AQUACULTURE PRODUCTIVITY

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Assessment of Fish Production in Aquaculture

K. ALAGARAJA*

Introduction

More than half of the world's population has an insufficient and nutritionally unbalanced diet. An adequate diet requires an average of about 44 g per day protein, being about 10 to 12 g of the total caloric intake. Fish is an excellent source of protein, containing all the 10 essential amino-acids in desirable concentrations for human beings and available at cheaper rates.

Oceanic area of about 36,000 million hectares and fresh water area of about 600 million hectares sustain this resource. Continental shelves being 8 per cent of oceanic area contributes about 80 per cent of the total marine catch. Similarly in the case of fresh waters well managed water area such as ponds yield more than other areas. For instance the average yield from fresh waters is about 10 kg per hectare. Whereas in a well managed pond it has been shown that production can be increased to 6,000 kg per hectare and above. The total fish catch in the world has touched 90 million tonnes.

Fish is a renewable resource of wealth. Unlike mineral and other fixed resources which do not have self-generating capacity to replenish the loss due to natural causes and or human exploitation, fisheries is a dynamic resource which when judiciously exploited replenishes the loss and hence a maximum sustainable yield from this resource is possible. Fisheries can broadly be divided into two types, namely, capture fisheries and culture fisheries. In capture fisheries human intervention comes in the stage of harvesting only whereas in culture fisheries it is involved in all stages starting from rearing the stocks to harvesting.

There are direct and indirect methods of assessing aqua-production.

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Under direct method comes (Beverton and Holt, 1957; Ricker, 1975) exploratory surveys involving acoustics, aerial surveys and remote sensing using satellites and analytical studies involving vital statistics of exploited stocks such as mortality and growth. Primary productivity studies and yield comparison with the areas where full exploitation is done are indirect methods.

Analytical approach has been studied extensively both for capture and culture fisheries. Models have been developed though mainly deterministic. The other methods of assessing production require extensive studies involving quantitative approach. Much work could be done in this area.

In capture fisheries under analytical approach, there are at present two models, namely, micro-analytic model (Beverton and Holt, op. cit.) and macro-analytic model (Schaefer, 1957). In micro-analytical model all the components such as age, growth and mortality require intensive study and coverage. However, there are areas where collection of vital statistics for micro-analytical model becomes almost impossible. For instance, determination of age of fish in tropical waters (using hard parts) as in the case of temperate zones is not possible. Hence macro-analytical approach is preferred in which catch and effort expended are the main items required for estimation of potential yield.

In culture fisheries since human agency is involved right through all the stages of development as mentioned earlier, collection of vital statistics poses no problem. We shall consider here this problem in detail.

Aqua-production is a three-dimensional one as compared to two-dimensional terra production. The factors involved in aqua-production can be grouped under three categories: (i) condition of water resource, (ii) seed introduction, and (iii) feeding characteristics.

Growth of fish depends on the fertility of the water in which it lives. Inherent fertility may not be sufficient for the maximum growth of fish sustainable by the water resource. Proper manurial practices such as liming and applying fertilisers will increase the fertility of a water resource. Growth of fish is found to be directly proportional to the fertility of the water up to a certain level. Then the fertility becomes ineffective beyond this maximum level and it may even prove harmful to the growth of fish, once the fertility level is very high. Another important factor is the water area available for culture. In this case it is found that the growth or yield rate is inversely proportional to the water area. The height of the water column also plays an important role in the overall yield. A minimum height of three feet is required to sustain fish in a water column in tropical areas for water bodies with less water columns which become very hot for fish to survive. However, a too deep water resources may not yield as much as its water column can afford to, since light penetration may not be effective in deeper waters and hence the fertility of deeper waters are less when compared to shallow water areas.

Thus we see inherent fertility, manuring, water area, and depth of water column are important factors affecting production of water body in different ways.

Production from aqua or terra regions depends on the quality of seed introduced. In the case of fish culture rate of growth depends on the size of the fish stocked. An ideal recruitment is one when natural mortality is minimum and growth rate is maximum. Natural mortality and growth also depend on the season of the recruitment. For instance, if fish are stocked during winter, then natural mortality may be high and growth rate minimum. Hence appropriate period of stocking should be determined for obtaining maximum production.

Productivity of water area depends on the density of the seed introduced. As the density increases to a certain level the production also increases. Beyond this critical level the production declines and that too sharply. Production can be increased by introducing fishes preferring different niches and not competing with each other for food. Polyculture is the solution for this. For instance in prawn culture ponds introduction of mullets and milk fish do not affect the growth of prawns and at the same time contribute to the overall production of the water body. Similarly in composite fish culture, adopted in fresh water ponds, *catla*, the surface feeder, *rohu*, the column feeder and *calbasu*, the bottom feeder together with exotic species such as Chinese carps all grow well, compatible to each other and this combination utilises the entire volume of water body. In polyculture experiments the ratio, in which different species are to be introduced, is to be determined for obtaining maximum production.

In short, the stage of quality seed recruitment, time of recruitment, density and ratio of species recruited are the important factors under recruitment that determine the productivity of a water body individually and collectively.

Carrying capacity of a water body is the maximum weight of fish which can be sustained by the water body (Hickling, 1962). Inherent productivity of a water body is not the only factor for its carrying capacity but it depends on fish pond management methods (Tal, 1972) that too mainly on the levels of supplementary feeding.

Quality of supplementary feed needs no emphasis. The best combination of different items that make the supplementary feed, requires extensive experimental studies. Much work has already been done in this regard. Quantity or rate of feeding is also to be determined so that feed is not wasted without being consumed by fish and this unconsumed food will decay and turn toxic for life. Overfeeding may not lead to proportional growth and undernourishment arrests growth. This aspect also requires extensive experimental studies. Methods of feeding such as supplying feed once a day or twice a day, spraying the food evenly over the water body or placing the feed at fixed points for the fish to come there and feed are some of the items to be studied under this aspect. The important items under supplementary feeding can be then summed up to quality, quantity and methods of feeding. In polyculture the effect of these factors on each species is also to be taken into account.

Harvesting schedule may improve the production. Multiple harvesting will lead to continuous harvesting of marketable size with suitable seed replacement. To sum up, physical chemical characteristics of the water body such as its size, shape and depth, salinity, DO_2 etc., seeding schedule including the suitable size of the seed for the better growth and less mortality, season of its introduction, density and proportion combination in polyculture, feeding schedule, harvesting pattern and proper management are the factors to be considered for successful operations of pisciculture activities. Thus pisciculture assumes multidimension and ordinary quantitative analysis becomes too inadequate to lead one to any valid conclusion. Hence system analysis and simulation process should be taken up to study the overall effects of these multidimensional factors.

Limited number of water resources such as ponds for experimental studies does not allow extensive studies using suitable designs of experiments for getting information on the overall affects of factors considered earlier. At present mostly few factors alone are considered at a time keeping other factors at a known level. Even then suitable variance functions are not available to compare productions from different water bodies to see the effect of the treatments. Alagaraja (op. cit.) has developed variance functions suitable for application. Here we shall see in a nutshell the development of production functions and their associated variance functions.

As Ricker (1971) puts it, Biomass is the amount of substance in a population expressed in material units, such as living or wet weight, dry weight, ash-free weight, nitrogen contents etc. It is also termed as standing crop. Biomass can be expressed as

$$B_t = N_t \overline{W}_t \tag{1}$$

where at time 't' B_t is the biomass, N_t the number of fish in the pond and W_t is the average weight of a fish.

Production in a given time interval is defined as (Ivleve, 1966) the total elaboration of animal tissue during that time interval including what is formed by individuals that do not survive till the end of that time interval. Though this general definition is broad enough to include the components such as released eggs, spawn etc. we shall confine our attention to the wet weight of the fish only. When individuals alone are considered such as a single fish, production and growth are synonyms. In temperate regions negative production may take place during winter months.

Let P_t be the production at time 't'. Then

$$\partial P_t = \overline{N}_t \, \partial \overline{W}_t \tag{2}$$

Where $\partial \overline{W}_t = \overline{W}_t + \partial_t - \overline{W}_t$ and $\overline{N}_t$ is the number of fish living during '∂t'.

$$\text{Hence} \quad \int_0^T \partial P_t = \int_0^T \overline{N}_t \, \partial \overline{W}_t \tag{3}$$

Case 1: when there is no mortality then

$$P_t = N_t(\overline{W}_t - \overline{W}_o) = B_t - B_o \qquad (4)$$

In the absence of any functional form of N_t and W_t it is difficult to solve (3).

To differentiate yield from production let us define that what is produced is production and what is harvested is yield. In fisheries the quantity harvested, in other words the final biomass may be termed as gross yield and net yield is the difference between final biomass and initial biomass. From (4) it is clear that production and net yield become one and the same if and only if there is no mortality. Yet Y_t be the net yield at time 't'. Then

$$Y_t = B_t - B_o \ldots\ldots\ldots \qquad (5)$$

Different production functions are proposed by many workers. Ricker (1946) and Allen (1950) propose

$$P_1 = G\overline{B} \ldots\ldots\ldots \qquad (6)$$

This form necessarily implies that growth follows exponential law, namely,

$$W_t = W_o e^{Gt} \ldots\ldots\ldots \qquad (7)$$

Where W_o is the initial average weight of a fish, C is the instantaneous mortality rate and $B = \int_0^1 B_t\,dt$, the mean annual biomass. Alagaraja (1980) has considered to more forms

$$P_2 = Y_t + Z\overline{B} \ldots\ldots\ldots \qquad (8)$$

and

$$P_3 = b\,\overline{N} \ldots\ldots\ldots \qquad (9)$$

In (8) it is implied that change in population numbers follows exponential law whereas growth may follow any law. However in (9) both growth and change in number are linear with time 't'. Z is the instantaneous mortality rate and 'b' is the rate of increase in weight. Hence

$$G = (\log_e W_T - \log_e W_t)/T{-}t \ldots\ldots\ldots \qquad (10)$$

$$Z = (\log_e N_t - \log_e N_t)/T{-}t \ldots\ldots\ldots \qquad (11)$$

$$b = (W_T - W_t)/(T{-}t) \ldots\ldots\ldots \qquad (12)$$

$\overline{B}$ and $\overline{N}$ are mean biomass and mean number of fish surviving during (t, T).

Alagaraja (op. cit.) has developed variance functions for (6), (8) and (9). The variance function for (6) considered by Chapman (1971) is not complete in the sense that he assumes that the covariance factor arising in the variance function is negligible. Alagaraja (op. cit.) has evaluated the amount of contribution from this covariance factor and thus has improved chapman's (op. cit.) result. To elucidate the procedure let us consider the following examples.

Example 1

In the beginning of a month 100 fish were there with an average weight of 50 g. After 10 days 20 die; overall average weight being 60 g. After another 10 days 10 die with average weight 80 g and the rest were alive to the end of the month reaching to an average weight of 100 g. What is the production and yield?

$$
\begin{array}{llll}
 & & & P_t \\
P_t \text{ in 1st} & 10 \text{ days} = & 100\times 60 - 100\times 50 & = 1{,}000 \text{ g} \\
P_t & \text{2nd } 10 \text{ days} = & 80\times 80 - 80\times 60 & = 1{,}600 \text{ g} \\
P_t & \text{3rd } 10 \text{ days} = & 70\times 100 - 70\times 80 & = 1{,}400 \text{ g} \\
 & & \text{Total} & = 4{,}000 \text{ g}
\end{array}
$$

$$\text{The yield } Y_t = B_t - B_o = 70\times 100 - 100\times 50 = 2{,}000 \text{ g}$$

Thus $P_t = 4.0$ kg and $Y_t = 2$ kg. From this it is clear that had the mortality been controlled, yield would have been almost double the present yield.

Example 2

Data taken from Chapman (op. cit.) are givan in Table 1. Only seven months data are considered here.

Table 1

Date	Mean wt. W (g)	Stock number N	B (N W) (kg)
May 1	1.5	8,000	12.0
June 1	2.0	4,500	9.0
July 1	2.5	3,500	8.7
August 1	3.5	3,000	10.5
September 1	4.5	2,500	11.2
October 1	6.5	2,000	13.0
November 1	6.9	1,900	13.1

Now let us take the period May-1 to June 1. ($t_2 - t_1 = 1$ month). Here $\overline{W}_1 = 1.5$, $\overline{W}_2 = 2.0$, $N_1 = 8{,}000$ and $N_2 = 4{,}500$. Hence for this period

$$G = \text{Log}_e\, 2.0 - \text{Log}_e\, 1.5 = 0.29$$
$$Z = \text{Log}_e\, 8{,}000 - \text{Log}_e\, 4{,}500 = 0.58$$
$$b = 2.5 - 2.0 = 0.5$$

$$N = \frac{8{,}000 + 4{,}500}{2} = 6{,}250$$

$B_1 = 12{,}000$, $B_2 = 9{,}000$. Hence $B = 10{,}500$. Similarly the corresponding values for other periods are calculated and presented in Table 2.

Table 2

Period	G	Z	$\overline{B}$ (kg)	$\overline{N}$	b (g)	$G\overline{B}$ (g)	$Z\overline{B}$ (kg)	bN (kg)
May-June	0.29	0.58	10.5	6250	0.5	3.0	6.1	3.1
June-July	0.22	0.25	8.8	4000	0.5	1.9	2.2	2.0
July-August	0.34	0.15	9.6	3250	1.0	3.3	1.4	3.2
August-September	0.26	0.18	10.8	2750	1.0	2.8	1.9	2.8
September-October	0.37	0.22	12.1	2250	2.0	4.5	2.7	4.5
October-November	0.06	0.05	13.0	1950	0.4	0.8	0.6	0.8
					Total=	16.3	14.9	16.4

Now $Y_t = 13.1 - 12.0 = 1.1$

Hence $P_1 = G\overline{B} = 16.3$ kg

$P_2 = Y_t + Z\,\overline{B} = 1.1 + 14.9 = 16.0$ kg

and $P_3 = b\,\overline{N} = 16.4$

It may be noted that all the three estimates are not differing much from each other.

The production function P_3 is comparatively easier to evaluate and so also its variance function. Moreover its variance function does not involve any covariance factor when independent samples are taken for evaluation of N_t and $\overline{W}_t$. Thus in culture operations where observations are taken at short intervals production for each such interval may be taken and total production becomes additive and so also the variance associated to the total production for any interval at the beginning and at the end of which independent samples are taken to evaluate N_t and $\overline{W}_t$.

In general to determine carrying capacity of a water body it is necessary to evaluate its production. For this, periodic sampling is required to determine the number of fish and their average weight. This helps to formulate feeding schedules on estimates of the population. Apart from this, difference between production and yield may throw light on factors such as mortality, that are responsible for the difference and thus may suggest ways to improve yield. Moreover evaluation of variance enables one to compare production of different water bodies in a more critical way.

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