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POPULATION DYNAMICS MODELS FOR POPULATION ANALYSIS IN FISHERIES

By

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ABSTRAK

MODEL-MODEL DINAMIKA POPULASI UNTUK PENGKAJIAN POPULASI DI BIDANG PERIKANAN. *Keberhasilan di bidang perikanan sangat ditentukan oleh pengetahuan kita tentang sifat dinamika dari pada populasi-populasi ikan. Beberapa model tentang dinamika populasi di bidang perikanan seperti : Surplus Production Model, Analytic Model, Hybrid Model, dan Ecosystem Model, serta latar belakang yang mendasari masing-masing model tersebut dibahas di dalam tulisan ini.*

INTRODUCTION

Fisheries are based upon stock of common-property resources (open-access resources). That is, the commercial fishery resources cannot be controlled in the direct and positive way that private owner administers his own property, i.e. controls either the resources or its exploitation. In general, such resources are open to exploitation by anyone (unlimited entry), and tend to become overexploited.

Principally, population dynamics may be defined as the study of the variation in number of natural populations of animals (PIELOU 1974). In so far as the fish stocks are always in fluctuation state, the success of the fisheries depends critically on a body of knowledge concerning with the dynamics of fish populations. Information on stocks, especially on the understanding of the mechanisms by which fish stocks are produced and how their quantity are managed; also of the effect on stocks of the fishing being intended to are important, particularly concerning with the kinds, amounts, and sizes of fish that can be harvested on a sustainable basis by various number or sorts of fishing (RICKER 1977).

In short, most fisheries problems are complicated and contain both human as well as biological dimensions which represent dynamic (time varying) systems with interacting components that may not be analysed separately (WALTERS 1980).

In recent years, there has been much thinking on how to translate physical of biological concepts about complex and interacting system into a set of mathematical relationship and manipulate the mathematical systems thus derived. This approach known as system analysis, while the mathematical system is called a model.

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WHAT IS A MODEL?

A model is a well—defined set of statements that describes complex systems and allows precise statements of how components of the systems are likely to interact. As a result, a model is an imperfect and abstract representation of the structure and function of real system.

Model may take in several forms. Since mathematical symbols provide a helpful shorthand for describing complicated systems, and mathematical equations able to describe clearly how components of the systems may be to interact, mathematical models are largerly used in describing the dynamics of fish populations. An example of mathematical model in fisheries is the well known von Bertalanffy growth model which describes fish length as a function of age;

$$1(t) = L_{oo} (1 - e^{-K(t-t_o)}).$$

The right hand side of the equation containts the age, t, and the other symbols such as L_{OO}, K, and t_O. These symbols are termed as parameters.

Models may be either stochastic or deterministic. Stochastic models attemp to incorporate the effect of random variability in forcing functions and parameters. Deterministic models ignore this chance variation.

An example of deterministic model of a pure birth process can be expressed as follows :

$$N_t \doteq N_o e^{\lambda t}$$

where N_t is the size of the population at time t which assumed to be exactly predictable, N_O is the initial size of the population at time t = 0; and λ is the rate of increase of each individual. The organisms are assumed to be immortal, with constant individual rate of reproduction, and there is no intrecation of one another. In contrast to the deterministic model of pure birth process, actually, population growth is a stochastic mechanism, i.e. instead of reproduce with absolut certainty, one can say that there is a certain probability that an organism will produce in a given time interval. In stochastic terms, the probability that the population is of size N at time t can be demonstrated by (PIELOU 1977, modified from Eq. (1.3))

$$pN(t) = \binom{N-1}{N_o-1} e^{-\lambda N_o t} (1 - e^{\lambda t}) ^{N-N_o}$$

In the formula of pN(t), X and t cannot be separated; they occur in the form of the product Xt. Figure 1 depicts an example of the distribution of N(t) when λt = 0.5 and N_O = 5. The mean for the expected size of the population at time t, that is M(N/t)

$$M(N/t) = N_o e^{\lambda t}$$

with the variance, var (N/t) is expressed by

$$var(N/t) = N_o e^{\lambda t} (e^{\lambda t} - 1)$$

The value of a model may be evaluated by its simplicity and the accuracy with values predicted by the models fit the factual observation. Consequently, a model cannot be regarded as wrong, but as presenting a significant fit to the fact over a wide or narrow range of conditions (e.g. to a number of different fish stocks). In conclusion, a good model is one that is mathematically simple, operates with relatively few and understandable of parameters, but gives a good fit (i.e. lead to results that close to the reality that we suppose to describe) over a wide range of several different conditions.

How does the von Bertalanffy growth model provide to this criteria of a good model? The mathematical equation of calculating length at t years, 1 (t), is quite simple, i.e. :

$$1(t) = L_{oo} (1-e^{-K (t - t_o)}).$$

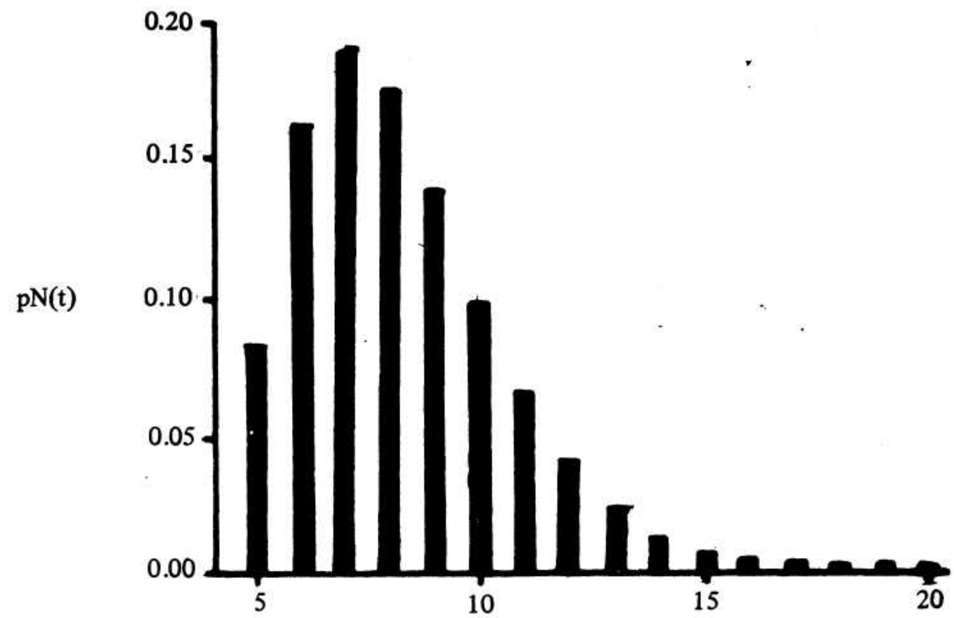

Figure 1. The probability distribution of the size at time t, pN (t), of a stochastic pure birth model : with t = 0.5 and N_0 = 5. The mean is M (N/t) = 8.24, and the variance is var (N/t) = 5.35. (Modified from PIELOU 1977).

After the value of L_{OO}, K, and t_O are estimated from the growth data, 1 (t) can be derived simply by performing a couple of multiplications and subtractions and a single of exponential. The von Bertalanffy growth model uses simple and understandable parameters, i.e., L_{OO} is called as length infinity that can be determined as the average of the longest fish captured. K is defined as growth constant which describes the rate at which the growth curve approches L_{OO}. As a consequent, short—lived species will have a great value of K, whereas long lived species will have small K value. The third parameter is t_O, which determines the length of a fish at age O. To illustrate the role of parameter K in determining how fast the fish obtains its ultimate; length, a family of growth curves with different K values are showed in Figure 2.

The closeness values predicated by the von Bertalanffy growth model can be demonstrated by the experience which has shown how the majority of fish species increase in length while they getting older. In general, the von Bertalanffy growth model proved to work well over fish and shellfish, so that this model applicable to a wide range of situation.

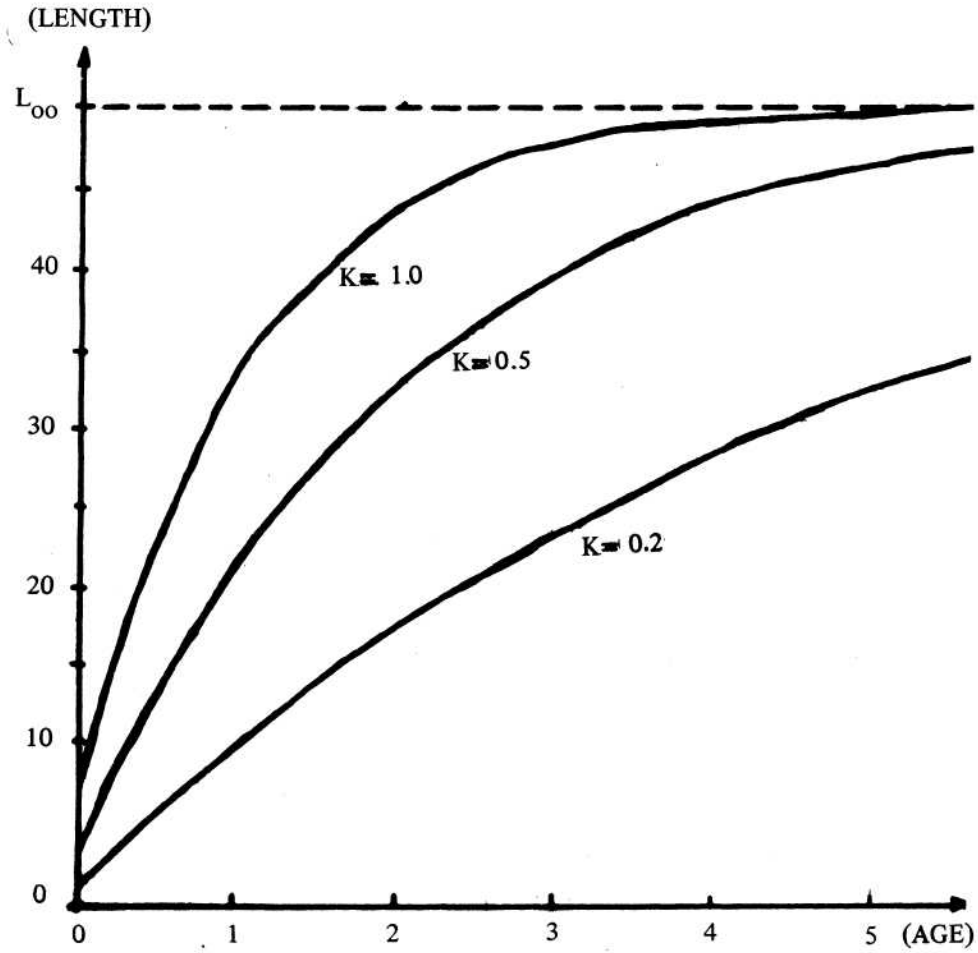

Figure 2. A family of growth curves with different parameters K.

POPULATION DYNAMICS MODELS IN FISHERIES

The simplest model in fish population dynamics is the surplus production models which treat a fish population as a single indivisible biomass, subject to simple rules of increase and decrease. These models enable an analysis to be performed whenever only very few information, especially on yield, stock abundance, and amount of fishing, are available. Unfortunately, these models cannot readily be adjusted to consider detailed biological information on the fish, or to provide detailed advice on the pattern of fishing. To this extent, production models are inadequate and more complicated models are called for.

A family of production models can be listed as follows:

1. Simple Production Model (Graham-Schaefer's Model)
   1.1. GULLAND'S METHOD (1961; 1982)
   1.2. UHLER'S METHOD (1979)
   1.3. SCHNUTE'S METHOD (SCHNUTE 1977; STOCKER & HILBORN 1981)
2. Generalized Production Models of PELLA & TOMLINGSON (1969)
   2.1. FOX (1970; 1975)
   2.2. RIVARD & BLEDSOE (1978)

The more complex models, i.e. analy tic models give attention to the separate characteristic growth of individual member of the fish population, mortality due to fishing and natural process (disease, predation, etc.), and recruitment, which simultaneously determine the fluctuation in stock abundance of the fish. These models, in the conditions which permit the parameters to vary in accordance with the density—dependent process, are the most complicated and realistic that are properly developed to provide predictive and quantitative advice. These analytic models are represented by the Ricker's (1954) and the BEVERTON & HOLT'S MODELS (1956).

A number of attemps were developed to hybridize the simple production models with the analytic models. Among these "hybrid" models are MARCHESAULT *et al.* (1976), DERISO (1980), WALTERS (1981), and CSIRKE & CADDY (1983).

Some modifications of analytic models are made which take into account of some other directly interacting species, e.g. competitors, food, or predators. These models are arbitrarily termed as the modern analytic models.

Since fisheries exploit a great variety of species, and the general impact of human's activities (including various forms of pollution) on the aquatic ecosystem getting more and more pervasive, even these analytic models, which treat each species more or less in its isolated manner, and are primarily limited to looking at equilibrium conditions, are getting less satisfactory. Consequently, ecoystem models are needed that able to analyse the ecosystem as a whole or able to handle the non—equilibrium events. GULLAND (1983) points out that while these models exist, they are still poor developed, and so far cannot generally be used to produce predictive of quantitative analysis. However, these models are already useful in providing some qualitative impression of the results of different actions, and in suggesting which tracks of investigation would be most productive and which data would be most valuable.

CONSULSIONS

As yet, the models of quantitative population analysis still based upon single species models which often progressing from surplus yield models to analytic models whenever accumulate data on fisheries are available. In the future, population analysis studies must become increasingly concerned with ecosystem models.

REFERENCES

BEVERTON, R.J.H. and SJ. HOLT 1957. On the dynamics of exploited fish populations. *U.K. Min. Agric. Fish., Fish. Invest.* (Ser. 2), 19 : 533 pp.

CSIRKE, J., and J.F. CADDY 1983. Production medelling using mortality estimate. *Can. J. Fish. Aquat. Sci.,* 40 : 43 - 51.

DERISO, R.B. 1980. Harvesting strategies and parameter estimation for an age structural model. *Can. J. Fish. Aquat. Sci.,* 37:268-282.

FOX W.W. 1970. An experimental surplus-yield model for optimizing exploited fish populations. *Trans. Am. Fish. Soc.,* 99(1): 80-88.

FOX, W.W. 1975. Fitting the generalized stock production model and equilibrium approximation. *Fish. Bull. NOAA/NMFS,* 73(1);23-36.

GRAHAM, M. 1935. Modern theory of exploiting a fishery and application to North Sea trawling. *J. Cons. Int. Explor. Mer.,* 10 : 264-274.

GULLAND, J.A. 1961. Fishing and the stocks of fish at Iceland. *U.K. Min. Agric. Fish., Fish. Invest.* (Ser.2), 23 (4): 52 pp.

GULLAND, J.A. 1982. Comment on "Short term forecasting in marine fish stocks". *Can. J. Fish. Aquat. Sci.,* 39:1071-1072.

GULLAND, J.A. 1983. *Fish stock assessment, A manual of basic method.* John Wiley & Sons, New York; 223 pp.

MARCHESSEAULT, *G.D.,* S.B. SAILA, and W.J. PALM. 1976. Delayed recruitment models and their application to the American lobster *(Homarus americanus)* fishery. *J. Fish. Res. Board Can.,* 33 (8) : 1779-1787.

PELLA, J.J., and P.K. TOMLINSON 1969. A generalized stock production model. *Inter-Am. Trop. Tuna Comm. Bull.* 13:419-496.

PIELOU, E.C. 1974. *Population and community ecology, Principles and methods.* Cordon and Breash Science Publisher, New York. 42pp.

RICKER, W.E. 1977. The historical development. *In:* Fish population dynamics, (J.A. Gulland, ed). John Wiley & Sons, New York: 1 - 26.

RIVARD, D., and L.J. BLEDSOE. 1978. Parameter estimation for the Pella Tomlinson stock production model under non—equilibrium conditions. *Fish. Bull. NOAA/NMES,* 76 (3): 523-534.

SCHAEFER, M.B. 1957. A study of the dynamics of the fishery for yellowfin tuna in the eastern tropical Pacific ocean. *Inter-Am, Trop. Tuna Comm. Bull, 2* : 247-268.

SCHNUTE, J. 1977. Improved estimates from the Schaefer production model: theoretical considerations. *J. Fish. Res. Board Can.,* 34 : 583-663.

STOCKER, M., and R. HILBORN. 1981. Short-term forecasting in marine fish stocks. *Can. J. Fish. Aquat. Set.,* 38:1247-1254.

UHLER, R.S. 1979. Least squares regression estimates of Schaefer production model: some Monte Carlo simulation results. *Can. J. Fish. Aquat. Sci.,* 37 : 1284-1294.

WALTERS, C.J. 1980. Systems Principles in fisheries management. *In:* Fisheries management (R.T. Lackey and L.A Nielsen eds.) Blackwell Scientific Publications, London, 167-183.

WALTERS, C.J., 1981. Optimum escapements in the face of alternative recruitment hypotheses. *Can. J. Fish. Aquat Sci.,* 38 : 678-689.