MACRO ANALYTICAL MODELS

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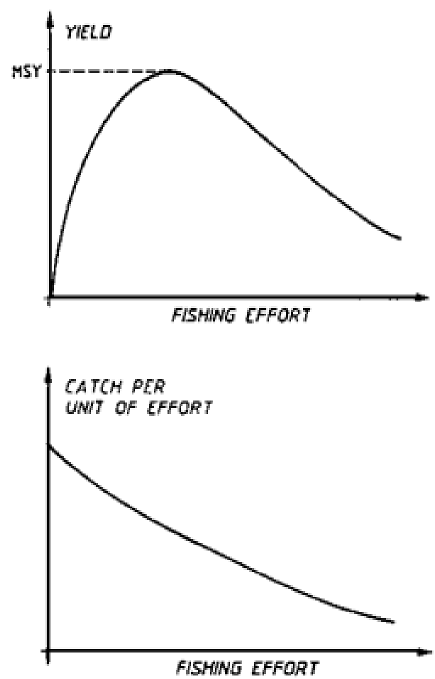
Introduction

Production models form one of the two groups of models used in studying fish population and assessing the state of the fish stocks. Unlike the analytical models, they do not consider the events within a population, and particularly ignore the growth and mortality of the individuals forming the population. These models view population as one unit of biomass, with all individuals having the same growth and mortality rates. The surplus production models deal with the entire stock, the entire fishing effort and the total yield obtained from the stock, without entering into any details such as the growth and mortality parameters or the effect of the mesh size on the age of fish capture etc. Surplus production models were introduced by Graham (1935), but they are often referred to as Schaefer-models.



The objective of the application of surplus production models is to determine the optimum level of effort that is the effort that produces the maximum yield that can be sustained without affecting the long-term productivity of the stock, or the maximum sustainable yield (MSY). Surplus production models assume that variation in population biomass results from increases due to growth and reproduction (termed production), and decreases from natural and fishing mortality.

Surplus production models use catch per unit effort as input. The data, which represent a time series of years, are usually collected from commercial fishery. The model is based on the assumption that the biomass of the fish in the sea is proportional to the catch per unit effort. Surplus production models are concerned with four basic quantities.

They are

- The population biomass B
- The catch
- The fishing effort
- The net natural rate of increase

The basic information used in surplus production models is catch-per-unit-effort (CPUE) data and records of landed catches. In this approach, consistent with most other stock assessment techniques, CPUE is regarded as an index of resource biomass or resource abundance.

The problem is to estimate

- the constant of proportionality linking CPUE to resource biomass, referred to as the catchability coefficient, and
- to estimate the resource carrying capacity and the scale of the surplus production curve.

Since the surplus production and hence the resource biomass cannot increase indefinitely (resource biomass is assumed to achieves a maximum level known as the resource carrying capacity), surplus production is zero both at a resource biomass level of zero (when there is no biomass then it cannot produce any surplus production) and at a resource biomass level equal to the carrying capacity. Somewhere between these two extreme resource biomass levels (zero and the resource carrying capacity) the surplus production must reach a maximum value. Most surplus production models assume that the relationship between surplus production and resource biomass is bell shaped, that is it is fairly symmetrical with a maximum about halfway between a resource biomass of zero and the carrying capacity In practice surplus production curves are seldom symmetrical and there are a variety of surplus production models which accommodate virtually all possible asymmetrical relationships that may be required for different situations. For example, in many finfish stocks the maximum is assumed to occur at a biomass smaller than the halfway point, whereas for whale stocks it is assumed to lie at a biomass larger than the halfway point.

The basic assumptions in Schafer's model are

- The net natural rate of growth is a decreasing function of the biomass
- The relationship is linear
- We are dealing with a unit stock.
- The population reacts instantaneously to any change in effort.
- The population has no size or age structure. There is no growth or ageing of individuals.
- Any loss is mortality
- No interaction with other species.
- No spatial and environmental variation.
- The stock is closed, no immigration and emigration.

The model can be applied for the fisheries which have undergone substantial increase or decrease in fishing effort over a long time series.

All discrete surplus production models are of the form

$B_{t+1} = B_t + g(B_t) - C_t$

where

Bt	the exploitable biomass at the start of the year t
g(Bt)	biomass dynamic as a function of current biomass
Ct	catch during the year t

The three most common forms for the function g(B) are

1.	$rB(1 - B/K)$	Schafer
2.	$rB\{1 - (\ln B)/(\ln K)\}$	Fox
3.	$r/p\, B\{1 - (B/K)p\}$	Pella Tomlinson

where

B	is the current biomass
r	the stocks intrinsic rate of increase in proportion to unit time.
K	carrying capacity or the maximum population size
p	the shape parameter

The Schafer form of the biomass dynamic function is equivalent to the Pella Tomlinson form with p=1. The fox form is the limit of Pella Tomlinson form as $p \rightarrow 0$

The Schaefer and Fox Models

The Schaefer model expresses the yield per unit effort (Y/f) as a function of the effort (f) in the simplest way as

$$Y/f = a + bf$$

In this model the catch per unit effort is considered as a linear function of effort and the linear relationship has negative slope and positive intercept. The catch per unit effort (Y/f) decreases for increasing effort (f); but the intercept (a) must be positive.

In this method,

The Maximum Sustainable Yield $MSY = \frac{-a^2}{4b}$

Optimum effort $f_{MSY} = \frac{-a}{2b}$

Yield for a given effort = af – bf^2

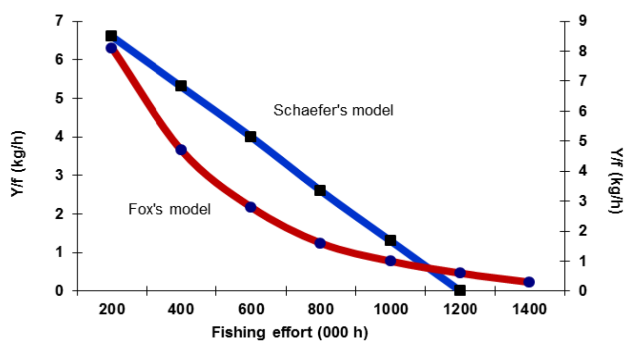
Using time series data on catch and effort by a linear regression of catch per unit effort (Y_t / f_t) (CPUE) on effort f_t, we can estimate the coefficients *a* and *b* and calculate MSY using this estimates.

In Fox model, an exponential relationship between *CPUE* and effort is assumed. The model is given by

$$\frac{Y(i)}{f(i)} = e^{c+d*f(i)} \quad \text{or} \quad \ln \frac{Y(i)}{f(i)} = c + d * f(i)$$

This function will have maximum value for the yield when $f_t = \frac{-1}{d}$ and the maximum value of yield (*MSY*) is given by $MSY = \frac{-1}{d} e^{c-1}$

Using time series data on catch and effort through a linear regression of logarithm of catch per unit effort $\ln(Y_t / f_t)$ on effort f_t, we can estimate the coefficients *c* and *d* and calculate MSY using these estimates.



Though the models of Schaefer and Fox conform the assumption that Y/f declines as effort increases, the straight line of Schaefer model implies that Y/f reaches zero for certain f value but the curved line in the Fox model implies that the Y/f never approaches zero, even at very high levels of effort.

Because holistic models are much simpler than analytical models, the data requirements are also less demanding. There is no need to determine cohorts and therefore no need for age determination. This is one of the main reasons for the relative popularity of surplus production models in tropical fish stock assessment. Surplus production models can be applied when data are available on the yield (by species) and of the effort expended over a certain number of years. This method is simpler since it makes no assumptions about the size and/or age composition of the catch or of the broader population. It is one of the simplest ways to deal with multispecies/multifleet system by pooling the catch of all species and the effort by all fleets. Application of the Schaefer model to the catch of all species by all types of fleets would give an estimate of MSY for the area in consideration. However, the problem of exploitation of the same stock by gear with different efficiencies has to be addressed by standardising the fishing efforts of all the gear that are engaged in the fishery.