Bull. Environ. Contam. Toxicol. (2004) 73:927–932

DOI: 10.1007/s00128-004-0515-9

Bulletin of Environmental Contamination and Toxicology

Impacts of Cage-Culture of *Oreochromis niloticus* on Organic Matter Content, Fractionation and Sorption of Phosphorus, and Alkaline Phosphatase Activity in a Hypereutrophic Lake, People's Republic of China

M. Zhang,[1] Y. Zhou,[1] P. Xie,[1] J. Xu,[1] J. Li,[1] D. Zhu,[2] T. Xia[3]

[1] Donghu Lake Ecosystem Experimental Station, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430072, People's Republic of China
[2] College of Resources and Environment, Huazhong Agricultural University, Wuhan 430070, People's Republic of China
[3] College of Resources and Environmental Sciences, Nanjing Agricultural University, Nanjing 210095, People's Republic of China

Received: 20 June 2004/Accepted: 8 September 2004

Fish farm waste is composed of a range of organic compounds, such as unconsumed food, fecal and excretory matter, and the excess organic matter accumulates in sediment (Hargrave et al. 1997; Riise and Roos 1997; Delgado et al. 1999), which has been identified as one of the sources of phosphorus pollution (Kibria et al. 1996). Sedimentary organic phosphorus compounds have been demonstrated to be decomposed and mineralized by enzymatic complexes such as phosphatases produced by microbes (Barik et al. 2001). Although cage-culture of freshwater fish is very popular in Chinese lakes and has contributed greatly to the substantial increases of inland fishery production during the past decades, studies are rare about the impacts of cage culture on the structures and dynamics of nutrients (i.e., phosphorus) in sediments. Therefore, we investigated changes in organic matter content, alkaline phosphatase activities, and the species composition and sorption behavior of P in sediments beneath and outside the cages, as well as to discuss the possible mechanisms underlying the changes caused by cage-culture.

MATERIALS AND METHODS

Net-cage culture had been conducted in Lake Donghu, a shallow subtropical hypereutrophic lake, from around 1985 to 1998. Fifteen net-cages (5×2.5 m) were used. The bottom of the cage almost reached the bottom of the lake (about 2.5 m deep in the water) and the upper rim was 0.7 m above the water surface. A food platform (2×1 m) was fixed at the middle of each cage, and about 1500 individuals of *O. niloticus* were stocked into each cage and reared for 90 days from the end of June to September every year. Fish were fed twice a day at 2.5-3% of body weight (Xie 1997). From March to August 2000, sediment columns beneath and outside the cages were obtained respectively using a hand driven stainless steel corer (50 cm long with an internal diameter of 3.5 cm). For depth profiles, sediment columns were sliced at 6.0-cm intervals. Twenty-four cores were collected at each site, then, the slices in the same interval were grouped at random into three parts. Each triplicate contained eight slices, which were mixed thoroughly. Organic matter (OM) and amorphous iron oxide contents were determined using the method described by Kalembasa and Jenkinson (1973)

Correspondence to: Y. Zhou or P. Xie

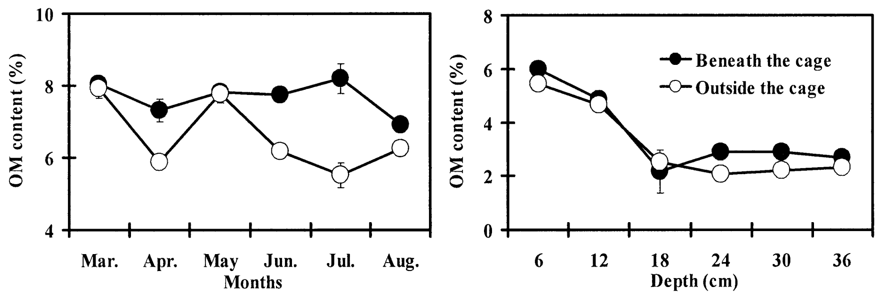

Figure 1. Organic matter content in sediment beneath and outside the culture cages in Lake Donghu. A. Seasonal changes in surface (0-6cm) sediments and B. vertical changes (samples were taken on 27 Apr. 2000).

and Xu and Chen (1980), respectively. Sediments for P sorption were air-dried and sieved through a 0.5-mm mesh. Sorption isotherms were conducted as described by Holford et al. (1974), but native adsorbed P was not determined or included in the sorption measurements. Both sorption capacities (X_m) and sorption strength (affinities, K) were determined from the simple Langmuir equation fitted to an isotherm measured over a final concentration from 0.78 to 31.0 mg P L^{-1}. P fractionation was carried out according to Petersen and Corey (1966), which grouped sediment P into aluminum-bound phosphate (Al-P), iron-bound phosphate (Fe-P), occluded phosphate (O-P) and calcium-bound phosphate (Ca-P). Alkaline phosphatase activity (APA) was determined using the method described by Garcia et al. (1993).

RESULTS AND DISCUSSION

OM content was significantly higher in the sediments beneath the cages than those outside the cages (ANOVA, $P < 0.05$, Fig. 1). Vertical profiles of OM content in the sediments showed that OM content was remarkably higher in the surface layers (0-12 cm) than in the deeper layers (18-36 cm). Same changes were also found in both P concentration (Fig. 2) and APA (Fig. 3). These suggested that cage culture of *O. niloticus* introduced a large amount of organic matter into sediment, and subsequently enriched phosphorus of different forms and increased APA. Zhou et al. (2001) reported that, in the same culture systems, V_{max} values of alkaline phosphatase in surface sediments increased markedly at sites immediately under and adjacent to the cage and peak V_{max} values in the top 5 cm of the sediment under the cage were also observed relative to their deeper control, and suggested this phenomenon was the result of deposition of organic matter, such as fish feces.

Fe-P made the largest contribution to the sediment P pool (Fig. 2), and the average Fe-P values in the surface sediment reached 1938.7 μg g^{-1} and 1480.6 μg g^{-1} beneath and outside the cages, respectively. All P species (Fig. 4), together with amorphous iron oxide (Fig. 5), exhibited significantly higher concentrations in the

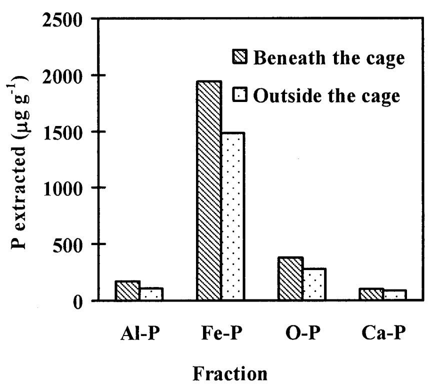

Figure 2. A comparison of the average values of P fractions pattern in surface (0-6cm) sediment beneath and outside the culture cages in Lake Donghu.

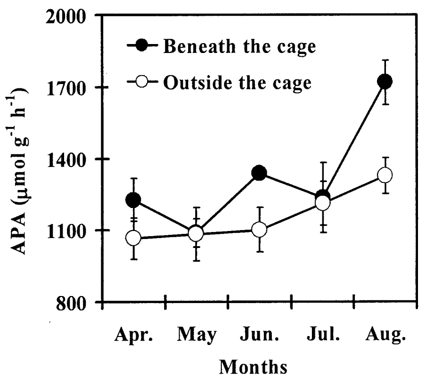

Figure 3. Changes in alkaline phosphatase activity in surface (0-6 cm) sediment beneath and outside the culture cages in Lake Donghu.

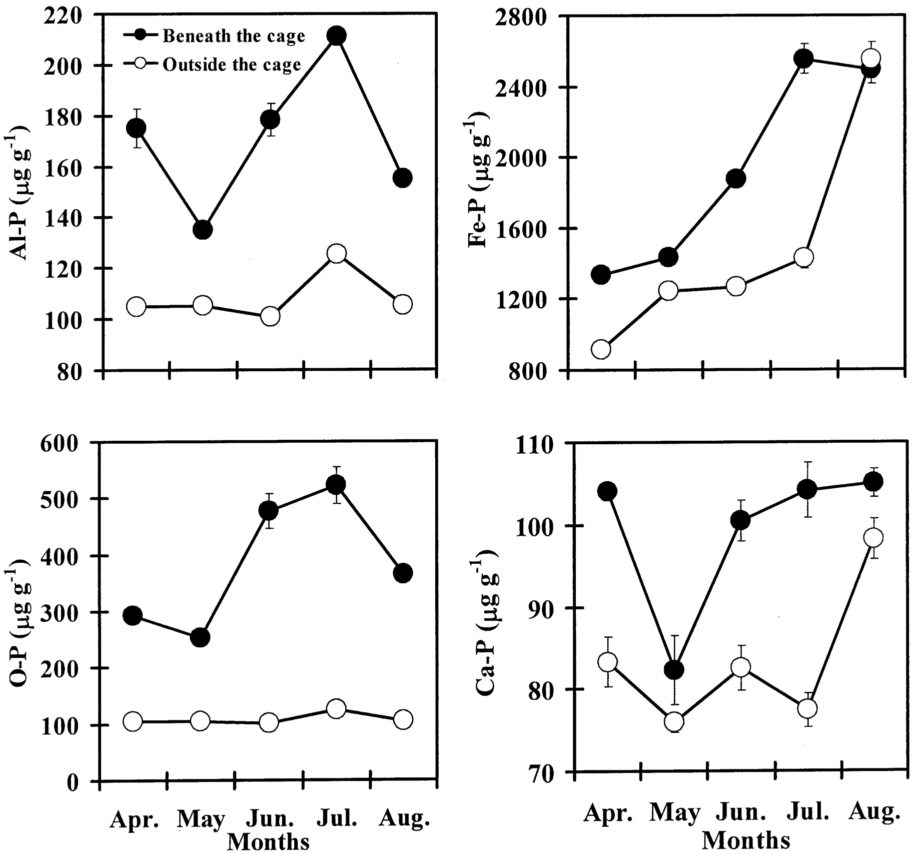

Figure 4. Changes in concentrations of P fractions in surface (0-6cm) sediment beneath and outside the culture cages in Lake Donghu.

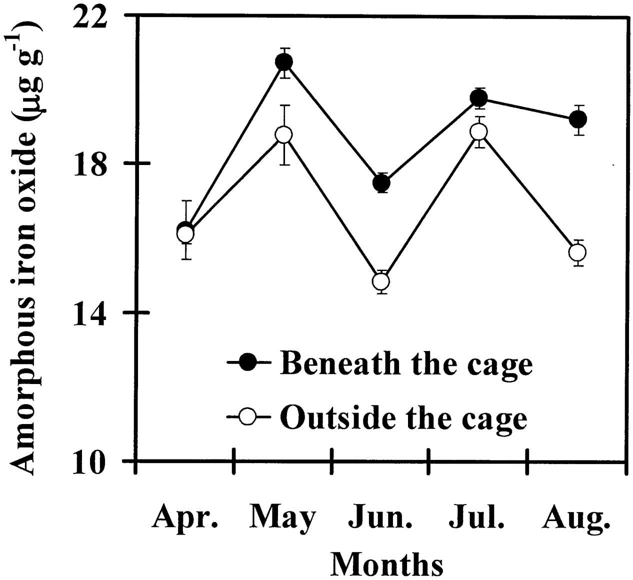

Figure 5. Changes in amorphous iron oxide content in surface (0-6 cm) sediment beneath and outside the culture cages in Lake Donghu.

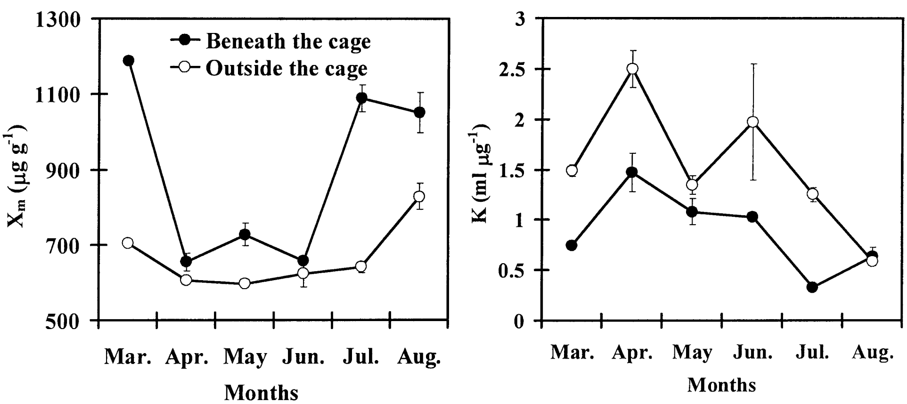

Figure 6. Changes in parameters of P sorption in surface (0-6 cm) sediment beneath and outside the culture cages in Lake Donghu.

surface sediments beneath the cages than those outside the cages (ANOVA, $P < 0.05$), which indicated that Fe-P may be a key component for P sorption in the sediment (Holford et al. 1997). In addition, the sorption strength (K) values were significantly lower in surface sediment beneath the cages than those outside the cages (ANOVA, $P < 0.05$, Fig. 6), which also indicated organic matter input derived from cage culture is retained in lake sediments, causing P loading and phosphatase stimulation, which could saturate the capacity for future P retention, thereby promoting eutrophication of lake water. In contrast, the relevant sorption capacity (X_m) values were significantly higher in surface sediment beneath the cages (654-1188 μg g^{-1}) than those outside the cages (596-828 μg g^{-1}, ANOVA, $P < 0.05$, Fig. 6). The elevated X_m values beneath the cages may be caused by increased sorption sites due to the increase in fine grain of the sediment affected by large amounts of organic matter induced by intensive fish culture (Cizkova et al. 1996, Diaz-Espejo et al. 1999, Madeyski and Bednarczyk 2000).

Acknowledgments. This work was supported by the grants from the National Science Foundation of China (39170165, 39670149 and 20177033), the State Key Laboratory for Freshwater Ecology and Biotechnology of China (FEBL), Donghu Lake Ecosystem Experimental Station.

REFERENCES

Barik SK, Purushothaman CS, Mohanty AN (2001) Phosphatase activity with reference to bacteria and phosphorus in tropical freshwater aquaculture pond systems. Aquac Res 32: 819-832.

Cizkova H, Strand JA, Lukavska J (1996) Factors associated with reed decline in a eutrophic fishpond, Rozmberk (south Bohemia, Czech Republic). Folia Geobot 31: 73-84.

Delgado O, Ruiz J, Perez M, Romero J, Ballesteros E (1999) Effects of fish farming on seagrass (*Posidonia oceanica*) in a Mediterranean bay: seagrass decline after organic loading cessation. Oceanol Acta 22: 109-117.

Diaz-Espejo A, Serrano L, Toja J (1999) Changes in sediment phosphate composition of seasonal ponds during filling. Hydrobiologia 392: 21-28.

Garcia C, Hernandez T, Costa F, Ceccanti B, Masciandaro G (1993) Kinetics of phosphatase activity in organic wastes. Soil Biol Biochem 25: 561-565.

Hargrave BT, Phillips GA, Doucette LI, White MJ, Milligan TG, Wildish DJ, Cranston RE (1997) Assessing benthic impacts of organic enrichment from aquaculture. Water Air Soil Pollut 99: 641-650.

Holford ICR, Hird C, Lawrie R (1997) Effects of animal effluents on the phosphorus sorption characteristics of soils. Australian J soil Res 35: 365-373.

Holford ICR, Wedderburn RWM, Mattingly GEG (1974) A Langmuir two-surface equation as a model for phosphate adsorption by soils. J Soil Sci 25: 242-255.

Kalembasa SJ, Jenkinson DS (1973) A comparative study of titrimetric and gravimetric methods for the determination of organic carbon in soils. J Sci Food Agric 24: 1085-1095.

Kibria GD, Nugegoda PL, Fairdough R (1996) Aspects of phosphorus pollution from aquaculture. Naga Manila 19: 20-24.

Madeyski M, Bednarezyk T (2000) Physical, chemical and rheological characteristics of bottom sediments in reservoirs and fish ponds, Poland. International Association of Hydrological Sciences, Publication 263: 237-241.

Petersen GW, Corey RB (1966) A modified Chang and Jackson procedure for routine fractionation of inorganic soil phosphate. Soil Sci Soc America Proc 30: 563-565.

Riise JC, Roos N (1997) Benthic metabolism and the effects of bioturbation in a

fertilised polyculture fish pond in Northeast Thailand. Aquaculture 150: 45-62.
Xie S (1997) Supplementary feeding for cage-cultured *Tilapia*: A bioenergetic modeling approach. Ph. D thesis, Institute of Hydrobiology, The Chinese Academy of Sciences, Wuhan, China.
Xu Z, Chen J (1980) The determination of amorphous iron oxide in soils. Chinese J Soil Sci 6: 32-34 (in Chinese).
Zhou Y, Li J, Fu Y, Zhang M (2001) Kinetics of alkaline phosphatase in lake sediment associated with cage culture of *Oreochromis Niloticus*. Aquaculture 203: 23-32.