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Assessment effects of cage culture on nitrogen and phosphorus dynamics in relation to fallowing in a shallow lake in China

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Abstract Nitrogen and phosphorus dynamics in relation to fallowing in a fish cage farm was investigated in a shallow lake in China. Four sampling sites were set: beneath the cages, at the cage sides, and 50 and 100 m east of the cage farm. Total nitrogen (TN) and total phosphorus (TP) in lake water and sediment were analyzed during a 2-year rearing cycle. The cage culture had a fish yield of 16.3–39.2 tonnes in the study period. Based on the mass balance equation, 1533–3084 kg TN and 339–697 kg TP were contributed to the lake environment. Nitrogen and phosphorous concentrations showed greater increase in the first culture period than in the second rearing cycle. No obvious changes were found at the sampling sites 50 and 100 m east of the cages during the study periods. Main impacts were found close to the cages (beneath the cages and at the cage side); the sampling points at the cage side showed relatively high TN and TP sedimentation. After 3 months of fallowing, water TN and TP decreased significantly but the sediment TN and TP contents remained high. Therefore, recovery seems to happen during fallowing but attention should be paid to whether the culture continues to operate in the future.

Keywords Cage fish farm · Nitrogen and phosphorous loading · Dynamic · Fallowing · Lake eutrophication

Introduction

The effluents of cage culture, mainly uneaten food, and faecal and urinary products, are released directly into the environment and result in many environmental problems such as eutrophication, fish growth retardation, and changes of benthos communities (Silvert 1992; Beveridge 1996; Liu et al. 1997; Guo and Li 2003; Yucel-Gier et al. 2007). Traditionally environmental monitoring has concentrated on a few key physical and chemical variables

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and organisms, but in recent years, increasing numbers of studies have focused on whole-system environmental assessment, including considerations of the assimilative capacity of specific systems and their ability to absorb and dilute perturbations (Osparcom 1998; Maroni 2000; Fernandes et al. 2001). In restricted exchange environments (e.g., shallow lakes), there is a risk of hypernutrification, potentially causing undesirable effects (Midlen and Redding 1998).

In most studies, the amount of nutrients released to the environment is calculated theoretically whereas only a few of them are based on direct measurements (Domíguez et al. 2001; Mazón et al. 2007). To assess the possible influences of fish cage culture on aquatic environment, it is necessary to quantify the amount of waste loading by models and/or food conversion ratios (FCR) (Beveridge 1996). Several studies have reported that nitrogen and phosphorus released from fish cage can affect chemical parameters of sediment (Beveridge 1996; Zhang et al. 2004; Yan 2005; Porrello et al. 2005; Kullman et al. 2007). Thus, monitoring of nutrients concentration in water and sediment during culture and fallowing periods could be useful for management of sustainable fish culture, such as obtaining the optimal time for fallowing, i.e., the duration required for the sediment to recover (Bron et al. 1993; McGhie et al. 2000; Macleod et al. 2004, 2006; Pereira et al. 2004).

In recent years, more attention has been paid to marine cage aquaculture. Unlike the marine environment with high current velocities, most freshwater lakes used for culture have relative low current velocities (NCC 1990), which are mainly caused by wind action and the magnitude of the horizontal current (Horne and Goldman 1994). In China, many shallow lakes are distributed along the middle and lower reaches of the Yangtze River. These lakes are usually productive, with a high diversity of fish species, and are an important base for fishery production (Cui and Li 2005). In order to increase the production of highly valuable fish species, many fish cages are established in these lakes. However, little information is available about the effects of fish farming on freshwater aquatic ecosystem in China (Liu et al. 1997; Guo and Li 2003; Cui and Li 2005).

In this study, nitrogen and phosphorus dynamics were investigated to assess the effects of cage culture on the water column and sediment in a shallow lake. The objective is to understand the nutrient loads of the cage culture with different nutrient loadings or fish yield in relation with fallowing over a 2-year cycle and obtain useful information for improving cage aquaculture practices in the future.

Material and methods

Study area and cage culture

The fish cages were located in a 35.3 ha bay of Lake Niushanhu (114°32′ E, 30°19′ N), a shallow lake in the middle reach of the Yangtze River, China (Fig. 1). Depth at the study site ranged from 1.8 to 2.5 m. Water current, mainly produced by the wind, was very low during the sampling period. Water temperature ranged from 9.1 to 30.5°C during the study period. The cages were built in 1997 and cultured mandarin fish (*Siniperca chuatsi*) until 1999 with a fish yield of about 1.0 tonne per year. Since 2000, the cages were used mainly to culture bluntsnout bream (*Megalobrama amblycephala*) and channel catfish (*Ictalurus punctatus*). A total of 100 and 180 floating polyethylene cages (each 3.3 × 3.3 × 2.0 m with a mesh size of 2 cm) were used in 2000 and 2001, respectively. Activities of cage culture were carried out from March to November every year and other months (December to February) were fallowing.

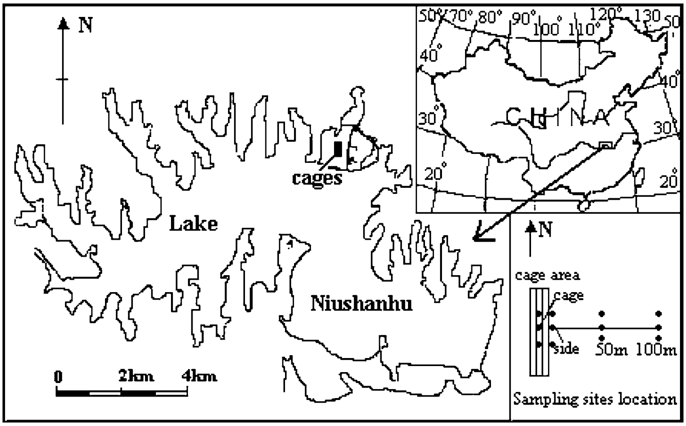

Fig. 1 Map of Lake Niushanhu and sampling sites locations

A total of 6576 kg juvenile mandarin fish, bluntsnout bream, and channel catfish were stocked in 100 cages and 5963 kg in 180 cages in 2000 and 2001, respectively. Stocking parameters are shown in detail in Table 1.

During the growing period of fishes in 2000 and 2001, Mandarin fish was fed with small live forage fishes during the entire experimental period. Bluntsnout bream and channel catfish were mainly fed with a commercial, pelleted and extruded diet (containing 29% protein, 1.2% P) at 2–4% of their body weight per day in three or four daily allocations. Some aquatic plants were supplied for bream at the beginning of the culture period. The feeding frequency was adjusted according to water temperature and growth of the fish in the cages. Three months were left for fallowing every year due to the harvesting by the end of November. The feed conversion rate by Bluntsnout bream ranged from 2.89 to 3.56 in 2000 and from 2.49 to 2.90 in 2001. Specific growth rates (SGR) and feed conversion ratio (FCR) of the cultured fishes were calculated monthly.

Sampling and analytical methods

Total nitrogen (TN) and total phosphorus (TP) in diets, fish bodies, water volume, and sediment were determined during a period of 2 years. In order to evaluate spatial distribution and temporal changes of nitrogen and phosphorus in water and sediment, four sampling sites were set, i.e., beneath the cages, at the cage side, and 50 m and 100 m east of the cages. Three replicates were taken at an interval of about 5 m at each sampling

Table 1 Stocking weight and fish yield of cage culture in 2000 and 2001

Species	Size (g ind.$^{-1}$)	Stocking weight (kg)		Fish yield ($\times 10^3$ kg)	
		2000[a]	2001	2000	2001
Mandarin fish	150–350	1272	430	1.9	0.6
Bluntsnout bream	25–175	3848	4310	11.5	31.7
Channel catfish	350–500	1456	1223	2.9	6.9
Total (kg)		6576	5963	16.3	39.2

[a] Data in 2000 from Guo and Li (2003)

location (Fig. 1). Samples were taken at bimonthly intervals from April to December 2000, February and August in 2001, and January in 2002.

Water quality and sediment nutrients were analyzed according to the methods described by Huang (1999). Water sampled from 0.5 m below the water surface and 0.5 m above the sediment were combined and taken for measurements of other parameters. TN was determined by the alkaline potassium persulfate digestion ultraviolet (UV) spectrophotometric method and TP digested with $K_2S_2O_8$ was determined by the ammonium molybdate spectrophotometric method. Sediment samples were taken about 10 cm from the top cores and then were dried at 60°C and stored at room temperature. TN in the sediment was determined by the Kjeldahl method and TP was digested using a perchlorate acid and sulfate acid and analyzed by the ammonium molybdate spectrophotometric method.

In order to calculate waste loads, N and P contents in extrude diets, forage fishes, and aquatic plants were analyzed. Then the N and P loadings from the cage culture were calculated with the following mass balance equation (Beveridge 1996):

$$\text{Input} = \text{Output} + \text{Accumulation} \tag{1}$$

In our study, the equation can be expressed as fallowing:

$$\text{Nutrient loadings} = \text{Dietary nutrient} - \text{fishbody deposition nutrient} \tag{2}$$

in which waste loading = sum of amounts of different foods fed (kg) × dietary nutrient content (%) − net fish biomass increase (kg) × nutrient content of caged fish (%).

Statistical methods

All data were analyzed using analysis of variance (ANOVA) followed by the post hoc Tukey test for multiple pairwise comparison (Statistica 6.0). One-way ANOVA was used to determine the difference between groups by sampling time, and two-way ANOVA was used to test for differences in the full data set (by sampling time and groups) (Aguado-Giménez and García-García, 2004). Student's *t*-test was used to compare different sampling sites between culture and fallowing periods.

Results

Fish growth in cage

From March to November, juvenile fish increased from 6.58 tonnes to 16.3 tonnes in 2000 and from 5.96 tonnes to 39.2 tonnes in 2001 (Table 1). Annual fish yield was 20.3 kg m^{-2} and 21.8 kg m^{-2} in 2000 and 2001, respectively. Monthly specific growth rates of the cultured fishes are shown in Fig. 2. The highest SGR value for mandarin fish (0.49% body weight day^{-1}) was observed in April. Bluntsnout bream showed the maximum SGR (1.0% body weight day^{-1}) from May to June. All cultured fishes had the minimum SGR in July. Very low SGR values were also found for all fishes in summer months.

Nitrogen and phosphorus loadings

The results of monthly nitrogen and phosphorus loadings from the diet in 2000 are shown in Table 2. Only 14.8% (8.2–24.4%) of TN and 11.0% of TP (3.3–19.0%) was assimilated by the cultured fishes. The highest waste loadings were found in summer (June–August).

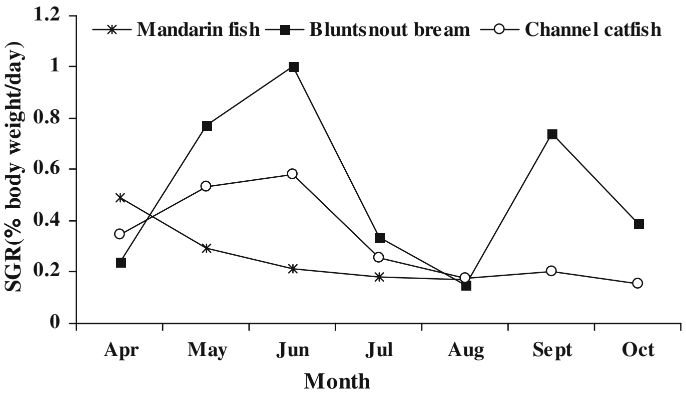

Fig. 2 Monthly specific growth rates of the cultured fishes in 2000. No data were available for mandarin fish due to cessation of culture after September

Table 2 Monthly nitrogen and phosphorous inputs of feed and loading into lake by cage-cultured fish from March to October in 2000 estimated by the mass balance equation

		Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Total
Feed (kg)	N	35.9	122	219	334	344	295	248	201	1799
	P	5.40	23.9	46.0	70.8	73.9	63.6	53.7	43.6	381
Assimilated by fishes (%)	N	14.2	14.3	18.6	19.1	8.30	4.30	21.5	23.0	14.8
	P	16.4	11.9	13.9	14.1	6.1	3.1	15.4	16.5	11.0

Monthly nitrogen and phosphorus loadings were not recorded in 2001. With the total feed input and fish production, the average conversion rates of TN and TP in feed to fishes were 22.9% and 17.0% in 2001. Based on annual fish yield, the nutrition loadings declined from 0.16 to 0.12 kg TN kg^{-1} fresh fish produced, and from 0.035 to 0.025 kg TP kg^{-1} fresh fish produced in 2000 and 2001, respectively.

According to Eq. 2, the cultured fishes were fed with 5.40 tonnes of forage fishes, 13.2 tonnes of aquatic plant and 118 tonnes of pellet feed, equivalent to 1799 kg TN, 381 kg TP and 4000 kg TN, 840 kg TP inputs in 2000 and 2001, respectively (Table 3). Based on the results of nutrients fed and assimilated by cage fishes, 1533 kg TN, 339 kg TP and 3084 kg TN, 697 kg TP were input to the lake environment in 2000 and 2001, respectively.

Table 3 Nitrogen and phosphorus budget of cage culture in 2000 and 2001

Year		Feed inputs (kg)			Total inputs (kg)	Assimilated by cultured fish (kg)	Wastes into water (kg)
		Forage fish	Pellet feed	Aquatic plant			
2000	TN	139	1624	35.5	1799	266	1533
	TP	25.2	350	5.20	381	41.7	339
2001	TN	27.5	3973	0	4000	916	3084
	TP	4.10	836	0	840	143	697

Table 4 Two-way (months × group) ANOVA for TNw, TPw (in water column), and TNs, TPs (in sediment)

Effect	TNw	TPw	TNs	TPs
Months	$F = 53.55$***	$F = 30.42$***	$F = 61.84$***	$F = 42.56$***
Groups	$F = 188.31$***	$F = 20.54$***	$F = 32.12$***	$F = 6.53$***
Months × groups	$F = 7.71$***	$F = 1.91$*	$F = 5.90$***	$F = 2.62$**

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Nitrogen and phosphorus dynamics in relation with sampling time and distances

In order to compare the interaction with different sampling times and sites, the results of two-way ANOVA with sampling times and sites are shows in Table 4. This indicated a significant effect of the interaction of both factors as regards TN concentration in water volume ($P < 0.001$), with gradual increases being shown from April to October in 2000. However, average TN or TP was significantly higher at the cage and cage side than at other sites in August (Tukey's HSD test, $P < 0.05$) and October of 2000 (Tukey's HSD test, $P < 0.001$) (Fig. 3a).

For TP, the interaction of both factors was significant ($P < 0.05$ or $P < 0.001$) (Table 4), but statistically significant differences were only observed between the sites of beneath cage and cageside. TP concentrations in water showed similar trend at the four sites during fish culture in 2000 (Fig. 3b). Also, TP increased from June 2000 and reached a maximum concentration in October 2000 at the stations at the cage and cage side. TP was significantly higher in June (Tukey's HSD test, $P < 0.001$), August ($P < 0.01$), October ($P < 0.05$) 2000 and August 2001 ($P < 0.01$) at the stations of cage and cage-side than at the stations 50 m and 100 m east of the cage farm.

As regards sediment TN, the interaction of both factors was significant ($P < 0.001$) (Table 4). The TN content in sediment and water showed similar trend, which increased greatly during fish culture in 2000 (Fig. 3c). There were significant differences between sampling sites during the study period (one-way ANOVA, $P < 0.001$) and the sediment TN content at the cage and cage side were significantly higher than at other sites (50 m and 100 m east of the caages) in August (Tukey's HSD test, $P < 0.05$) and October ($P < 0.01$) 2000 and even showed significant higher content beneath cage site in December ($P < 0.001$).

The sediment TP content showed similar trends as sediment TN (Fig. 3d). Significant differences of sediment TP between months and sampling sites were observed ($P < 0.01$) (Table 4). Sediment TP the cage and cage side sites showed significant increases ($P < 0.01$) from April to December in 2000 (Tukey's HSD test, $P < 0.01$). Higher content was observed at the cage side than at cage site from June to August but the opposite was observed in October and December.

Relationship between nitrogen and phosphorous in water column and in sediment

Matrix Pearson's correlation coefficients were calculated to assess relationships for the nitrogen and phosphorus variation both in water column and in sediment; the results are showed in Table 5. There were significant positive correlations between water TN concentrations and sediment TN at the cages and cage sides ($R = 0.68$–0.71, $P < 0.05$). However, only TP concentrations in cages were correlated significantly with TP contents in sediment ($R = 0.53$, $P < 0.05$). Meanwhile, both TN and TP concentrations at the cage

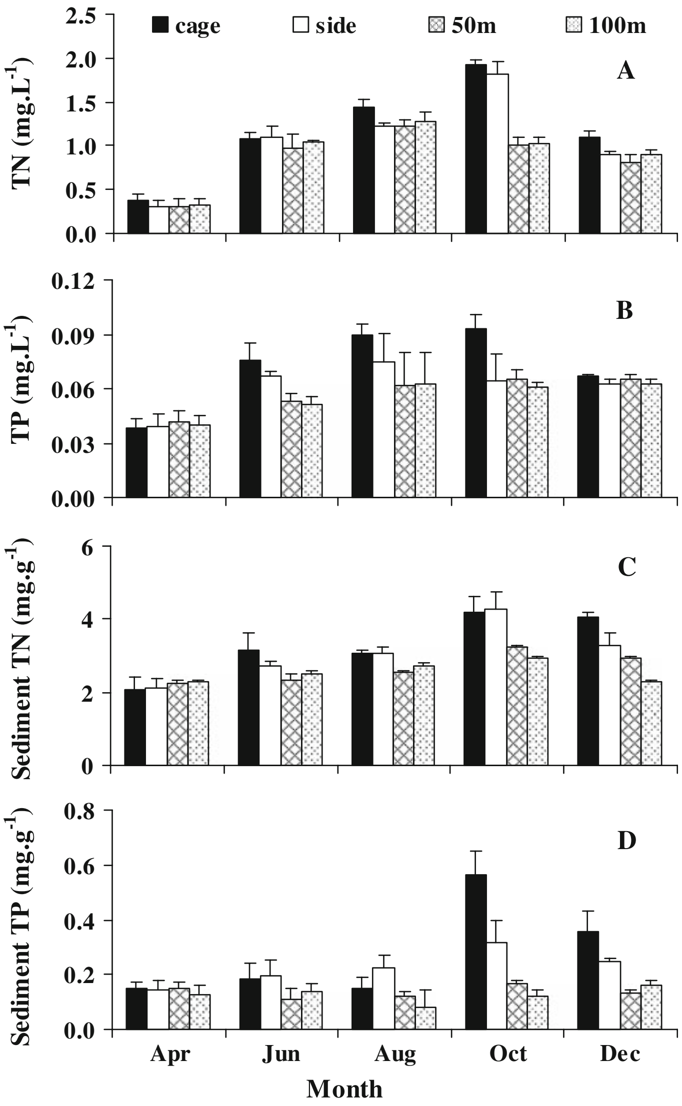

Fig. 3 Bimonthly nitrogen and phosphorus variation in water column and sediment in 2000 (**a**: total nitrogen concentration in water column; **b**: total phosphorus concentration in water column; **c**: total nitrogen content in sediment; **d**: total phosphorus content in sediment) (bars: standard error of mean)

and cage side interacted significantly due to their separation of less than 10 m from each other ($R = 0.69$–0.95 for TN and 0.53–0.73 for TP).

Comparisons of nitrogen and phosphorus variation between culture and fallowing periods

There were two fallowing periods during our study, i.e., December 2000 to February 2001 and January 2002 (Fig. 4). For TN in water column, a decreasing trend was observed

Table 5 Pearson's correlation coefficients for relationships between variables ($N = 23$)

	1-TNw	2-TNw	3-TNw	4-TNw	1-TNs	2-TNs	3-TNs	4-TNs
1-TNw	1.00							
2-TNw	**0.95**	1.00						
3-TNw	**0.85**	**0.78**	1.00					
4-TNw	**0.77**	**0.70**	**0.91**	1.00				
1-TNs	**0.71**	**0.68**	0.40	0.33	1.00			
2-TNs	**0.69**	**0.71**	**0.45**	0.38	**0.68**	1.00		
3-TNs	0.34	0.37	0.15	0.00	**0.55**	**0.54**	1.00	
4-TNs	**0.72**	**0.74**	**0.55**	**0.51**	**0.67**	**0.55**	**0.52**	1.00
	1-TPw	2-TPw	3-TPw	4-TPw	1-TPs	2-TPs	3-TPs	4-TPs
1-TPw	1.00							
2-TPw	**0.75**	1.00						
3-TPw	**0.56**	**0.69**	1.00					
4-TPw	**0.50**	**0.43**	**0.63**	1.00				
1-TPs	**0.53**	0.38	0.29	0.08	1.00			
2-TPs	**0.73**	0.39	0.16	0.24	**0.55**	1.00		
3-TPs	−0.07	−0.07	−0.23	−0.37	**0.53**	0.20	1.00	
4-TPs	−0.07	−0.22	−0.18	0.03	−0.23	−0.05	−0.31	1.00

1-cage, 2-side, 3-50 m, 4-100 m; TNw and TPw, total nitrogen and phosphorus in water column; TNs and TPs, total nitrogen and phosphorus in sediment

* values in bold mean significant correlation at $P < 0.05$

among all the sampling sites from the first to the second culture cycles with significant differences (one-way ANOVA, *F*-test, $P < 0.01$). No obvious changes for TP and sediment TN were found between culture and fallowing periods. However, sediment TP at the cage and cage-side sites increased significantly (one-way ANOVA, *F*-test, $P < 0.001$) from the first culture period to the end, while there were no obvious changes in the sites 50 m and 100 m from the cages (one-way ANOVA, *F*-test, $P >$ 0.0.05).

Discussion

Nitrogen and phosphorus loadings from cage aquaculture in freshwater lakes or reservoirs from this study and other similar fish cage studies are summarized in Table 6. Based on the feed conversion ratio (FCR) in the present cage system, about 160 kg TN, 35 kg TP and 120 kg TN, 25 kg TP were released into the environment for each tonne of fish produced over the 2-year production cycle. The TN loadings in our study were considerably higher than the averages from other countries. Meanwhile, the TP loadings were relatively high. These high TN and TP loadings reflect the higher FCR of the fish farm, which ranged from 2.56 to 3.56 in our study. In the present study, although 16.3 tonnes and 39.2 tonnes of fish yield were produced in 2000 and 2001, the waste loadings were decreased (0.16–0.12 kg TN and 0.035–0.025 kg TP kg^{-1} fresh fish produced in 2000 and 2001). This can be explained by the improvement of feed utilization in summer (June to August) over the 2 years. For example, 14.8% of TN (8.2–24.4%) and 11.0% of TP (3.3–19.0%) of feed were fixed by the cultured fishes in the summer of 2000 but the average conversion rates of

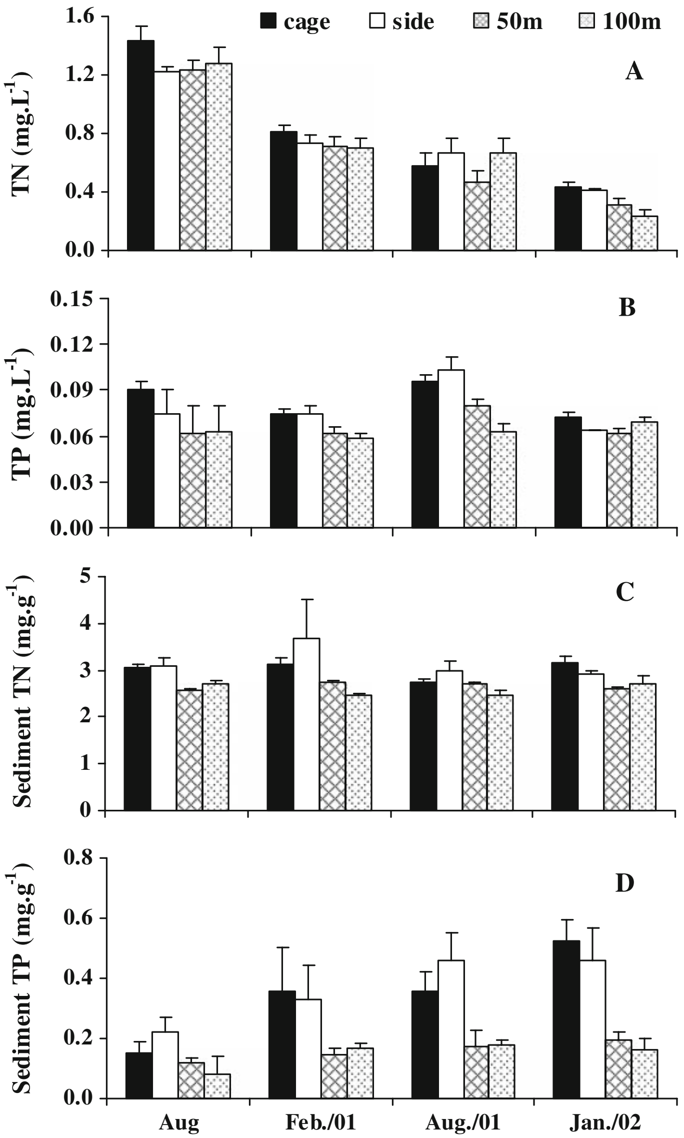

Fig. 4 Variations of TN and TP in water and sediment between culture (August in 2000 and 2001) and fallowing (February in 2001 and January in 2002) periods; bars represent the standard error of the mean

TN and TP in feed to fishes were 22.9% and 17.0% in 2001. Islam (2005) reported that 132.5 kg N and 25.0 kg P are released to the environment for each tonne of fish produced with FCR. So our results of nitrogen and phosphorus loadings were probably underestimated.

Due to the low current velocity in most freshwater cultured area, it is very important to assess the environmental responses to intensive aquaculture, e.g., oxygen depletion, benthic deposition, and eutrophication (Gowen et al. 1990; Silvert 1992; Beveridge 1996). Some models have been developed for environmental assessment in marine waters (Silvert

Table 6 Comparisons of wastes of N and P loading from cage fish farms (kg tonne^{-1} fish produced)

	TN	TP	Cultured species	Reference
Poland	100	23	Rainbow trout	Penczak et al. (1982)
Denmark	83	11	–	Warrer-Hansen (1982)
Finland	73.3	18.3	–	Sumari (1982)
UK	–	15.7	–	Solbe (1982)
Scotland	–	18.8	Rainbow trout	Phillips et al. (1985)
Ireland	124.2	25.6	Rainbow trout	Foy and Rosel (1991)
Canada	–	55.7	Rainbow trout	Cornel and Whoriskey (1993)
France	97.9	18.6	Brown trout	Merceron et al. (2002)
Japan	30.9–86.0	14.8–26.4	Common carp	Jahan et al. (2002)
Tailand	112	33	Red tilapia	Sumafish (2003)
	65	46	Giant gourami	
China	120–160	25–35	Chanel catfish and Bluntsnout bream	Present study

1992). Many of these results apply to freshwater culture as well. During the study period, high waste loadings caused not only large benthic communities change (Guo and Li 2003) but also high nitrogen and phosphorus in the water column and sediment under the cage area. Some studies report that waste of nitrogen output from cage farm is in dissolved form and particulate nitrogen output is low (Beveridge et al. 1991; Domíguez et al. 2001; Aguado-Giménez and García-García 2004). In the present study, TN concentration at the cage and cage-side sites in October 2000 changed along with the sediment TN contents, with a correlation of 0.68–0.71 ($P < 0.05$). As for TP in water column and sediment, a significant correlation was found at the cage side, suggesting that TP in the water column is affected by TP in sediment. This could be explained by the following two reasons. Firstly, some wild fishes from outside of the cages gathered beneath the cages to feed on waste from the cages, which probably produced higher water movement beneath the cage sites and increased the sedimentation at the cage side. Secondly, the cage farm resulted in a large amount of organic matter in the sediment and most of the enriched phosphorus was probably bound as iron phosphate of low solubility; see, e.g., Zhang et al. (2004), who reported that cage culture resulted in Fe–P accounting for more than 60% of the sediment P pool in Lake Donghu, a similar shallow lake.

Overall, cage aquaculture in freshwater lakes has produced significant increases in lake water TP level (Yan 2005). In the present study, TP in both lake water and sediment showed an obvious increase in the area of the cages. Therefore, waste loadings affected TP concentration around the cage area.

In marine cage aquaculture, the fallowing of fish culture sites is mainly related to the cessation of input of waste though seasonal variations in sediment and environment parameters (Pereira et al. 2004). Periodic abandonment is one of the best management tools for sustainable fish farming (Carroll et al. 2003). Macleod et al. (2006) reported that short-term fallowing of marine cages could be used as a strategy for the management of recurring organic enrichment. The sediment showed some improvement in the community structure over a 3-month fallow period, and the rate and extent of recovery were affected by culture location, the initial impact of the sediments, and the length of the fallow period. Few studies have investigated fallowing of aquaculture in freshwater fish culture. In the present study, TN and TP in the water of the cage and at the cage side showed obvious decreases during fallow periods, although sediment TN and TP retained high values.

Therefore, the cessation of culture practices from December to February in shallow lakes under present fish production methods seems to be an effective way to decrease nitrogen and phosphorus accumulation, though TP concentration in the lake water showed a slight increase. As Macleod et al. (2004) reported that the recovery of sediment was less impacted in tropical than in northern temperate areas. Therefore, more biological parameters should be added to evaluate the recovery of sediment chemistry in the future.

In summary, nitrogen and phosphorus dynamics around the cage area were affected by cage aquaculture practices. The most abundant waste load from the cage culture was sediment phosphorus throughout the studied 2-year production cycle. Although recovery seems to occur during fallowing, careful attention should be paid to whether the culture continues to operate, and more frequent samplings are required in the future.

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