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Assessment of primary productivity of integrated multi-trophic aquaculture ponds

Nesar Uddin, Abu Syed Md. Kibria and Mohammad Mahfujul Haque

Abstract
Primary productivity in integrated multi-trophic aquaculture (IMTA) systems was investigated in experimental earthen ponds. The experimental design consisted of three treatments (T_1, T_2, and T_3) in triplicate, T_1: carps and *shing*; T_2: carps, *shing* and snail; T_3: carps, *shing*, snail, tilapia and water spinach. Carps, *shing* and tilapia were fed with a supplementary feed. Five classes and 34 genera of phytoplankton were identified: Chlorophyceae was the most dominant group. Although no significant differences (P>0.05) in abundance of phytoplankton were found, productivity was the highest in T_3, average concentration was $43\times10^5\pm94\times10^4$, $36\times10^5\pm19\times10^5$, and $49\times10^5\pm91\times10^4$ cells/l T_1, T_2, and T_3, respectively. Water quality parameters were within the suitable ranges of aquaculture in all treatments, except decreasing temperature in November when phytoplankton production increased. The results suggest that IMTA systems do not change the nature of primary productivity and water quality parameters significantly, and IMTA could be more productive towards increasing nutrition and income of the poor fish farmers.

Keywords: Primary productivity, Polyculture, water quality, earthen pond, IMTA

1. Introduction
The importance of fisheries and aquaculture sector cannot be described in words in the economy of Bangladesh. The greater share of the annual fish production comes from aquaculture, and most of the aquaculture is practiced in closed- and fresh- water bodies, and its production is increasing day by day. Fish production from closed water body was 1.86 million MT. Pond is an important part of close water aquaculture. Indian major carps, Chinese carps, catfish, prawn etc. are mainly cultured in the ponds. Approximately 0.37 million ha area is under close water bodies (i.e. ponds). Fish production in ponds is increasing day by day. On the other hand, production from open water capture fisheries does not show such improvement (DoF, 2014) [7].

Now-a-days, pond aquaculture is being commercialized for higher production, easy management and the most important things is high profit in short period of time. Commercialization diverts the culture system to intensive from extensive and semi-intensive. In commercial aquaculture, high stocking density, high volume of feed application in low volume of water create some problems like accumulation of waste feeds and fecal matters on the bottom of the ponds and their rapid decomposition deteriorate water quality, which causes diseases and mortality of fish and even failure of aquaculture industries. To solve the problems, rapid exchanging of pond water and removal of pond bottom soil make aquaculture practices more time consuming, labor and money intensive which creates problems to make it a profitable business. As a result, commercial aquaculture has become more challenging to the farmers. A low-cost technology has been developed that can solve such problems in a sustainable way and increasing in aquaculture developed countries, which is called integrated multi-trophic aquaculture (IMTA) (Ridler *et al.*, 2007; Costa-Pierce, 2010) [22, 6].

IMTA refers to the farming of aquatic organisms of different trophic levels in the proximity in a way that allows one species' wastes to be recycled as feed and fertilizer for another. Typically, IMTA systems combine an aquaculture species that requires external feeding (e.g. carps and catfish) with the species capable of deriving nutrients from the wastes of the fed aquaculture species. IMTA systems can be land-based or open-water systems, marine- or fresh- water systems, and may comprise several species (Barrington *et al.*, 2009) [3].

Primary productivity is an important ecological parameter of pond aquaculture, which refers to the quantity of new organic matters produced by the photosynthetic and chemosynthetic organisms such as algae of different groups and aquatic macrophytes. It has great influence to the fish production especially in extensive and semi-intensive aquaculture practices. Primary productivity by the phytoplankton is the most important phenomenon and reflects the nature and the degree of productivity in the aquatic ecosystem. Phytoplankton what is the base of the food chain of aquatic ecosystems is the most important component of primary productivity.

Primary productivity is the basic natural food supply of an aquatic ecosystem and it has direct relationships with the secondary productivity that means the production of fish in IMTA ponds. If the primary productivity is maintained at the optimum levels, fish production can greatly be increased, which in turn minimizes the dependence on artificial feeds. As a result, the production cost can greatly be minimized. Moreover, its optimum level has great contribution to water quality maintenance. It has vital relationships with the other factors of aquatic ecosystems like secondary and tertiary productivity. Although some phytoplankton are the indicators of presence of pathogens and pollutants in waters, most of the planktons are directly related to primary productivity and can easily be understood the importance of assessing the primary productivity of IMTA ponds. Though various aspects of IMTA ponds have been studied so far (Kibria and Haque, 2014) [14], a major factor, primary productivity, yet to be studied. Therefore, the present was undertaken to determine the qualitative and quantitative productivity of phytoplankton and to the assess water quality parameters in IMTA systems.

2. Materials and Methods

The experiment was conducted in nine earthen ponds for a period of 6 months from May to November 2013 at the Department of Aquaculture, Bangladesh Agricultural University (BAU), Mymensingh-2202, Bangladesh.

2.1 Description of experimental ponds

Nine earthen ponds were used to conduct the experiment. All of them were situated to the Southwest side of wet laboratory complex, Faculty of Fisheries, BAU, Mymensingh (Fig 1). The ponds were rectangular in shape, 40 m^2 in size, 1 m in depth, and having strong dykes, flat bottom etc. All of the ponds were well exposed to sunlight, free from unwanted aquatic vegetation and well managed and equipped with inlets and outlets. However, the inlets and outlets were sealed with polythene sheets.

A

T_3R_2 Carps, *Shing*-in-cage, Snail and Vegetable	T_2R_1 Carps, *Shing*-in-cage, and Snail	T_1R_2 Carps and *Shing*-in-cage
T_1R_3 Carps and *Shing*-in-cage	T_2R_3 Carps, *Shing*-in-cage, and Snail	T_3R_1 Carps, *Shing*-in-cage, Snail and Vegetable
T_3R_3 Carps, *Shing*-in-cage, Snail and Vegetable	T_2R_2 Carps, *Shing*-in-cage, and Snail	T_1R_1 Carps and *Shing*-in-cage

B

Fig 1: (A) GPS view of the experimental ponds (source: www.google.com), and (B) composition of socked species in different treatments**.**

2.2 Experimental design

The experiment consisted of three treatments (T_1, T_2, and T_3) with three replications for each treatment: T_1 - carps and *shing*; T_2 - carps, *shing* and snail; and T_3 - carps, *shing*, snail, tilapia, and water spinach (Fig 1). Eighty carps (catla, silver carp, rui, mrigal = 3:1:2:2) and 100 *shing* in a 1 m^3 cage were stocked per 40 m^2 pond area in all the three treatments. An additional cage of same volume stocking with 100 tilapia was set in T_3. Snail was stocked at the rate of 250 g/40m^2 of pond area in T_2 and T_3. Water spinach was cultivated on four floating trays in T_3 only.

2.3 IMTA pond preparation

All the ponds were dried out completely. The undesired small fish, aquatic weeds etc. were removed from the ponds. Excess bottom mud was removed and used to repair the broken and uneven dykes. Lime and compost were applied at 250 and 680 kg/ha during pond preparation. Compost was prepared in a pit of a dyke using mustard oil cake (36.5%), cow dung (36.5%), urea (9%) and water hyacinth (18%), and applied as basal manure for feeding snail and enhancement of primary productivity.

2.4 Sample collection

All of the samplings were done in the morning between 9.00 and 10.00 AM for the estimation of phytoplankton. A 500 ml glass jar was used for the collection of 1000 ml water. After collection of water from the surface of ponds, it was concentrated to 90 ml passing through a bolting silk plankton net and then kept in a vial. Then the collected samples were preserved in 10% formalin and transferred to the laboratory as soon as possible for further analyses.

2.5 Phytoplankton Study
Two types of studies were done in the laboratory using the collected samples: qualitative and quantitative. A qualitative study gives an idea on the types of phytoplankton present in the experimental ponds; on the other hand, quantitative study estimates the number of various phytoplankton in water of the experimental ponds. Finally, primary productivity of the experimental ponds was determined by quantitative study.

2.5.1 Qualitative study
The qualitative analyses of phytoplankton were done up to the genus level according to Pennak (1953) [18] and Bellinger (1992) [5]. The identification of phytoplankton was done using a digital microscope (ANOVA 950 ES).

2.5.2 Quantitative study
Estimation of phytoplankton was done with a plankton counting cell named Sedgewick- Rafter cell (SR cell) which is a special type of thick slide having a cell in the center, which is divided into 1000 small squares on the surface. Phytoplankton was counted by placing the cell under a high power microscope with the projection of 10×15 and the number of phytoplankton was expressed as cells/l.

2.5.2.1 Preparation of slide
The Sedgewick-Rafter (S-R) counting cell is 55 mm long, 20 mm wide and 1 mm deep, and volume of the chamber is 1 ml, the counting chamber is equally divided into 1000 fields, each of the fields having a capacity of 1 micro liter. One ml from the concentrated volume of the phytoplankton samples was taken on the S-R cell with a dropper. Then the counting chamber was covered with a cover slip so as to eliminate the air bubbles and left to stand for a few minutes to allow the phytoplankton settle down. Further analyses were done placing the cell under the microscope.

2.5.2.2 Study under microscope
One ml sub-sample was transferred to the Sedgewick-Rafter (S-R) counting cell and placed under a binocular microscope (ANOVA 950 ES). Phytoplanktons were counted from 10 random fields of the S-R counting cell, and was expressed numerically cell per liter of water according to APHA (1992) [2].

2.5.2.3 Calculation
Phytoplankton was counted using the following formula:

$$N = \frac{A \times 1000 \times C}{V \times F \times L}$$ (Rahman, 1992) [21]

Where,
N = Number of phytoplankton (cells/l)
A = Total Number of phytoplankton counted
C = Volume of final concentration of samples (ml)
V = Volume of a field (mm^3)
F = Number of the fields counted
L = Volume of original water (l)

2.6 Studies on water quality parameters
The water quality parameters namely temperature (°C) - was recorded using a Celsius thermometer; pH and dissolved oxygen (mg/l) - were measured using HACH kit (Model: FF-1A) fortnightly during the experimental period. Samples were collected from 09.00 to 10.00 AM and analyses were performed in the Laboratory of the Department of Aquaculture, BAU, Mymensingh, Bangladesh.

2.7 Data analysis
The collected data were entered a Microsoft Excel spreadsheet and then analyses were done using a statistical software, SPSS (Statistical Package for Social Sciences) Version-16.0. One way analysis of variance (ANOVA) was employed to analyze any significance of difference among the treatments means followed by Duncan's multiple range test (Duncan, 1955) [8] and the level of significance was assigned at 0.05 (Zar, 1999) [29].

3. Results
Primary productivity of a pond is mainly indicated by phytoplankton, because they are situated at the bottom of a food chain of fish and snail. They are the basic and direct food of many aquatic animals. The major classes or groups of phytoplankton identified in the study were Bacillariophyceae, Chlorophyceae, Rhodophyceae, Cyanophyceae, Euglenophyceae etc.

3.1 Qualitative productivity of phytoplankton
Thirty genera of phytoplankton were identified in the samples collected from T_1, of which 9 belonged to Bacillariophyceae, 10 belonged to Chlorophyceae, 1 belonged to Rhodophyceae, 8 belonged to Cyanophyceae and rest of the 2 belonged to Euglenophyceae. From the ponds of T_2, 34 genera of phytoplankton were identified, of which 9 belonged to Bacillariophyceae, 14 belonged to Chlorophyceae, 2 belonged to Rhodophyceae, 7 belonged to Cyanophyceae, and 2 belonged to Euglenophyceae. From the IMTA ponds of T_3, 31 genera of phytoplankton were identified, of which 9 belonged to Bacillariophyceae, 12 belonged to Chlorophyceae, 2 belonged to Rhodophyceae, 6 belonged to Cyanophyceae and 2 belonged to Euglenophyceae.

3.2 Quantitative production of phytoplankton
The highest abundance of phytoplankton was found in the T_3, although there were no significant differences (P>0.05) among the treatments during the study period. The average phytoplankton production was $43\times10^5\pm94\times10^4$, $36\times10^5\pm19\times10^5$, and $49\times10^5\pm91\times10^4$ cells/l in T_1, T_2, and T_3, during the study period, respectively.

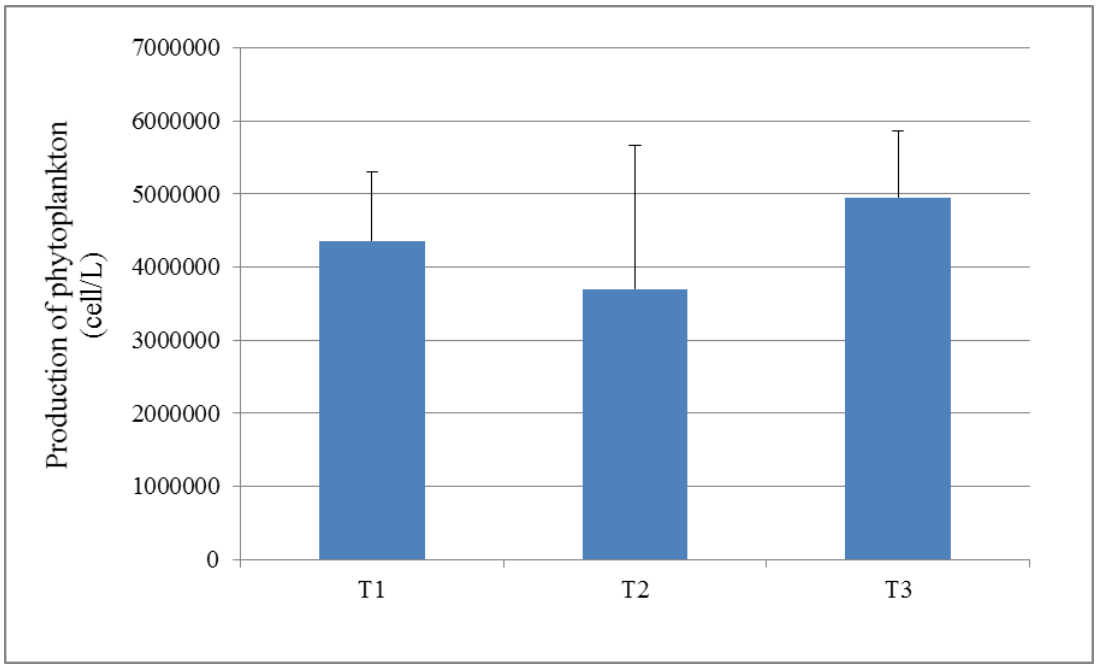

Fig 2: Average (±SD) primary production in different treatments during the experiment.

The highest production of phytoplankton was $55\times10^5\pm37\times10^5$ cells/l at the final sampling in November in T_1 while the lowest was $33\times10^5\pm17\times10^5$ cells/l recorded at the first sampling in July (Table 1). In T_2, maximum production of phytoplankton was 54×10^5 $\pm37\times10^5$ cells/l at the final sampling in November, while minimum was $36\times10^5\pm15\times10^5$ cells/l recorded in October (Table 1). In T_3, maximum production of phytoplankton was $61\times10^5\pm52\times10^4$ cells/l at first sampling in July while minimum number was $36\times10^5\pm18\times10^5$ cells/l recorded in October (Table 1).

There were no significant differences ($P>0.05$) among the treatments in the abundance of various groups of phytoplankton in all the samplings. However, in the first sampling, a significant difference ($P<0.05$) was found in case Euglenophyceae. In the first and second sampling, the mean value of phytoplankton production in T_3 was $61\times10^5\pm52\times10^4$ cells/l and $46\times10^5\pm21\times10^5$ cells/l, respectively, which was the highest among the treatments. However, it becomes $36\times10^5\pm18\times10^5$ cells/l in the third sampling which was the lowest in comparison among the three treatments. In the final sampling, primary productivity of the three treatments were almost same and the mean (±SD) of the three treatments in last sampling was $55\times10^5\pm37\times10^5$, $54\times10^5\pm37\times10^5$, $54\times10^5\pm26\times10^5$ cells/L, respectively.

Table 1: Mean (±SD) abundance of phytoplankton in different treatments during the study

Sampling	First	Second	Third	Fourth	Fifth
Treatments	**Average ± SD**	**Average ± SD**	**Average ± SD**	**Average ± SD**	**Average ± SD**
T_1	33×10^5 $\pm17\times10^5$	34×10^5 $\pm21\times10^5$	45×10^5 $\pm37\times10^5$	49×10^5 $\pm36\times10^5$	55×10^5 $\pm37\times10^5$
T_2	38×10^5 $\pm10\times10^5$	36×10^5 $\pm15\times10^5$	42×10^5 $\pm23\times10^5$	47×10^5 $\pm35\times10^5$	54×10^5 $\pm37\times10^5$
T_3	61×10^5 $\pm52\times10^4$	46×10^5 $\pm21\times10^5$	36×10^5 $\pm18\times10^5$	48×10^5 $\pm25\times10^5$	54×10^5 $\pm26\times10^5$

3.3 Group wise phytoplankton production

3.3.1 Chlorophyceae

The most dominant group found in all the treatments was Chlorophyceae. The maximum production of Chlorophyceae in T_1 was $26\times10^5\pm$ 46×10^4 cells/l at final sampling while the minimum was $12\times10^5\pm10\times10^4$ cells/l recorded in the first sampling in July (Table 2). In T_2, maximum production of Chlorophyceae was $27\times10^5\pm49\times10^4$ cells/l at the last sampling in November while minimum was $12\times10^5\pm11\times10^4$ cells/l recorded in October (Table 2). In T_3, maximum production of Chlorophyceae was $25\times10^5\pm40\times10^4$ cells/l at the final sampling in November while minimum number was $15\times10^5\pm$ 14×10^4 cells/l at the first sampling in July (Table 2).

Fourteen genera were found in the three treatments namely *Actinestrum*, *Chiamydomonus*, *Chlorella*, *Chlorogonium*, *Closteridium*, *Coelestrum*, *Palmella*, *Pediastrum*, *Tetradesmus*, *Tetraedon*, *Synedra*, *Treubaria*, *Ulothrix* and *Uroglena*.

Table 2: Mean (±SD) abundance of Chlorophyceae in different treatments during the study

Sampling	First	Second	Third	Fourth	Fifth
Treatments	**Average ± SD**	**Average ± SD**	**Average ± SD**	**Average ± SD**	**Average ± SD**
T_1	$12\times10^5\pm104\times10^4$	$13\times10^5\pm14\times10^4$	$21\times10^5\pm29\times10^4$	$24\times10^5\pm26\times10^4$	$26\times10^5\pm46\times10^4$
T_2	$15\times10^5\pm13\times10^4$	$12\times10^5\pm11\times10^4$	$18\times10^5\pm27\times10^4$	$23\times10^5\pm25\times10^4$	$27\times10^5\pm49\times10^4$
T_3	$15\times10^5\pm14\times10^4$	$18\times10^5\pm11\times10^4$	$16\times10^5\pm19\times10^4$	$23\times10^5\pm25\times10^4$	$25\times10^5\pm40\times10^4$

3.3.2 Euglenophyceae

The second dominant group found in all the three treatments was Euglenophyceae. The highest production of Euglenophyceae in T_1 was $43\times10^5\pm22\times10^4$ cells/l at the final sampling in November while minimum was $16\times10^5\pm88\times10^4$ cells/l recorded at the first sampling in July (Table 3). In T_2, the highest production of Euglenophyceae was $16\times10^5\pm88\times10^4$ cells/l at the final sampling in November while minimum was $69\times10^4\pm48\times10^4$ cells/l recorded at the first sampling in July (Table 3). In T_3, the highest production of Euglenophyceae was $28\times10^5\pm18\times10^5$ cells/l at the first sampling in July while the lowest was $10\times10^5\pm72\times10^4$ cells/l recorded in October (Table 3).

Under this group, some genera were found in all the three treatments viz *Euglena* and *Phacus.* The maximum number of *Euglena* was 21×10^5 cells/l and minimum was 26×10^4 cells/l, on the other hand, minimum number of *Phacus* was 11×10^4 cells/l and maximum was 98×10^4 cells/l.

Table 3: Mean (±SD) abundance of Euglenophyceae in different treatments during the study

Sampling	First	Second	Third	Fourth	Fifth
Treatments	Average ± SD	Average ± SD	Average ± SD	Average ± SD	Average ± SD
T_1	$43\times10^4\pm22\times10^4$	$98\times10^4\pm62\times10^4$	$13\times10^5\pm90\times10^4$	$14\times10^5\pm79\times10^4$	$16\times10^5\pm88\times10^4$
T_2	$69\times10^4\pm48\times10^4$	$92\times10^4\pm62\times10^4$	$13\times10^5\pm88\times10^4$	$16\times10^5\pm90\times10^4$	$17\times10^5\pm95\times10^4$
T_3	$28\times10^5\pm18\times10^4$	$14\times10^5\pm90\times10^4$	$10\times10^5\pm72\times10^4$	$15\times10^5\pm89\times10^4$	$16\times10^5\pm90\times10^4$

3.3.3 Bacillariophyceae

The third dominant group among the three treatments was Bacillariophyceae. The highest production of Bacillariophyceae in T_1 was $10\times10^5\pm93\times10^4$ cells/l at the first sampling in July while the lowest was $59\times10^4\pm88\times10^4$ cells/l recorded in October (Table 4). In T_2, the highest production of Bacillariophyceae was $99\times10^4\pm10\times10^4$ cells/l in July while the lowest was $45\times10^4\pm55\times10^4$ cells/l recorded in October (Table 4). In T_3, the highest production of Bacillariophyceae was $11\times10^5\pm12\times10^4$ cells/l at the first sampling on July, while the lowest was $60\times10^4\pm80\times10^4$ cells/l recorded in October (Table 4).

Under this group, 12 genera were found in the study in all the three treatments which were *Actinella, Cosmarium, Diatoma, Melosira, Pleurococcum, Navicula, Aphanotheca, Nitzschia, Tabellaria, Fragillaria, Surirella* and *Synedra.*

Table 4: Mean (±SD) abundance of Bacillariophyceae in different treatments during study

Sampling	First	Second	Third	Fourth	Fifth
Treatment	Average ± SD	Average ± SD	Average ± SD	Average ± SD	Average ± SD
T_1	$10\times10^5\pm93\times10^4$	$64\times10^4\pm96\times10^4$	$59\times10^4\pm88\times10^4$	$65\times10^4\pm84\times10^4$	$66\times10^4\pm78\times10^4$
T_2	$99\times10^4\pm10\times10^4$	$77\times10^4\pm10\times10^4$	$47\times10^4\pm60\times10^4$	$45\times10^4\pm55\times10^4$	$55\times10^4\pm65\times10^4$
T_3	$11\times10^5\pm12\times10^4$	$81\times10^5\pm10\times10^4$	$55\times10^5\pm71\times10^5$	$60\times10^4\pm80\times10^4$	$66\times10^4\pm96\times10^4$

3.3.4 Cyanophyceae

The fourth dominant group found in the three treatments was Cyanophyceae. The highest production of Cyanophyceae in T_1 was $36\times10^4\pm46\times10^4$ cells/l in October while the lowest was $50\times10^4\pm51\times10^4$ cells/l recorded in November (Table 5). In T_2, the highest production of Cyanophyceae was $64\times10^4\pm65\times10^4$ cells/l in October while the lowest was $33\times10^4\pm36\times10^4$ cells/l recorded in October (Table 5). In T_3, the highest production of Cyanophyceae was $51\times10^4\pm60\times10^4$ Cells/l in November while the lowest was $50\times10^4\pm46\times10^4$ Cells/l recorded in October (Table 5).

Under this group, 10 genera found in the three treatments were *Anabaenopsis, Chroococcus, Gleocapsa, Gomphospharia, Merismopedia, Nostoc, Oscillatoria, Pleurococcus* and *Spirulina.*

Table 5: Mean (±SD) abundance of Cyanophyceae in different Treatments during the study

Sampling	First	Second	Third	Fourth	Fifth
Treatments	Average ± SD	Average ± SD	Average ± SD	Average ± SD	Average ± SD
T_1	$42\times10^4\pm35\times10^4$	$49\times10^4\pm52\times10^4$	$36\times10^4\pm46\times10^4$	$37\times10^4\pm38\times10^4$	$50\times10^4\pm51\times10^4$
T_2	$39\times10^4\pm46\times10^4$	$64\times10^4\pm65\times10^4$	$50\times10^4\pm76\times10^4$	$33\times10^4\pm36\times10^4$	$44\times10^4\pm39\times10^4$
T_3	$47\times10^4\pm37\times10^4$	$50\times10^4\pm46\times10^4$	$40\times10^4\pm56\times10^4$	$37\times10^4\pm42\times10^4$	$51\times10^4\pm60\times10^4$

3.3.5 Rhodophyceae

The fifth dominant group found in during the study was Rhodophyceae. The highest production of Rhodophyceae in T_1 was $81\times10^3\pm57\times10^3$ Cells/l at the final sampling in November while the lowest was $30\times10^2\pm21\times10^2$ Cells/l recorded in October (Table 6).

In T_2, the highest production of Rhodophyceae was $51\times10^3\pm36\times10^3$ Cells/l at the final sampling in November while the lowest was $30\times10^2\pm21\times10^2$ Cells/l recorded in October (Table 6). In T_3, the highest production of Rhodophyceae was $63\times10^3\pm31\times10^3$ Cells/l at the first sampling in July, while the lowest was $33\times10^3\pm23\times10^3$ Cells/l recorded in October (Table 6).

Under this group, one genus was found in all treatments, which was *Hildenbrandia*. The lowest number was 65×10^3 cells/l in T_2, and the highest was 70×10^3 cells/l in T_3.

Table 6: Mean (±SD) abundance of Rhodophyceae in different Treatments during the study

Sampling	First	Second	Third	Fourth	Fifth
Treatment	Average ±SD	Average ±SD	Average ±SD	Average ±SD	Average ± SD
T_1	$48\times10^3\pm33\times10^3$	$30\times10^3\pm21\times10^2$	$27\times10^3\pm19\times10^3$	$12\times10^4\pm44\times10^3$	$81\times10^3\pm57\times10^3$
T_2	$42\times10^3\pm21\times10^3$	$30\times10^3\pm21\times10^2$	$90\times10^3\pm63\times10^2$	$90\times10^3\pm31\times10^3$	$51\times10^3\pm36\times10^3$
T_3	$63\times10^3\pm31\times10^3$	$33\times10^3\pm23\times10^3$	$39\times10^3\pm27\times10^3$	$10\times10^4\pm38\times10^3$	$42\times10^3\pm29\times10^3$

3.4 Trend of abundance of phytoplankton groups

The productivity trend of Chlorophyceae was found increasing from the first to final sampling among the phytoplankton groups such as Bacillariophyceae, Chlorophyceae, Rhodophyceae, Cyanophyceae and Euglenophyceae observed in the experimental ponds (Fig 3). As with Chlorophyceae, the Euglenophyceae also showed increasing trend of abundance.

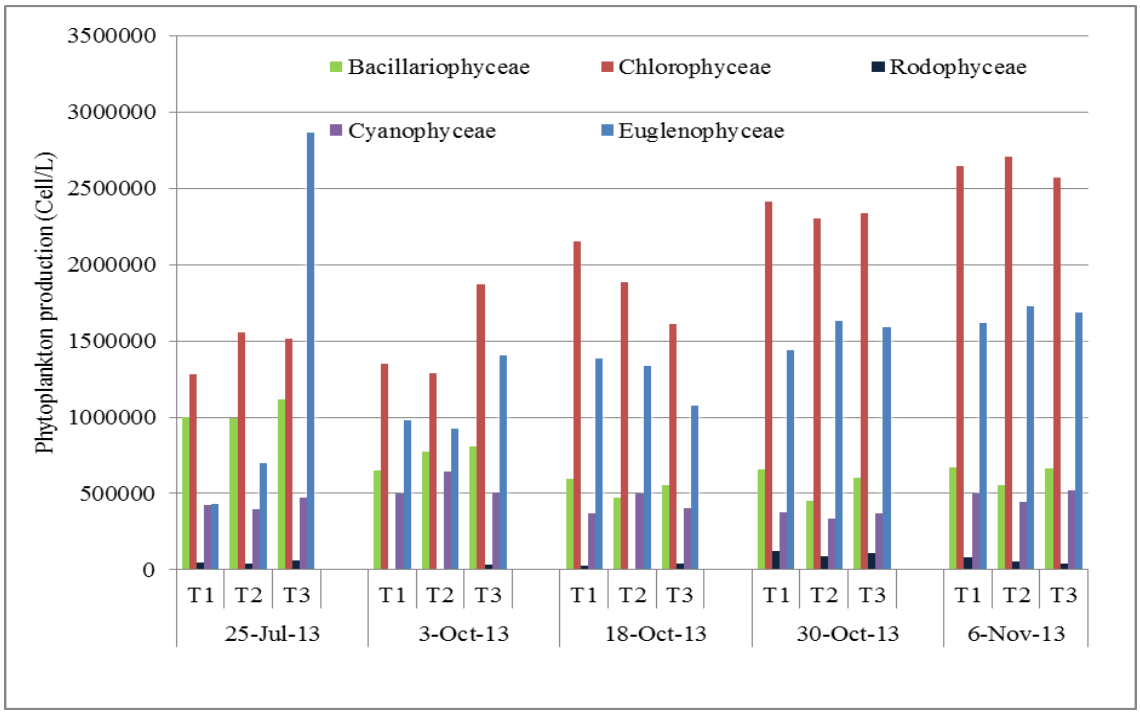

Fig 3: Mean abundance of different phytoplankton in the treatments during the study.

3.5 Water quality parameters

Various water quality parameters such as pH, dissolved oxygen (mg/l), water temperature (°C) were investigated during the study period.

3.5.1 pH

The highest mean value of pH was 8±0 in October and the lowest mean value was 7.33±0.29 observed in October in T_1 (Table 7). In T_2, the highest mean value of pH was 8±0.5 in October and the lowest mean value of pH was 7.33±0.29 observed in October (Table 7). In T_3 of IMTA ponds, the highest mean value was 8±0 in October and the lowest mean value was 7.17±0.29 in October (Table 7).

3.5.2 Dissolved oxygen (mg/l)

In T_1, the highest mean value of dissolved oxygen (DO) was 7±1 mg/l in October and the lowest was 5±1 mg/l at the first sampling in July (Table 7). The highest mean value of DO was 7.33±0.58 mg/l in October and the lowest mean value was 5±1 mg/l at first sampling in July (Table 7) in the ponds of T_2. In T_3, the highest mean value was 7.67±0.58 mg/l in October and the lowest mean value was 6±1 mg/l at first sampling in July (Table 7).

3.5.3 Water temperature (°C)

The highest mean value of water temperature was 33.67±0.58 °C at the first sampling in July and the lowest mean value was 25.5±0.5 °C which was observed in November in T_1 (Table 7). In T_2, the highest mean value of water temperature was 33.5±0.5 °C at the first sampling in July and the lowest mean value observed in November was 25.83±0.29 °C (Table 7). The highest mean value was 33.83±0.29 °C at the first sampling in July and the lowest mean value was 25.5±0.5 °C in November in IMTA ponds of T_3 (Table 7).

Table 7: Mean (±SD) values of water quality parameters along with primary productivity in the treatments during the study

Sampling	Treatment	Tem±SD	DO±SD	pH±SD	Cells/l±SD
First	T_1	33.67±0.58	5±1	7.67±0.29	$33\times10^5\pm17\times10^5$
	T_2	33.5±0.5	5±1	7.5±0	$38\times10^5\pm10\times10^5$
	T_3	33.83±0.28	6±1	7.67±0.29	$61\times10^5\pm52\times10^4$
Second	T_1	30.67±0.58	7±1	8.0±0	$34\times10^5\pm21\times10^5$
	T_2	31±0	7.33±0.58	8.0±0.5	$36\times10^5\pm15\times10^5$
	T_3	30.5±0.5	7.67±0.58	8.0±0	$46\times10^5\pm21\times10^5$
Third	T_1	32±0	5.67±0.58	7.33±0.29	$45\times10^5\pm37\times10^5$
	T_2	32.83±0.29	6±1	7.67±0.29	$42\times10^5\pm23\times10^5$
	T_3	32.83±0.29	6.67±0.58	7.33±0.29	$36\times10^5\pm18\times10^5$
Fourth	T_1	31.33±0.29	6±1	7.33±0.29	$49\times10^5\pm36\times10^5$
	T_2	31±0	6±1	7.33±0.29	$47\times10^5\pm35\times10^5$
	T_3	30.67±0.29	7±1	7.17±0.29	$48\times10^5\pm25\times10^5$
Fifth	T_1	25.5±0.5	6.33±0.58	7.67±0.29	$55\times10^5\pm37\times10^5$
	T_2	25.83±0.29	6±1	7.67±0.29	$54\times10^5\pm37\times10^5$
	T_3	25.5±0.5	6.67±0.58	7.83±0.29	$54\times10^5\pm26\times10^5$

4. Discussion

4.1 Phytoplankton production

Plankton populations in the experimental ponds were found to be consisted of 5 phytoplanktonic groups namely Bacillariophyceae, Chlorophyceae, Cyanophyceae, Euglenophyceae and Rhodophyceae (Nakumura *et al.*, 1993; Rosy, 1993) [16, 23]. The most dominant group was Chlorophyceae followed by Euglenophyceae, Bacillariophyceae, Cyanophyceae and Rhodophyceae (Haque *et al.*, 1998; Yeamin, 2000; Uddin, 2002) [10, 28, 27]. There were 34 genera identified from the study which belonged to the five groups. The result is more or less similar to the results of Hasan (1998) [11], Uddin (2002) [27], Rahman (2004) [20] and Hasan (2009) [9]. The phytoplankton found in the IMTA ponds (i.e., T_3) indicate that it can support the production of wide range of biologically important planktivore aquatic organisms which has great contribution to the live food production. An important thing in this study is that there is no statistical difference (P>0.05) among the treatments for phytoplankton groups. Exception is that a significant difference (P<0.05) was found in case of Euglenophyceae.

- Average production of phytoplankton was $43\times10^5\pm94\times10^4$, $36\times10^5\pm19\times10^5$, and $49\times10^5\pm91\times10^4$ cells/l in T_1, T, and T_3, respectively (Fig 2). The abundance of phytoplankton was higher than that reported by Kohinoor *et al.*, (1998) [15]. There were no significant differences (P>0.05) among the treatments for the abundance of phytoplankton during the experiment, however, the abundance was the highest in the T_3.

Irrespective of treatments, whether IMTA or common ponds, total plankton production was the highest in IMTA ponds, although it was not statistically significant. This means that IMTA pond can enhance phytoplankton production quantitatively. Even seasonally, the quantitative abundance of phytoplankton did not vary among the different treatments. This means IMTA systems can provide planktonic food for the carps all the year round.

The highest phytoplankton productivity in T_1 was 55×10^5 $\pm37\times10^5$ cells/l at the final sampling and the lowest value was 33×10^5 $\pm17\times10^5$ cells/l at the first sampling. In T_2, the highest phytoplankton production was 54×10^5 $\pm37\times10^5$ cells/l at the final sampling and the lowest was 36×10^5 $\pm15\times10^5$ cells/l in the second sampling. Finally, the highest production of phytoplankton was 61×10^5 $\pm52\times10^4$ cells/l at the first sampling and the lowest was 36×10^5 $\pm18\times10^5$ cells/l at the third sampling in T_3. The average production of phytoplankton recorded in this study ranged from 33×10^5 cells/L to 61×10^5 cells/L, which is more or less similar to the findings of Hasan (2009) [9]. It indicates that the phytoplankton productivity of IMTA pond was very good in comparison with the control pond.

Phytoplankton populations in the water of the experimental ponds were found to be consisted of 5 phytoplanktonic groups which are Bacillariophyceae, Chlorophyceae, Cyanophyceae, Euglenophyceae and Rhodophyceae. The most dominant group was Chlorophyceae followed by Euglenophyceae, Bacellariophyceae, Cyanophyceae and Rhodophyceae (Saha *et al.*, 1971) [24]. There were 34 genera identified from the study which belonged to the five groups. The result is more or less similar to the findings of Yeamin (2000) [28] and Bashar (2007) [4]. The phytoplankton finding in the IMTA pond indicates that it can support a wide range of biologically important phytoplankton and it has great contribution to the live food for various fish.

Chlorophyceae was the most dominant group in all the treatments during the study period (Hossain, 1996) [12]. Rahman (2007) [19] reported that Chlorophyceae was the second dominant group. The highest production of Chlorophyceae was $26\times10^5\pm$ 46×10^4 cells/l at final sampling at T_2 and the lowest was $12\times10^5\pm10\times10^4$ cells/L in the first sampling in July. Various important species under Chlorophyceae were *Actinestrum, Chiamydomonus, Chlorella* and *Chlorogonium etc.*

Third dominant group was Bacillariophyceae which is similar with the findings of Rahman (2007) [19]. The highest production of Bacillariophyceae was $11\times10^5\pm12\times10^4$ cells/l at the first sampling in July in T_3. However, the lowest was $45\times10^4\pm55\times10^4$ cells/l in T_2 recorded in October.

Cyanophyceae was the fourth dominant group. Ten genera were found under this group in all the treatments. *Anabaenopsis,* and *Nostoc* are two harmful phytoplanktos under Cyanophyceae. However, the most important phytoplankton *Spirulina* was available in the IMTA ponds.

The fifth dominant group was Rhodophyceae and the highest production of Rhodophyceae was $81\times10^3\pm$ 57×10^3 Cells/l in T_1 at the final sampling in November and the lowest was $30\times10^2\pm$ 21×10^2 Cells/l in October. *Hildenbrandia* was only one genus under it. Rahman (2007) [19] found that Euglenophyceae was the last dominant group in a study. It may be due to difference in stocked species, management practices, season of the experiment etc.

4.2 Water quality parameters

The excellent combination of the stocked species like, surface, column and bottom layer fish with vegetables and snail in IMTA ponds functioned as buffering tools and maintained almost constant and suitable water quality parameters during the investigation.

Water quality parameters such as temperature, dissolved oxygen and pH were recorded. Water temperature ranged from 25.5 °C to 33.83 °C during the experimental period. The highest water temperature was recorded in July, might be due to the bright sunshine and rainless days, and the lowest temperature was 25.5 in November, might be due to low intensity of sunshine. The mean temperatures in different treatments recorded during the study period were more or less similar to the findings of Islam (2007) [13] and Salam (2009) [25].

Dissolved oxygen is the most important chemical factor for all aquatic organisms. In the present study, mean value of dissolved oxygen varied from 5.00±1.00 to 7.67±0.58 mg/l, and the mean values were 6.00, 6.06 and 6.80 mg/l in T_1, T_2, and T_3, respectively. Alam (2008) [1] found dissolved oxygen content of water ranging from 5.25 to 6.46 mg/l, which indicates that dissolved oxygen content of IMTA ponds was within a good productive range. A little lower value was reported by Salam (2009) [25].

pH is considered another important chemical factor in fish culture. pH indicates the acidity-alkalinity condition of water body. It is also called the productivity index of a water body. The acidic pH of water reduces the growth rate, metabolic rate and other physiological activities of fishes. pH values ranging from 6.5 to 9 is suitable for pond aquaculture (Swingle, I957) [26], and values more than 9.5 is unsuitable because of unavailability of free CO_2. On the other hand, pH less than 6.5 reduces fish growth, physiological activities and tolerance to toxic substances. Parasites and diseases easily

attack fish. On the other hand, fish die pH values above 11. The ranges of pH value were found in the present study very close to the findings of Asadujjaman (2013) [17] and Salam (2009) [25]. It indicates that IMTA systems support pond environment with good pH.

5. Conclusion

Water quality parameters influence the primary productivity of aquaculture ponds. Different problems arising in aquaculture due to commercialization of aquatic food production systems can be prevented through the application of IMTA principles for the sustainable production in high density commercial aquaculture practices. The approach of IMTA should be disseminated at the farmers' level to enhance production of traditional polyculture ponds.

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