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REPORT

Eutrophication in a Chinese Context: Understanding Various Physical and Socio-Economic Aspects

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Abstract Eutrophication is now a ubiquitous water quality impairment in China. The first step toward restoration of eutrophicated water bodies is a marked reduction of nutrient loadings in their drainage basins. However, the combination of a number of physical and socio-economic factors is now producing compounded increases in nutrient loads while the nutrient assimilation capacities of natural systems are decreasing. Meanwhile, most of the lakes in densely populated part of China are shallow and very susceptible to anthropogenic alteration. Therefore, in spite of ascending efforts in eutrophication control upward trends of algal blooms in both fresh and coastal waters have been observed for the past two decades. Huge knowledge gap exists in our understanding of the sources and pathways of nutrient losses to aquatic ecosystems. Successful water quality restoration of China's eutrophic waters relies not only on more resource input but also more emphasis on basic, integrated, and management-oriented research.

Keywords Eutrophication · Nutrient loads · Water quality management · China

INTRODUCTION

China is extremely short of natural resources, given its enormous population. It ranks sixth in the world in terms of total water resources, but is almost the lowest in terms of per capita water resource availability (Niu and Harris 1996). Chronic water stress in parts of Northeast China and in almost all of Northwest China is a widely recognized crisis. With the rapid growth of its population and a rising standard of living, water consumption will increase and China is surely expected to face more severe water shortage problems in the future. Water scarcity in the country is now further exacerbated by pollution of its surface and ground waters. China's rapid economic development over the past three decades has exerted a significant toll on its natural endowments, particularly water resources. As a result of increased pollutant emission, rampant water pollution threatens to undermine China's growth prospects (Liu and Diamond 2005; Oyang and Wang 2000).

As in many parts of the world, eutrophication is one of the most pervasive water quality problems in China. Other water quality problems may be confined in some specific areas. Eutrophication, however, is now a ubiquitous water quality impairment. Lakes which can be classified as eutrophic in China have increased dramatically during the past decades. A recent investigation indicates that only 6% of surveyed lakes are in oligotrophic state, while 44% are in eutrophic, and 22% in hypotrophic state (Jin 2003). Of six largest fresh water lakes in China, only Poyang Lake is in the state of mesotrophic. Other five lakes are all in eutrophic or even hypotrophic state [State Environmental Protection Agency (SEPA) 2007]. Frequent algal blooms of three of these largest lakes, namely Taihu Lake, Chaohu Lake, and Dianchi Lake, result in not only heavy economic and ecological damages, but also substantial social instability (Jin 2003; Qin et al. 2007). A clear upward trend in red tide incidents has also been recorded in China's coastal area. In the 1960s, there was only one recorded red tide incident every 5 years in China's coastal waters. But now there are 90 red tides each year on average (Zhou et al. 2008). Although this dramatic increased figure may partly be explained by the improved monitoring in recent years, it is well accepted that we are now having more worst red tides (Li and Daler 2004; Yang and Hodgkiss 2004).

Although the growth of aquatic biomass is influenced by a number of factors including the supply of nutrients, light, temperature, water flow, turbidity, zooplankton grazing and toxic substances, the principal factor ultimately controlling the growth of algae in natural waters is the supply of nutrients. Therefore, protection and restoration of eutrophicated water bodies rely primarily on the reduction of nutrient loadings in their drainage basins. China has strongly committed to restoring its environmental quality since the advent of the new millennium and eutrophication control is among the top priorities of governments of different levels. However, just as the mechanism of eutrophication process is not sufficiently understood, the knowledge of the sources of nutrients and the ways nutrients moving into receiving waters are still rather limited. China is a large country with much diversified natural landscapes as well as socio-economic conditions, environmental degradations manifest in quite different ways throughout the country. In the mean time, many environmental problems in the country are unique due to its huge population and its political and economic history. The causes and effects of eutrophication in China deserve close attention of both scientific community and decision makers. In this article, some prominent physical and socio-economic factors which are believed not only to be closely related to the eutrophication problems but also have distinct Chinese characteristics are addressed, with an expectation to improve our understanding of eutrophication processes in this most populated country and thus to contribute to the formation of more effective restoring strategies.

NUTRIENT ENRICHMENT IN CHINA'S SURFACE WATERS

Despite increased pollution control effort in recent years, there has been water quality improvement only in some specific water bodies over the last decade. There are no signs of significant improvement in China's most threatened fresh water lakes. On the contrary, elevated levels of nitrogen and phosphorus have been observed in Taihu Lake, Chaohu Lake, and Dianchi Lake, the three large lakes which are listed as national priority for eutrophication control (Mao et al. 2005; Qin et al. 2007; Shang and Shang 2007).

Times series of nutrient concentrations in Chinese major rivers and estuaries can be used to depict the overall trend of nutrient levels in surface waters of the country. It is reported that the levels of nitrate throughout the Yangtze River system remained fairly constant before 1970s (Duan et al. 2007). Recent results, however, showed that at the mouth of the Yangtze River the nitrate concentration has increased about three-fold in 40 years, from 1.3 mg l^{-1} in the 1960s to 3.7 mg l^{-1} in the 1980s and to 5.0 mg l^{-1} in 1990–2004. Phosphate concentration increased by a factor of 30%, from 0.056 mg l^{-1} in the 1980s to 0.073 mg l^{-1} in 1990–2004 (Zhou et al. 2008). Monitoring stations at the lower reach of the Yellow River, China's second longest river, revealed a three-fold increase in nitrogen concentrations over the 10 years between 1990 and 1999 (Xia et al. 2002). Sharp increases in nitrate nitrogen and ammonia nitrogen were also observed in Huaihe River, a large river in Central China, between 1990 and 2002 (Mao et al. 2003). Increasing nutrient loads from municipal sewage and agriculture and decreasing assimilation capacity of natural settings are producing compounded elevation in nutrient concentrations in China's fresh and coastal waters.

THE EFFECT OF RAPID URBANIZATION

Fueled by rapid economic growth, urban sprawl has greatly accelerated in the last three decades in China. Urban population tripled from 172 million in 1978 to 472 million in 2000 (Fig. 1). The net increase in urban population during the last two decades was 300 million, equivalent almost to the entire population of the United States and Canada put together. However, the development of water infrastructure and treatment are not keeping up with urban sprawl. Most cities are underserved by sewers and wastewater treatment plants. In 1997 only 11% of the municipal sewage was subject to treatment. It is targeted that treatment facilities will grow to have a capacity to treat 40% of urban municipal sewage in 2010 (Oyang and Wang 2000). So, at present less than half urban municipal sewage receives treatment. But still there are at least two factors that defect the claimed treatment capacity. One is that sewer systems are usually lagging behind treatment capacity. In many cities, treatment plants have been built as required by higher level government, but adequate sewer systems cannot be finished in time to introduce waste water, resulting in underutilized wastewater treatment

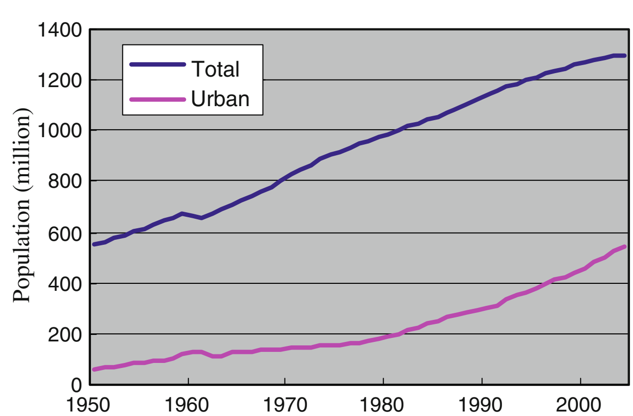

Fig. 1 Population growth in China

capacity. The other factor is that among the finished treatment facilities only low level treatment is now available for sewage effluents, allowing very limited removal of nutrients. There is hardly any tertiary treatment of urban sewage in contemporary China.

Without proper waste disposal facilities, massive urban sprawl exerts great pressure on the environment, one prominent effect being a dramatic increase in nutrient discharge. In rural China, human excreta are typically collected into some kind of cesspits for fermentation before being distributed on farmlands. This practice, although having its undesirable effects from hygienic point of view, proved to be a very efficient way for nutrient recycling. The widespread use of flush toilets improves the sanitation conditions of urban residents but results in water quality problems, given the lack of waste treatment. The combination of a rapidly increasing urban population, increasing urban water supply service levels, and increasing per capita urban consumption are producing compounded increases in municipal wastewater flows and nutrient loads.

INCREASING CONTRIBUTION FROM AGRICULTURE

Land resources in China have been very intensively used since long ago. Historically, Chinese farmers successfully managed to maintain a modest soil fertility and agricultural productivity by efficient recycling of nutrients within agro-ecosystems. Until the early 1950s, nutrient inputs into agro-ecosystems in the country still originated almost a hundred percent from organic sources. However, with nearly all land potentially suitable for cultivation already in use and current cultivated land shrinking at a very high rate due to urban sprawl and other non-agricultural uses, China's agriculture has no alternative but to rely on high synthetic fertilizer input to ensure a high productivity for its huge and ever growing population. Over the last several decades, China has experienced rapid increases in chemical fertilizer use, from 12.69 million tons in 1980 to 41.46 million tons in 2000 (Table 1), sharing about 30% of global fertilizer consumption at present. Since 1970s, both nitrogen and phosphorus input/out balance in Chinese agriculture have turned positive as a whole (Zhou et al. 2000). N and P surpluses in economically more developed eastern part of the country are far more serious because of the regional disparity in fertilizer consumption (Gao et al. 2006a).

In China the contribution of agriculture to water quality deterioration has been of increasing concern in recent years. Excessive usage of fertilizers is attributed as the primary reason for elevated nutrient concentrations in ground and surface waters. Separate investigations covering large areas in Northern China revealed that over half of groundwater samples had a nitrate concentration higher than 50 mg l^{-1}, the WHO recommended safety level for drinking water, even nitrate concentrations higher than 300 were frequently detected. High nitrate concentrations in groundwater were mostly observed in areas with very heavy fertilizer dosage (Dong et al. 2005; Liu et al. 2000; Zhang et al. 1996). In southern China, the losses of N via leakage and runoff from paddy fields ranged from 6.7 to 27.0 kg N ha^{-1} and from 2.5 to 19.0 kg N ha^{-1}, respectively, while N leaching from uplands ranged from 30.1 to 46.1 kg N ha^{-1} under fertilization rates from 75 to 225 kg N ha^{-1} (Sun et al. 2003). In the past decades nitrogen concentrations in large rivers such as the mainstream of the Yangtze has had a rising trend. A good correlation between nitrogen concentration in river waters and nitrogen fertilizer applied in their catchments existed (Chen et al. 2000; Duan et al. 2000). The risk of phosphorus loss from agricultural land was also growing (Liu et al. 2007; Sheng et al. 2004). Jin (1995) reported that up to 35% of N and 68% of P in surveyed lakes were from agriculture runoff. With increased fertilizer application and nutrient accumulation in cultivated soils, contribution of nutrients from non-point agricultural sources is predicted to increase (Gao et al. 2006a).

Table 1 Synthetic fertilizer consumption (in million tons) in Chinese agriculture from 1949 to 2005

Year	N fertilizer	P fertilizer	Compound fertilizer
1949	0.01	0	0
1957	0.32	0.05	0
1965	1.33	0.11	0
1975	3.41	1.66	0.33
1980	9.34	2.73	0.27
1990	16.38	4.62	3.42
2000	21.62	6.91	9.18
2005	22.29	7.44	13.03

THE ROLE OF ANIMAL CULTURE

The rapid development of livestock husbandry and aquaculture is another reason for more nutrient discharge into aquatic ecosystems. Animal stocks in China have been growing remarkably since the early 1980s (Fig. 2) along with rising living standard. Increasing incomes and changing diet preferences stimulate production intensification with a growing share of livestock and poultry products coming from industrial and specialized enterprises in urban and peri-urban areas (Yang et al. 2001). Since animal wastes are usually bulky and expensive to

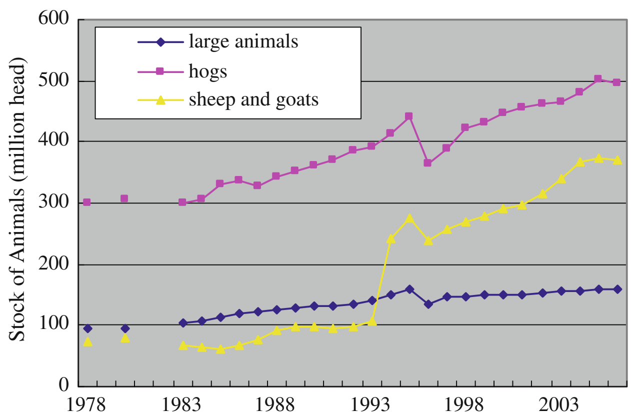

Fig. 2 Stocks of animals in China since 1978. Large animals refer to horses, donkeys, buffalos, beef, dairy cattle, etc.

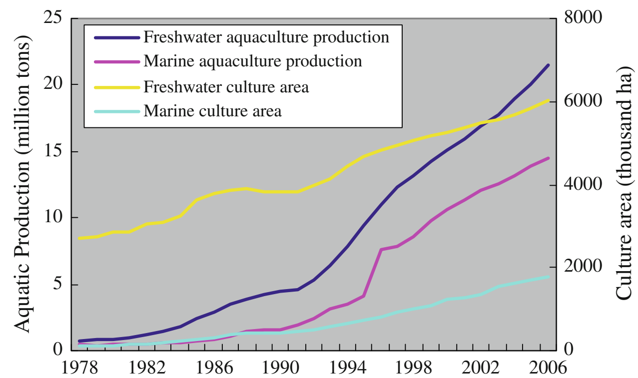

Fig. 3 Aquaculture production in China since 1978

transport over long distances, the detachment of animal production from areas of feed production precludes the efficient recycling of the excess nutrients near animal production centers. The regional balance between nutrients in animal excreta and nutrient demand of crops is disrupted. Excessive application of animal manure in limited land leads to increasing risk of non-point source pollution. Meanwhile, accidental and deliberate spills of livestock housing wastes because of poor on-farm management practices pose direct threat to aquatic ecosystems. Total emissions of nitrogen and phosphorus from livestock farming in the year 2002 were estimated to be 870,000 and 345,000 tons, respectively (Gao et al. 2006a). As a result, areas with concentrated animal production are very susceptible to water quality degradation, especially algal blooms (Wang 2005; Yang et al. 2001).

China is the world's largest producer of aquaculture-grown food, and is the sole country in which aquaculture provides more fish and aquatic foods than wild fisheries (Liu and Diamond 2005). Aquaculture has great potential for animal protein supply and, therefore, is of particular importance to this most populated country in the world. Over the last 20 years China has seen a steep increase both in freshwater aquaculture and in marine aquaculture production, rising from 0.76 and 0.45 million tons in 1978 to 21.5 and 14.5 million tons in 2006, respectively (Fig. 3). This growth has been achieved mainly through scale expansion. It is highly possible that this food industry will grow continuously at a high rate in the near future. However, the potentially deleterious impacts of aquaculture are widely documented. In addition to pollution, destruction of sensitive habitats and threats to aquatic biodiversity, an increasingly significant effect of intensive aquaculture is eutrophication of the water surrounding rearing pens or the rivers receiving aquaculture effluent. On the one hand, fish farms emit nutrients in the form of uneaten food and faeces. On the other hand, applying organic and inorganic fertilizers to stimulate plankton growth to retain a higher fish production is a common practice in China. On per unit area basis, fish pond culture even receives higher fertilization rates than crop farming (Li et al. 2001). So, rapidly growing aquaculture is another factor leading to rising nutrient levels in Chinese waters. The negative effects of aquaculture on eutrophication have been increasingly documented (Guo and Li 2003; Qin et al. 2007). For instance, coastal aquaculture has been suggested as the main reason for the sharp increase in red tide frequency in Chinese coastal waters in recent years (Xu et al. 2007; Yang et al. 2004).

THE IMPACT OF MONSOON CLIMATE

A large part of China's territory is characterized by a monsoon climate: the East Asian monsoon over eastern China and the Indian monsoon over southwestern China. Owing to the impact of the monsoonal circulation, about 60% of total annual precipitation normally occurs in the period April–August, when daily rainfall frequently exceeds 100 mm. Concentrated rainfall has a profound impact on the nutrient transports from diffuse sources. Previous studies and our own observations indicate that a large proportion (up to 90%) of annual nutrient exports from agricultural land have been associated with only very few unusually large and intense storm events (Edwards and Owens 1991; Gao et al. 2005; Ramos and Martínez-Casasnovas 2004). So heavy monsoon rains result in heavy non-point source pollution. Given that the agricultural practices in southern and central China are dominated by wheat–corn, rice–wheat, rice–rapeseed, as well as rice–rice rotation, cultivated lands in the area are especially susceptible to soil erosion and nutrient losses during monsoon season when harvesting, tilling, sowing, transplanting, fertilization, and other agronomic activities are most intense and when the land surfaces are often left barely or partially covered between previous and follow-up crops and at early seedling stages. The monsoons are known to be irregular, their timing, and particularly their intensity, varies from year to year. In addition to this, the Yangtze basin is located at the meeting point of the Indian and the East Asia monsoons; this makes the rainfall exceptionally difficult to forecast in a vast agricultural region. Therefore, little can be done to avoid heavy nutrient losses during this critical season.

DECREASING NUTRIENT RETENTION IN DRAINAGE NETWORKS

Wetlands play a vital role in maintaining environmental stability. One of the most important functions of wetland ecosystems is the retention of nutrients from the inflowing water from their drainage basins. It was estimated that the annual nutrient removal capacities from waters by China's current wetlands are 4.6 Tg nitrogen and 0.6 Tg phosphorus (An et al. 2007). However, natural wetlands in China have been suffering great loss and degradation since the early 1950s mainly due to reclamation, pollution, desertification, hydrologic modification, and climatic change. Historically, land reclamation activities such as impoldering were often adopted in China to promote agricultural yields. Over the last 60 years land reclamation has been significantly accelerated to meet the need of food consumption of a fast growing population. The scale of ecosystem change in wetlands is staggering. The Sanjiang Plain in northeast China was formerly the largest marshland complex in the country. However, the area of marshland in this region decreased from 53,400 km^2 in the early 1950s to 8,400 km^2 in 2000, with most of lost marshlands converted to agricultural use (Liu and Ma 2000). Comparing with the beginning of 1950s, the wetland area within Haihe River basin in northern China decreased from 10,000 to 1,000 km^2 at present (Xia and Zhang 2008). China's lakes lost a total area of more than 12,000 km^2 over the 30 years between the early 1950s and the early 1980s (Table 2). The largest loss happened in the Xinjiang-Inner Mongolia Plateau in northwestern China. Climate change was suggested as the main reason for this drastic reduction in lake surface area in the region (Jin et al. 1990). In other areas reclamation was the primary cause for lake losses (Li 1999). Dongting Lake in Hunan Province has shrunk to half of its original size measured in 1949 due to reclamation of marginal land (Fig. 4). This China's former largest fresh water lake has now given place to Poyang Lake, another lake in central China which shrank less but also remarkably in its size (Gao and Li 2001). China also lost 21,900 km^2 of its coastal wetlands in the past 60 years. Large areas of mangrove forest along nearshore waters have been cleared to give way for the development of aquaculture and land reclamation. The country's area of mangrove declined by 73% in the second half of twentieth century (Liu and Diamond 2005; Zhang et al. 2005).

In terms of the total area, China lost 23.0% of its freshwater swamps, 16.1% of lakes, 15.3% of rivers, and 51.2% of coastal wetlands over the past 60 years. As a result, the country lost 8.5% of its water storage capacity, and the reduction of annual water purification capacities is estimated to be 2.8 Tg for nitrogen and 0.4 Tg for phosphorus (An et al. 2007).

Heavy pollution of river systems by other toxic substances is also suggested as an important factor for the decreasing nutrient assimilation capacity of natural ecosystems. As the result of collapse of the aquatic food web, the purifying function of ecosystem is inevitably damaged.

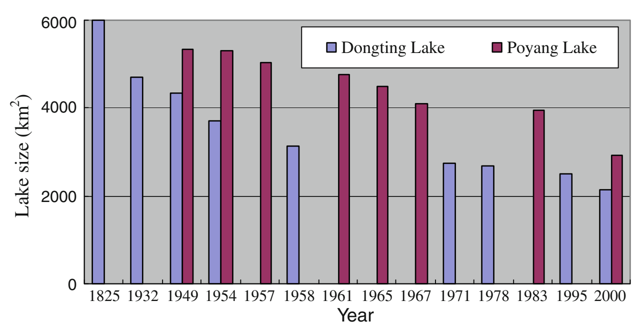

Fig. 4 Size variations of China's two largest fresh water lakes, based on Gao and Li (2001)

Table 2 The loss of surface area of lakes in different part of China between 1950s and 1980s

Subregion	Lake area in the early 1950s (km^2)	Lake area in the early 1980s (km^2)	Area loss (km^2)
Qinghai–Tibet Plateau	38,700	36,889	1,811
Eastern Plain	22,900	20,842	2,058
Xinjiang–Inner Mongolia Plateau	16,400	9,411	6,989
Northeastern China	3,800	2,366	1,434
Yunnan–Guizhou Plateau	1,200	1,108	92
Total	83,000	70,616	12,384

Source Jin et al. (1990)

Unfortunately, the amount of waste water discharged has been increasing steadily, and water quality in most Chinese rivers and groundwater sources is poor and declining (Liu and Diamond 2005).

LIMNOLOGICAL FEATURES

Most of the lakes in densely populated eastern China are very shallow (<7 m mean depth) either due to genetic reasons or because of long time siltation resulted from severe soil erosion in their drainage basins (Jin et al. 1990). Shallow lakes do not have well-defined thermoclines with distinct epi- and hypolimnions. Other features such as intense N-fixation, light limitation, and being more susceptible to human influence add complexities to the relationships between nutrient inputs, in-lake nutrient concentrations, and the biomass of algae in the water column of shallow lakes (Havens et al. 2001). Therefore, current empirical nutrient loading models derived mostly from deeper, dimictic lakes are less effective in predicting shallow lake algal responses to nutrient reductions (Havens et al. 2001; Nixdorf and Deneke 1997). Shallow, polymictic lakes are also known to be more resistant to recovery techniques following considerable reductions in external nutrient loading because wind-generated currents can cause frequent resuspension of nutrient-enriched bottom sediments and their continued release of nutrients (Zhu et al. 2005).

Most of the lakes in eastern China are endangered by eutrophication because of heavy nutrient loadings from their relatively large catchment areas which are very densely populated and land resources intensively used. Population density can be as high as 1,200 km^{-2} while cultivated land comprises typically almost half of their catchment areas (Table 3). Furthermore, to meet various needs of a large population in their drainage basins these shallow lakes have been subjected to profound human influence. Numerous dams and sluice gates have been built on China's rivers and at the inlets and outlets of many lakes to serve the purpose of flood control, power generation, navigation, irrigation, and drinking water supply. Regulated by dams, dikes, and sluice gates, many lakes and rivers have turned out to be managed reservoirs with prolonged residence time. One of the most obvious negative impacts of this kind of hydromodification on water quality is the enhanced algal growth. Due to the combined consequences of reduced flow velocity and prolonged hydraulic retention time, increased phytoplankton biomass within Three Gorges Reservoir has been observed since the closure of the dam (Zeng et al. 2006). The construction of the sluice gate at the outlet of Lake Chaohu was suggested as a leading cause for the increased eutrophication of the lake (Zhou et al. 2007).

Table 3 General features of the two largest eutrophic lakes in China

Attribute	Lake Taihu	Lake Chaohu
Lake area (km^2)	2,428	760
Mean depth (m)	1.89	3.06
Maximal depth (m)	2.60	6.78
Mean volume (10^6 m^3)	4,430	1,900
Residence time (day)	264	136
Watershed area (km^2)	36,500	13,486
Area of cultivated land (km^2)	17,700	6,480
Human population	45,330,000	8,770,000
Population density (km^{-2})	1,242	650

EUTROPHICATION CONTROL IN CHINA: ARE WE WELL PREPARED?

China has been strongly committed to combat eutrophication of its waters since early 1980s. Restoration of three of China's most eutrophied large lakes, namely Taihu, Chaohu, and Dianchi, has been set as one of the top national priorities under the 1995 national environmental strategy. Concrete stipulations on the targets, tasks, and measures in the watersheds of these lakes have been specified. Action plans included a variety of strategies and measures to reduce point and diffuse nutrient inputs, dredging of stream and lake sediments, and restoration of wetlands in the drainage basins of those lakes. With efforts for many years, remarkable achievements in the wastewater treatment have been made. However, achieved reductions in nutrient discharge in some sectors can hardly offset compounded increases in nutrient loads from others. As results, no declining trend of nutrient levels in those prioritized lakes can be observed. On the contrary, nitrogen and phosphorus concentrations at most observatory stations of those lakes have increased in recent years (Fig. 5). There are considerable evidences (surface water chemistry, sediment cores, and satellite imagery) indicating that these three lakes are experiencing significant increases in algal productivity both over time and space (Duan et al. 2009; Shang and Shang 2007; Wang et al. 2009; Zhu 2008). From 1987 to 2007, algal blooms in Taihu Lake occurred at increasing frequency and on lengthened duration while the distribution area became larger and larger year by year (Duan et al. 2009). The average TSI (Trophic State Index) of western Chaohu Lake increased slightly from 72.6 between 1984 and 1991 to 75.4 between 1998 and 2004 in spite of the fact that during last two decades a series of measures have been taken by national and local government to restrain the eutrophication process in the lake (Shang and Shang 2007).

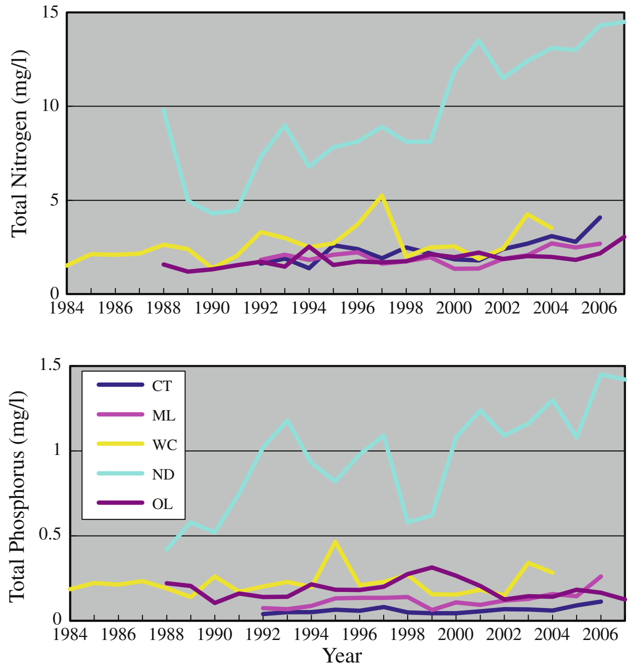

Fig. 5 Nutrient dynamics in three prioritized large fresh water lakes. *CT* Central Taihu Lake; *ML* Meiliang Bay, Taihu Lake; *WC* Western Chaohu; *ND* Northern Dianchi Lake; *OL* Out Dianchi Lake (redrawn from Wang and Chen 2009; Shang and Shang 2007; Zhu 2008)

Before 1980, primary productivity in Dianchi Lake was relatively constant. During the years between 1980 and 2004, a pattern of progressively enhanced productivity can be revealed from sedimentary record (Wang et al. 2009). Accelerating trend of algal blooms in frequency and intensity of these three lakes are just microcosms of what is happening in the rest of the country. Eutrophication is now one of the most serious environmental problems we are facing, and its control is one of the environmental objectives that is most difficult to achieve.

Failure to alleviate eutrophication in China may be ascribed to two major reasons: insufficient resource input and huge knowledge gap. The country has allocated substantial resources to fight eutrophication in the past two decades. However, to create conditions not suitable for algal blooms drastic reductions in nutrient load will be needed. Considering that only a small portion of municipal sewage is treated at present, there is great potential to reduce nutrient loads from this section. Existing plans of resource input are far from enough to improve current waste water treatment systems to facilitate a substantial reduction in nutrient loading. Result of a simulation study indicates that planned growth in waste treatment capabilities in the highlighted Taihu Lake drainage basin can only slightly reduce phosphorus emission from its present level during the next two decades (Dai et al. 2007). Massive investments are needed not only to increase waste water treatment rates but also to upgrade current treatment systems in order to remove more nutrients from treated water. Whether China can achieve its water quality objectives set for the next two decades depend largely on its ability and willingness to invest in waste water treatment infrastructures.

Successful water quality restoration calls for integrated and cost-effective watershed management strategy. Before formulating a comprehensive management plan it is essential to bridge the knowledge gap which exists in our understanding of the sources and pathways of nutrient inputs to aquatic ecosystems. Although the factors controlling algae bloom are quite complicated, eutrophication first is the consequence of elevated nutrient levels. So the first step toward effective eutrophication control is achieving a substantial reduction in nutrient loads in the affected watershed. China is still a developing country and a marked increase in waste water treatment capabilities over a short period cannot be expected. Therefore, it is of great importance to bear in mind that the reduction of the N and P loads in a specific watershed should always take place where it is cheapest. Management practices must incorporate accurate and cost-effective targeting of measures to control a number of different sources. So catchment scale nutrient source apportionment should be conducted before pinpointing and prioritizing where control measures should best be targeted. However, shortage in source inventories and hydrochemical monitoring data excludes the possibility of using proper models to get satisfying estimation of the contribution from different sources even in those best-studied lakes at the moment. We have to manage a situation where there is a great deal of uncertainty about the need for measures and the prospects of achieving the desired effects.

Experiences from other countries can be of significant relevance to improved decision making. At current stage successful examples mostly have come from developed countries of the temperate zone. Applying these control measures in China without modification is questionable. Nevertheless, some of the experiences are of great importance. Successful examples include determining the limiting nutrient of a specific water body and identifying critical non-point source areas in the watershed. Focusing control efforts on limiting nutrient and in a small part of the land are far more cost-effective. In many areas especially North America, phosphorus based nutrient management strategies have been proved quite practical and effective. However, prioritized control of limiting nutrient has rarely been discussed, let alone been practiced so far in China.

Despite the factor that substantial funding has been allocated to promote research activities in recent years, the knowledge base on which management efforts relies is still very limited. Management guidelines are often based on experiences or even policy-maker's will. Very often a large-scale outbreak of algal bloom shocked government into radical actions and the eager for quick success resulted in very unrealistic water quality objectives, reflecting that the complicated cause and effect relationships behind eutrophication were still poorly understood and the complexities involved in eutrophication restoration largely underestimated. One example is that large-scale dredging of stream and lake sediments is now ongoing in many places with the purpose of reducing internal nutrient loads where external nutrient inputs are still very poorly controlled.

With the rise of environmental awareness and the rapid growth in Chinese economy there can be a quick increase in resource input for waste water treatment capacities, and it can be expected that pollution from point sources can be effectively controlled in the foreseeable future. Nevertheless, there are no quick and simple solutions to the control of nutrient losses from agricultural land. Processes leading to nutrient runoff from agriculture and the retention of nutrients on their way to drainage networks are still very poorly understood. The knowledge gap of complicated processes of nutrient discharge and its interactions with physical and socio-economic processes is still huge. It takes considerable time to accumulate necessary data to bridge this gap. Far more emphasis has to be given to basic, integrated, and management-oriented research. Otherwise eutrophication control in China will remain a more distant target.

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