Fertilization and stocking of unmanaged ponds through temporal plankton community structure map (PCSM): A nascent concept in aquaculture planning

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Background: This paper deals with a non-conventional approach called PCSM model. It was developed to aid in horizontal expansion of aquaculture through utilization of unmanaged ponds for modified extensive aquaculture. This model applies to small lentic water bodies like ponds (<10 ha area) where plankton count and limnological parameters are naturally within permissible range for fish culture or survival. It can only help in – '*modified extensive aquaculture*' by increasing the abundance of plankton groups that are most preferred. This is only applicable for culturing planktophagus fishes.

Methods: PCSM incorporates annual plankton community dynamics (data) of some representative '*unmanaged*' ponds of the region. Only the dynamics of top two highly palatable and highly preferable Phytoplankton (*Chlorophyceae* & *Bacillariophyceae*) and Zooplankton (*Rotifera* & *Copepoda*) groups for Indian Major Carps were focused upon. The monthly composition of each plankton group in each pond of the region was averaged and plotted into a graphical model called Multiple Spline Curve with 5% padding using SigmaPlot.

Results: The model here has been developed in reference to pond based polyculture of 3 Indian Major Carps (*Catla catla*, *Labeo rohita* and *Cirrhinus mrigala*), which is still a dominant practice in the unmanaged freshwater ponds in India. The model can help in deciding two things – Fertilization timing (PCSM: Fertilization Module) and Stocking time (PCSM: Stocking Module). It is region specific and presently developed for Raipur district of Chhattisgarh, India.

Discussions: Through PCSM, effective pond fertilization period is 7 months out of 12 (April, June, August, September, October, December and February). Moreover, year round multiple stocking multiple harvesting based fish culture can be ensured in unmanaged pond through PCSM guided stocking schedule (June, August, November and December).

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Running Head: *Aquaculture Planning through PCSM*

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TEMPORAL PLANKTON COMMUNITY STRUCTURE MAP (PCSM) BASED AQUACULTURE PLANNING IN UNMANAGED PONDS: A NASCENT CONCEPT

ABSTRACT

Background: This paper deals with a non-conventional approach called PCSM model. It was developed to aid in horizontal expansion of aquaculture through utilization of unmanaged ponds for modified extensive aquaculture. This model applies to small lentic water bodies like ponds (<10 ha area) where plankton count and limnological parameters are naturally within permissible range for fish culture or survival. It can only help in – '*modified extensive aquaculture*' by increasing the abundance of plankton groups that are most preferred. This is only applicable for culturing planktophagus fishes.

Methods: PCSM incorporates annual plankton community dynamics (data) of some representative '*unmanaged*' ponds of the region. Only the dynamics of top two highly palatable and highly preferable Phytoplankton (*Chlorophyceae* & *Bacillariophyceae*) and Zooplankton (*Rotifera* & *Copepoda*) groups for Indian Major Carps were focused upon. The monthly composition of each plankton group in each pond of the region was averaged and plotted into a graphical model called Multiple Spline Curve with 5% padding using SigmaPlot.

Results: The model here has been developed in reference to pond based polyculture of 3 Indian Major Carps (*Catla catla*, *Labeo rohita* and *Cirrhinus mrigala*), which is still a dominant practice in the unmanaged freshwater ponds in India. The model can help in deciding two things – Fertilization timing (PCSM: Fertilization Module) and Stocking time (PCSM: Stocking Module). It is region specific and presently developed for Raipur district of Chhattisgarh, India.

Discussions: Through PCSM, effective pond fertilization period is 7 months out of 12 (April, June, August, September, October, December and February). Moreover, year round multiple stocking multiple harvesting based fish culture can be ensured in unmanaged pond through PCSM guided stocking schedule (June, August, November and December).

Keywords: Unmanaged ponds, modified extensive aquaculture, carp polyculture, stocking time, fertilization schedule, PCSM approach

INTRODUCTION

The FAO in its several series publications like Code of Conduct for Responsible Fisheries and Aquaculture; State of World Fisheries and Aquaculture; Climate Change Adaptation in Fisheries and Aquaculture have been repeatedly stressing upon development of alternate ecosystem based aquaculture management approaches (FAO 1995, FAO 2014, Shelton 2014). Taking the limitations of vertical expansion of aquaculture into consideration, India is now giving impetus to horizontal expansion of 'regulated' aquaculture and rational aquaculture practices. '*More area needs to be brought under fish culture'* as reflected through mandates given by Indian Council of Agricultural Research (ICAR) and Vision documents of pioneer Indian fisheries research institutes (ICAR 2011, CIBA 2011, CIFA 2011, CIFRI 2011, CMFRI 2011, DCFR 2011, CIBA 2015, CIFA 2015, CIFRI 2015, CMFRI 2015, DCFR 2015). Even the recently launched scheme of the Govt. of India for fisheries and aquaculture sector under NFDB, called 'Blue Revolution', is focusing on ways to promote and popularize fish culture over wider areas (PIB 2015). Greatest constraints in horizontal expansion of aquaculture include - ownership issues, multiple ownership dependent reluctance in investment, multiple use of the water including domestic/household purposes, poaching problem, benefit-cost ratio, environmental/aesthetic concerns of local people and etc. Similarly, the problems in developing ecosystem based aquaculture packages include - Climate change impacts, region specific nature of water bodies due to varying agro-climatic and soil characteristics, high allochthonous stocking will alter ecosystem trophic dynamics, high aquaculture inputs will change hydrobiology of water body and etc.

India is bestowed with 2.5 million ha of ponds, of which only 50% is scientifically exploited for fish culture on a commercial scale. Carp culture *alias* Composite Fish Culture in India is still the most popular and dominant practice of fish culture in pond (ICAR 2011, PIB 2015, DAHDF 2014). Principally two types of carp culture exist in ponds of India, *semi-intensive* and *extensive*. The former involves stocking with carp fingerlings (>8 cm) @5000-10000 nos./ha and includes the provision(s) of aeration, supplementary feeding, fertilization. The latter practice is more traditional and relies more on natural productivity of the unmanaged ponds. The stocking density of carp fingerlings is often low to very low (<0.2 nos./ha) as it does not involve provisions of feeding and fertilization. The extensive culture practice is more prevalent in rural parts of the country and is especially of interest to marginal fish farmers who have limited capacity to invest or bear risk. Owing to the low output of around

600-1500 kg/ha/year from these extensive practices, majority of the fish farmers have switched to semi-intensive culture that produce 3000-15000 kg/ha/year. However there are still a sizeable portion of farmers who could not afford or dare to upgrade themselves to semi-intensive methods. In such a situation, they are adopting *modified-extensive* culture methods in pursuit of higher production *vis-à-vis* income with minimum possible risk (main criterion). These methods involve increasing fish food abundance in such extensively cultured ponds (discussed above) through intermittent fertilization practices at superficial doses. Neither supplementary feeding nor other water quality management practices are adopted. Stocking rate remains similar or maintained around 2000-2500 fingerlings/ha to achieve an annual production of 1500-2500 kg/ha (ICAR 2011, Pillai and Katiha 2004). In pond fish culture, India has encountered many pond fertilization strategies over the last few decades ranging from phase fertilization, Secchi-disk transparency based fertilization to sediment based fertilization and standard C:N:P ratio based fertilization packages (Jhingran 1991, Das and Jana 1996, ICAR 2011).

The present study tried to hint an innovative, alternative, orthodox fertilization along side a stocking strategy suitable for *modified-extensive* aquaculture in those unmanaged ponds having permissible conditions for fish culture. The main objective was to develop a software assisted, resource and region specific aquaculture management decision support system for modified extensive aquaculture in these unmanaged ponds practicing traditional carp polyculture having a gross 1:1:1 proportion of surface, column and bottom feeders. This non-conventional model/concept may help bring a new approach to the existing extensive fish culture practices in the unmanaged ponds. It may help in rationalizing this unscientific fish culture by a few more inches (literally!) which was the sole purpose of this research.

MATERIALS AND METHODS

Study area

Raipur is the capital of the state Chhattisgarh, India. Among the three agro-climatic zones of the state i.e. – northern hill region, Bastar plateau and Chhattisgarh plains, Raipur comes under plains zone of Chhattisgarh. It is located on 21°16' North latitude and 81° 36' East longitude with an altitude of 289.6 m above mean sea level. Raipur has River Mahanadi bordering it on its eastern side. The climate of Raipur is hot and sub humid. The region receives 1200- 1400 mm rainfall normally, out of which about 85% is received during rainy season (June end to mid October) and 15% during winter season (early November to February end). The average annual rainfall is 1326 mm (based on 80 years mean). The rainfall pattern has high rate of variation during any given rainy season from year to year. The maximum temperature ranges from 17 to 45.2°C and minimum from 8 to 22°C during the year. May is the hottest and December is the coolest month of the year (Roy 2014). Meteorological conditions that prevailed during data collection of the study are given in Table 1.

Table 1: Meteorological conditions in the study area during study period (2013-2014)

Sampling and Analysis

Monthly sampling for pond water, sediment and plankton were done following standard protocols of APHA (1998). Sampling was done for a year (April 2013 to March 2014). Samples were simultaneously collected from each pond on a single day (15th of each month), from different spots and depths of water; and finally made into a composite sample (Gomez and Gomez 1984). Sampling was done between 7:30-9:00 am to get a holistic plankton sample and capturing those plankton which practice vertical diurnal migration.

For plankton collection, 10 liters of water from different areas and depths of the pond were filtered through 25 μ mesh plankton net. The collected sample was concentrated in 30 ml receptacle glass tube, attached at the end of the plankton net (Hossain *et al*. 2007). Plankton samples were preserved in phosphate buffered formalin at 3% concentration along with one drop of glycerin (Gupta and Dey 2012). The preserved samples were kept in refrigerated condition at 4-6°C and analysed within 30 days. Plankton was counted by Sedgewick-Rafter cell counting method (APHA 1998). All individuals were counted as a single unit whether colonial, single-celled or filamentous. The results were expressed in number of units per liter. The groupwise composition was expressed in percentage of total count after identification with the help of plankton identification manuals (Needham and Needham 1962, Battish 1992, Bellinger 1992, APHA 1998, Vuuren *et. al*. 2006).

Monthly hydrobiological (water quality) profiling of each pond was also done for serving as a reference information to assess if the pond is really worthy for fish culture round the year. All water samples were analyzed within 36 hours of sampling. Among physico-chemical parameters – Transparency (cm), Temperature (°C), pH (units), Electrical Conductivity (mS

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cm^{-1}), Total Dissolved Solids (ppt) were determined through ESICO made µP based portable soil and water analysis kit while Free CO2 (ppm), Total Alkalinity (ppm), Total Hardness (ppm) and Dissolved Oxygen (ppm) were analysed titrametrically as per standard procedures given in APHA (1998). Among nutrient parameters - Ammonia-N (ppm), Nitrate-N (ppm) and Orthophosphate-P (ppm) were determined through spectrophotometry (APHA 1998). Among primary productivity parameters – Gross primary productivity (mg C m^{-2} day^{-1}) and Net primary productivity (mg C m^{-2} day^{-1}) were studied by light and dark bottle method at 24 hours incubation period (APHA 1998). Soil samples from each sampling site were randomly collected with the aid of a self-designed underwater soil sampler consisting of a bamboo pole and a 5 cm diameter stainless steel can (Banerjea 1967) and a composite soil sample was prepared for the analysis of available nitrogen (AN), available phosphorus (AP), exchangeable potassium (EP) as described by Subbiah and Asija (1956), Olsen (1954) and Muhr (1965) respectively. Soil pH and electrical conductivity (EC) was measured according to Piper (1967). Organic carbon in soil was determined by Walkley (1947) method.

Site characteristics

The author took one urban (P1) and one rural pond (P2) of Raipur, Chhattisgarh (India) to be representative and cover enough diversity in the observations. The term '*unmanaged*' implies those ponds wherein standard pre-stocking, stocking and post-stocking aquaculture management practices are not in vogue; rather the only major management intervention include only stocking and harvesting of fish. Two unmanaged perennial ponds were selected for the present study, denoted as P1 and P2. P1 (located 21°14'21.55"N, 81°39'33.57"E) is a perennial urban pond, influenced by urban drainage. The pond is trapezoidal in shape with an area of 9.78 ha and average depth of around 5 m. P2 (located 21°12'27.12"N, 81°42'45.23"E) is a perennial rural pond, used by the villagers for multiple purposes. The pond is rectangular in shape with an area of 2.26 ha and an average depth of 2.5 m. Hydrobiological profile of the ponds (P1 and P2) during study period is given in Table 2.

Table 2: Annual hydrobiological profile of the studied ponds in Raipur, Chhattisgarh (India) and their suitability for fish culture

Methodology used to create PCSM

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PCSM incorporates annual plankton community dynamics (data) of some representative '*unmanaged*' ponds of Raipur, Chhattisgarh (India). The monthly composition of each plankton group in each pond of the region was averaged. It was plotted into a graphical model called Multiple Spline Curve with 5% scientific padding and without any missing values, using Systat SigmaPlot v11.0. The X axis denoted the months and Y axis denoted the percentage scale. The graph area was provided with X-major and Y-major gridlines. Lifelines of preferred plankton groups (*i.e.* - curves of each group) were highlighted over others. The graphical model was optimized by using visual aids like arrows, balls and pyramids. Only the dynamics of top two highly palatable and highly preferable Phytoplankton (*Chlorophyceae* & *Bacillariophyceae*) and Zooplankton (*Rotifera* & *Copepoda*) groups for Indian Major Carps were focused upon (Hora and Pillay 1962, Khan and Siddiqui 1973, Jhingran 1991, Sarkar 2010, Mahboob 2011, Khabade 2015) while rest were left unattended. Following '*The Rules*' for each module (discussed below), the graphical model *aka* PCSM was optimized by using visual aids in order to make them '*readable*' and make sense.

Development of PCSM: Fertilization module (The Rules)

1. Only four plankton groups were focused upon.
2. The pits made in each of their life-line due to dips in population are our areas of interest. These pits must be provided support through reinforcement in the form of pillars *aka* fertilization.
3. Hence, these pits are perceived as opportunities for fertilization.
4. Pits are identified by the yellow ball, getting settled down.
5. Each pit lying within the jurisdiction of a particular month is its property.
6. In case of a conflicting pit distributed over 2 months, the month getting maximum no. of pits is chosen for fertilization. If it is still unresolved, the month where the pit begins to form is selected.

Development of PCSM: Stocking module (The Rules)

1. Only four plankton groups were focused upon.

2. The peaks made in each of their life-line due to rise in population are our areas of interest.
3. These peaks are perceived as opportunities for stocking.
4. Minimum two peaks are necessary (one from phytoplankton and one from zooplankton) for validating a stocking schedule in a month.
5. Peaks identified by the blue pyramid, sitting on top.
6. Each peak lying within the jurisdiction of a particular month is its property.
7. In case of conflicting peak distributed over 2 months, the month getting maximum no. of peaks is chosen for stocking. If it is still unresolved, the month where the peak begins to form is selected.

RESULTS

The model or concept showcased here bypasses most of the constraints of horizontal expansion of fish culture discussed before, given that some conditions (assumptions) are maintained based on which the model has been hypothesized. This model applies to small lentic water bodies like ponds (<10 ha area), where plankton count and limnological parameters are naturally within permissible range for fish culture or survival. It can only help in – '*modified extensive aquaculture*', *i.e.* aquaculture practice wherein low/ natural stocking density (< 0.5 fingerlings/m^2; < 10 fry/m^2) is maintained. No supplementary feed is given. The fish is solely raised on natural food (plankton) which is periodically boosted through intermittent application of fertilizers and/or manures at superficial doses. This is only applicable for culturing planktophagus fishes occupying lowest positions in food chain. The model here has been developed in reference to pond based polyculture of 3 Indian Major Carps (*Catla catla*, *Labeo rohita* and *Cirrhinus mrigala*), which is still a dominant practice in the unmanaged freshwater ponds in India. The model has two facets, *i.e.* it can help decide on two things – Fertilization timing (PCSM: Fertilization Module) and Stocking time (PCSM: Stocking Module). This is a conceptual model. It needs further experimentation and implementation in field. It is region specific and here it has been developed for Raipur district of Chhattisgarh. The model has been named as PCSM (Plankton Community Structure Map)

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and it is very first of its kind. This is only a primitive form and will require further optimization, modification and upgradation.

PCSM: Fertilization Module

Based on the generated *PCSM: Fertilization Module* (Figure 1), it was observed that the ponds of the region may benefit from scheduling fertilization programmes during the months - April, June, August, September, October, December, February. Effective pond fertilization period can be 7 months out of 12, which will be big saving, less risky for the marginal farmers and presents minimal environmental impact/ alteration as well. The fertilization dosage requirement for each of the above mentioned months is derived from sediment fertility status of the ponds in the region, as already established by Roy (2014). Recommendations from *PCSM: Fertilization Module* is summarized in Table 3.

Fig 1 - PCSM: Fertilization Module for unmanaged ponds of Raipur, Chhattisgarh

Table 3: PCSM: Fertilization Module – Recommendations (Refer Figure 1)

PCSM: Stocking Module

Based on the generated *PCSM: Stocking Module* (Figure 2), it was observed that some good time windows (months) exist for stocking carp fry/fingerlings in the unmanaged ponds of this region which sync with the presence of preferred plankton groups in dominant state and may ensure proper foraging of the stocked seeds. Four Months *i.e.* – June, August, November and December were found to be suitable for stocking. As most of the hydrobiological parameters in the ponds of the region were within the permissible range for fish culture throughout the year (Table 2), following this PCSM guided stocking schedule would not be a problem from biological point of view. Moreover, fish seeds are now available almost round the year and with this approach, year round MSMH (Multiple Stocking Multiple Harvesting) based fish culture can be ensured in unmanaged ponds of the region. However it must be kept in mind that cumulative stocking density of carps in the above 4 months must be restricted below 0.5 fingerlings/m^2 (0.3-0.4 fingerlings/m^2 ideally) and below 10 fry/m^2 (7-8 fry/m^2 ideally) having a gross 1:1:1 species mix ratio (surface: column: bottom feeders) for fitting into modified-extensive aquaculture principle, based on which this PCSM model stands. Recommendations from *PCSM: Stocking Module* is summarized in Table 4.

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Fig 2 - PCSM: Stocking Module for unmanaged ponds of Raipur, Chhattisgarh

Table 4: PCSM: Stocking Module – Recommendations (Refer Figure 2)

DISCUSSIONS

Ponds are shallow fresh water impoundments in the tropics that are becoming increasingly important as sources of fish, and various methods including introduction of new species, adoption of improved culture technologies and ecosystem based management approaches are being undertaken in the hope of improving fisheries (Dokulil *et al.* 1983). Inland aquaculture or freshwater aquaculture in India is still being practiced predominantly in ponds and tanks. It is estimated that only 40% of the available area of 2.36 million ha of ponds and tanks has been put to use, and there is ample scope for expansion of area under freshwater aquaculture (ICAR 2011). As ponds play a vital role in commercial fisheries, sound ecosystem based management is necessary and it is pre-requisite to study their fundamental ecosystem dynamics for proper utilization or conservation (Rao *et al.* 1999, Paria and Konar 2003). Maintenance of a healthy aquatic environment and production of sufficient fish food organisms in ponds are two factors of primary importance for successful pond cultural operations (Banerjea 1967). There is a well established and very strong relationship between net algal productivity and the net fish yield for fishes whose diets consists of natural food produced in the pond (Knud-Hansen 1997). More than 75% of freshwater fish feed on plankton at one or the other stage of their life cycle. Phytoplankter are the primary producers of water bodies and these are the main source of food directly or indirectly to the fish population. Moreover, the availability of zooplankton as food for larval fish is thought to be one of the key factors that strengthen commercial fisheries (Wetzel 1975, Kane 1993). Seasonal fluctuations of all the nutrients in sediment and water column decide the availability, succession and distribution of various plankter groups (Das *et al*. 2012).

Recent studies implying high potentiality of unmanaged ponds for fish production in India are already evident (Manjare *et al.* 2010, Singh and Bhatnagar 2010, Simpi *et al*. 2011, Sharma and Jaiswal 2012, Singh *et al*. 2012, Pathak and Mankodi 2013, Sundaresan and Senthil 2013, Roy 2014). Roy (2014, 2015) had urged that the present extensive fish culture practices in the unmanaged ponds of Raipur, Chhattisgarh should be upgraded for their proper utilization and maximizing the present level of fish production, both at state and national level. The statement is equally applicable to any hydrobiologically suitable

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unmanaged pond lying under-utilized in terms of fish culture. The knowledge of plankton dynamics is a potential tool to determine the availability of fish food organisms in an unmanaged pond at any particular time of the year (Sayeshwara *et al.* 2011). Unmanaged ponds or tanks in southern India exhibited a common pattern in their seasonal variation of various physicochemical characteristics that is manifested into a near similar plankton population dynamics in such water bodies (Rani and Sivakumar 2012). The PCSM concept described here itself stands on the rationale that the unmanaged ponds of a region have their signature plankton community dynamics owing to the agro-climatic and soil characteristics prevailing in the area. Moreover, they exhibit some degree of similarity in the burst phase and lag phase of its plankton groups that can be manipulated slightly to serve our purpose. Given that most of the hydrobiological parameters in the unmanaged ponds of Raipur, Chhattisgarh have an annual range that is permissible for undertaking fish culture (Table 2), identification of burst phase (peak) and lag phase (lean) of preferred plankton groups will give us an opportunity to treat the pond as a large live feed culture unit wherein fishes can be raised.

Looking deeper into the aspects of annual plankton dynamics, the phytoplankton exhibited a bimodal pattern in the unmanaged ponds of Raipur, Chhattisgarh. One peak of phytoplankton was observed in summer and second peak was observed in the winter (Roy 2014, 2015). Similar findings were made by Singh *et al.* (2010), Dubey *et al.* (2012), Rani and Sivakumar (2012) and Benarjee and Narashima (2013) from other parts of India. The unmanaged ponds of the region had chlorophyceae as the dominant group of phytoplankton followed by bacillariophyceae (Sarkar 2010, Roy 2014, Roy 2015), which is considered ideal for inland fish culture ponds (Hora and Pillay 1962). The zooplankton population on the other hand showed no such bimodal pattern although it closely followed the peaks and drops in phytoplankton abundance (Roy 2014), showing the natural dependence of zooplankton population on phytoplankton abundance for nutrition and propagation in unmanaged water bodies (Watson and Wilson 1978, Horne and Goldman 1994, Jana 2007). Members of copepoda and rotifer constitute the major group among the zooplankton community in unmanaged ponds of Raipur, Chhattisgarh (Kumar 2006, Sarkar 2010, Roy 2014), which is also considered desirable for a fish culture pond (Hora and Pillay 1962). PCSM concept discussed here aims to selectively boost the presence of these naturally pre-existing dominant plankton groups in the unmanaged ponds of the region, that are also regarded as most preferred and palatable plankter for the candidate carps (Hora and Pillay 1962, Khan and Siddiqui 1973, Jhingran 1991, Sarkar 2010, Mahboob 2011, Khabade 2015) (Table 4).

A food chain of interest in most extensive or semi-intensive carp culture ponds is the one where phytoplankton is eaten by zooplankton, which (either/both) is further eaten by the fishes. Moreover the detritus generated from components of this food chain are utilized by the bottom feeders (ICAR 2011). As low stocking density (Table 4) will barely alter this pre-existing trophic structure in these natural unmanaged ponds, fish production from such water bodies may be partly increased with least investment and risk by promoting selective proliferation of the aforementioned plankton groups as guided by the PCSM: Fertilization module (Table 3) (Fig 1). Also, syncing the release of fish seeds (Fig. 2) during the burst phase of at least 2 preferred plankton groups (1 phytoplankton & 1 zooplankton) may ensure proper grazing/foraging, given that the hydrobiological parameters especially plankton abundance is not a concern in those unmanaged ponds (Figure 2). This is the basis of the PCSM: Stocking module (Table 4).

A closer look on the plankton community interactions (dynamics) already existing in the unmanaged ponds of Raipur, Chattisgarh as recorded in Roy (2014) gives hope on the viability of the proposed PCSM: Fertilization module concept. For example – the growth of diatoms (bacillariophyceae) and green algae (chlorophyceae) seemed to suppress the growth of blue green algae (cyanophyceae). Similarly, a natural competition exists between chlorophyceae and bacillariophyceae population to become dominant in these unmanaged ponds of the region although they move along somewhat synchronously for some parts of the year which is conducive from fish farmers' point of view (Roy 2014). However, except during monsoon months, diatoms fail to gain an upper hand over the green algae population which might be due to the fact that diatoms are able to grow in conditions of weak light and low temperature which are less suitable for other algae (Lund 1965, Roy 2014). An alternating succession between copepoda and rotifera were also observed. As rotifers have a very short life cycle, periodic bursts in rotifer population is observed which is immediately followed by a subsequent increase in copepod population (Roy 2014). This can be explained by the fact that copepods predate upon smaller zooplankton like rotifers for food. Both groups of zooplankton are known to be highly palatable for most fishes including carps (Dhanapathi 2000, Kalff 2002). Dependence of rotifers on diatoms and green algae has also been revealed, however more intensely with the diatoms. An Increase or decrease in abundance of either diatoms or green algae was followed by a subsequent increase or decrease in the rotifer population (Roy 2014). Rotifers being among the smallest members of zooplankton are known to feed upon the smallest phytoplankton and detritus particles (Dhanapathi 2000, Vuuren *et al.* 2006). Furthermore, maintenance of a healthy diatom population in the ponds will keep undesirable blue green algae in check (Vuuren *et al.* 2006), as evident from the inverse trend observed between Bacillariophyceae and Cyanophyceae (Roy 2014). Maintenance of a stable diatom population in these water bodies will warrant the abundance of rotifers and this increase in rotifers will result in an increase in copepod abundance, based on observations. This cascading relationship of green algae-diatoms-rotifers-copepods observed in the ponds of this region can provide an opportunity for exploitation and manipulation (Roy 2014). PCSM based fertilization concept targets to maintain the aforementioned cascading relationship in the ponds and gives equal importance to each of its component by providing fertilization reinforcements during the dips in their annual population lifeline. Zafar (1964) opined that calcium rich water bodies have high number of diatoms. Patrick (1948) has observed that high pH favoured the high abundance of diatoms. PCSM: Fertilization module includes the practice of intermittent application of lime as well in addition to fertilizers. This will not only serve as source of carbon input but will also create favorable conditions for diatom population. It is quite well established for pond fish culture that diatoms bloom with split applications of phosphorus fertilisers in small doses and under alkaline conditions. Green algae bloom easier under ambient light and dissolved oxygen conditions with combined application of nitrogen and phosphorus fertilizers (Boyd and Tucker 1998, Adhikari 2003, ICAR 2011). In addition to boosting algal production, application of organic manures also increases the abundance of rotifers and copepods since they are known to thrive well on the particles of organic matter in addition to algal cells (Dhanapathi 2000, ICAR 2011). PCSM concept takes all these facts into account and includes the practice of applying nitrogen, phosphorus and organic carbon inputs together (Table 3). The only thing that makes this approach non-conventional is its strategy which involves application of fertilizers during lean season of target plankton groups rather than Secchi Disk readings or plankton count (Figure 1). As most of the hydrobiological parameters especially plankton abundance in the unmanaged ponds of the region showed an annual range that is acceptable for fish culture (Table 2), this strategy may be acceptable. Some fish farmers involved with modified-extensive aquaculture of IMCs in unmanaged ponds of Raipur, Chhattishgarh (India) have reportedly been applying fertlizers/manures in superficial

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doses at random times (depends on their will) to get better fish yields (Anon 2013, Roy 2014). In order to upgrade and rationalize this practice a step further, the PCSM based approach may serve as an option in addition to conventional pond fertilization strategies to promote modified-extensive aquaculture of carps in unmanaged ponds of the region with minimal impact on environment and expenditure incurred.

Future Directions

The model needs to be implemented in field. Presently, this model is applicable for unmanaged ponds of Raipur, Chhattisgarh (India). PCSM model can also be generated for any region. Reliable data from published reports on plankton dynamics in the unmanaged ponds of a particular area need to be averaged and plotted into multiple spline curves (with 5% padding and without any missing values) using Systat SigmaPlot. The X axis shall denote the months and Y axis shall denote the percentage scale. The graph area must be provided with X-major and Y-major gridlines. Lifelines of preferred plankton groups (*i.e.* - curves of each group) need to be highlighted over others. Following the rule book for each module, as discussed above, the graphical model is optimized by using visual aids. In this way, a new region specific PCSM Model comprising of Fertilization module and Stocking module, for aquaculture planning in the unmanaged ponds of a particular area can be developed.

The model must be updated every few years with a fresh plankton community survey from some representative unmanaged ponds of the region. This is to counteract any adverse impacts of climate change and changes in plankton succession due to selective promotion of only a few preferable plankton groups over the years. This model will also promote climate change resilient aquaculture planning in unmanaged ponds. If IPCC (2014) AR5 predictions for South-East Asia are taken into account, plankton dominance and succession will most likely get altered. In such a situation, PCSM model in its frequently updated form will give a '*climate change ready*' aquaculture planning because it will keep on changing with time as well.

Through this tool, a region specific fertilization and stocking schedule may be possible for modified-extensive aquaculture of Indian Major Carps including other potential candidate carp species in unmanaged ponds. The proposed practice can warrant sustainable, farmer friendly and eco-friendly exploitation of unmanaged ponds as well with higher fish production than extensive fish culture practices commonly in practice.

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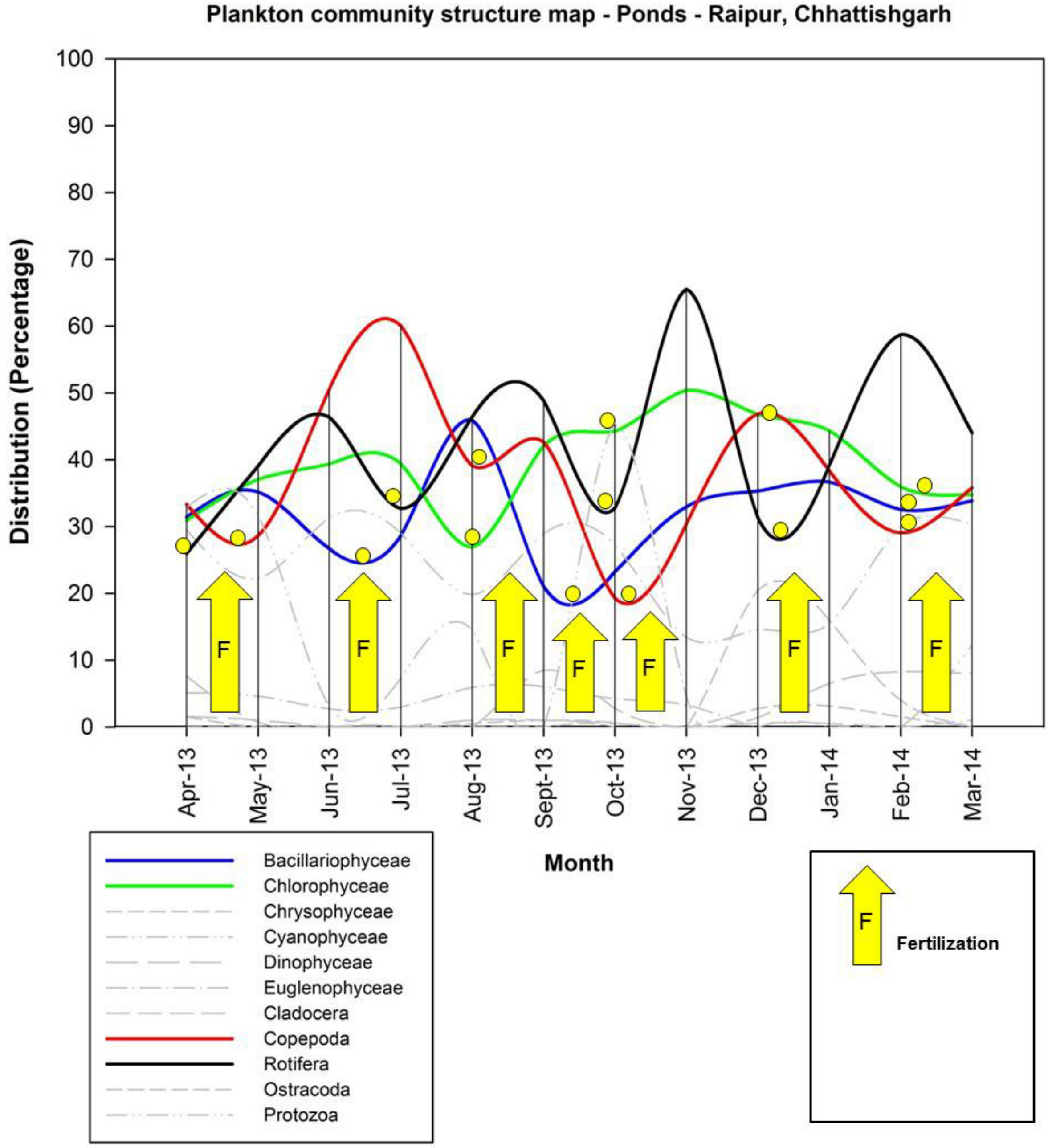

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613 **Fig 1 - PCSM: Fertilization Module for unmanaged ponds of Raipur, Chhattisgarh**

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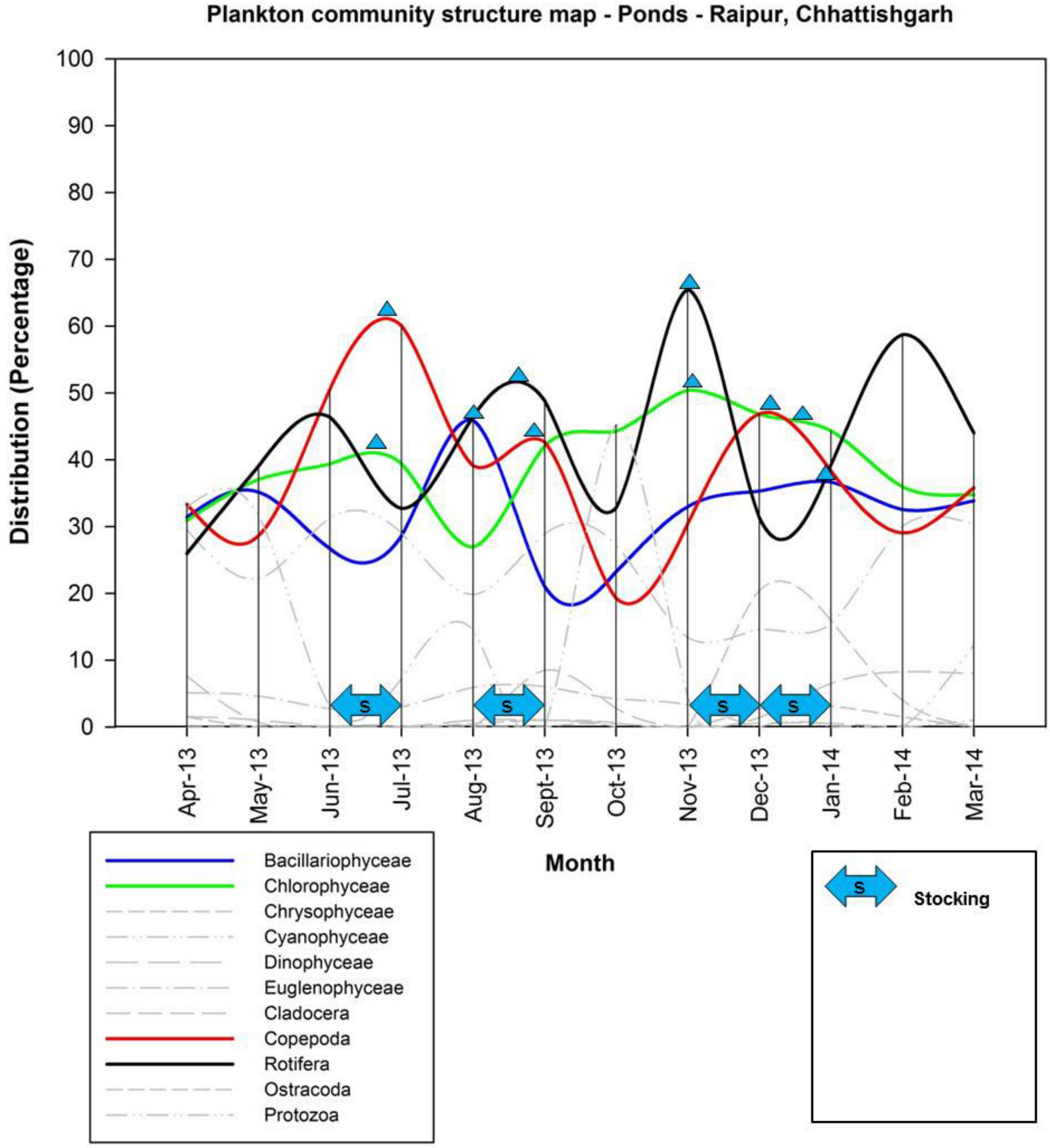

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615 **Fig 2 - PCSM: Stocking Module for unmanaged ponds of Raipur, Chhattisgarh**

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616 **Table 1: Meteorological conditions in the study area during study period (2013-2014)**

Parameter	Value
Mean air temperature	19.77-35.83 °C
Total Annual Rainfall	1704.7 cm
Photoperiod	1-10 hours
Source: *Department of Agrometeorology, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh* (Roy 2014).	

617 **Table 2: Annual hydrobiological profile of the studied ponds in Raipur, Chhattisgarh**
618 **(India) and their suitability for fish culture**

S.No.	Parameters	Pooled Values (Min-Max)*	Suitability for carp culture*
Physico-chemical parameters			
1.	Transparency (cm)	16.6-45	Good
2.	pH (units)	7.25-8.55	Good
3.	Water Temperature (celsius)	15.6-32.6	Good
4.	EC (mS/cm)	0.305-0.63	Good
5.	TDS (ppt)	0.22-1.18	Good
6.	Salinity (ppt)	0.23-0.47	Good
7.	Free Carbon dioxide (ppm)	0-4.5	Good
8.	Total Alkalinity (ppm)	109-244	Good
9.	Total Hardness (ppm)	71-114	Good
10.	Dissolved Oxygen (ppm)	1.5-9.1	Good (except in summer)
Ecological productivity parameters			
11.	NPP (mg C/m^2/day)	150-3675	Sub-optimum
12.	GPP (mg C/m^2/day)	375-4462.5	Sub-optimum
13.	CR (mg C/m^2/day)	112.5-2212.5	Sub-optimum
Dissolved and sediment exchangeable nutrients			
14.	Ammonia-N (ppm)	0.035-0.18	Permissible
15.	Nitrate-N (ppm)	0.015-0.65	Sub-optimum

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16.	Orthophosphate-P (ppm)	0.015-0.13	Sub-optimum
17.	Soil pH	6.2-7.75	Good
18.	Soil EC (ms/cm)	0.17-1.03	Good
19.	Soil Available N (kg/ha)	213.25-545.67	Sub-optimum
20.	Soil Available P (kg/ha)	6.09-22.85	Sub-optimum
21.	Soil Available K (kg/ha)	347.37-681.12	Good
22.	Organic Carbon (percent)	0.77-0.78	Sub-optimum
Plankton abundance and diversity parameters			
23.	Phytoplankton count (units/L)	$5.31 \times 10^5 – 17.5 \times 10^5$	Good
24.	Zooplankton count (units/L)	900-4800	Permissible
25.	Menhinik generic diversity index - Phytoplankton	0.9-1.81	N.A.
26.	Menhinik generic diversity index - Zooplankton	4.4-7.2	N.A.
Groupwise distribution of plankton classes			
27.	Bacillariophyceae (%)	20.15-47	Good
28.	Chlorophyceae (%)	17.35-50.4	Good
29.	Chrysophyceae (%)	0-3.2	Permissible
30.	Cyanophyceae (%)	11-38.25	Permissible
31.	Dinophyceae (%)	0.1-1.55	Permissible
32.	Euglenophyceae (%)	0-8	Permissible
33.	Cladocera (%)	0-10	Permissible
34.	Copepoda (%)	6-63	Sub-optimum
35.	Rotifera (%)	12.9-71.1	Good
36.	Ostracoda (%)	0-20.4	Permissible
37.	Protozoa (%)	0.61.2	Good
**Source:* Roy (2014, 2014a, 2014b, 2015, 2016).			

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Table 3: PCSM: Fertilization Module – Recommendations (Refer Figure 1)

Months of scheduled fertilization	Seven (April, June, August, September, October, December and February)
Fertilization dosage requirement (each month)[a]	12.5 to 16.6 kg N/ha; 8.3 to 10.4 kg P_2O_5/ha; 666 kg organic C/ha; Lime @ 41 to 58.3 kg/ha.
[a] *Source: Roy (2014a)*	

Table 4: PCSM: Stocking Module – Recommendations (Refer Figure 2)

Months of scheduled stocking	Four (June, August, November and December)
Cumulative stocking density (for four months)[a]	< 0.5 fingerlings/m^2 (0.3-0.4 fingerlings/m^2 ideally) Or, < 10 fry/m^2 (7-8 fry/m^2 ideally)
Gross species ratio (suitable for unmanaged ponds)[a, b]	1:1:1 (*Catla catla*: *Labeo rohita*: *Cirrhinus mrigala*)
Other compatible carp species (Indian preference)[c]	Surface feeders: *Hypophthalmichthys molitrix* Column feeders: *Puntius gonionotus* Bottom feeders: *Cyprinus carpio, Labeo bata, Labeo fimbriatus, Labeo calbasu, Labeo gonius, Puntius sarana*
Source: [a]Based on practical experiences; [b]Assumed ideal; [c]Das (2012)	