

Some Remarks in Estimating Natural Mortalities in Population Dynamics of Fish Resources

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1) Preface

In the study of population dynamics of fish resources, one of the most difficult works is to separate natural mortality from that caused by fishing. Several methods have been considered to estimate natural mortalities, but it is not saying too much that no definite method has been devised yet, here the author intends to relate on the significance of estimating natural mortality, make some remarks on several methods on present use particularly from the standpoint of their efficiencies, and present some opinions how to overcome the difficulties.

2) Significance of natural mortality in population analysis

A caution should be taken that the estimation of natural mortality is important, but it has not any significance *per se*, it is no more only one of vital statistics in population analysis than survival rate or recruitment.

Sometimes, the value of natural mortality seems a keypoint of the analysis, but sometimes it does not.⁽¹⁾⁽²⁾

We must not confuse whether the value of natural mortality is high with that its value has much to do with analysis. Even if that value is high, its fluctuation may not cause any significant difference in other discussions.

After notations of WIDRIG⁽³⁾, a rate of exploitation u in a given period can be expressed in the form,

$$u = \frac{p}{p+q} [1 - e^{-i}] \dots\dots\dots (1)$$

here p , q , and i , show instantaneous fishing, natural, and total mortality coefficients respectively.

The total mortality coefficient $p + q = i$ can be calculated by age compositions, therefore it is more convenient to express the same formulae in the following form in order to deal with the effect of the variation of natural mortality coefficient q upon that of the value of u .

Then
$$u = \frac{i-q}{i} (1 - e^{-i}) \dots\dots\dots (2)$$

$$\Delta u = \frac{-1}{i} (1 - e^{-i}) \Delta q \dots\dots\dots (3)$$

and
$$\frac{\Delta u}{u} = - \frac{\Delta q}{q} \left(\frac{q}{p} \right) \dots\dots\dots (4)$$

Therefore when the value of i is high, in another saying, the survival rate

is low, the variation of natural mortality coefficients has little to do with estimates of rate of exploitation, and moreover, the relative variances of them are influenced much by those of natural mortality coefficients in cases when the values are much larger than those of fishing mortality coefficients.

Bottom fishes such as SOHACHIGAREI (*Cleithris herzensteini*) or MUSHIGAREI (*Eopsetta girgorjewi*) seem to belong to the former category after the study of trawl fisheries resources carried out by Japan Sea Regional Fisheries Research Laboratory⁽¹⁾, while MAIWASHI⁽²⁾ (*Sardinops melanostica*), to the latter one.

Tab. 1 Effects of the shift of natural mortality coefficient q upon that of estimated rate of exploitation u .

| Sohachigarei (<i>Cleithris herzensteini</i>) in Japan Sea $i = 1.14$ | | Mushigarei (<i>Eopsetta girgorjewi</i>) in Japan Sea $i = 1.07$ | | Maiwashi (<i>Sardinops melostica</i>) in Kyushu $i = 0.56$ | |
|---|------|--|------|---|------|
| q | u | q | u | q | u |
| 0.20 | 0.69 | 0.30 | 0.70 | 0.20 | 0.27 |
| 0.30 | 0.67 | 0.40 | 0.66 | 0.30 | 0.20 |
| 0.40 | 0.61 | 0.50 | 0.61 | 0.40 | 0.12 |
| | | 0.60 | 0.57 | | |
| (1951-54) | | (1951-54) | | (1952-55) | |

As can be seen from these examples the effect of the shift of q upon that of u is not constant but varies case by case.

3) Precision of estimated natural mortality coefficient

One of the orthodox methods estimating natural mortality is the regression analysis of i s against fishing efforts. This can be shown in a simple equation of the form,

$$i = QF + q \dots\dots\dots (5)$$

WIDRIG ('54)

here, Q is the instantaneous unit fishing intensity coefficient and F is the amount of the fishing effort.

Two unknown parameters are included in this equation, so if the number of unit period for observed exceeds three, we can solve them by ordinary least square methods. Then the unbiased estimates should be,

$$\hat{q} = \frac{\sum iF \sum F - \sum i \sum F^2}{n \sum F^2 - (\sum F)^2} \dots\dots\dots (6)$$

$$\hat{Q} = \frac{\sum F \sum i - n \sum iF}{n \sum F^2 - (\sum F)^2}$$

here n is the number of unit periods.

By σ_F , σ_i and $cov. iF$, we denote the variance of F and i and their covariance respectively, then we have,

$$\hat{Q} = \frac{Cov.(Fi)}{V(F)} = \frac{\rho(iF) \sigma_F \sigma_i}{\sigma_F^2} = \rho(iF) \frac{\sigma_i}{\sigma_F}, \quad \hat{q} = \frac{\sum F_i}{n} - \frac{\sum F - i \sum F^2}{S(F)} \dots (7)$$

Here $\rho(iF)$ means the correlation coefficient between i and F .

Then the variances of these estimates have the forms,

$$Var.q = \frac{\hat{\Delta}}{n-2} \times \frac{\Sigma F^2}{n\Sigma F^2 - (\Sigma F)^2} \quad Var.Q^2 = \frac{\sigma_i^2(1-\rho^2)}{n(n-2)} \frac{n}{\sigma_f^2} \dots\dots (8)$$

here $\hat{\Delta} = \sigma_i^2(1-\rho^2)$

$$\text{therefore } Var.q = \frac{\hat{\Delta}}{n-2} \frac{\Sigma F^2}{S(F)} = \frac{\sigma_i^2(1-\rho^2)}{(n-1)(n-2)} \left(1 + \frac{1}{C_F^2}\right) \dots\dots\dots (9)$$

$$\text{here } C_F = \frac{\sigma_F}{F} \quad Var.Q = \frac{\sigma_i^2(1-\rho^2)}{n-2} \frac{1}{\sigma_F^2} \quad Var.Q/Q^2 = \frac{1}{n-2} \left(\frac{1-\rho^2}{\rho^2}\right) \dots\dots(10)$$

As these formulae show, i) The accuracies of Q as well as of q are high when there is high positive correlation between F and i , ii) The accuracy of q is high in cases when either the number of the time unit is large or the variance coefficient of fishing effort is large enough. iii) The accuracy of Q also depends upon the value of that correlation coefficient, but the dependency upon the number of unit periods is less important than in the case of q .

Here we considered $Var. q$ for q and $(var. Q)/Q$ for Q . It is due to the fact that the value of q is itself of logarithmic form, so its standard deviation means the relative error of its estimates.

Very few fisheries in Japan can afford such data of long period enough to clarify this correlation. For California sardine, the author obtained the values of $C_f=0.34$, $\sigma_i=0.65$ and $\rho=0.63$, pretty high values, by data shown by WIDRIG('54), in this case, $\sigma_f = 0.16$.

But only few fisheries seem to have such high correlations between i and F .

In Japan, the above mentioned SOHACHIGAREI caught by trawl fisheries in the Japan Sea is one example which has data of comparatively long period. This gives results, $n=7$, $S_i=0.34$, $\rho=0.31$ and $C_f=0.12$ the variance of efforts is not so high and the precision of q is rather poor ($q=0.39$ $\sigma_q=1.4$).

In other fishes caught by trawl nets in Japan or MAIWASHI these correlations are rather low, even and negative value sometimes.

Sometimes we deal the decreasing of population within a fishing season, in such cases we cannot increase n beyond a certain limit, for most fisheries the fishing season lasts only for several months, so if we can get the fisheries statistics by month, the value of n cannot exceed six or seven usually, in most cases, as shown in the cases of MAIWASHI⁽²⁾(1956) this is only three or four.

In addition, the values of i s have inevitable sampling errors because most fisheries statistics in Japan is tabulated in weights, so we must convert them into number by dividing them into the average body weight obtained by measuring. The number of a certain age must be estimated by age determination, so the values of total mortality suffer from many considerable sources originating errors, some of which can be, however, reduced by devising powerful sampling

methods. But costs limit such improvement of sampling methods practically.

It is considered that in order to increase the value of n catch statistics should be arranged for shorter units, for example for weeks or days, but we can easily suppose that this sacrifices at the same time the precision of each value, and increase the difficulty in arranging statistics.

At the other hand, in cases when we deal annual survival rates by age composition statistics of a long period, we expect to increase the number of n by continuing the survey for a long term, but in this case we cannot always expect that the fundamental hypothesis of constant natural mortality stands constantly.

This paradox occurs similarly also for the variance of fishing efforts. Big variance of efforts makes a high precision of those estimates, but at the same time it means a change of fisheries situations, so in such cases we should rather assume that there must be some change either in environment or social conditions, so the parameters in fundamental equation cannot be constant.

4) *Comparison with DE LURY's methods*

In cases catch per unit effort decreases with the accumulation of catch or efforts, DE LURY's methods⁽⁴⁾ are applicable. His original methods do not consider natural mortality, but he mentioned cases in which two or more kinds of gears affect on population, and referred that natural mortality can be dealt as one kind of fisheries which has always a constant effort. Then we have the following form of equation.

$$k_i = \log. (S_0/S) = Q \Sigma F_i + nq \dots \dots \dots (11)$$

Here S_0 and S_i represent the catch per unit at the beginning and the i -th period respectively, while ΣF_i , the accumulated catch up to that period.

$$\frac{k_i}{n} = Q \bar{F}_i + q \dots \dots \dots (13)$$

Here \bar{F}_i is the average of accumulated effort, So k_i/n is so called mean accumulated decreasing rate.

By this equation, it is shown that both decreasing rate and number of effort diminish their variances as they are averaged by increasing n and so we cannot expect to increase the correlation between effort amounts and decreasing rates, neither can we expect to improve the precision of estimates by these methods.

5) *Some reflections upon mathematical models*

As mentioned in earlier chapters, we confront an inevitable difficulty in population estimation. Is this due to the deficiency of these fundamental mathematical models? Let us consider this question from another angle of view.

OSHIMA ('54)⁽⁵⁾ made an experiment with TENAGAEBI (*Palaemon nipponensis* de Haan) by an aquarium and showed that the estimation of population by

mathematical analysis coincides with the actual size within confidential limits*. In this case, $n=11$, $q=0.2$, $\sigma_q=0.15$ $s_i=0.53$ $s_F=0.31$ while $\rho=0.31$. In such enclosed area we can expect good results.

It was also shown by the same experiments that catch per unit effort had no significant differences from the linear regression on the actual number of shrimps at that time within the confidential limits. Therefore it seems possible to make catch per unit be proportionated to the population size in controllable experiment in a limited area.

Another experiment concerns with the following question. We are sometimes confronted with examples of fisheries in which catch per unit effort decrease monotoneously with the ellaps of time. Can we consider this phenomenon is caused by the decreasing of population by fishing alone in such case? Is there no risk for us to make an erroneous conclusion, by computing with catch and effort data, attributing the decreasing to the effect of fisheries even when the natural mortality occupies the main part of total mortality?

In order to solve these questions, let us try one thought experiment as follows.

Assume an ideal population with natural mortality of 50 % for a unit period, fishing mortality being one thousandth per unit gear and the original population size is one million.

Under a shift of the number of effort between 20 and 100, that is, the fishing mortality lies between 0.1 and 0.02, we can get values of catch per unit effort as follow.

Table 2. Thought experiment on catch and efforts

| N | F | C | c/u |
|------|-----|-------|------|
| 100 | 100 | 10 | 1000 |
| 40 | 50 | 2 | 400 |
| 18 | 30 | 0.54 | 180 |
| 8.63 | 100 | 0.85 | 85.6 |
| 4.38 | 70 | 0.24 | 33.8 |
| 1.45 | 20 | 0.029 | 14.5 |

By inverse calculation from these data, we can get $e^{-q}=0.52\pm 0.02$

These values coincide with the actual ones successfully.

By these considerations, we know that even if the value of natural mortality is high we can separate natural mortality from that of fisheries with good precision when the population is in an ideal condition.

6) *What makes the precision poor in population analysis?*

Equations (9) and (10) show that the values of ρ , the correlaton coefficients between fishing efforts and total mortality have much to do with precisions, and the actual data in our hands show that one of the chief reasons of these poor precisions can be considered to be due to the low correlations among them. This infers a very important fact in population analysis in fisheries, *at least, which we*

* Computed by YAMANAKA

have been studied in Japan. This means that the variation of total mortality caused by the change of efforts does not occupy the main part of it.

It can be supposed that i) the natural mortality which hitherto dealt as constant is, in fact, a variable with a pretty wide range, ii) there are other factors giving influences upon the variation of total mortalities.

If we can find out these factors besides fishing mortality, we can improve the correlation by multiple regression analysis, because multiple correlation is always larger than single correlation.

Biological consideration are required to explain natural mortality and its variation if it exists. But this is beyond this aim of this report.

But one of the factors which give influence upon mortality besides fishing is the change of availability, that is, because of the selectivity of gear or fisheries itself, only one part of stock can be fished, so catch per unit effort does not always represent the magnitude of population size in itself but does it only the magnitude of *available stock*. When only one part of total stock is available, mortalities obtained from age composition are not real ones, but are *apparent* ones which contain the relative changes of availability.

WIDRIG dealt the residues of total mortality coefficients from the linear regression against the effort numbers as caused by the variation of availability, and he applied this idea to California sardine and calculated relative values of availabilities.

The author calculated with his data and obtained the correlation coefficient between the relative availability and catch per effort as ca. 0.64, whereas, the change of total mortality and that of availability has positive correlation more than 0.9.

In Japan, many studies have been done on the relation between hydrography and fisheries conditions, but very few of them are quantitative. Hydrographic conditions seem to affect availability powerfully, so it should be necessary to make study of availability and hydrographic conditions in order to make the quantitative prediction available.

But WIDRIG's method can be applicable only when the change of availability has no autocorrelation and can be dealt as random residues from that regression line. When we deal data year to year for long period like California sardines this assumption may be available, but when there is a tendency in the change of availability, this method cannot be used. We are confronted with such cases frequently when we deal with data *within* a fishing season, for example, the monthly change of catch per effort within a season; in such analysis we sometimes obtain negative values for either natural or fishing mortalities by these methods, this often can be inferred by the systematic change of availabilities⁽²⁾. caused by oceanographic or biological changes.

7) *A comment on tagging analysis*

Thus we cannot but be confronted with a grave difficulty in estimating natural mortality. In order to overcome this difficulty, let us consider the alternative methods besides the catch and effort analysis. Does the tagging help to overcome it?

Tagging is used for finding the migration habit as well as for estimating population size, but many difficulties have already been discussed on them: for example, the dropping the tags, the differences of behavior of tagged fish from others, and misfinding of recaptures.

In order to overcome these difficulties, BEVERTON⁽⁶⁾ showed the estimating method by obtaining the ratio of two succeeding time units.

Assume the number of release N_0 , the length of time unit t , and the sum of natural mortality and thus by tagging X , then we have,

$$\frac{n^{\gamma}}{N_0} = \frac{QF^{\gamma} + X}{QF^{\gamma}} e^{Ft + ((\gamma-1)Xt)} (1 - e^{-(F\gamma + X)}) \dots\dots\dots(12)$$

then
$$\frac{n^{\gamma}}{N^{\gamma}} = \frac{QF_{\gamma}}{QF_{\gamma} + X} (1 - e^{-QF_{\gamma}^{\gamma} - X}) \dots\dots\dots(14)$$

Here, N_{γ} is the number of tags remaining after the γ -th time unit.

His equations is completely equivalent to those which represent the relation between fishing efforts and exploitation ratio so we have a same form of equation as the previous one.⁽⁶⁾

This equation aims to eliminate the abundant death immediately after releasing, and moreover to eliminate the effect of misreports by using the rate between two recaptures, but by these procedure, its form becomes same to that of (5). So we must be troubled by the same difficulties as are related in the Chapter 3).

8) *Scouting survey by fish finders*

YOKOTA et al. ('53)⁽⁷⁾ devised a method estimating fish population by fish finders. Here the research boats with fish finders cruise periodically along the appointed courses, the numbers of shoals are estimated by number of shadows on recording papers, and the magnitude of each shoal by the length, width, and thickness of each image.

If we may assume that the number of shoals thus obtained is proportional to the magnitude of stocks, we can make same equations as in Chapter 3), only by substituing this value for each per unit effort as an index of stock size. But this method will be applicable only for solving the variation of population size within a fishing season, because by this method we cannot know the age composition of catches unless we sample fishes from these shoals, and moreover, even in such a case, the increase of body weigh caused by growth should be taken

into account.

Theoretically there is no difference between the catch and effort analysis and this method from mathematical viewpoint, so the difficulties in population calculation lie in the same points as been discussed in earlier chapters. In this method we can expect to estimate the number of shoals with pretty precision by applying appropriate design of courses. So long as the images on recording papers represent the actual shoals in the ocean, they seem more suitable than catch per efforts as indices of stock size, because they do not rely upon catch statistics. But it is a well known fact that sometimes a dense shoal does not make an apparent image, because the appearance of image are associated with the structure or depths of shoals in the ocean. But these problems would be solved by the proceeding of acoustical and technical studies of fish finders, and moreover, it can be easily supposed that the estimated shoal abundance must have high correlation with actual abundance of fish population, so this method can be expected much improvement for practical use in future.

9) *Natural mortality before recruiting stage.*

Hitherto have been dealt chiefly about the adult fishes which suffer fishing and natural mortality contemporarily, but as has been mentioned in the earlier chapter, natural mortality after commercial stage has not always to do seriously with the result of population analysis. On the other hand, the natural mortalities of some species in their early stage of lives makes crucial effect on their recruitment to commercial adults, only a slight shift of their values making wide fluctuation of year classes originated by this brood.

NISHIMURA ('56) classified the causes of natural mortalities of early stage of lives⁹⁾.

It can be suggested that there are three types of recruitments, first, with pretty steady forms like flat fishes, second, with sporadic forms like cod or herrings, and last, of undeterminable form like sardines.

It is an important problem whether there is any association between the number of parent fishes and that of year class originated by it, and no definite conclusion has been obtained⁹⁾. As for Japanese MAIWASHI it is more probable that there is no such relation¹⁰⁾. In such a case we can say that the natural mortality in early stage determines the abundance of recruitment. Let us adopt NISHIMURA's opinion that the main cause of that natural mortality is the starvation in larval stage, then in order to discuss this relation we must plot the regression of the strength of recruiting year classes against the food abundances (or some merkmal of them) which coexist with sardines. As both larval sardines and their food material seem to make patches in their distribution, so the total abundance of food is not sufficient as a factor determining natural mortality, but we must consider the probability of encountering of fishes to their food. Knowledge

on patterns of their spacial distribution are necessary to access this problem, and the estimation of the abundance of food which utilized for nursing of larvae cannot but to have pretty amounts of errors. Sorrowfully the author has no actual data for this computation, but it is clear that long series of time is required in order to make regression analysis of this relation, especially considering that both of them are inevitably estimated values with pretty large errors.

10) *Conclusion*

Thus it has been theoretically clarified that the population analysis especially concerning natural mortality cannot be expected unless we accumulate data of long series of period. Each data should be improved in their precisions in order to diminish the scattering of points from the estimated regression lines. And we must not rely upon only one method, but should compare the results obtained by methods several each other.

To study biological mechanism of each cause of natural mortality for example, predation, starvation, cannibalism and so one is effective, but it is not sufficient for our aim, because we must not forget that every factor influences upon the variation of population stochastically but not deterministically. So we must test the results statistically which had been obtained by biological experiments.

Population analysis must be steadily carried out with endurance.

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