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Relationships Between Plankton Primary Productivity, Biotic and Abiotic Variables of Carp Fish Ponds

Doychin I. Terziyski[1*], Roumen K. Kalchev[2], Hristina V. Kalcheva[2], Vesselin P. Alexandrov[3]

1 - Institute of Fisheries and Aquaculture, 248 V. Levski Str., 4003 Plovdiv, BULGARIA
2 - Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences, 1 Tsar Osvoboditel Blvd., 1000 Sofia, BULGARIA
3 - Medical University Plovdiv, 15-A Vasil Aprilov Blvd., 4002 Plovdiv, BULGARIA
* Corresponding author: doichint@abv.bg

Abstract. Experiments measuring primary productivity, biotic and abiotic environmental factors in carp ponds were carried out within three consecutive years (2004, 2005 and 2006). The aim of the study was investigation of the relations between the biotic and abiotic variables, their influence on the primary productivity and the effect of manuring on the fish ponds. The influence of environmental factors onto primary productivity was investigated in ponds with and without organic manure. Nitrate nitrogen demonstrated the closest relationship with the gross primary productivity followed by chlorophyll a level and N/P ratio in manured ponds. When no manuring was applied, the importance of the nutrients along the food chain: nutrients– phytoplankton – zooplankton decreased. Trends, which can be used for increasing of productivity in carp ponds, were obtained. They give indications to improve the existing practices for better management of production efficiency and water quality in fish farms.

Key words: primary productivity, carp fish ponds, environmental factors.

Introduction

Fishponds are specific open aquatic systems inhabited by a simple community of living organisms including the main trophic levels (nutrients, phyto-, zooplankton and fish). The primary productivity (PP) is a fundamental biological characteristic being on the lowest trophic level of the food chain and is result of phytoplankton photosynthesis. Therefore, by measuring intensity of photosynthesis we could estimate the PP and get insight into the transformations of the matter and energy in aquatic ecosystems (JANA, 1979; NORIEGA-CURTIS, 1979).

Hence, the investigations of PP in carp fish ponds, its relations to biotic and abiotic environmental factors their strength of influence on PP is of a great scientific interest and have a practical significance.

Measurement of primary production for fish ponds gives the best picture of the outcome of the applied cultivation activities (in particular fertilization) and the rate of photosynthesis, as a first step towards the materialization of the natural fish productivity. That is why one of the prospects for aquaculture is through better utilization of primary productivity to increase the production of filter-feeding fish in extensive or semi-intensive pond systems.

Materials and Methods

The institute of Fishery and Aquaculture, Plovdiv is located in the northern part of the city of Plovdiv, in the

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western Upper Thracian valley. The region is characterized by a transitional-continental climate. The study was carried out in the Plovdiv base during three consecutive years (2004, 2005 and 2006). The ponds are supplied with water from Maritsa River by means of "Eni-Ark" irrigation canal. Seven earthen ponds were involved in the experiment, which individual size varies between 1.8 and 3.9 da (Table 1). According to ZHANG *et al.* (1987) the ponds of this size are among the most productive and easy for management. Their bottom is silty, but the periphery and the shallowest parts of some of them have a strip of 1-2 m width with increased content of sand.

The pond size, their shallowness, vertical and horizontal homogeneity are part of the preconditions for choosing them for model object. About 3000 $kg.ha^{-1}$ mineralized manure once in April each year was applied to ponds No 6, 12 and 17. Additionally to the natural food grain forage was given to the fish according to a scheme related to their seasonal growth rate. The periodical examination did not reveal any fish diseases. The ponds No 6, 12 and 17 were fertilized with mineralized manure (approx. 3000 $kg.ha^{-1}$) once per year (each April). The ponds No 8, 15, 16 and 18 were used as control ponds without manuring. Additionally, the fish were fed with natural grain feeds according to the seasonal growth rate. The periodical examination did not reveal any fish diseases.

The applied polycultural technology (NIKOLOVA *et al.*, 2008a, b) included mixed breeding of 30 individuals per da^{-1} one-year old bighead carp (T_1), (*Aristhichthys nobilis* Richardson, 1845), 50 individuals per da^{-1} one-year old common carp (K_1), (*Cyprinus carpio* Linnaeus, 1758) and 10 individuals per da^{-1} grass carp (one and two-year old) ($A_{1/2}$), (*Ctenopharyngodon idella* Valenciennes, 1844).

Table 1. Design and schedule of the ponds included in the experiments in the period 2004 - 2006.

Year	**Variants of breeding**	
	Manured ponds, $num.da^{-1}$	Control ponds, $num.da^{-1}$
	Pond No (area in da)	
2004	6 (3.8) 17 (2.6)	8 (3.8) 16 (2.7) 15 (3.1) 18 (1.8)
2005	12 (3.9) 17 (2.6)	8 (3.8) 16 (2.7)
2006	12 (3.9) 17 (2.6)	8 (3.8) 16 (2.7)

The samples were taken from a station localized 1-2 m away the shore before the outlet device (savak) of each fishpond. The sampling was carried out fortnightly between 8:30 and 11:00 a.m. from May to September (2004, 2006) and from June to September (2005). The final sampling was carried out in the last decade of September. Due to the large number of investigated characteristics some of the samples were taken with one to three days difference.

All the samples were taken from the surface layer (0.3-0.5 m depth) according to the Bulgarian and European standards (e.g. EU Water Framework Directive 2000/60/EC).

The total solar radiation in MJ m^{-2} was recorded by pyranometer type M 80 M. The water column transparency was measured by the Secchi disk method.

The PP ($g.O_2.m^{-2}.24\ h^{-1}$) was determined by a light/dark bottle technique in its oxygen modification. Firstly, the pond water was taken and homogenized in a 10 l plastic bucket and then the bottles were filled with water. Three pairs of light and dark bottles were used for each sample. The determination of the exposure period of the bottles was calculated as the light part of the day was separated in 5 equal time intervals. The bottles were exposed for a period including the second and third part of the above mentioned five time intervals. Within this period about 55-60% of total daily production has been synthesized according to VOLLENWEIDER *et al*. (1969). The exposure depths depended on the measured Secchi disk transparency and they usually were in the range 0.25.S - 3.S approximately.

Due to the big productivity of fishponds we frequently had to shorten the exposure time. In fact, the exposure time took one hour in most of the cases. In order to avoid the problem with oversaturation of water with oxygen and bubbles appearance in the bottles an original author's methodology was developed. The water sample was transferred to an empty plastic bottle double bigger volume than the sample. The bottle was pressed by hand until the liquid reached the bottleneck. Then the bottle was tightly closed and vigorously shaken. The elastic bottle walls tried to return to its normal position by creating lower pressure insight the bottle. This drove the excessive oxygen to convert into a gaseous phase. Finally, the oxygen concentration in the water was lower than the saturation value under the instant atmospheric pressure and there were no bubbles in the bottles during the exposure. The obtained productivity values were calculated for 1 m^2.

The diverse characteristics of fishponds presented by a great number of measurements allowed applying statistical methods. The difference between manured and control ponds was tested by Wilcoxon rank paired test and the relations beween the variables were revlealed by multiple linear regression with STATISTICA 7.0 (SOKAL & ROHLF, 1997; MCGARIGAL *et al*., 2000).

Results and Discussion

The relation between pond gross primary productivity (GPP) and the factors influencing it is illustrated on Fig. 1. The effect of these factors was best pronounced in the manured ponds. The correlation coefficient of the multiple regression ($R=0.65$) is highly significant ($p<0.000062$). The relation between pond factors (independent variables) and the gross primary productivity (GPP) in the equation decreased from the right to the left of regression equation. The highest relationship was demonstrated by Nitrate nitrogen ($p=0.002$), followed by the chlorophyll *a* level ($p=0.01$), the N/P ratio ($p=0.014$) and the flow rate of water which regression coefficient was not significantly related with GPP ($p=0.10$).

A similar relation of GPP was revealed by means of multiple linear regression including three independent variables - T, NO_3 and Chl *a* within field experiments at Srebarna Lake (KALCHEV *et al*., 2012). A statistically significant positive correlation with the nitrogen has been found by other researchers as well (GARG & BHATNAGAR, 2000). The positive effect of the manuring, leading to nutrient enrichment (especially phosphorus) and increasing of the PP was revealed in different lakes (KAGGWA *et al*., 2009; JANA *et al*., 2012). KIPKEMBOI *et al*. (2010) showed the manure positive effect onto chlorophyll *a*. According to other researchers, GPP is related with the solar radiation and chlorophyll *a*, but not with the total phosphorus or total inorganic nitrogen concentration (IWAKUMA *et al*., 1989). Research works found out that the regression analysis gives predictable relationship between PP and total inorganic nitrogen or total phosphorus in the water (DIANA *et al*., 1991).

The multiple regression for the control ponds delivered the following equation: $lgPgross=0.39 + 0.40lgChl\ a + 0.31lgNH_4 + 0.017TR - 0.17lgPO_4 - 0.09lgBMclad - 0.43lg Oxid$. The significance levels of regression coefficients were for lgChl *a* $p=0.0001$, $lgNH_4$ $p=0.01$, TR $p=0.02$, $lgP0_4$ $p=0.046$, lgBMclad $p=0.059$, lgOxid $p=0.052$, respectively.

Legend: BMclad – *Cladocera*'s biomass; Oxid - water oxidability.

The highest correlation with the GPP showed the chlorophyll *a* content in the phytoplankton, ammonium nitrogen, total radiation, phosphate concentration, *Cladocera*'s biomass and water oxidability. The correlation coefficient of the multiple regression ($R=0.69$) was a little bit higher compared to the manured ponds ($R=0.65$). The significance level ($p<0.000043$) was high as well. The GPP in the control ponds was related with more factors compared to manured ponds. Apparently the lack of manure seemed to decrease the role of nutrients along the food chain: nutrients – phytoplankton – zooplankton. As a result, there was an increased water transparency in the control ponds compared to manured ponds (Fig. 2).

Therefore, there was an increased macrophyte growth, which overshadowed the phytoplankton (HOLOPAINEN *et al.*, 1992), utilized the phosphate phosphorus and negatively changed the N/P ratio for the phytoplankton (ABDEL-TAWWAB, 2006). The negative relation with the phosphate phosphorus and the positive relation with the ammonium lead to possible nitrogen limitation (HARGREAVES, 1998). Probably the stronger macrophyte development (more than the phytoplankton) in the control ponds contributed for increasing of oxidation. In fact, this was the negative relation with the PP. It is known that the copepods and rotifers are less efficient phytoplankton filtrators than the cladocerans and the latter are negatively related with the phytoplankton production only (KAGGWA *et al.*, 2009; DODSON *et al.*, 2000; POTUŽÁK *et al.*, 2007).

The multiple regression for chlorophyll *a* in phytoplankton as dependent variable in manured ponds delivered the following equation: lgChl *a*=2.9 – 0.025Secchi – 0.15lgBMbenthos – 0.35lgN/P + 0.36lgNO_3 with regression index significance levels for Secchi p=0.00005, lgBMbenthos p=0.00045, lgN/P p=0.0029, lgNO_3 p=0.0028, respectively, and multiple correlation index R=0.75 with significance level p<0.0000001 (Secchi - Secchi transparency of water column).

Probably the higher turbidity in manured ponds limits both the phytoplankton growth and the immersed macrophyte (HOLOPAINEN *et al.*, 1992). The negative relation with the N/P ratio indicated possible indirect phosphorus influence. The positive regression coefficient of the nitrogen confirmed the results of PP equations for possible nitrogen limitation, while the negative regression coefficient with the zoobenthos most probably was due to the different time occurrence of the growth peaks of both groups of organisms and there was no real casual connection between them.

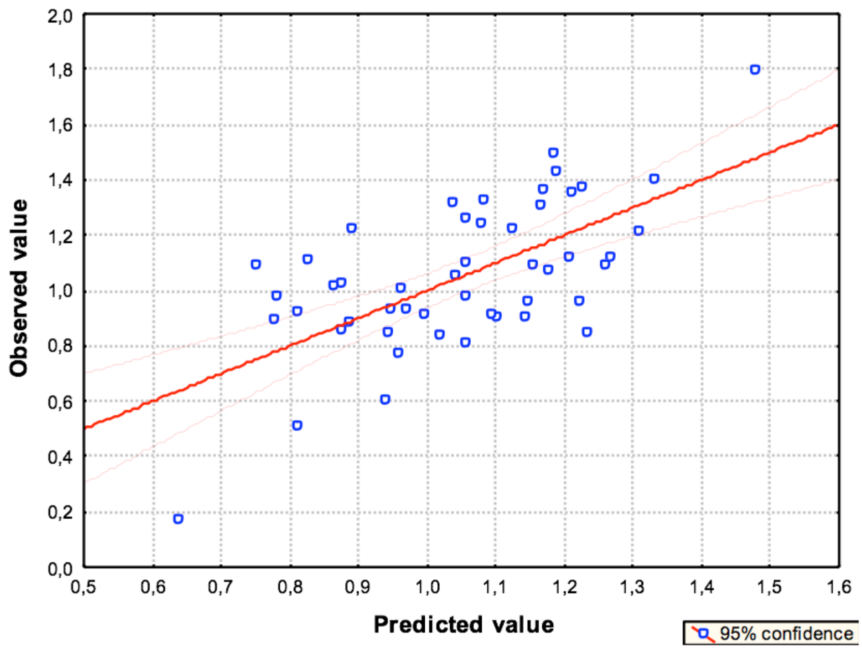

Fig. 1. Observed and predicted values of multiple linear regression of GPP, as a dependent variable, NO_3, Chl *a*, N/P and Flow-rate as independent variables in manured ponds for 2004/05/06 investigation period. The regression equation is lgPgross=0.58 + 0.29lgNO_3 + 0.20lgChl *a* + 0.18 lgN/P +0.056lgFlow-rate with regression coefficient, significance levels for lgN0_3 p=0.002, lgChl *a* p=0.01, lgN/P p=0.14, lgFlowrate p=0.10, respectively, multiple correlation coefficient R=0.65, with level of significance p<0.000062.
Legend: GPP and Pgross – Gross primary productivity; Chl *a* - chlorophyll *a*;

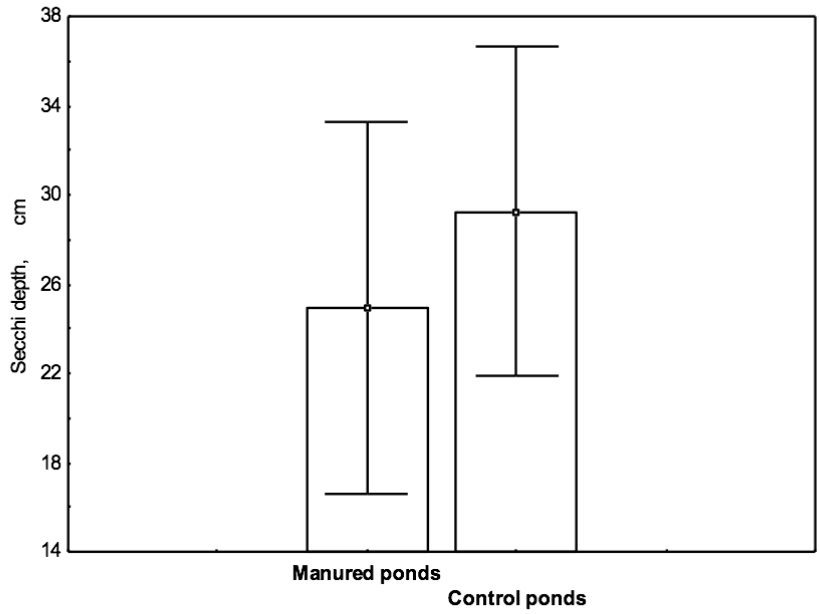

Fig. 2. Average values and standard deviations of Secchi disk transparency in manured and control ponds significantly different for P=0.004 (Wilcoxon test).

The multiple regression of Chl *a* in control ponds delivered the following equation: lgChl *a*=1.92 + 0.28lgBMrot – 0.17lgBMcald – 0.14lgMacroph with regression coefficients, which significance levels were for lgBMrot p=0.0009, lgBMclad p=0.0014, lgMacroph p=0.024, respectively, and multiple correlation coefficient R=0.64, for level of significance p<0.00001 (legend: BMrot - rotatorian biomass; Macroph – macrophyte)

Apparently the lack of enhanced nutrient factors in the control ponds had a significant influence on the regression equation and suggested lower levels of trophy in these ponds. The „top-down“ influence was expected to be stronger along the food chain in water of lower trophy (McQueen *et al.,* 1986). Therefore, the biomass of the *Cladocera*, which are more efficient filtrators, had a negative regression coefficient compared to the *Rotatoria*, which have a positive regression coefficient. The rotifers seem to utilize more effectively the phytoplankton and their growth peaks match more closely with the chlorophyll's peaks (Potužák *et al.,* 2007). Macrophytes also demonstrated a negative relationship because of their expressed domination in the control ponds compared to manured ponds causing negative effect on phytoplankton.

Percentage of utilized solar energy (PEU%) in manured ponds repeated more or less the already established relations between the phyoplankton and biotic and abiotic factors from previous two equations. So, the PEU positively correlated with Pgross/Chl *a* (p=0.0000001), chlorophyll *a* (p=0.0000001) and N/P ratio (p=0.009). There was a weak, negative insignificant relation between the PEU and the nitrate ions (p=0.28). The correlation index of multiple regression (R=0.83) was high with significance level p<0.0000001.

The following regression equation for PEU of the control ponds was derived: PEU=3.27 + 1.45lgChl *a* + 1.27lgPgross/Chl *a* – 0.23lgNzoop – 2.1lgT, with significance levels for lgChl *a* p=0.0000001, lgPgross/Chl *a* p=0.0000001, lgNzoopl p=0.0036, lgT p=0.013, respectively (Nzoop - zooplankton numbers).

The correlation coefficient of multiple regression (R=0.81) for the control ponds was high with significance level p<0.0000001. As in the manured ponds, utilizing of solar energy in the control ponds was related with the chlorophyll *a* concentration and Pgross/Chl *a* ratio. The zooplankton numbers and the temperature here were negatively related with PEU. Not the biomass, but the zooplankton numbers was the factor which more actively influenced the phytoplankton. The result was a decreased light utilization. Presumably the reason was the prevalence of small living forms in the zooplankton, surviving under the strong fish pressure.

The multiple regression for the ratio GPP/chlorophyll *a* (lgPgross/Chl *a*), known as assimilation number (AN), repeated some relations observed in the above mentioned equations. On the other hand, it demonstrated markedly weaker relation to the variables selected by the regression analysis.

The correlation coefficient of the multiple regression of respiration in manured ponds was R=0.71 with significance level p<0.000002, respectively. There was a positive relation with the chlorophyll *a* (p=0.0047), nitrate ions level (p=0.015) and a negative relation with the rotifer biomass (p=0.023) and the total nitrogen (p=0.076). The relation between the chlorophyll *a* and the nitrate nitrogen was already discussed above. The green pigment concentration elevation as an indicator for enhancement of the pond trophy led to increasing of the respiration intensity. As they are the largest zooplankton group, the rotifer biomass and total nitrogen are indirectly related by the respiration. It was difficult to establish a causal relationship on the current data basis. The intensity of catabolic processes seemed to decrease with the increase of the total nitrogen in manured ponds, where the anabolic processes prevailed.

The regression equation for respiration in the control ponds is following: R24= -15.3 + 4.1lgNzoop – 5.6lgNH_4 – 0.15Secchi + 1.9lgFlow-rate, with regression coefficient significance levels for lgNzoop. p=0.002, lgNH_4 p=0.023, Secchi p=0.028 and lgFlow-rate p=0.069. The correlation index of multiple regression (R=0.52) was not too high and was with significance level p=0.004.

There was a positive correlation of respiration with the zooplankton numbers (p=0.002) in the control ponds and a negative correlation with the ammonium nitrogen (p=0.023). The respiration increased with the increasing of zooplankton numbers, while the increasing of the ammonium nitrogen was accompanied by the oxygen decrease and reduction of the respiration, respectively. The enhanced macrophytes level in the control ponds apparently suppressed the phyto- and the zooplankton development. An indirect sign for this was the water transparency which demonstrated a negative relation with the respiration. Increasing the flow rate led to the turbulence enhancement of the water followed by the increasing of the oxygen concentration and the respiration, respectively. The mineralization in the flowed ponds was more intensive and there was more expressed turbulent mixing of water compared to the lentic ponds (KONSTANTINOV, 1979).

Conclusions

1. The nitrate nitrogen, followed by the phytoplankton chlorophyll *a* concentration and N/P ratio are the factors which are related with and have a significant influence on the GPP in manured carp ponds with an applied polyculture technology. GPP correlates with more factors in control ponds (without manure) compared to manured ponds. The lack of manure decreases the significance of nutrients along the food chain: nutrients– phytoplankton – zooplankton.

2. The phytoplankton chlorophyll *a* concentration in the manured ponds is significantly influenced by the Secchi disk transparency of the water column, zoobenthos biomass, N/P ratio and nitrate nitrogen. The shortage of nutrient elements in the ponds without manure leads to lower trophy levels. The „top-down" influence on the food chain presented by the zooplankton components is more enhanced.

3. The percentage of utilized solar energy in the manured ponds correlates positively with Pgross/Chl *a* (AN), chlorophyll *a* and N/P ratio. Utilizing of the solar energy in the control ponds is also positively correlated with the Pgross/Chl *a* ratio and the chlorophyll a level, but the zooplankton and water temperature have a negative influence.

4. The plankton respiration in the manured ponds shows a positive relation to

the chlorophyll *a*, the nitrate ions, and the total nitrogen. There is a positive correlation in the control ponds with the zooplankton numbers and the flow rate of the water. A negative correlation is found out with the NH_4-N and the water transparency.

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