Fish yield prediction through morpho-edaphic index and estimation of stocking density for Indian reservoirs

V. V. SUGUNAN, S. K. MANDAL AND D. S. KRISHNA RAO
Central Inland Fisheries Research Institute, Barrackpore 700 120, Kolkata, India

ABSTRACT

A maximum sustainable yield (MSY) prediction model based on morpho-edaphic index (MEI) applicable for the Indian reservoirs has been constructed for the first time as MSY = 0.9897 * MEI \(^{1.3888} \) (\( R^2 = 0.7366 \) ). A non-linear positive relation exists between MEI and MSY of all species. A model for estimating the present mean yield has also been worked out. Observations on present mean catch from seventeen reservoirs show that correlation between depth and fish yield is non-significant. Significant negative correlation is reported in respect of yield and size of water body. A positive correlation exists in specific conductivity and MEI. A formula has been proposed to calculate the stocking density of medium and large reservoirs in India based on difference between MSY and estimated mean yield, growth rate of stocked fish, rearing time and estimated mortality factor. The paper presents formulae for (1) predicting MSY and (2) calculating stocking density in reservoirs where no record of present catch is available.

Introduction

It has been well recognized that the reservoirs constitute the prime inland fishery resource of India both in terms of surface area and production potential. More than 3 million ha of man made lakes in the country offer immense scope for fish yield optimization through capture fisheries, culture-based fisheries and various other forms of enhancement. In India, reservoirs are classified as small (<1000 ha), medium (1000-5000 ha) and large (>5000 ha) (Sugunan, 1997). Nearly half of the surface area of reservoirs in India comprises small reservoirs, which are by and large managed as culture-based fisheries. Medium and large reservoirs spread over more than 1.5 million ha, where a combination of capture and culture-based fisheries is practiced. In spite of the vast area and fish production potential of these categories of reservoirs no attempts have been made to construct their fish yield prediction models based on Morpho-Edaphic Index (MEI). There is a similar need to estimate the stocking rate for these reservoirs based on maximum sustainable yield. It is relatively easier to estimate the stocking density in culture-based fisheries as the management is based on a stocking and recapture basis. Stocking and other management strategies to be followed in small reservoirs of India have
been described by many workers (Jhingran, 1988; Jhingran and Sugunan, 1990 and Sugunan, 1997). These include methods for calculating the stocking density on the basis of individual growth rate of stocked fish and expected fish yield of the water body (Welcomme, 1976; Sugunan and Sinha, 2000). However, such formulae have little applicability to medium and large reservoirs, where natural populations contribute a considerable part of the catch. In larger water bodies the main objective of management is still on exploitation of naturalized populations. Stocking, whenever resorted to, is done with a view to augmenting the yield. Cowx (1994) and Welcomme (1996) emphasized the need for developing stocking strategy for reservoirs and De Silva (2001) stressed the importance of stocking based on the potential yield, predicted through the use of appropriate empirical models. This paper is a first ever attempt in India to construct models for estimating fish yield potential and stocking density based on morpho-edaphic index.

Ever since Rawson (1952) suggested that the fish yield potential is related to the mean depth of inland lakes and reservoirs, many authors have tried to assess fish yield potential from a number of physico-chemical and morphometric parameters (Hayes, 1957; Northcote and Larkin, 1956). However, the models were cumbersome involving too many physico-chemical and morphometric parameters. Ryder (1965) developed morpho-edaphic index (MEI) by taking into account total dissolved solids and mean depth to represent respective edaphic and morphometric characteristics of the lakes. This tool has since been used to determine potential yield from reservoirs in Canada (Ryder, 1965), North America (Matuszak, 1978), Africa (Henderson and Welcomme, 1974), Sri Lanka (Wijayaratne and Amarasinghe, 1984; Nissanke et al., 2000) and Bangladesh (Hasan et al., 2001). An (2001) reported models to predict yield based on chlorophyll a and specific conductivity. Estimation of potential fish production made through morpho-edaphic index (MEI) can be utilized for calculating the stocking densities of fish fingerlings in inland reservoirs (Welcomme, 1976). Workers on North American lakes (Jenkins and Morais, 1971; Youngs and Heimbuch, 1982) have opined that surface area can alone be the predictor of fish yield. But this model based on area can not be considered useful to estimate yield from reservoirs as both edaphic and morphometric parameters need to be used as the basis for prediction (Ryder et al., 1994). At present most of the Indian reservoirs are overexploited and there is scope for enhancing the fish production by stocking the reservoirs. However, no mathematical model is available for working out the stocking rate of major carps. There is a strong need to develop a model to estimate the maximum production potential keeping in view the factors of controlling the fishing effort and manipulating the stocking of the reservoirs. Maximum sustainable yield (MSY), where fishing effort and recruitment are the deciding factors, may be one of the estimates of production potential or an estimate of maximum benefit from the water resource.

Although more than 100 reservoirs in India have been subjected to scientific investigations, most of them are limited to limnological and faunistic survey, with very little emphasis on population dynamics (Sugunan, 2000). In order to develop guidelines for estimating stocking densities in medium and large reservoirs, it is essential to estimate the fish production potential. An attempt has been made to establish a relationship between MEI and Maximum Sustainable Yield (MSY) of all species and also a relationship be-
Fish yield prediction for Indian reservoirs

The relationship between MEI and present yield from reservoirs in India. The relationship between yield and other characters like area, depth and specific conductivity has been worked out. Further, a method of estimating stocking requirement of reservoirs has been attempted.

**Materials and methods**

Time series data on catch and effort as well as specific conductivity, area and mean depth for seven reservoirs were collected from published literature. Maximum sustainable yield was calculated using Schaefer’s model (Sparre et al., 1989). Data on area, depth, specific conductivity and yield on seventeen reservoirs were collected from published literature in order to examine the relationship between yield and MEI. Morpho-edaphic index was calculated by dividing specific conductivity in µmhos cm\(^{-1}\) by mean depth in meter (Henderson and Welcome, 1974). The relation between yield and other characters was worked out and regression lines were fitted using standard statistical tools (Snedecor and Cochran, 1967) and MS Excel computer software.

**Results and discussion**

The values of area, MSY and MEI for seven reservoirs are presented in Table 1. The relation between MSY and MEI has been found to be non-linear and significant. It can be described by the equation:

\[
Y = 0.9897 \times X^{1.3888} (R^2 = 0.7366)
\]

where Y represents MSY and X MEI (Fig 1).

**Table 1.** Details of reservoirs in respect of area, mean depth, specific conductivity, MEI and maximum sustainable yield.

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Area (ha)</th>
<th>Mean Depth (m)</th>
<th>Specific conductivity (µmhos cm(^{-1}))</th>
<th>MEI</th>
<th>MSY (kg ha(^{-1}))</th>
<th>Source of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bhavanisagar</td>
<td>7876</td>
<td>11.9</td>
<td>120</td>
<td>10.08</td>
<td>31.8</td>
<td>Natarajan et al., 1981</td>
</tr>
<tr>
<td>Rihand</td>
<td>46538</td>
<td>22.8</td>
<td>92.24</td>
<td>4.046</td>
<td>3.9</td>
<td>Natarajan et al., 1982</td>
</tr>
<tr>
<td>Pong</td>
<td>24629</td>
<td>35.7</td>
<td>181.4</td>
<td>5.82</td>
<td>23.4</td>
<td>Sugunan, 1995</td>
</tr>
<tr>
<td>Tungabhadra</td>
<td>37814</td>
<td>9.9</td>
<td>197</td>
<td>19.9</td>
<td>89.6</td>
<td>Singit et al., 1987</td>
</tr>
<tr>
<td>Stanley</td>
<td>15346</td>
<td>17.24</td>
<td>281.2</td>
<td>16.311</td>
<td>23.3</td>
<td>Sreenivasan, 1976</td>
</tr>
<tr>
<td>Govindasagar</td>
<td>16867</td>
<td>11.9</td>
<td>195</td>
<td>16.39</td>
<td>46.13</td>
<td></td>
</tr>
</tbody>
</table>

![Fig 1. Relationship between MSY and Morpho-edaphic index](image)
The details of seventeen reservoirs in respect of area, yield (mean) and MEI are presented in Tables 2 and 3. The relation between depth and yield has been found to be non-significant. The relationship between yield and area of water body is non-linear, significant (Fig. 2) and negative indicating decrease of yield with the increase of the size of water body. This is in agreement with the findings in Chinese and Mexican reservoirs (Welcome and Bartley, 1988 a & b). However, the relationship between yield and specific conductivity is positive (Fig. 3).

**Table 2. Source of secondary data**

<table>
<thead>
<tr>
<th>Name of the reservoirs</th>
<th>Source of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemavathi</td>
<td>Devaraj, et al., 1987</td>
</tr>
<tr>
<td>Kabini</td>
<td>Murthy, et al., 1986</td>
</tr>
<tr>
<td>Mettur</td>
<td>Sreenivasan,1992</td>
</tr>
<tr>
<td>Ravishankarsagar</td>
<td>Desai &amp; Soni, 1994</td>
</tr>
<tr>
<td>Nagarjunasagar</td>
<td>Natarajan &amp; Pathak, 1983</td>
</tr>
<tr>
<td>Tawa</td>
<td>Srivastava et al., 2000</td>
</tr>
<tr>
<td>Pong</td>
<td>Ramakrishniah &amp; Govind, 1993</td>
</tr>
<tr>
<td>Tilaiya</td>
<td>Ramakrishniah &amp; Govind, 1993</td>
</tr>
<tr>
<td>Hirakud</td>
<td>Sugunan, 1995</td>
</tr>
<tr>
<td>Marconahalli</td>
<td>Ramakrishniah et al., 1998</td>
</tr>
<tr>
<td>Vaigai</td>
<td>Sreenivasan, 1992</td>
</tr>
<tr>
<td>Sathanur</td>
<td>Sreenivasan, 1992</td>
</tr>
<tr>
<td>Morel</td>
<td>Kaushal &amp; Sharma, 2001</td>
</tr>
<tr>
<td>Guda</td>
<td>Kaushal &amp; Sharma, 2001</td>
</tr>
<tr>
<td>Panchana</td>
<td>Kaushal &amp; Sharma, 2001</td>
</tr>
<tr>
<td>Baretha</td>
<td>Kaushal &amp; Sharma, 2001</td>
</tr>
<tr>
<td>Ramgarh</td>
<td>J hingran, 1989</td>
</tr>
</tbody>
</table>

**Fig.2. Relationship between Yield and Area of water body**

**Fig.3. Relationship between Yield and Specific Conductivity of water body**
which indicates that yield increases with the increase of specific conductivity. The relationship in case of area and specific conductivity has also been found to be significant at 1% level. But the models based on area or specific conductivity are seldom used for estimation of yield. The concept of morphoedaphic index has been evolved over the years by different workers, who established relation among abiotic and biotic variables in reservoir ecosystem. Essentially, these formulae strived to incorporate all the variables (both morphometric as well as edaphic) having a bearing on productivity. A global formula should be simple with minimum number of variables in order to enable the managers to use it with ease. Recognizing this, mean depth and total dissolved solids were taken as two key variables, which can represent morphometric and edaphic characteristics of the lake respectively (Ryder et al., 1974). Since Ryder (1965), MEI has been taken as the standard tool for predicting yield. The increase of specific conductivity has also been found to be significant at 1% level. But the models based on area or specific conductivity are seldom used for estimation of yield. The morphoedaphic index is a tool for predicting yield. The increase of specific conductivity has also been found to be significant at 1% level. But the models based on area or specific conductivity are seldom used for estimation of yield. The morphoedaphic index is a tool for predicting yield.
The relationship between mean yield (Y) and morpho-edaphic index (MEI) has been found to be non-linear and significant and presented below and shown in Fig 4:

\[ Y = 3.984 \times X^{0.6374} \quad (R^2 = 0.4681) \]  

This formula can be used for calculating the mean yield of Indian reservoirs.

\[ Y = 3.984 \times X^{0.6374} \quad (R^2 = 0.4681) \] 

Fig.4. Relationship between Yield and MEI

It is apparent from Table 3 that the present level of production as estimated by the relationship between yield and morpho-edaphic index is 33.7 kg, whereas the MSY is 169.27 kg, thus an average increase of 135.58 kg may be obtained from the reservoirs. This can be achieved by stocking the reservoirs with fingerlings, based on the calculation made by following equation:

\[ S = \frac{MSY_{est} - Y_{est} \times e^{(t_1 - t_0)}}{W} \]  

\[ S = \text{Number of fish fingerlings to be stocked in addition to the present recruitment to achieve the estimated value of maximum sustainable yield.} \]

\[ Z = \text{Total mortality rate (can be substituted by extrapolated values as suggested by Welcomme, 1976).} \]

\[ t_1 = \text{Age at capture} \]

\[ t_0 = \text{Age at recruitment} \]

\[ W = \text{Mean weight of fish at capture} \]

\[ MSY_{est} = \text{Maximum Sustainable Yield estimate using Morpho-edaphic Index relationship (formula -1)} \]

\[ Y_{est} = \text{Present mean yield estimated by using Morpho-edaphic Index (formula-2)} \]

The estimated number to be stocked has been shown in Table 3, based on the following assumptions:

a) The average weight of fish harvested from medium and large reservoirs is 500 g, and

b) The total mortality (z) of the stocked fingerlings is -1.00, which has been worked out on the basis of Welcomme (1976) taking survival as 37%.

Ryder et al. (1974) and Henderson and Welcomme (1974) have discussed the weaknesses and strengths of the yield prediction models involving MEI. In India, many workers have expressed reservations (Natarajan, 1979; Sreenivasan, 1989) about the use of MEI in the Indian context. The main drawbacks pointed out by them are the wide fluctuation in the discharge rates. However, this problem is common to man-made lakes everywhere. Welcomme (1976) expressed the view that MEI can be used to estimate yield in the lakes where the volume and temperature are fairly constant throughout the year and the ionic composition of water is dominated by carbonate and bi-
carbonate ions. While temperature variation in Indian reservoirs is within a relatively narrow range (Sugunan, 1995) compared to their counterparts in temperate countries, the condition about carbonate and bicarbonate ions is adequately met. Model developed by Henderson and Welcomme (1974) takes into consideration 19 African lakes, which have similar heterogeneous components. Reservoirs of Sri Lanka shares comparable morpho-edaphic profiles with those of peninsular India and the MEI models developed for Sri Lankan reservoirs are reported to be working with satisfactory results (Mendis, 1965; Wijayaratne and Costa, 1981 and Vijayaratne and Amarsinghe, 1984). Marshal (1984) examined the relevance of morpho-edaphic index and its components as attributes to predict yield in African reservoirs. Notwithstanding the various drawbacks, which are inherent to the system of creating models based on a limited number of parameters, some forms of yield prediction models are necessary to initiate management norms for reservoirs in India. Therefore, the model suggested in this paper can be used for making a first approximation of fish yield potential of reservoirs in India.

The significance of the regression suggests the validity of the models. Stocking density in general are calculated by dividing the yield rate with individual growth before adding some allowances to loss due to mortality (Huet, 1960; Welcomme, 1976). However, Welcomme pointed out that such models are not applicable in reservoirs where the natural recruitment has a significant contribution. Moreover, unlike the culture-based fisheries of small reservoirs, where the yield is dependent totally on stocked fish, in medium and large reservoirs, stocking is done to complement/augment the fish production, thus necessitating a stocking strategy based on MSY. Therefore, the expected yield rate ‘P’ (in the numerator of Welcomes’s formula) has been replaced with MSYest-Yest in order to avoid possible over-stocking.

The model presented in this paper has been developed on the basis of MSY of all species. However, in multi-species fisheries, it is possible to estimate the stocking requirement of each species if MSY is known separately for the species (Welcomme, 1976). India has large area of small, medium and large reservoirs which need to be developed on the basis of culture-based fisheries. At present, no reliable scientific advice is available to estimate the stocking rate. The formula (3) is an attempt to provide scientific guidelines for stocking Indian reservoirs. Although not very accurate, it can be considered as a first attempt to develop such stocking guidelines.

Equation (1) presented in this paper can be tentatively used for calculating the maximum sustainable yield of Indian reservoirs and equation (2) can be used for estimating the present mean yield based on morpho-edaphic index. Methods described by Huet (1960) and Welcomme (1976) are adequate to calculate the stocking density of culture-based fisheries of small reservoirs in India. The stocking rate for medium and large reservoirs can similarly be estimated, using the equation (3) given in this paper.

Acknowledgements

The authors are thankful to the scientists of Central Inland Fisheries Research Institute for their assistance in preparation of this paper.

References

ian Centre for International Agricultural Research, Canberra. P. 235-245.


Natarajan, A. V. 1979. Ecosystem approach to the development of fisheries in man made lakes in India. Lecture delivered
Fish yield prediction for Indian reservoirs

at summer institute on capture and culture fisheries of man made lake in India, Central Inland Fisheries Research Institute, 7 July to 6 August 1979.


Sreenivasan, A. 1976. Fish production and fish population changes in some south Indian reservoirs. Indian J. Fish., 1 & 2: 133-152.


Sugunan, V. V. 1997. Guidelines for management of small reservoirs in India. Fish-


