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A Modeling Approach to Determine the Harvest Potential for Sustainable Fishery in Stocked Reservoirs

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ABSTRACT

India is bestowed with rich inland water resources – *viz.* ponds, lakes & reservoirs, and rivers among others. Inland fish production – especially from reservoirs - over the years has grown steadily contributing much to the nutritional security of the people, poverty alleviation, community development and women empowerment. Recent advancements in modeling offer tremendous scope to determine population harvest from open waters. In reservoirs, fish harvest levels are of paramount importance because they should ensure sustainability of the fisheries and economic viability. Since stocking is resorted to enhance fish production in reservoirs these days, in this paper, a modeling approach has been attempted for sustainable fishery exploitation in stocked reservoirs. Accordingly, a modified Verhulst-Schaefer model that takes into account the impact of stocking of fingerlings in reservoirs on fish population growth – was applied in one stocked reservoir. Catch/effort and stocking data from Bargi reservoir (Madhya Pradesh, India) was used in model validation and in the estimation of *Maximum Sustainable Yield (MSY)*. The present study not only be helpful to estimate impact, but also to understand how different stocking regimes impact the fish harvest potential at varying levels of efforts for effective fisheries management of reservoirs.

Keywords : Verhulst-Schaefer model, reservoir fishery, stocking, effort, CPUE, MSY, fishery management

INTRODUCTION

Reservoirs are emerging as the harbinger of inland fish production in India. With its total water spread area of 3.51 million ha (Sarkar and Mishal. 2017), reservoirs have the potential to substantially increase the country's inland fish production if they are properly managed (Sugunan 1995; Sarkar et al. 2018). The fisheries in small reservoirs can be enhanced manifold by using a range of technologies (Kolding and Zwieten 2006). The reservoir resources are diverse and therefore the strategies to be adopted for optimizing yields are also different (Bhukaswan 1980; Cowx 1994; De Silva 2001). In fishery management studies, Surplus-Production Models (SPM) are the ones that are commonly used (Chen and Andrew 1998; Clark and Munro 1975 ;Laloë 1995). The general practice adopted in the development of reservoir fisheries is *stocking and harvesting*. So, in this paper, one of the SPM - a modified Verhulst-Schaefer model that factors stocking (of fingerlings) also in addition to effort, has been developed which can be used to estimate sustainable harvest levels from stocked reservoirs.

MATERIAL AND METHODS

The fish stock abundance in a given area is a function of interaction between the fish stock characteristics and the environmental factors that influence them. At a particular set of environmental conditions, the stock tends to stabilize (Gulland 1977). Surplus Production Models (SPM) are based on the principle that fish populations, on an average, produce more offspring than necessary to replenish themselves and that the fisheries, on an average, harvest this excess (surplus) production without endangering the population. The SPM are in general very flexible and also exhibit variations. Some of the best known SPM are Verhulst-Schaefer model (Schaefer 1954), Gompertz-Fox model (Fox Jr 1970) and Pella-Tomlinson model (Pella and Tomlinson 1969) and these models have helped immensely in the management of fisheries (Clark, Clarke, and Munro 1979; Seijo, Defeo, and Salas 1998).

Population growth is depicted in several ways, but the most commonly used model to characterize this population growth has been the logistic growth model and the same is being used to fit a large number of natural populations as well as the ones in captivity (Kingsland 1982). The Verhulst/Pearl SPM (Verhulst 1838; Pearl and Reed 1920; Pearl 1925) that defines the change in population biomass per unit of time (Clark 1990) is described by the logistic equation:

$$\frac{dX}{dt} = rX\left[1 - \frac{X}{K}\right] = F_{(X)}$$

where ***F(X)*** – *Natural population growth*
X – *Stock biomass*
r – *Intrinsic growth rate*
K – *Carrying capacity*

In general, as fish populations are being exploited by fishers, the effect of fishing (*i.e.* harvest) has to included as a factor in the logistic growth model (C.W Clark 1985; Clark, Clarke, and Munro 1979; Clark and Munro 1980). Schaefer model (Schaefer 1957) is one of the SPMs, based on Verhulst-Pearl model wherein the catch rate (H) of the fishery is introduced and this resultant model (Verhulst-Schaefer model) is given by

$$\frac{dX}{dt} = rX\left[1 - \frac{X}{K}\right] - H$$

where ***H*** = ***qEX***
q – *Catchability coefficient*
E – *Fishing effort*

For the purpose of stock assessment of the reservoir, the Verhulst-Schaefer model can be applied to obtain initial reference points that can be used in the scientific management of the reservoir. But, to enhance the fish production, fish fingerlings are frequently introduced in the reservoirs and this stocking directly influences the dynamics of the fish population (Cowx 2002). Since, the stocking has profound impact on the growth of fish population, a modified Verhulst-Schafer model (that includes stocking as one of the factors) is proposed as follows:

$$\frac{dX}{dt} = (r_0 + aS)X\left[1 - \frac{X}{K}\right] - H$$

where ***(r_o + a S)*** – *Intrinsic growth rate affected by stocking* ***S***

Here, the sustainable equilibrium occurs when

$$\frac{dX}{dt} = 0$$

That is when

$$\frac{dX}{dt} = (r_0 + aS)X\left[1 - \frac{X}{K}\right] - qEX = 0$$

By rearranging the above equation, we get the *Stock Biomass Function* as follows:

$$X_{(E,S)} = K\left[1 - \frac{qE}{r_0 + aS}\right]$$

Substituting $X_{(E,S)}$ in the *Harvest Function (H=qEX)*, we get

$$H_{(E,S)} = qEK\left[1 - \frac{qE}{r_0 + aS}\right]$$

Since catch per unit effort (CPUE) is estimated from the harvest and effort expended, the *CPUE Function (H/E)* is deduced as follows:

$$CPUE_{(E,S)} = qK\left[1 - \frac{qE}{r_0 + aS}\right]$$

Catch/effort and stocking data from Bargi reservoir (George and Swamy Kumar 2002) was used in model validation.

RESULTS

Bargi reservoir, constructed on Narmada river system, India is about 43 km south-east of Jabalpur city in the state of Madhya Pradesh in India. This reservoir has a catchment area of about 14556 km^2 and a water spread area (at FRL) of about 27297 ha. The fishery management at the reservoir was by the Madhya Pradesh Federation of Fishermen Co-operatives, Bhopal and all data pertaining to the fishery at Bargi reservoir was maintained by the Federation. Catch/effort and stocking data from Bargi reservoir (Table 1) was used in model validation.

Standard effort (E), expressed in 100000s man-days, was obtained by multiplying the number of active fishermen and the average number of fishing days in a year whereas stocking (S), expressed in tonnes, was

Table 1. Details of catch, effort and stocking in Bargi reservoir (from George and Swamy Kumar 2002)

Year	Fish Landings (t)	Effort (men)	Effort (days)	Std. Efforts (X 10^5)	Stocking (no.)	Stocking (t)
1993-94	536.042	344	264	0.90816	2731000	8.193
1994-95	574.628	648	243	1.57464	4475000	13.425
1995-96	582.086	966	292	2.82072	3275000	9.825
1996-97	406.024	826	284	2.34584	3680000	11.04
1997-98	422.110	880	293	2.57840	4000000	12.00

obtained by multiplying the number of fingerlings stocked and the average weight per fingerling.

Parameter Estimation

At sustainable equilibrium, CPUE is an index of stock abundance which is given by the function

$$CPUE_{(E,S)} = qK\left[1 - \frac{qE}{r_0 + aS}\right]$$

whose parameters a, q, r_0 and K can be solved by using a non-linear regression model (Gallant 1987). The numerical solutions of the above function were carried out by *Mathematica 7* (Wolfram 2008) and the parameter estimates along with the ANOVA are given Table 2 and Table 3.

Relationship of CPUE With Effort And Stocking Levels

The estimated parametric values from the table are substituted in the CPUE function to get the estimated CPUE equation as follows:

$$\widehat{CPUE}_{(E,S)} = (0.685126)(0.013872)\left[1 - \frac{0.685126\,E}{0.614290 + 0.137866\,S}\right]$$

where the unit of effort E is 100000 days of fishing, stocking S is tonnes of stocked fingerlings and CPUE is tonnes per day of fishing. The CPUE curve is given in Fig. 1.

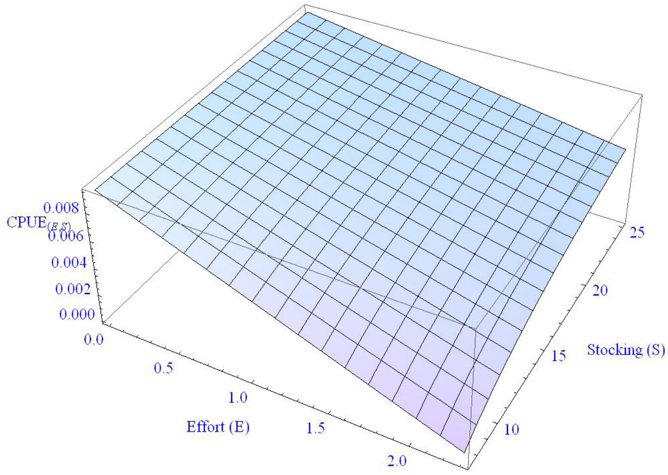

Figure 1. Relationship of CPUE with effort and stocking

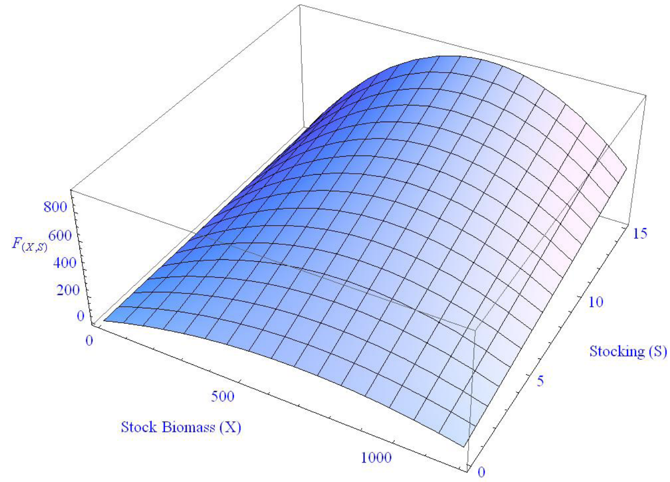

Figure 2. Relationship of population growth with stock biomass and stocking

Impact of stocking on population growth

Substituting the parametric values in the growth function, the estimated growth function is deduced as follows:

$$\hat{F}_{(X,S)} = (0.614290 + 0.137866\,S)X\left[1 - \frac{X}{1387}\right]$$

and the growth curve is depicted in Fig. 2.

Relationship of the harvest regime with effort and stocking levels

The estimated harvest function is given as

$$\hat{H}_{(E,S)} = (0.685126)(0.013872)E\left[1 - \frac{0.685126\,E}{0.614290 + 0.137866\,S}\right]$$

and the corresponding harvest curve is expressed in Fig. 3.

Table 2. Estimated parameters of the non-linear regression

Parameters	Estimate	Standard Error	t-Statistic	p-Value	Confidence Interval
q	0.685126	0.0169756	40.3596	0.0157705	(0.469431, 0.900821)
k	0.013872	0.0002738	50.6548	0.0125662	(0.010392, 0.017351)
r_0	0.614290	0.0203674	30.1604	0.0211001	(0.355497, 0.873083)
a	0.137866	0.0063954	21.5569	0.0295109	(0.056604, 0.219128)

Table 3. ANOVA Table

	df	SS	MS
Model	4	0.0000580899	0.0000145225
Error	1	$1.15944*10^{-9}$	$1.15944*10^{-9}$
Uncorrected Total	5	0.0000580911	
Corrected Total	4	0.0000131912	

$R^2 = 0.99$

In the management of fisheries, the concept of *Maximum Sustainable Yield (MSY)* is very widely used and the MSY is defined as the maximum catch (in numbers or mass) that can be removed from a population over an indefinite period.

DISCUSSION

One of the aims of stocking of fingerlings in reservoirs is to replenish the depleted fish stocks and also to address the issues arising out of overexploitation (Cowx 2002). At the time of stocking the reservoirs, its impact on the fish population growth is hardly studied or taken into consideration. The present study helps not only to estimate this impact, but also to understand how different stocking regimes impact the fish harvest at varying levels of efforts. The graph depicting the relationship of CPUE with effort and stocking (Fig. 1) shows that the CPUE decreases with increasing effort whereas an increase in stocking results in an increase in CPUE also. From the relationship of population growth with stock biomass and stocking (Fig.2), it is observed that the stocking rate and population growth are positively correlated. Similarly, the stocking is found to have a positive correlation with fish harvest levels (Fig. 3)

The stocking program in any reservoir should be guided by the knowledge about its carrying capacity. Very often, this is being ignored conveniently on the general

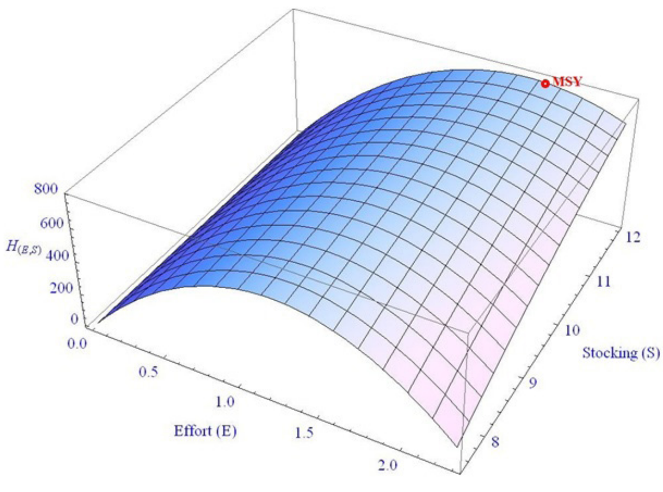

Figure 3. Relationship of harvest with effort and stocking

perception and rationale that more stocking yields more fish catch. The detrimental effect of such indiscriminate and unscientific stocking in reservoirs is huge and multi-dimensional (Agostinho et al. 2010). As there are guidelines to stock reservoirs in India and also because of the cost constraints, non-availability of sufficient quality seeds during stocking seasons, etc., there are limitations in stocking a reservoir beyond a limit. All these aspects are to be taken into account (as priori information) while estimating a model for sustainable harvest levels in stocked reservoirs. Accordingly, while estimating the model parameters in this present study, the bounds of the stocking (as well as effort) are restricted to pragmatic levels to draw realistic and valid inferences. The same was applied while estimating the reference point MSY.

The harvest function depends on effort and stocking. The MSY can be obtained when partial derivatives of the harvest function are obtained and equated to zero as follows:

$$\dot{H}_{(E)} = qK - \frac{2q^2KE}{r_0 + aS} = 0 \Rightarrow E_{MSY} = \frac{r_0 + aS_{MSY}}{2q}$$

$$\dot{H}_{(S)} = \frac{aE^2q^2K}{(r_0 + aS)^2} = 0 \Rightarrow S_{MSY} = \frac{2E_{MSY}\,q - r_0}{a}$$

The estimates of E_{MSY} and S_{MSY} were obtained by numerical methods (using the software package - *Mathematica 7*) as follows:

$E_{MSY} = 1.66$
$S_{MSY} = 12.0$

Substituting the estimates of E_{MSY} and S_{MSY} in harvest function, *Maximum Sustainable Yield (MSY)* was obtained.

$$MSY = (0.685126)(1387.2)E_{MSY}\left[1 - \frac{0.685126\,E_{MSY}}{0.614290 + 0.137866\,S_{MSY}}\right]$$

$$= (0.685126)(1387.2)(1.66)\left[1 - \frac{0.685126\,(1.66)}{0.614290 + 0.137866\,(12.0)}\right]$$

$MSY = 787$ tonnes (at E_{MSY}=1.66 and S_{MSY}=12.0)

The modified Verhulst-Schaefer model predicted the fish catch at Bargi reservoir fairly well ($R^2 = 0.99$) and the same is given Table 4.

CONCLUSION

The reservoir fishery has a huge potential to contribute to the overall fish production in India, especially in the inland fishery sector. So, proper management of reservoir fisheries is very important as the livelihood of a large number of fishers depends on it and also as it ensures the nutritional security of people. There are several tools, in the form of models, available to administrators and

Table 4. Predicted fish catch at Bargi reservoir during 1993-98 (Using Modified Verhulst-Schaefer Model)

Year	Actual Catch (t)	Predicted Catch (t)	% Difference in Catch
1993-94	536.04	537.15	-0.21
1994-95	574.63	570.71	0.68
1995-96	582.09	579.21	0.49
1996-97	406.02	409.51	-0.86
1997-98	422.11	424.20	-0.49

policy makers for scientific management of reservoir fisheries. But, the data requirement for most of the models are elaborate, stringent and demanding. Very often, they are not easily available or not obtainable in the required format. This is a common phenomena in the inland fishery scenario of India as the resources here are huge in numbers, geographically wide spread and the fish landing centres (where from fish catch data are collected) are in remote places. To alleviate these problems of inland fisheries, particularly the last mile connectivity issue, innovative mobile applications (Android App) are being used in the data collection (Karthikeyan et al. 2019). Since the usage of such mobile based applications is now at a nascent stage, the non-availability of authentic data from reservoir fisheries still persists. In such a scenario, the models that require minimum and easily available data will be of immense use to the fishery administrators for the effective management of reservoirs fisheries. The modified Verhuslst-Schaefer model, proposed in this paper, requires data that are easily available or obtainable and hence can be readily used to determine the sustainable harvest levels in any stocked reservoir. This would greatly enhance the fish production from reservoirs in a sustainable way bringing more revenue from inland fishery sector besides providing the nutritional security to the people. The present study will not only be useful to estimate the impact, but also to understand how different stocking regimes impact the fish harvest at varying levels of efforts.

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