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Model based Assessment and Management of Fisheries in Reservoirs

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SUMMARY

Fish production from inland fisheries in India largely caters to the needs of domestic consumption as against marine fisheries, which is primarily diverted to exports. An increase in the production of inland fish would bridge the gap between domestic supply and demand while meeting the nutritional requirements of the population. Culture-based fisheries in reservoirs is a successful aquaculture practice in vogue in many parts of the world and also in India for enhancement of fish production. Population dynamics of stocked fishes in the reservoirs can be studied using density dependent growth models (Lorenzen, 1996, Lorenzen *et al.,* 1997) which offer a sound framework for adopting management measures for production enhancement. Kanjirapuzha reservoir with a total area of 515 ha is a small reservoir located at Palakkad district of Kerala which is less productive compared to other small reservoirs. In order to suggest appropriate management measures for production enhancement, the growth performances of Catla and Mrigal stocked at Kanjirapuzha reservoir was evaluated using density dependent model. The growth of Catla was high in the reservoir (0.73 per year) compared to Mrigal (0.3 per year). The competition coefficient of the stocked fishes ranged from 0.0059 to 0.0095 $g^{1/3}$ $hakg^{-1}$ indicating positive effect of population density on growth. The biomass for catla was estimated using the cohort analysis and it varied from 11 $kgha^{-1}$ to 23.6 $kgha^{-1}$ for the different age groups.

Keywords: Culture-based fisheries, Stocking, Enhancement, Density dependent models.

1. INTRODUCTION

The extent and share of inland fisheries in total fish production has increased manifold over the past five decades after aquaculture has taken a bigger dimension in fish production and marketing. A look at the trend in fish production from India for the past five decades suggests that boost in aquaculture production has played a major role in overall increase in fish production (Fig. 1). The inland fisheries accounts for 65% of the total fish production from India.

Reservoir fisheries form an important part of inland fisheries and contribute substantially to the total inland fish production from India. There are a total of 19,500 reservoirs in India spreading over nearly 30 lakh ha of water spread area. Culture based fisheries is practiced in Indian reservoirs which were constructed and maintained primarily for power/irrigation. The yield of target fish species are based entirely on stocking of the reservoir with no or very little recruitment taking place. Indian reservoirs hold enormous potential for intensification of aquaculture practices to enhance the productivity per unit area. At present the annual fish production from reservoirs is around 95,000 MT and this is only 35% of the potential yield. Active scientific management and enhancement strategies can optimize the yield from reservoirs.

Stocking in reservoirs is effective in increasing fish production when the stocking densities are appropriate. It is essential that the cost of stocking and managing the species is economically viable. From management point of view, to make an appraisal of expected harvest from fisheries and maintain optimum stocking, the dynamics of the stock in response to harvesting and environmental factors has to be studied. This will evolve a broad-based analysis of culture-based fisheries, quantitative evaluation of the management options exercised in the reservoir and facilitate improvement of the poor economic performance of fishery. Quantitative modeling aids in proper understanding of interaction between management action and natural process.

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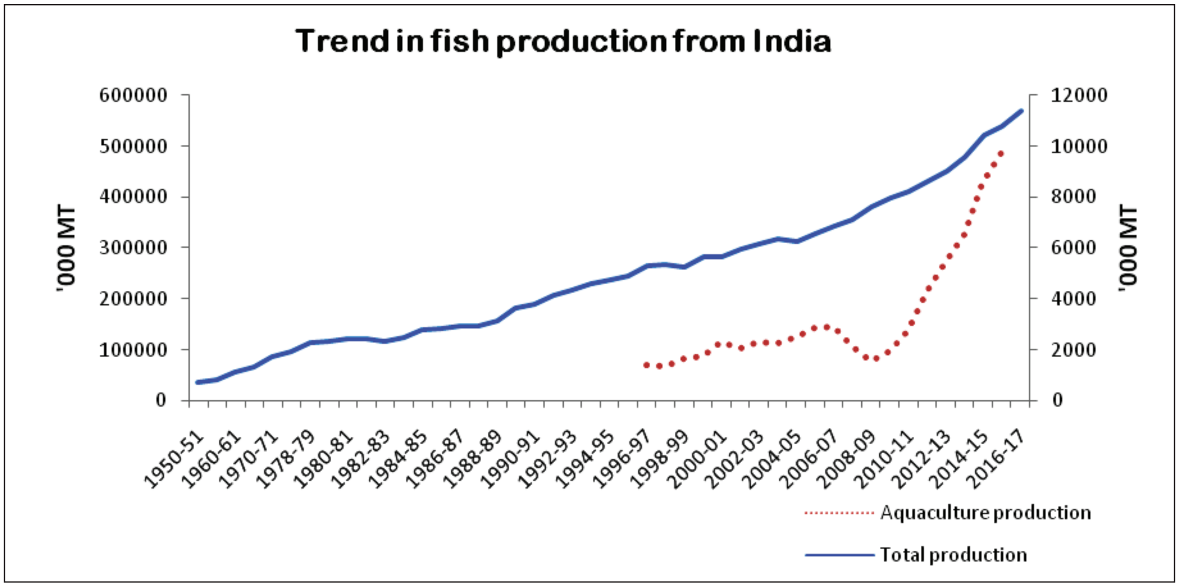

Fig. 1. Trend in fish production

The derived model may be used to evaluate different management actions.

This paper discusses the various models used in the evaluation and management of culture based fisheries in reservoirs including Lorenzen's density dependent models and presents the results of an empirical study conducted pertaining to Kanjirapuzha reservoir fishery.

2. FISH POPULATION DYNAMICS AND CULTURE BASED FISHERIES

In culture-based fisheries, hatchery reared fishes are released into a waterbody which is not primarily managed for fisheries and recaptured upon attaining marketable size. Conventional fisheries models divide the life cycle of fish into recruited phase where mortality is constant and independent of population density and pre-recruit phase where non-specified density dependent processes give rise to stock-recruitment relationship. Indian reservoirs are stocked with fingerlings of pre-determined size and this belongs pre-recruit phase. Prior to entering exploited phase i.e. fishing, they are prone only to natural mortality. Therefore, the fish population dynamics in culture-based fisheries is determined by density-dependent growth and size-dependent mortality

3. GROWTH MODELS IN FISHERIES

Mathematical models are extensively used in the study of fisheries. Starting from Von Bertlanffy growth model for fish growth, many models have been developed for prediction and management of small scale fisheries in lakes and reservoirs (Von Bertalanffy1938):

$$L(t) = L_\infty\left(1 - e^{-K(t-t_0)}\right).$$

Gulland and Holt (1959) reformulated this classical model to measure growth through time at any age or fish length

$\frac{dL}{dt}$=-K(L-L_∞) , where K and L_∞ are intercorrelated and one has to fix any parameter to estimate the other.

Information on mortality is key to the study of population dynamics of exploited fish stocks. Empirical formula based on L, K and t (annual temperature) due to Pauly (1980), is widely used in estimating natural mortality.

In culture based fisheries, assessment is carried out to evaluate the effect of exploitation regimes on variables of management interest such as yield or catch rates using empirical models. These models are mostly single or multiple regression models relating to yield like indicators of productivity, fishing effort, water level etc and have been developed for fisheries in reservoirs for prediction of yields. When data is available for a wide range of conditions, such as yield, effort and trophic status indicators for a number of different water bodies, these models are useful for comparison (Ryder, 1965, Nissanka *et al.* 2008) Hanson and Leggett (2011) developed two new indices, based on total phosphorus concentration and macrobenthos biomass/mean depth, to predict fish yield from lakes and established their superiority over morphoedaphic index.

Production models estimate optimal effort levels in the culture based fisheries, using time series data on catch and effort (Manase *et al.*, 2002). In fisheries science, Schaefer (1954; 1957) model and its improvements were extensively used in assessing fish stocks (Fox, 1970; Schnute 1977). A range of models are available for estimation of both Maximum Sustainable Yield (MSY) and Maximum Economic Yield (MEY) (Pauly, 1983; Crul and Roest, 1995; Henderson and Welcomme, 1974; Mclack, 1976, Petersen *et al.* 2007). Catch and effort data analysis software (MRAG, 1992a, 1992b) enables computation of MSY estimates. Biological parameters of fishery resources at Cirata reservoir was studied by Anna *et al.* (2017) using bio-economic models. Commercial catch data from fishing units employing multifilament gill nets at Lake Naivasha was analyzed by Hickley *et al.* (2002) using a version of Schaeffer model and Maximum sustainable yield (MSY), optimum effort and equilibrium yields were calculated.

Predictive modelling using multivariate approach is widely employed to examine the management scenarios for enhancing yield from reservoirs. Hopkins & Pauly (1993), have advocated a multiple linear regression model.

Z = $a + b_1X_1 + b_2X_2 + \cdots + b_nX_n$ where Z is total mortality and $X_1, \ldots X_n$ are environmental and treatment variables simultaneously recorded during the culture period. The authors have analyzed the effect of various nutrient input regimes (eg. inorganic fertiliser, manure, feed and various combinations of these inputs) and season on fish yield and water quality for Nile Tilapia stocks from ponds of Philippines.

Graal & Prein (2005) have used data from 116 growth experiments conducted for 3 years with Nile Tilapia as main crop to get insight into the major environmental factors influencing the growth rate K using standard multiple regression of the form

$K = \alpha + \beta_1X_1 + \cdots + \beta_nX_n$ where $X_1, X_2, \ldots, X_n$ are environmental & treatment variables simultaneously recorded during the growth increment.

Apart from these models, eco-path models are also available to study fishery in small water bodies. The Ecopath model is an approach which analyses trophic interactions within an ecosystem. This approach uses the concept of mass-balance in a steady state or equilibrium. It was first used by Polovina (1984) for the estimation of biomass and food consumption of various elements (species or group of species) of an aquatic system and subsequently combined with various approaches from theoretical ecology.

4. DENSITY DEPENDENT GROWTH

Dynamic pool models are models based on stock assessment approach which breaks down abundance and biomass dynamics into the component processes of growth, mortality and reproduction, and allow the assessment of management options formulated at a high level of technical detail (eg. mesh size regulations). A variety of approaches to estimation of growth and mortality parameters from length composition data has been developed in case of Tilapia fishery. Lorenzen (1995, 1996) and Lorenzen *et al.* (1997) have developed a framework for studying population dynamics of stocked species from reservoirs and extended the conventional VBGF to account for density dependence resulting from competition for food. The model assumes a linear relationship between asymptotic length and population biomass (and equivalent relationship for asymptotic weight).

Lorenzen (1996) expressed asymptotic length as a linear decreasing function of population biomass density (Biomass per unit area or volume) as

$L_{\infty B} = L_{\infty L} - gB$ where $L_{\infty B}$ is asymptotic length at biomass B, $L_{\infty L}$ is limiting asymptotic length of the growth curve in the absence of competition and g is the competition coefficient. Using the isometric growth relation ($W = aL^3$) between length and weight of fish Lorenzen (1996) rewrote the equation as

$W_{\infty B} = (W_{\infty L}^{\frac{1}{3}} - cB)^3$, where $W_{\infty B}$ is the asymptotic weight at Biomass B and $W_{\infty L}$ is the limiting asymptotic weight. The competition coefficient for weight 'c' is related to 'g' by $c = ga^{1/3}$ where 'a' is the coefficient of the isometric length-weight relationship (Le Gren, 1951) and describes the decline in asymptotic weight with increasing biomass. The expression describes how steeply the asymptotic weight decreases with the increasing biomass.

Denoting $W_{\infty r}$ as the asymptotic weight at reference biomass B_r Lorenzen *et al.* (1997) gave the model for asymptotic weight $W_{\infty B}$ as $W_{\infty B} = (W_{\infty r}^{\frac{1}{3}} - c(B - B_r))^3$.

4.1 Cohort analysis and estimation of density dependent models

If the proportion of fish harvested is expressed as an exponential fishing mortality rate $F_{a,t}$ then the terminal numbers alive $N_{a,t}$ (at age a and time t) are given by

$N_{a,t} = \frac{C_{at}}{1-e^{-F_{at}}}$ where C_{at} is the terminal catch. The younger age groups in the cohort are reconstructed by successively working backwards from the terminal group. Assuming the weight-dependent natural mortality rate M_W corresponding to the weight at mean length as

$M_W = M_r\left(\frac{W_{a-1,t-1}^{\frac{1}{3}} + W_{a,t}^{\frac{1}{3}}}{2W_r^{1/3}}\right)^{3b}$, the number alive during the previous year $N_{a-1,t-1}$ is defined as $N_{a-1,t-1} = C_{a-1,t-1}\frac{N_{a,t}}{e^{-M_W}}$.

The exponential fishing mortality rates $F_{a,t}$ on the non-terminal groups are calculated from

$F_{a,t} = -\ln\left(1 - \frac{C_{a,t}}{N_{a,t}}\right)$ and are proportional to the effort expended on fishing and to the selectivity of fishing gear for the respective age (size) groups. Once all the cohorts have been reconstructed, the total population biomass B_t in year 't' is calculated as

$$B_t = \sum_{a=o}^{a_{max}} N_{a,t} W_{a,t}.$$

The density dependent VBGF predicts the mean individual weight $W_{a,t}$ as a function of $W_{a-1,t-1}$ and of $W_{\infty B}$:

$W_{a,t} = \left(\left(W_{\infty B}^{\frac{1}{3}} - \left(W_{\infty}^{\frac{1}{3}} - W_{a-1,t-1}^{\frac{1}{3}}\right)e^{-K}\right)\right)^3$. The best estimate of growth model parameters are the values that minimizes the sum of squared differences (SSQ) between the observed and expected weights.

5. EMPIRICAL STUDY

Kerala state has 43 reservoirs of which 25% of them are located in Palakkad district. A look at the fish production from the reservoirs of Palakkad (Table1) indicates that the small reservoirs like Chuliyar can be highly productive when managed effectively for fisheries.

Table 1 also points out the fact that fish production of Kanjirapuzha reservoir is low compared to other small reservoirs even though it is a perennial reservoir and has the advantage of absence of carnivorous fishes which affects stocked fishes. The reservoir gets stocked with fingerlings of the Indian major carps viz., Catla, Mrigal and Rohu size 10 cm annually along with grass carp and common carp. Fish production from this reservoir varies from 4.2 to 5.3 tonnes with very less recovery of Rohu.

Table 1. Fish production from the reservoirs of Palakkad district of Kerala (2017-18)

Location of reservoir	Water spread area	Annual production (kg)
Pothundy	363	5888.02
Mangalam	393	41875.70
Meenkara	259	10204.30
Malampuzha	2313	44481.50
Kanjirappuzha	512	5392.30
Chulliyar	159	33118.15
Walayar	289	3698.10
Total		144658.10

The assessment of culture based fishery at Kanjirapuzha was conducted using the density-dependent growth model developed by Lorenzen *et al.* (1997). Stocking experiments were conducted and length-weight data of Catla and Mrigal were collected by adopting experimental fishing at Kanjirapuzha reservoir in order to study growth and production. The fingerlings were stocked at the density of 909 no.s ha^{-1} and 1696 no.s ha^{-1} during 2008-09 and 2009-10 respectively. Using cohort analysis, fishing and mortality rates were estimated and the population biomass dynamics over the period of experiment was reconstructed.

The length frequency composition of Catla catla and Cirrhinus mrigala and their increase in weight at monthly intervals are given in Fig. 2 and 3 respectively. The length weight data indicated that catla and mrigal support the fishery of Kanjirapuzha. Rohu although stocked in good numbers was recovered negligibly.

The Fig.2 indicates growth and length composition of Catla during 2008-09. Good recovery of Catla in length range 320-370 mm was observed corresponding to the weight range 325 to 1125 g from 7^{th} month of stocking mostly caught by 100 to 125 mm mesh size nets. Fig. 3 gives the length composition of Mrigal from Kanjirazha reservoir during 2008-09. Mrigal was recovered in good numbers in the length range 200 to

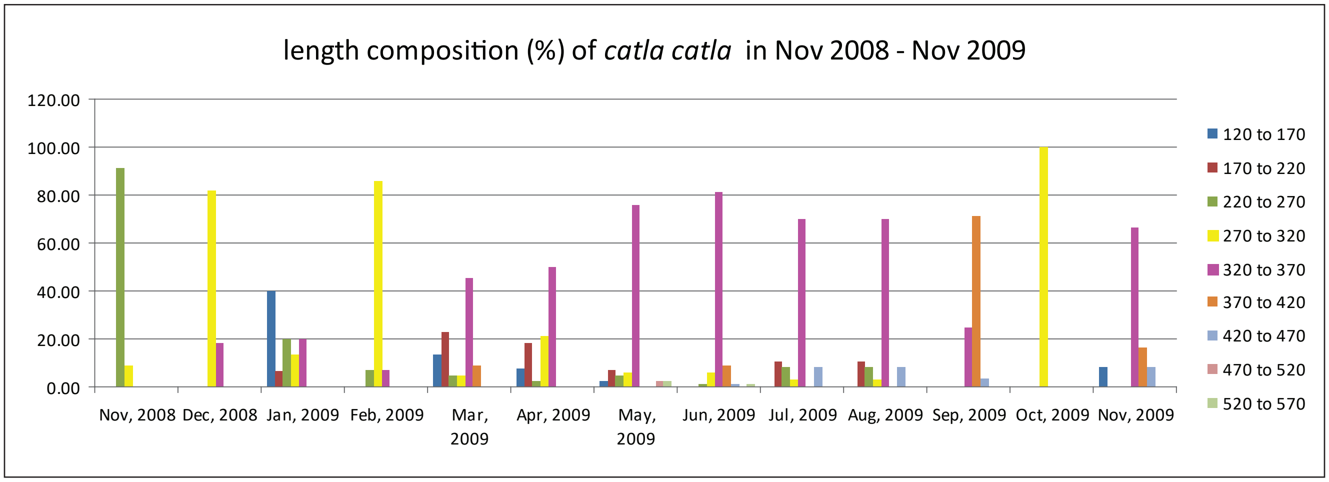

Fig. 2. Length composition (%) of Catla catla in Nov 2008 – Nov 2009

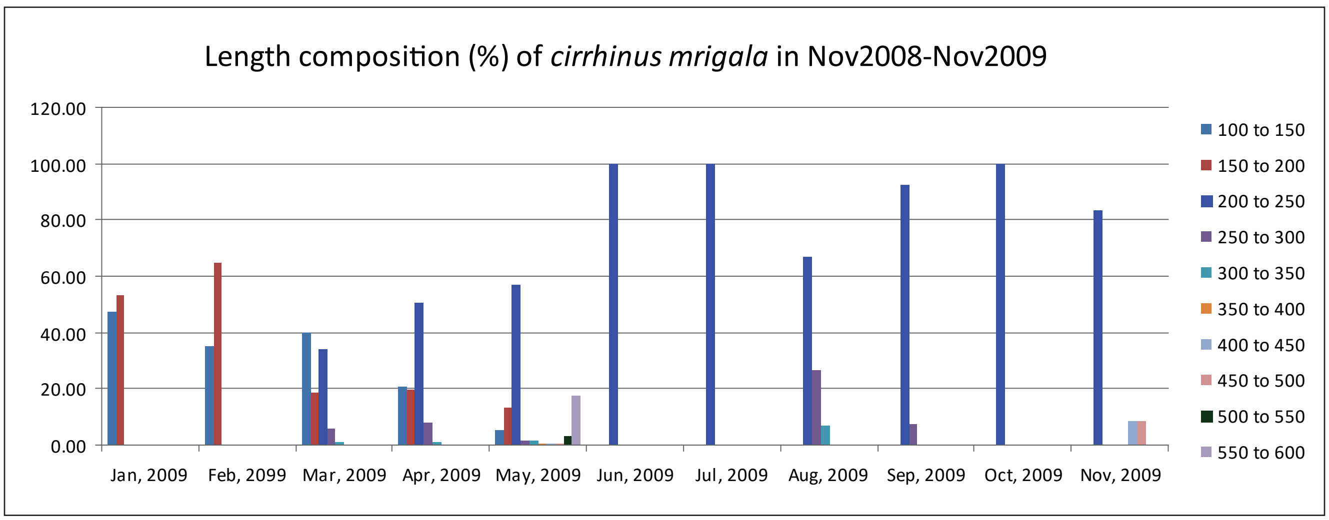

Fig. 3. Length composition (%) of C. mrigala in Nov 2008 – Nov 2009

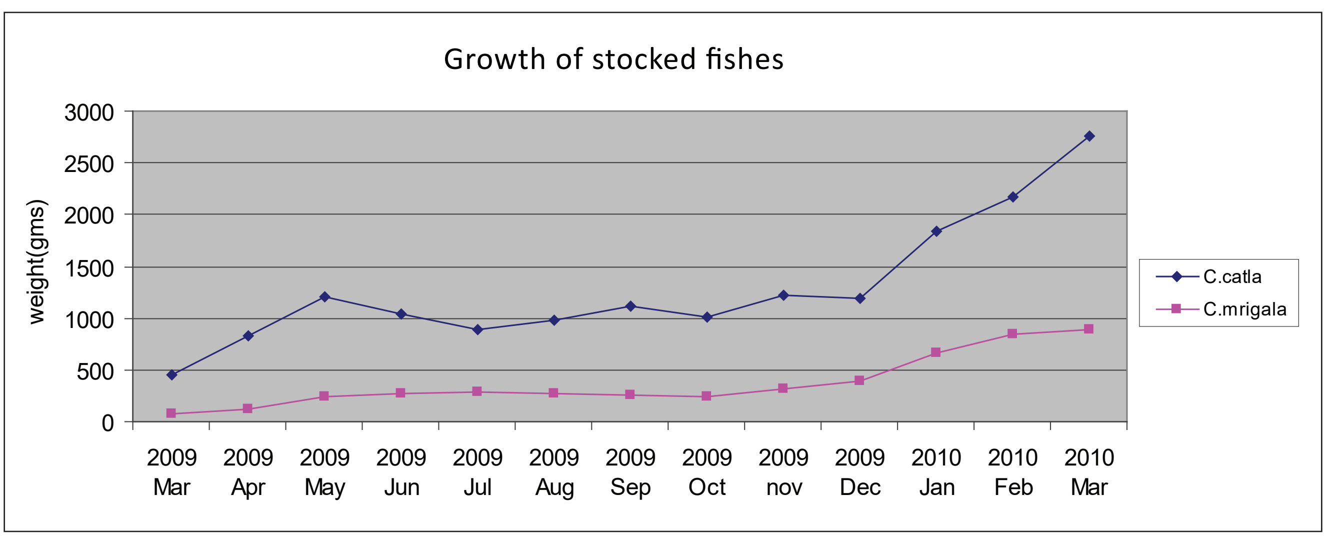

Fig. 4. Growth of stocked fishes

250 mm size corresponding to the weight range 180 to 390 g at 7th month and this length group persisted in dominance in the succeeding 8 months.

Analysis of the growth performance of Catla (Fig.4) indicated that after 14 months of stocking, fishes weighing more than 2 kg were caught in 180 mm mesh net and in general, growth was excellent in this reservoir. Growth of Mrigal (fig.4) shows gradual increase over the period but at a lesser growth rate compared to catla. Comparing the growth performance of two cohorts of catla pertaining to 2008-09 and 2009-10, it was observed that the 1st cohort outperformed the second, registering 1122 g (at 89 nos. ha^{-1} of stocking density) over 1070 g (at 447 nos. ha^{-1}) after a span of 12 months. In case of mrigal, the significant growth difference between two batches were not observed at stocking density of 368 nos. ha^{-1} (2008-09) and 482 nos. ha^{-1} (2009-10).

Using cohort analysis population of Catla and Mrigal was reconstructed separately and fishing mortality estimated for various age groups. In case of catla the average fishing mortality for the 1st age group was 0.38 and it was 1.1 for the second age group. Whereas in case of Mrigal, the averages fishing mortality for 1st age group was 0.23 and for the 2nd age group it was 0.69. The estimated population biomass for catla was ranging from 11 $kgha^{-1}$ to 23.6 $kgha^{-1}$ in the 1st age group and comparatively more (22 $kgha^{-1}$ to 28 $kgha^{-1}$) in the second age group. For Mrigal the population biomass ranged from 25.1 $kgha^{-1}$ to 37 $kgha^{-1}$ indicating that unexploited fish stock is available in all age groups for exploitation. From management point of view results of the cohort analysis indicates that fishing effort can be increased further. The fishermen should adopt standardized fishing gear to target the unexploited biomass in the 2nd age group so that the overall production can be increased.

The spreadsheet layout formulated by Lorenzen *et al.* (1997) was used for the estimation of density-dependent growth parameters. Based on biomass reconstruction at b=-0.3, the model parameter values were estimated ($p<0.05$) together with their 95% confidence limits through Cohort analysis. The reference biomass for Catla was 50 $kg.ha^{-1}$ and for Mrigal it was 246 $kg.ha^{-1}$. The best estimate of growth model parameters for Catla and Mrigal along with the 95% confidence limitswhich minimised the SSQ are presented in Table 2. The reference biomass B_r (average biomass in 2008-2011) for Catla was 50 $kgha^{-1}$ and 46 $kgha^{-1}$ for Mrigal.

Table 2. Density-dependent growth model estimation

MODEL PARAMETER	CATLA	MRIGAL
$W_{\infty r}$	3800 g (8700,10498)	11234 g (9789,12869)
K per year	0.73 (0.67,0.79)	0.33 (0.23,0.43)
c ($g^{1/3}ha.kg^{-1}$)	0.0059 (0.0046, 0.007)	0.0095 (0.0085, 0.0105)

The growth parameter K for catla was 0.73 which is very high indicating good growth performance of the species at the reservoir. Very low values of the competition coefficient indicate the conduciveness of the water body for growth of carps. The growth parameter for Mrigal was estimated as 0.33 per year which is very low compared to catla. This indicates that Kanjirazha reservoir fishery is catla based with more scope for exploitation of Mrigal.

The fitted growth models are given below :

Catla : $W_{\infty B} = (21.3 - 0.0059.(B - 50))^3$

Mrigal : $W_{\infty B} = (22.4 - 0.0095.(B - 46))^3$

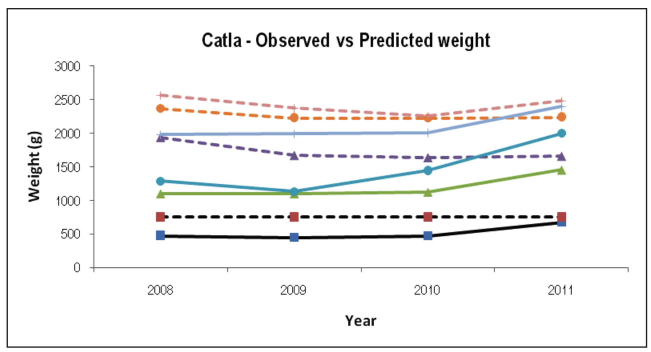

Fig. 6. Best fit of growth model for Catla : (■- Age 1, ▲- Age 2, ●- Age 3, + - Age 4) Weight (in g) – Solid lines indicate observed values and broken line indicate Fitted values

Fig.6 depicts the graph of observed vs. predicted age over period of the density dependent growth models fitted for Catla and Mrigalin Kanjirapuzha reservoir.

The analysis carried out for fitting density dependent growth models comprised of stocking and catch data including age-related data on catch composition and body weight which was obtained using batch marking of seed fish. Different management options can be explored using the fitted models, by varying the competition coefficient and fishing mortality and the change in yield brought out i.e. predict the increase or

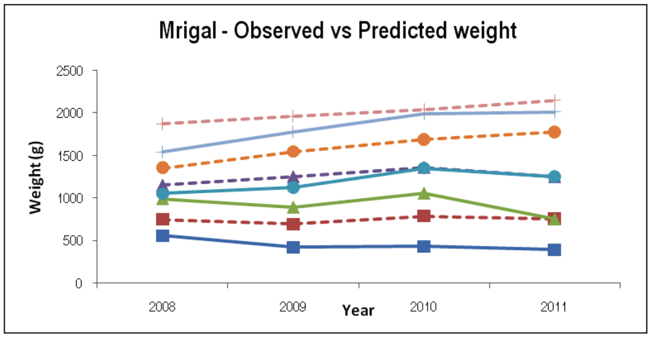

Fig. 7. Best fit of growth model for Mrigal : (■- Age 1, ▲- Age 2, ●- Age 3, + - Age 4) Weight (in g) – Solid lines indicate observed values and broken line indicate Fitted values

decrease in yield (Lorenzen *et al.,* 1997). The fishery manager's perception of uncertainties and attitude to risk must be taken into account in the evaluation of management options.

6. CONCLUSIONS

Mortality and growth of the stocked fish depend on the natural conditions of the water body and the key technological management problem is to identify stocking and harvesting regimes that enhances production and assure the sustainability of fisheries. The stocking density should be such that the food resources of the ecosystem are fully utilized and optimum population maintained consistent with normal growth. The cost of stocking and managing the species must be economically viable. Situations where two or more species use the same or similar resource, such as food or space, leads to overcrowding and poor growth rate of fishes. Under a higher than optimum stocking rate, though production may be high, the individual growth rates will be so small that to attain a marketable size a long growing period will be needed. On the other hand, if bigger fishes are needed the rate of stocking should be lowered and low production will have to accepted. Similarly when marketable size is to be attained, in a shorter period, stocking rate has to be lowered to allow faster growth. Thus a desirable balance among stocking rate, biomass and growth is to be maintained. Density-dependent growth model provides the manager the relevant information upon which decision can be based as to which management regime is to be adopted to sustain the fishery.

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