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MODIFIED SURPLUS PRODUCTION MODELS METHODS OF GULLAND (1961), AND SCHNUTE (1977)

by

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ABSTRAK

MODIFKASI DARI MODEL "SURPLUS PRODUCTION" CARA GULLAND (1961) DAN CARA SCHNUTE (1977).*Model "surplus production" yang juga dikenal dengan sebutan model Graham-Schaefer, menganggap bahwa hasil tmgkapan per satuan upaya-penangkapan (catch per unit effort, CPUE) pada suatu saat semata-mata hanya ditentukan oleh besamya upaya-penangkapan pada saat tersebut GULLAND (1961) mengemukakan pendapatnya, bahwa CPUE tidak saja ditentukan oleh upaya-penangkapan pada saat itu, tetapi juga oleh upaya-penangkapan beberapa waktu sebelumnya.*

SCHNUTE (1977) mengetengahkan versi lain dari model "surplus production", yang bersifat dinamik, "descrete in time", serta stok stokastik sebagai lawan dari model yang statik "continuous in time", serta determirdstik dari cara Graham-Schaefer. Baik cara Gulland maupun cara Schnute diuraikan secara rinci dalam tulisan ini.

INTRODUCTION

In its simple forms, surplus production models require only catch and fishing effort data. In fitting these data, care should be taken, since the data may not entirely satisfy the basic assumptions of the standard statistical technique employed. In regressing catch per unit effort (CPUE) on effort, as independent variable, effort must be fixed or measured without error. In fact, the value of fishing effort is often not known precilely, and can be subject to errors in various steps in estimation (e.g. in taking into consideration of changes in the fishing power of the vessels). As a result, the usual least squares regression will not express the function relation between the actual fishing effort and CPUE, but will give a prediction of the expected CPUE relating to a given estimated of fishing effort.

Another possible source of error happening when fitting a regression of CPUE on effort, is the presence of effort in both axes which makes dependent and independent variables in the regression are not statistically independent. Consequently, the plot of. CPUE on effort provide a negative correlation which equivalent to relating variable x to its reciprocal, 1/x, a hyperbola is obtained.

Wrong conclusions about the effects of fishing on the stock were caused, first, by high positive autocorrelation of fishing effort with time, e.g. as the fishery developed fishing effort generally will increase, and second, by negative correlation of CPUE with time, e.g. as stocks were diminished, consequently, CPUE will decrease.

Actually, surplus production can be defined as the sum of individual growth increment plus recruitment less natural

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mortality. In general, growth is a function of stock size, while stock size itself is not only a function of fishing effort in the current and previous years but also a function of recruitment. In fact, recruitment is a function of environmental conditions as well as a function of stock size some years before, particularly of the stock size of mature fish, which in turn depends partly on the fishing effort of the earlier years.

GULLAND (1961) provided a method of examining the relationship between the present conditions of stock and past events. This method is not only more reasonable but also, in principle, overcomes the presence of fishing effort as independent variable in both axes of regression analysis which biases the plot towards an inverse correlation, by replacing effort with its moving average of the previous observed and present values.

SCHNUTE (1977), on the other hand, provided dynamic, stochastic, and discrete time model of the surplus production model as opposed to static, deterministic, and continuous time model of the other Graham-Schaefer's.

GULLAND'S METHOD (1961)

In fitting a surplus production model to an actual data, it is important to examine what lags there might be in the system, i.e. the degree of with past levels of fishing effort affect the current stock abundance.

If the level of recruitment of young fish to the fishery is significantly influenced by the abundance of the adult fish, then the amount of fishing effort in one year could affect the abundance of one or more generations (and hence perhaps will last for several years depend upon the life span of the fish) later. Consequently, the analysis using the methods of surplus production models would be complicated. If enough detailed biological information are available such as data on rates of growth, recruitment, natural mortality, and fishing mortality, then the more complex analytical methods of analysis may be employed.

GULLANDY method (1961) assumed that there exists some relationship between abundance and past effort, if recruitment and natural mortality are reasonably steady. A direct clue that recruitment might be being affected comes from the size of the catch. If recruitment remains stable under developing heavy fishing, the average size of individuals caught will decrease. In contrast, if the average size of the fish captured remain unaltered while the abundance (or CPUE) falls, there is some indications that recruitment is being affected.

In a steady state recruitment, fishing in one year can affect the stock only as long as some fish exposed to fishing in that year remains in the exploited population. This time period, i.e. the potential life span in the fishery, provides an upper limit that needs to be considered (GULLAND 1983). In general, most fish in the exploited population will exist in a much shorter period than their potential life span. Further, GULLAND (1983) suggested that the average life span in the fishery of one half to one third of the potential life span will be a reasonable approximation, and the average of the past fishing effort determined over that period. For example, GULLAND (1961) used the mean of fishing effort of 3 years immediately prior to the current one for the Icelandic cod *(Gadus morhua)* and plaice *(Pleuronectes platessa)* based upon the fact that about 7 year-classes contributed appreciable the fishery. RICKER (1975) pointed out that actually it is not crucial in defining the exact best period, since fishing effort in adjacent years, generally tend to be changed slowly.

The relationship derived between CPUE and the moving average of effort (f) was sometimes approximately straight, sometimes curved. Whatever the relationship is. GULLAND (1961) argued that in a steady state fishery, the line will be very close to the relationship between CPUE as an index of relative abundance and fishing effort.

The linear relationship of the GULLAND's method can be expressed as

$$U_i = a + b\bar{f}_i \quad \ldots \quad (1)$$

where $\bar{f}_i$, is the average effort exerted over K years proceeding and including year i; K is the mean life span of an individual in an exploited stock; a is estimate of U_∞ or qB_∞ ; b is estimate of (q/k) U_∞ or q^2B_∞/k; and $a^2/4b$ is estimate of maximum equilibrium yield (MSY).

Actually, the proper relationship of CPUE and effort may be defined by using either PRODFIT (FOX 1975) in the GENPROD computer program or CURFIT (SPAIN 1983) computer program.

Numerical Example

For an example let us use the catch and effort date of lemuru, *Sardinella longiceps,* from the Bali Strait (SUJASTANI and NURHAKIM 1982), and let arbitrarily assume that the potential life span of lemuru is 5 to 6 years. If the mean life span equals to one-third of the potential life span, than K equals to 2-year. The complete data of the annual yield and annual fishing effort are depicted in Table 1.

First step, plot the CPUE each year against the moving average effort regarding to that year. Graphically, the relation between CPUE and average effort can be illustrated in Figure 1 which its appropriate fit can be made by using the PRODFIT (FOX 1975) or CURFIT computer program (SPAIN 1982). However, let assume that the curve showed in Figure 1 is a linear model, as defined by Eq. (1)

$$U_i = a + b\bar{f}_i$$

The next step is to determine the regression parameters, i.e. by employing simple linear regression of least squares concept, the coefficient of regression b can be estimated as -1.04, and Y intercept a is equal to 377.9 with coefficient of determination, r^2 = 0.96.

Since a is the estimate of maximum CPUE, so that

$$U_\infty = 377.9 \text{ tons}$$

MSY can be estimated by employing equation

$$MSY = a^2/4b = 34\ 329 \text{ tons}$$

Optimum fishing effort, i.e. fishing effort which produces MSY can be estimated as

$$f\,(opt) = a/2b = 182 \text{ units of purse seine.}$$

Table 1. Annual yields (tons), annual fishing effort (unit of purse seine), annual CPUE (tons), and 2-yr moving average effort for lemuru, *Sardinella longiceps,* from the Bali Strait, demonstrating Gulland's method.

Year	Yield (Yi)	Effort (fi)	CPUE (Ui)	Average effort ($\bar{f}2$)
1974	6 383	17	375.3	
1975	22 900	70	327.1	44
1976	35 204	126	279.4	98
1977	45 506	193	235.8	160
1978	27 915	228	122.4	210
1979	31 155	304	102.5	266
1980	25 701	237	108.4	270

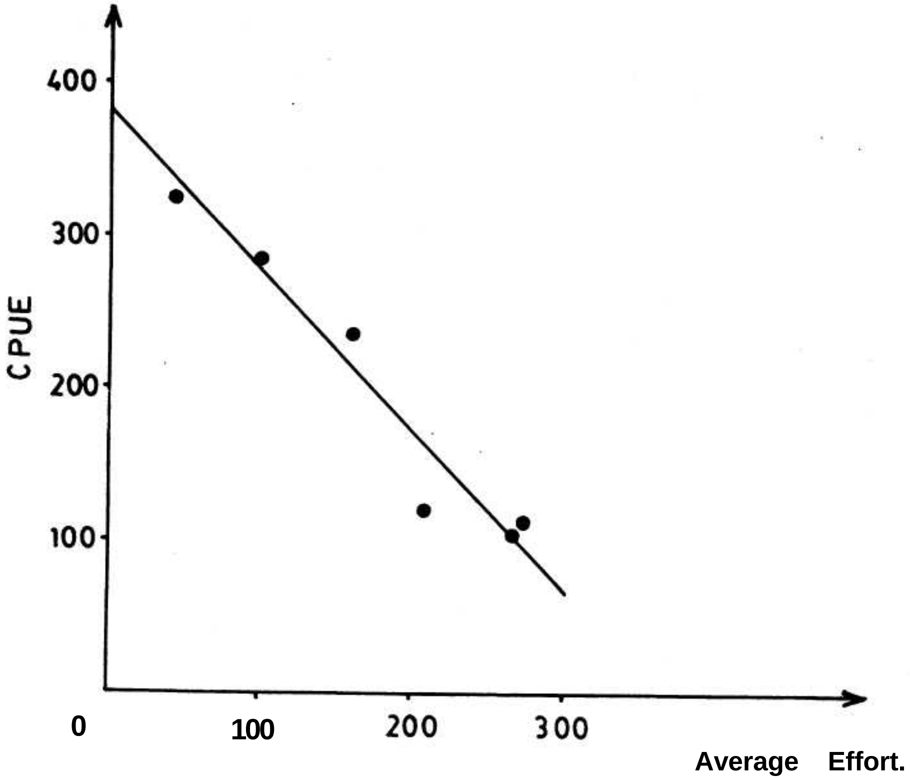

Fig. 1. CPUE as a function of moving average fishing effort.

SCHNUTE'S METHOD (1977)

A surplus production model, a model of catch and effort data, may take various possible expressions. The first from, perhaps the simplest view of a fishery is that the catch is a function of the effort of the same year, i.e.

$$Cy = g\ (fy) \ldots (2)$$

where Cy is the catch rate (in ton/year) during year y

fy is the effort rate (in boat-day/year) during year y

g is some function of the terms within parentheses.

Equation (2) assumes that the catch has no relation to the past fishing effort, which means that heavy fishing last year would not have effects on this year's catch. To allow for that possibility, Eq. (2) can be expanded and becomes

$$Cy = g\ (fy,\ Cy\text{-}i,\ fy\text{-}i) \ldots (3)$$

By contrast, model (3) is *dynamic,* i.e. the present stage of fishery is function of its previous as well as current state. As far as model (2) ignores the past, it implied if and only if conditions in fishery change slowly, or in other words, fishery in equilibrium.

Undoubtedly, model (3) is more realistic than model (2), but, actually it is never possible to predict the catch precisely, since there are always factors unaccounted for by the data. To allow for the unexplained, Eq. (3) could be redefined becomes.

$$Cy = g(fy, Cy\text{-}i, fy\text{-}i, Ey) \ldots \quad (4)$$

where Ey is a random predicted error which equals to Cy — Cy (Cy is the true catch and Cy is the predicted catch), Model (4) is not only *dynamic* but also *stochastic,* i.e. it allows for the unpredictable influences in the fishery, and makes it possible to estimate uncertainty (or variance) in the parameters as well as the parameters themselves.

Both the surplus production model of Graham-Schaefer and generalized production model of PELLA & TOMLINSON (1969) as well, are based upon differential equations of continuous process in time. In contrast to those models, Eq. (3) and Eq. (4) are *discrete-time* models, which involved the transition from one year to the next.

In conclusion, Schnute's method is to recast the surplus production model in the form of *dynamic, discrete-time,* and *stochastic* model, which makes it superior to the traditional model of Graham-Scahefer. In its simplified version of Schnute's model can be expressed in the form

$$1\,n \left[\frac{CPUEy + i}{CPUEy}\right] k - \left[\frac{k}{qB_\infty}\right]$$

$$\left[\frac{CPUEy + CPUEy + i}{2}\right] - q \left[\frac{fy + fy + i}{2}\right] .. (5)$$

where CPUE : catch per unit effort (ton/ boat-day)
k : natural growth rate (per year)
q : catchability coefficient (per boat-day).

This model has the form of a multiple linear regression which in general can be expressed as :

$$y = a — bx_1 — cx_2$$

i.e., the linear regression of one dependent variable y on two independent variables X_1 and x_2. Estimation of intercept a = k, coefficients of regression $b = k/qB_\infty$ and c = q can be estimated by the linear regression of y on x_1 and x_2.

At equilibrium condition, maximum catch rate

$$MSY = (kB_\infty/4) \;\ldots\; (6)$$

achieved when

f (opt) = (k/2q); CPUE (opt) = $qB_\infty/2$); B(opt) = ($B_\infty/2$) . . . (7) from Eq. (6) and Eq. (7)

$$C\ (opt) = CPUE\ (opt), f\ (opt) \ldots . \quad (8)$$

Numerical Example

Input data

The input data to the model consists of a time series of catch and effort data for a certain number of periods. These data can be used to estimate C (opt) (optimum sustainable catch rate), f (opt) (optimum effort rate), CPUE (opt), population size B (opt), and MSY.

Steps on the computations

Two related types of computations in fitting the model can be used; first, an approximate linear regression on a programmable hand calculator, second, a nonlinear regression which gives more precise results, but requires an iterative procedure on a computer.

Only an approximate linear regression procedure presented here, which begins with the calculation of (fy + fy+l)/2, (CPUEy + CPUEy+l)/2 and 1n (CPUEy+1/ CPUEy).

Let us use the same data as those of Table 1, and put the complete calculations in Table 2.

Table 2. Catch and effort data for the *lemuru, Sardinella longiceps,* from the Bali Strait, illustrating Schnute's method.

Year	fy	CPUEy	(CPUEy+ CPUEy+1)/2	(fy+fy+1)/2	ln(CPUEy+1/CPUEy)
1974	17	375.3			
1975	70	327.1	351.2	43.5	–0.1375
1976	126	279.4	303.3	98.0	–0.1576
1977	193	235.8	257.6	159.5	–0.1697
1978	228	122.4	179.1	210.5	–0.6557
1979	304	102.5	112.5	266.0	–0.1774
1980	237	108.4	105.5	270.5	0.560

Estimation of parameters of regression :

r^2 = 0.02
a = 1.00
b = 0.0029
c = 0.0033

Estimation of fishery-related parameters :

a = k (natural growth) = 1.00 per year
b = (k/qB_∞) = 0.0029
c = q (catchability coefficient) = 0.0033 per unit of purse seine
f (opt) = k/2q = 151 units of purse seine
MSY = $(a^2/4bc)$ = kBoo/4 = 26 123.2 tons.

CONCLUSIONS

Gulland's Method

It is worth noting that CPUE at any moment not only subject to the effort of that moment, or during particular years, but also to the effort in preceding periods (i.e. the everage effort in some previous years up to and including the current year). Even the estimation of the length of period is not crucial (RICKER 1975), but GULLAND (1983) suggested that the length period of one-third to one-half of the potential life span of an individual species of fish in the fishery, is the convenient one.

Schnute's Method

An approximate version of the model can be fitted using multiple linear regression performed on a programmable calculator. In addition, Schnute gives a method of deriving an exact results for MSY and f (opt) for each year, using nonlinear regression on a computer, which able to provide variance or confident limit of the parameters (yield and fishing effort values) for a given confident level.

The results obtained by Gulland's and Schnute's method from the numerical examples in estimating MSY and optimum effort is depicted in Figure 2.

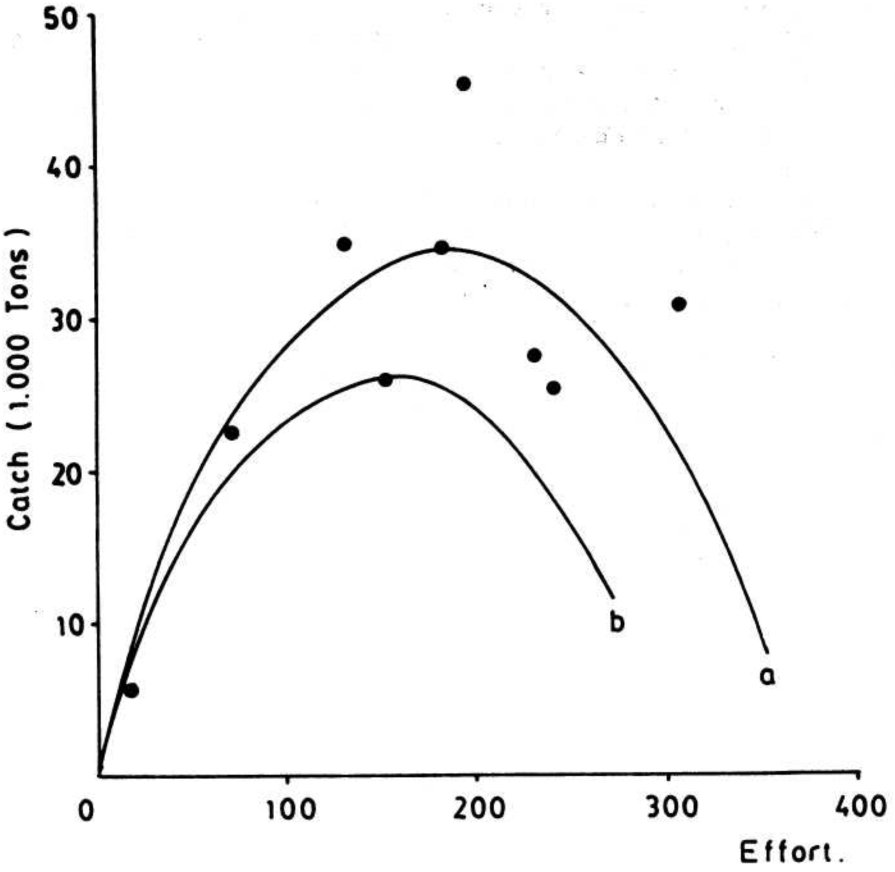

Fig. 2. Yield curves for *lemuru (Sardinella longiceps)* fishery of the Bali Strait, obtained by cmploying Gulland's method (curve a) and by Schunte's (curve b).

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