the effect of errors in the model would be serious because the errors tend to be accumulated in the estimates. Fortunately, H and L have little significance in the present purpose. Coefficients F , D , and M which are directly

concerned with the estimation of the rate of exploitation are considered to be fairly free from the errors in the model such as variability of coefficients.

The estimates of F and D vary depending on the range of the area of release which is applied for computation. If the area is defined to cover many fishing grounds, D value would be small since the transports between fishing grounds are cancelled out, and F value would be affected by the heterogeneity of fishing intensity among fishing grounds. It may be desirable, if possible, to divide the areas concerned corresponding to each fishing ground. Also the range of coast for the recoveries of tags drifted ashore should be confined within a limited area to keep the homogeneity in conditions. This means that tags recovered from places far from the area of release should not be used for computation. The tag releases off Tokushima Prefecture provided 18 recoveries by mojako fishery and 15 of them were recaptured in water around the release points. Calculated values from these 15 tags were $\bar{t}_e=5.47$, $D+\kappa F+M=0.183$ and $\alpha\kappa F=0.025$, instead of 6.28, 0.159 and 0.026 from all 18 tags, respectively. The differences are what were anticipated.

Fishing effort may vary depending on the season and so F may not be constant. However, the effect of the variability is expected to be reduced by limiting the period under consideration.

Statistical error could be considerably large particularly when the number of recoveries is small. The effect of this type of error is also considered to be large for the estimates of H and L . Estimated value of F which is derived from the recovery rate and the mean number of days after release would be rather stable against the sampling error. Of course, it is possible to evaluate the sampling error provided that the basic model is valid.

Discovery rate and rate of reporting cannot be estimated from the data on tag recoveries only and require a specially planned survey. It is necessary to pay due consideration to make these rates as high as possible. In case of mojako fishery, it is expected that α and κ are close to one. On the other hand, β could be considerably lower than one and variable depending on seasons and places.

In this paper the estimations are made for drifting seaweeds, but our final purpose is to obtain values for mojako. Considering the manner of fishing operation, there must be a chance for fish to escape from the net. It is said by some fishermen that the rate of escapement is as high as one third. If this value is correct, fishing coefficient for majako is about two third of that for drifting seaweeds. Furthermore, there is a good possibility that some of mojako are freely migrating independently of seaweeds and hence fishing intensity on mojako stock is considerably weakened. More knowledge on ecology of mojako is required. In order to convert the fishing coefficient into the rate of exploitation, the rate of emigration of mojako from fishing grounds must be known. This would require tagging experiments on mojako themselves.

In spite of the difficulties mentioned above, the author believes that tagging experiments on drifting seaweeds is effective in studying the rate of exploitation of mojako. One reason for this belief is that even a rough estimate of the rate of exploitation for mojako can serve as valuable information for planning the management program of mojako fishery. Another reason is that if the conditions involved in the experiments and data obtained are examined in the light of relevant information furnished from various other sources and then the formulae given in this paper are applied carefully, the difficulties would be overcome to some extent.

References

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