Eutrophication in the Great Lakes of the Chinese Pacific Drainage Basin: Changes, Trends, and Management

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William Y. B. Chang

Abstract

China has 25 of the world's great lakes (> 500 km^2). This number of great lakes is exceeded only by Canada and Russia. Tectonic uplift and fluvial actions are the primary mechanisms resulting in the formation of these lakes. Long-term climate changes have significant impacts on these lakes, especially in terms of: (1) lake size and depth and (2) chemical characteristics. In recent years, the increased temperature has also led to the onset of the blue-green alga *Microsysti* in the Pacific Drainage Basin (PDB). Over the most recent 40 years, human activities have had a visible effect on the large lakes situated in the human-dominated PDB. Large lakes in this basin have become depositories of agricultural, industrial, and household wastes and have shown an increased level of eutrophication and toxic chemical accumulation. These great lakes have changed from oligotrophic in the 1960s, to eutrophic in the 1980s, and to hypereutrophic in the 1990s, with increased occurrence of blue-green *Microsysti* blooms. These blooms have become serious concerns for water supplies and the health of people and aquatic ecosystems.

Continuing disposal of untreated domestic and industrial wastes has contributed to this change. Lake management practices, such as dams and weirs for flood control and extensive use of littoral area and wetland for farming, aquaculture, and home construction, have also contributed to the acceleration of this process.

With its enormous population and increasing use of large lakes, China needs to integrate its lake management programs and to plan for sustainable use of its aquatic resources. The management plan should take into consideration the environmental costs of development and the ecological service that the lakes provide. The reduction or recycling of wastes by industries needs to be closely controlled. The involvement of average citizens in decisions in environmental planning and lake management is another key to the success of managing these important water bodies.

Keywords

Eutrophication · Great lakes · Water quality · Management

8.1 Introduction

China is the most populous country in the world and ranks third in territory. Lakes account for more than 80,000 km^2. It has 25 of the world's great lakes with a total area reaching over 30,000 km^2. These lakes have been used extensively

W. Y. B. Chang (✉)
Office of International Science and Engineering,
National Science Foundation, 4201 Wilson Blvd,
Arlington, VA 22230, USA
e-mail: wychang@nsf.gov

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Table 8.1 The number and total area in each lake size category (Academia 1981; Chang 1987)

Lake size (km^2)	Number	Total area (km^2)
1–10	2,383	9,129
10–50	234	4,932
50–100	107	7,365
100–500	96	19,830
500–1,000	14	9,213
>1,000	11	27,629
Total	2,845	78,098

and play an important role in flood control, fishing and aquacultural production, supplying drinking and irrigation water, transportation, and recreation. Large increases in urbanization over the last 40 years and accelerated industrial development since the 1980s have greatly extended the uses of the great lake environment in the Pacific Drainage Basin (PDB). Under the market-based economy, such uses have rapidly changed lake physical environments and increased the complexity of managing these aquatic environments (Chang 1993, 1996). This chapter reports on trends and changes at the five great lakes situated in the PDB and the current challenges being faced in the management of these lakes.

8.2 Distribution, Origins, and General Characteristics

China has more than 2,800 lakes larger than 1 km^2 occupying approximately 80,000 km^2 (Table 8.1) and constituting approximately 0.8% of the entire national territory. Twenty-five are among the world's great lakes (>500 km^2) with a total area of 36,842 km^2 representing 47.2% of the total national lake area. Lakes from 1–10 km^2 are the most numerous, numbering more than 2,000 and covering a total area of 9,000 km^2 (11.6% lake area; Table 8.1). Of the Chinese great lakes, five are situated in the PDB; these lakes are facing increasing anthropogenic pressure. This chapter focuses on these five great freshwater lakes: Lakes Chao, Dongting, Poyang, and Tai in the Yangtze Basin and Lake Hongtze in the Huai River Basin (Fig. 8.1). These lakes are not only in the PDB, but also are close to major urban centers. They provide water supplies to the surrounding cities and receive both the household and industrial wastes from these cities.

Tectonic movement and river action are two major mechanisms contributing to the formation of great lakes in China. The great lakes situated in the PDB are primarily a result of river action. They are shallow and eutrophic. Changes in river courses (primarily that of the Yellow River) and river sediment deposits were the major factors leading to the formation of lakes in the Yangtze River Drainage Basin and the Huai River Drainage Basin. When the Yellow River changed its course between 1194 and 1845 A.D. to run along the old course of the Huai River as it drained into the sea, large amounts of sediment were deposited at the mouth of the Huai River. Eventually, these deposits blocked access to the sea. The Yellow River pushed out yet another outlet to the sea, while the sediment blocking the Huai River Basin gave rise to a series of lakes. These include two great lakes (Lakes Chao and Hongtze) as well as many smaller lakes. Similarly, the sediments brought down by the Yangtze River and other rivers gave rise to Lakes Dongting and Poyang (Zhang and Chang 1994) and contributed to the formation of Lake Tai and of chains of small lakes in the Yangtze River Delta area in Jiangsu Province. These riverine lakes are shallow and eutrophic and have been used for food production, waste disposal, flood control, transportation, irrigation, and recreation. These lakes are surrounded by urban centers and are closely related to the daily life of the people. They have been used extensively by people in the PDB, which is the home of more than 95% of the Chinese population.

8.2.1 Hydrology

River inputs and precipitation are the primary means of replenishing water to the large lakes in China's PDB. Seasonal monsoons and melting snow are two major water sources. The moisture brought by the seasonal monsoon is the principal source of water for the large lakes situated in the PDB. The Yangtze and Huai Rivers are the major water carriers to these large lakes. Precipitation directly onto the lake surface constitutes a relatively small percentage of the total input of water (<5%; Academia 1981; Shi et al. 1989). Annual evaporation is generally balanced by annual precipitation onto the lakes in the PDB. The major water output is by way of river outflow.

In the PDB, high lake levels correspond with the monsoonal rains in June, July, and August. Fluctuations in both water level and size can be over 10 m in riverine lakes, which drain directly into the Yangtze River. In riverine lakes, such as Lakes Dongting and Poyang, the annual fluctuations in levels are 13.6 and 7.3 m, respectively. The size of these lakes also varies greatly with seasons. For example, Dongting Lake varies in size from 2,740 to 12,000 km^2, depending on time of year. The extent of fluctuation in water level and size has been found to be related to the catchment basin and lake surface ratio. Lake Dongting has a ratio of 86.6:1 and Lake Poyang has a value of 46.1:1 (the catchment basin of the Yangtze River is not included in these statistics; Academia 1981; Shi et al. 1989). In contrast, the value for both Lakes Chao and Tai is 16:1, while the water level differences are only 2.5 and 1.3 m, respectively. Because lakes such as Dongting and Poyang have no embankments and dams, they not only fluctuate greatly in size and water level, but also have much greater water exchange rates (flushing rates). For example, the flushing rate for Lake Dongting is 13 days, while that for Lake Tai is 263 days.

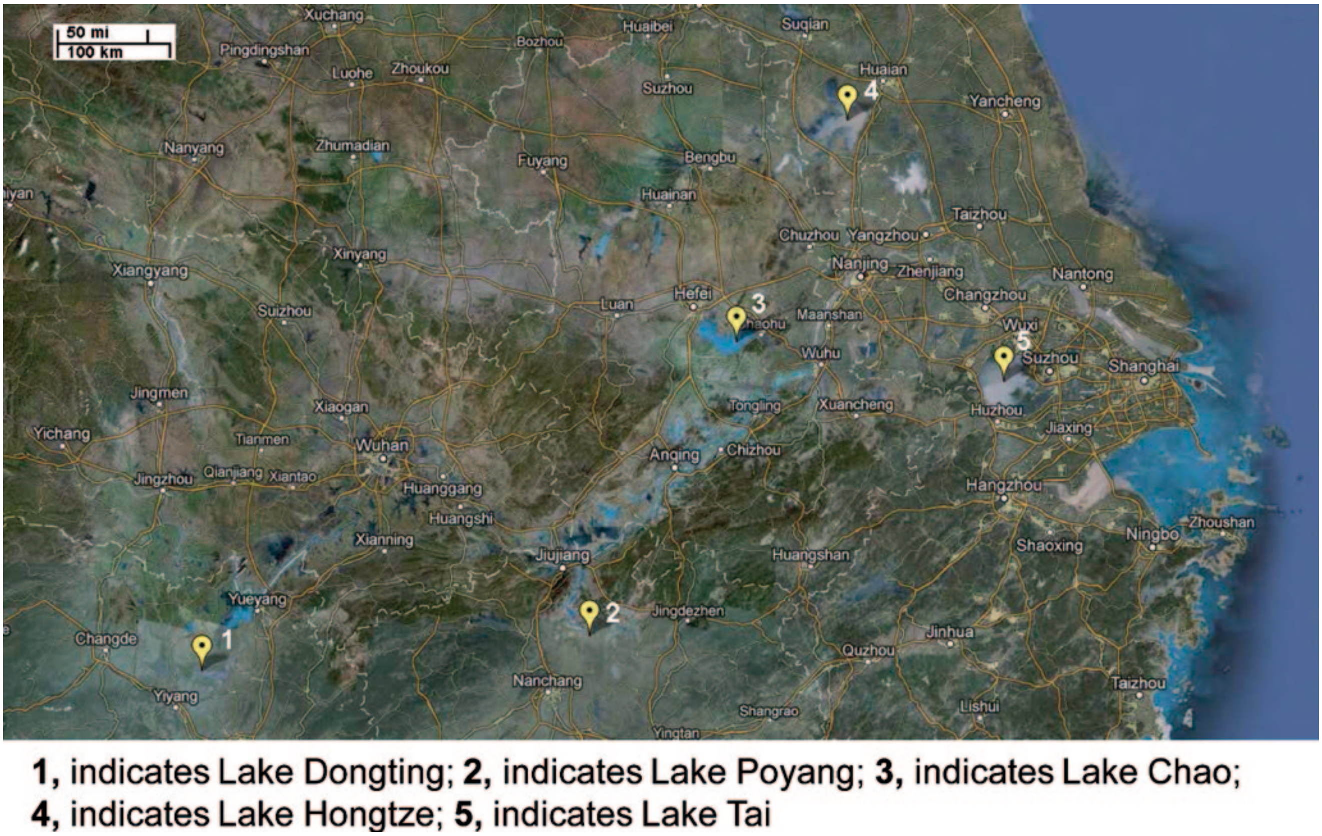

Fig. 8.1 Map of five great lakes in China

The result of these differences is that although the amounts of nutrient input loads to these lakes are similar, effects in term of eutrophication in these lakes are different. Lake Dongting has remained eutrophic, while Lakes Chao and Tai, with more limited water exchanges, are now hypereutrophic.

8.2.2 Water Quality Trends

Changes in water quality in the lakes in the PDB have been particularly noticeable during the most recent 40 years, as large increases in urbanization along these lakes and accelerated industrial development in the lakes' watershed have increased urban and agricultural run-off to the lakes. These changes have made water quality a top environmental concern in China. In general, population levels in a lake watershed are a good first approximation for determining the level of the lake's eutrophication. The higher the population density, the greater the likelihood that serious pollution and water quality problems are found (Chang 1993). Water quality is deteriorating in most lakes close to urban centers (Shu 1991). Large lakes such as Lakes Tai and Chao are hypereutrophic and are the final destination of sewage and industrial wastes from the surrounding urban centers (Yang et al. 2008).

The change in water quality in Lake Tai is a case in point. Anthropogenic inputs to the lake have been increasing since 1950, as population and human activities in the immediate watershed of the lake have increased. However, the rate of the change was slow in the 1960s and 1970s, the types of the inputs during those periods were primarily agricultural and household wastes, and the amounts involved were relatively low. Strong currents provided vigorous water circulation in the lake and a relatively high dissolved oxygen (DO) level. During the 1970s, the DO level was greater than 7 ppm, even at the bottom of the lake. During the 1960s, Lake Tai was generally oligotrophic (Table 8.2), with inputs of primary organic matter from the immediate watershed.

Untreated effluents from the watershed draining into Tai Lake have increased substantially over the last 30 years. The total amount of untreated effluents was estimated in 1987 at 33.83×10^6 tons per year (Chang 1996). This amount has increased substantially, primarily from small chemical and manufacturing plants close to Lake Tai. This untreated effluent rapidly began to change the degree of eutrophication in Lake Tai and affected the water quality of the lake. Table 8.2 shows the average concentration of nitrogen (N) and total phosphate in 1960, 1980, and 1988. The eutrophication thresholds of phosphorus (P) for freshwaters are from 0.02 to 0.10 mg P L^{-1} and of N are from 0.500 to 1.00 mg N L^{-1} (Lin et al. 2008; Xu et al. 2010). In 1960, Lake Tai was categorized as oligotrophic;

Table 8.2 Changes in nutrient concentrations in Lake Tai between 1960 and 1988. (Adapted from Sun and Huang 1993)

	1960	1980–1981	1987–1988
No3-n (mg L^{-1})	0.02 (0.01–0.09)	0.75 (0.60–1.15)	0.95 (0.01–5.80)
Nh3-n (mg L^{-1})	0.02 (0.01–0.03)	0.12 (0.01–0.22)	0.19 (0.01–3.87)
Tin (mg L^{-1})	0.05	0.89	1.16
Top (mg L^{-1})		0.006	0.022 (0–0.56)
Tp (mg L^{-1})	0.02		0.032 (0–0.61)
Phytoplankton counts (Cells L^{-1})	19,240	10,116,000	38,170,000

The values in the parentheses are the minimum and maximum values measured in milligram per liter
TIN total inorganic nitrogen, *TOP* total organic phosphate, *TP* total phosphate

total inorganic nitrogen (TIN) in the lake was only 0.05 mg N L^{-1}, SRP was 0.02 mg P L^{-1}. By 1981, TIN had increased to 0.89 mg N L^{-1} and SRP remained stable (Table 8.2). In 1988, TIN and TN concentrations were 1.12 and 1.84 mg N L^{-1}, respectively, and total phosphorus (TP) was 0.032 mg P L^{-1} (Sun and Huang 1993). However, by the end of year 1988, TIN and TN concentrations had increased to 1.58 and 2.34 mg N L^{-1}, whereas TP was 0.085 mg P L^{-1} (Qin et al. 2007). Increases of more than one order of magnitude were seen in total N concentrations and total phosphate between 1960 and 1988. As the lake became more eutrophic, seasonal changes in nutrient concentrations also became greater. The concentrations of TIN and TP change inversely with the dry and wet periods. By 1988, TIN and TP concentrations were three times higher during the low water dry period than during the high water wet period (Sun and Huang 1993). Many areas in the lake showed the effects of advanced culture eutrophication during the dry period, while eutrophic conditions improved during the wet period. The highest nutrient concentration was usually found in March, before the onset of the monsoon rains, while the lowest in situ concentration was in September at the end of the monsoon period (Sun and Huang 1993). Precipitation in this case plays a significant role in water quality conditions in this lake. The rate of increase in TP and TN continued; TP increased from 32 µg L^{-1} in 1987–1988 to 108 µg L^{-1} in 2001–2003, while TN increased from 1,160 µg L^{-1} from 1987–1988 to 1,771 µg L^{-1} in 2001–2003.

8.2.3 Phytoplankton

More than 125 genera of algae have been reported from the large lakes in the PDB (Nanjing Institute of Geography 1982). Of these 125 genera, the diatoms contribute a major proportion of the total assemblage in all seasons; in some lakes, however, spring and sometimes autumn have relatively higher diatom assemblages. Lack of clear seasonal diatom cycles may be a result of the absence of a seasonal thermocline, since lakes are shallow and diel vertical mixing occurs whenever wind is strong, and nutrients from sediments are resuspended in the water column. The diatom assemblages of sheltered bays and open waters have been found to differ substantially from each other in forms and numbers.

The green algae are also a key group of phytoplankton, but are transitory species. The population density peaks in spring and decreases in summer. Blooms are found on the surface of shelter bays and in the littoral zone of large lakes.

The blue-greens appear late spring and bloom in summer when the temperature is high in these lakes. The blooms occur in the lakes where the flushing rate is slow and where nutrient inputs are high, such as Lakes Tai, Cao, and Hongtze. The blooms are often found on the surface of the water and comprise *Mycrocystis* and *Anabaena.* Regional climate changes in recent years appear to be catalyzing the algal surge by raising average water surface temperatures and increasing water column stratification, leading to more bloom of blue-greens, and especially of the blue-green alga *Mycrsystis aeruginosa*. The blue-greens produce toxins that can damage the liver, intestines, and nervous system. Blue-green blooms in Lakes Tai and Chao are becoming annual occurrences and they threaten drinking water supplies and sustainability of freshwater ecosystems (Stone 2011).

The steep increase in TP and TIN concentrations after 1980 is the result of the use of N-P-K fertilizers in the catchment basin and of receiving industrial waste effluents from nearby chemical factories. In the last 30 years, small manufacturing plants have sprung up as part of the Chinese economic revolution that made the Yangtze River Delta part of a global factory. Most of these factories have no water treatment equipment and use the lakes for waste water disposal. As a case in point, in 1987 there were 3,000 factories in the Lake Chao Basin; only 2.5 % of effluents were treated, and this lake received 140 million ton of industrial effluents annually (Jin et al. 1990). The N concentration in the lake increased more than 20-fold from 1963 to 1984 and the blue-green algae and diatoms increased 3.15- and 2.47-fold, respectively (Jin et al. 1990). There are only a very limited number of waste water treatment plants; moreover, the number following appropriate operational guidelines is even smaller. The amount of effluents to this and other lakes have not been abated. The same phenomena are observed in all five of these great lakes, all of which are receiving increasing amounts of the waste

Table 8.3 Large lakes in the human-dominated Pacific drainage basin and their TP, TN, and chlorophylla-a. (Adapted from Chang 1996)

Lake names	Lake area (km^2)	TP (ug L^{-1})	TN (ug L^{-1})	Chlorophylla-*a* (ug L^{-1})
Chao (Hyper-Eu)	770	192.5	3,035.0	15.67
Dongting (Eu) riverine lake	2,433	44.0	1,087.0	3.9
Hongtze (Hyper/Eu)	2,069			
Poyang (Eu) riverine lake	2,933	47.0	617.0	2.65
Tai (Hyper-Eu)	2,425	108	1,771.0	7.89

Hyper-Eu hypereutrophic, *Eu* eutrophic

Table 8.4 Phytoplankton biomass, percentage, and major species. (Adapted from Sun and Huang 1993)

Algal group	Biomass (mg^{-1})	%	Dominant taxa
Blue-Greens	2.76	37	*Microcystisaeruginosa*
			Chroococus
Cryptomonas	1.81	25	*Cryptomonaserosa*
Diatoms	1.58	22	*Melosiragranulata*
			Navicula
			Cyclotella

effluents. Lakes Dongting and Poyang are, however, blessed by their high flushing rates. Owing to their low water retention rates, the waste effluents enter the Yangtze River and then flow into the East China Sea. The TPs for these lakes are under 50 µg L^{-1} (Table 8.3). In contrast, Lake Cao has 192 and 3,035 µg L^{-1} of TP and TN, respectively, while Lake Tai's TP and TN are 108 and 1,771 µg L^{-1}, based on a survey conducted in 2001–2003 (Table 8.3).

Yang et al. (2008), based on their survey of the lakes in the Yangtze floodplain, reported that a TP concentration of 80–110 µg L^{-1} is a critical range for a shift from epiphytic diatom taxa to planktonic species, because the latter are more tolerant of turbid waters and high nutrient concentrations. They noted a similar trend for the transformation from macrophyte-dominated systems to algal-dominated systems. Jeppesen et al. (1990) also found a similar switch if the critical TP ranges are 80–150 µg L^{-1} in lakes in Denmark. Following this trend, macrophytes in Lake Tai lose ground to algae beginning in 1990. Scientists at the Chinese Academy of Science have now reintroduced cultivated macrophytes in Lake Tai, by curtaining off sections of the lake and seeding them with macropytes. The plants have flourished in the experimental areas, but outside that area, they have failed because the water is too polluted.

In response to substantial increases in nutrient enrichment, the phytoplankton assemblages in the lake have also changed greatly since 1960. Species diversity has been decreasing since 1960 and the lake is currently dominated by a few species with exceedingly high abundance. Phytoplankton counts in 1960, 1980, and 1988 showed a geometrical increase (Table 8.4). The predominant algal groups found in the 1988 lake samples are the blue-greens, the crytomonas, and the diatoms; the biomass, percentage, and dominant species in each of these groups in 1988 is shown in Table 8.4. The dominant taxa of phytoplankton found in Lake Tai are the forms most commonly appearing in eutrophic waters.

Control of N, P, or availability of both controls phytoplankton growth. It is generally accepted that N is the prime limiting nutrient in marine systems, whereas P is the prime limiting nutrient in freshwater systems. Xu et al. (2010) reported that the eutrophication threshold of P for freshwaters is from 0.02 to 0.10 mg P L^{-1}, and that of N is from 0.50 to 1 mg N L^{-1}. They used the N concentration at the onset of blooms of the toxin-producing cyanobacteria *Microcystis spp*. in the summer of 1980 as a threshold for this spp. The onset N concentration was therefore determined at 0.8 mg NL^{-1}. Using this threshold N level and in situ bioassay, Paerl et al. (2011) and Xu et al. (2010) suggested that when P enrichment as >0.20 mg P L^{-1} and N enrichment >0.80 mg N L^{-1}, growth of *Microcystis spp.* is not nutrient-limited, and the availability of N during the summer is a key growth-limiting factor for the proliferation and maintenance of toxic *Microcystis spp.* blooms. N load reduction in this case is essential for controlling the magnitude and duration of blue-green blooms in Lake Tai.

8.3 Anthropogenic Impacts

More than 95% of the Chinese population has settled in the PDB. The population growth rate in this basin is also the highest in the country and the total basin population tripled within only 40 years, reaching 1.1 billion in 1991. This high population density has sharply increased the need for lake resources and has multiplied the uses of lake environments (Chang 1990). These great lakes in this area not only serve as sources for drinking water, fish, and aquatic food production, but also play important roles in transportation, flood control, and waste disposal. In general, large lakes close to urban centers also receive disproportionately large amounts of household and industrial wastes. As a result, they have become increasingly eutrophic and have elevated concentrations of organic toxics, with frequent occurrence of cyanobacteria blooms.

The economic initiatives of the 1980s stimulated major industrial development resulting in a great increase in industrial effluents. Since industries were treating only about 25 % of these effluents (even that amount is an optimistic estimate), most of the raw effluents, containing a large number of contaminants, have been draining into lakes. High levels of metals and toxic organics have already been found in lake sediments and benthic fishes in large lakes close to urban centers, such as Lakes Tai and Chao. These contaminants include mercury, arsenic, phenol, copper, cyanide, zinc, lead, and chromium, and can be readily associated with the nearby major industrial sources (Nanjing Institute of Geography 1982; Sun and Wu 1989; Sun and Huang 1993).

The economic initiatives that began in the 1980s also led to new sources of pollution from rural industry. Prior to the early 1980s, most major Chinese industries were situated in urban areas. The primary sources of industrial pollution were the industries in urban centers and this situation was known to local inhabitants. However, in the late 1980s, many rural industries sprouted up. These industries are usually operated by one or a few families and are spread throughout all rural communities in China. They are generally poorly equipped with little or no environmental treatment facilities. These rural industries have become a major source of toxic chemicals and have been responsible for the spread of these chemicals from primarily urban centers to many rural communities, which are experiencing increasing amounts and deadlier types of pollution. These rural industry sources have had an extensive impact on tributaries and lakes in many places quite far from previously known pollution sources.

Extensive use of the littoral areas of lakes for aquaculture and farming to increase the food production in China has led to an increase in eutrophication and is responsible for the substantial reduction in lake areas in the PDB. The rate of reduction in the size of the PDB great lakes is high. For example, increased use of wetland and littoral zones in Lake Tai beginning in the 1950s significantly reduced the lake size. The total area of the littoral zone converted to farmland and ponds between 1950 and 1980 was 160 km^2 (Sun and Huang 1993). The highest annual rate of conversion was during the 1970s.

The conversion of lake areas for rice and fish farming also had major ecological effects on Lake Tai (Chang 1996). This conversion reduced the area covered by aquatic vegetation, which is important to many littoral species for spawning, foraging, and protection during maturation. As a result, many species that depend on this environment have been declining, most notably fish species such as common carp *Cyprinus carpio* and crucian carp *Carassius auratus*. With the reduction in carp species, the families *Engraulidae* and *Salangidae*, which prefer open water and prey primarily on large zooplankton, have quickly become dominant in the lake. These opportunistic fish species are small in size (adults have an average size of 7–10 cm), with a short maturation period of about 1 year. Wong showed an inverse relationship between the population of fish species *Engraulidae* and *Salangidae* and the zooplankton population in the lake. A large increase in *Engraulidae* and *Salangidae* populations has had a major effect on the zooplankton population. The depressed zooplankton population, in turn, results in a relatively high density in the phytoplantkon population. The effects of littoral conversion have significantly changed the trophic dynamics and the fish population in Lake Tai. This could indirectly affect the effort to control unwanted algal blooms in that lake (Chang 1996).

The Chinese government has recognized the severe impacts of littoral conversions, which include the reduction of the floodwater holding capacity of the large lakes and significant changes in lake ecosystems. In 1980s, it announced a program of returning the farmland previously claimed from lakes to lake use. This program was only minimally successful since the trend of population growth and need to use this area for housing construction and urban expansion acted against it.

8.4 Lake Management

8.4.1 Institutional Arrangements

Management of Chinese lakes falls under several different authorities. The Ministry of Water Resources is responsible for flood controls and the construction of dams and weirs. The National Environmental Protection Administration (NEPA) has the authority for pollution regulation and for establishment of environmental laws related to lakes. The Ministry of Agriculture provides guidelines for managing fisheries and natural resources, which are primarily focused on increasing the production of fish and aquatic products. The daily management of lakes is, however, the responsibility of provincial, county, and township authorities. The level of the local authority responsible for managing a lake depends on the lake's size, location, and ownership. A Lake Management Commission is usually established for lakes of significant economic importance. Because flood controls, environmental pollution, and the development and use of natural resources are directed by different agencies, the Lake Management Commissions play an important role in the coordination between these different agencies, accommodating various needs and uses. When this coordination is inefficient or fails, the signs of deterioration can often be seen at many lake sites.

The changes in eutrophication conditions in Lake Tai reflect a general trend of nutrient enrichment in large lakes in the PDB. Chinese authorities have realized the seriousness of halting this continuous deterioration in water quality and have established laws for controlling industrial effluents and provided funding to study eutrophication issues. A case in point is the action taken by NEPA, the major agency in China, dealing with environmental and water quality issues. This agency has conducted several national lake surveys to better understand the extent of lake pollution problems and has provided funds for treating eutrophication problems. Lake Tai has also received funds from NEPA for its water quality studies with additional funds from the Chinese Academy of Science, the Chinese Natural Science Foundation, and Jiangsu Province. In addition to these efforts, Lake Chao in Anhui Province has also received a sizable grant from NEPA and Anhui Province to study and improve lake water quality. However, water quality continues to worsen in the lakes in the PDB and many have developed seasonal or regional anoxic conditions.

In May 2007, an algae outbreak sparked by unusually hot weather overwhelmed a water filtration plant that supplies Wuxi City on Lake Tai's north shore, leaving more than 2 million people without drinking water for a week. This outbreak prompted Wuxi City and its Environmental Protection Bureau to take the unusual action of forcing hundreds of small chemical and manufacturing plants near Lake Tai to close or relocate. They instituted strict controls on effluents from the factories that were permitted to stay in order to cut down on pollution and the massive influx of N and P. These actions leveled off the continuing downturn of water quality conditions in that lake (Stone 2011).

Industries are the primary sources of lake pollution in the PDB since they contribute more than 75 % of the total untreated run-off and have the greatest impact on lake quality. Industrial run-off also has the most severe impact on aquatic environments. Monitoring and controlling industrial pollution is NEPA's responsibility; NEPA issues guidelines for industrial effluents and assists the local EPA in monitoring run-off from factories. The day-to-day responsibility for monitoring and controlling industrial pollution, however, rests with the local EPA. The level of regional supervision of polluted industries depends on those factories' official classification. For example, the provincial EPA supervises the provincial industries, while the county EPA has authority with respect to county enterprises and factories. In general, the factories that have received national attention are monitored carefully and have installed pollution devices to meet the Chinese water quality standards. However, these factories are in the clear minority. Despite the creation of national and regional environmental agencies in China, the development of major environmental laws and the creation of an impressive network to enforce these regulations, most industrial wastes are not monitored and no routine lake survey has been carried out for most lakes. Furthermore, because many regional authorities (at both the county and municipal levels) lack sufficient operating revenues, regional EPAs rely heavily on the funds from pollution fines to operate. This dependency provides little incentive for regional authorities to control industrial pollution and to reduce industrial run-off. As a result, the decline of public waterways continues. Water quality in most lakes in the PDB faces further deterioration.

8.4.2 Flood Control

water resource management and flood control are the two major lake management activities carried out by the Ministry of Water Resources. In order to control floods and maximize the use of water resources, the Ministry of Water Resources and the regional water authorities have installed weirs and dams in most waterways and lake tributaries since the 1950s, except in those lakes, such as Lakes Poyang and Dongting, where the quantity of the water flowing in and out of the lakes is so large that controls are impractical. The management of water quantity and levels in lakes, and decisions regarding opening and closing dams, are the responsibility of water resources authorities. In most cases, the floodgates are raised in winter to drain lake water and provide the capacity needed to accommodate peak flow in spring and summer; floodgates are closed for most of the rest of the year. There is little or no water outflow in spring, summer, and fall except where lake water levels become unsafely high. The construction of dams and weirs since the 1950s has reduced potential damage to lowland areas in several major floods and has increased the use of lakes and waterways for other activities such as irrigation and transportation.

However, the construction of dams and weirs for flood control, while useful in other respects, has greatly affected fisheries resources and aquatic life, especially those species, which use riverine spawning grounds and live in the lakes. Recruitment of these species in most lakes is impossible as a result of dam construction and some carp and crab species have experienced noticeable population reduction. Fingerling and larval fish stocking programs are now the major means of maintaining lake fish productivity in order to sustain lake fisheries. These dams and weirs have also reduced water exchange and have increased accumulation of urban and industrial wastes. Because of the large amount of wastes accumulated by these dams and weirs, their sudden annual opening often leads to anoxic and toxic conditions downstream and death of many aquatic species.

8.5 Lake Management Concerns

8.5.1 Eutrophication Control

Remarkable increases in urbanization during the past century in China have resulted in major changes in the ecology of Chinese inland waters (Dudgeon et al. 1993). Increased anthropogenic inputs from household, agricultural, and industrial effluents have turned many inland waters eutrophic and urban lakes hypoeutrophic. These changes are most notable in the lakes close to large population centers (Shu 1991). To mitigate the increased nutrient loads, various approaches have been used: (1) to reduce, remove, or divert the nutrient loadings from the sources to lakes; (2) to channel the increased nutrients for the production of aquatic products such as food and fish, which are then harvested, thus removing the nutrients; and (3) to dredge the lakes to remove nutrient-rich sediment.

As noted earlier, beginning in 2007, the Wuxi City Environmental Protection Bureau and the Jiangsu Provincial Government forced hundreds of small chemical and manufacturing plants near Lake Tai to close or relocate to cut down pollution and influx of N and P. The results have been improved river conditions and a leveling off of the amount of industrial wastes in the lake.

Since more than 70% of urban eutrophication is owing to point-source inputs of industrial and household effluents, reduction and diversion of these sources of loading are needed to reduce lake enrichment (Jin et. al. 1990). Waste water treatment plants are an efficient means of retrieving a large quantity of nutrients and organic matter from point sources. Some of the large cities in China, including Shanghai, Beijing, and Hangzhou, began to construct sewage treatment plants in 1990s to reduce waste loading of inland and coastal waters.

As for large lakes, pollution predominantly enters through river systems and originates primarily from urban sources and agricultural effluents. Removal of the nutrient loads from river systems by biological nutrient uptake techniques using aquatic plants has been tried at many selected sites in the tributaries of Lakes Tai and Chao, but is still in the experimental stage. These experiments have shown that these plants are responsible for substantial uptake of nutrients and heavy metals but to date, this methodology is not very efficient in controlling eutrophication and its application is often limited by the type of plants available and by limitations on their active growing periods.

Most of the large lakes in the PDB are shallow and meromictic. Reducing loadings from external nutrient sources to shallow lakes has a limited effect on the reduction of eutrophication, because sediment resuspension plays a significant role in contributing nutrients to the water column. Sediment removal has been used to reduce the level of eutrophication in these lakes (Chang 1993).

Another approach involves channeling the increased nutrients for food and fish production, then removing the nutrients by harvesting the aquatic products. This can be a useful yet sustainable methodology and has been used in many large lakes and impoundments. Integrated lake farming is an example of this approach. However, if eutrophication is to be controlled, the ratio between stocking fish and the biomass of aquatic macrophytes must be adjusted so that the large amounts of nutrients released by remineralization by fish can be absorbed by plants (Chang 1994). So far, such systems appear to contribute to the additional nutrients through the remineralization by fish.

8.5.2 Institutional Coordination

As noted earlier, large lakes in China are governed by several different agencies of the central government in Beijing. The Ministry of Water Resources has authority over flood control and regulation of water level and as a part of this authority, it controls the timing for closing and opening the floodgates of dams. The Ministry of Agriculture has responsibility for managing fisheries, particularly fish production, and aquatic natural resources. NEPA is responsible for pollution monitoring, control, and regulation. However, since many of these mandates are not coordinated, management conflicts have arisen.

The conflict posing the greatest concern deals with the regulation of water levels in lakes by controlling the opening and closing of floodgates (Pu et al. 1989). Decisions regarding opening and closing of the floodgates are in the hands of the water resources authority. In most cases, the floodgates are raised in winter to drain lake water and are closed for most of the rest of the year. Fish recruitment, however, occurs in spring when the fish spawn in rivers and the larvae find their way to lakes to settle. Prior to the construction of dams and weirs in Chinese waterways, recruitment occurred every spring. After the constructions of these dams and weirs and the adoption of new ways of managing water levels, natural recruitment no longer took place in most inland waters. This has led to depletion of many fish species and of other aquatic resources in lakes. A coordinated approach to lake management by the various oversight agencies is needed. The need for strong institutional coordination increases with the increased use and abuse of lake resources. Furthermore, the responsibility for managing lakes and for coordination among agencies should be given to the regional lake commissions, whenever possible, since the regional lake commissions are familiar with the local environment and can best accommodate the specific local needs for the enhanced use, protection, and operation of lakes.

8.5.3 Control of Wetlands and of Littoral Resources

The wetland and littoral zones are important areas for fish spawning, nesting ground for birds, reducing the influx of pollutants, and controlling erosion. However, the wetland and littoral zones of the large lakes in China's PDB are vanishing quickly as these areas face increasing pressure for development. Owing to the population expansion over the past two decades and to the expanded economic development, which began in the 1980s, the wetlands and littoral areas in the PDB are now disappearing at even faster rates than in the 1970s. Many wetlands are currently used not only for farming, but also for housing developments and factories. An absence of legal restraint on development and the lack of overall conservation planning for wetland and littoral zones are largely responsible for this abuse. It is, therefore, highly recommended that an integrated lake basin development program be established to control abuses and to foster the conservation of these critical zones.

The riparian and littoral zones have long served as filters for reducing sedimentation and the influx of nutrients and toxic substances into lakes. The use of littoral and riparian systems to control nutrient loadings and the influx of toxic substances can be a low-cost method of reducing eutrophication and toxic pollution of lakes. The establishment of riparian zones along lakes and waterways has been found to be effective in protecting inland waters in North America. It is highly recommended that China establishes a coherent plan to manage its riparian zones in the absence of monitoring programs and effluent controls, because the PDB has a high population density, increased nutrient loadings, and large influx of toxic substances. Such a zone can at least serve as a first line of protection by reducing the amounts of wastes entering the lakes. Lake Tai authorities are currently contemplating the creation of a buffer zone several hundred meters in width, where near-shore farms and villages would be converted into wetlands and parks, but such relocation plan close to urban centers will be costly.

8.5.4 Management Strategy

With its enormous population and increasing use of large lakes, China needs to integrate the lake management programs and to plan for sustainable use of its aquatic resources. The management plan should take into consideration the environmental costs of development and the ecological service that lakes provide, and should reduce the current focus solely on boosting aquatic production and on the use of the lake for waste disposal. The reduction or recycling of wastes needs to be encouraged by industries, which are responsible for waterborne hazards such as industrial toxins and untreated sewage, and for losses in aquatic habitats. Mounting public concern about drinkable water, clean lakes, and sustainable natural resources has begun to bring about an awareness of better integrated plans for managing inland waters. Such awareness, however, is far from the elaboration of an integrated lake development strategy, which would include plans for watershed development, control of waste run-off, sustainable resource management, and the effective protection and management of surface waters. Continued encouragement and promotion of environmental consciousness is necessary, since incentives in China for focusing on sustainable uses of inland waters are not high. Instead, people's primary concerns are near-term profits. Annual growth in GDP has been considered more important than environmental protection and conservation. This attitude is characteristic even of most water and lake management authorities. To increase awareness of more sustainable lake management alternatives, international funding organizations can play an important role in persuading local officials to include environmental costs and the protection and conservation of natural resources in development projects, and to encourage local authorities to form integrated development teams. Such teams would involve developers, environmental scientists, county/city officers, and village representatives in project planning from the onset. The ultimate responsibility for managing a large lake environment rests upon all citizens living in its watershed. Unless the majority of citizens recognize the importance of sustainable uses of lakes and are willing to protect these precious resources, many large lakes in China will cease to serve the people who have depended on them over thousands of years.

8.6 Summary

Anthropogenic inputs to China's great lakes in the PDB have been increasing since 1950, as population and human activities in their immediate watersheds have increased. However, the rate of the change was slow in the 1960s, the types of the inputs during those periods were primarily agricultural and household wastes, and the amounts involved were relatively low. During the 1960s, large lakes were generally oligotrophic with inputs of primary organic matter from the immediate watershed.

The new economic initiatives of the 1980s stimulated major industrial development, resulting in a great increase in industrial effluents. In addition to nutrient inputs, high levels of metals and toxic organics have already been found in lake sediments and benthic fishes in China's great lakes, such as Lakes Tai and Chao. These contaminants include mercury, arsenic, phenol, copper, cyanide, zinc, lead, and chromium, and can be readily associated with the nearby major industrial sources. Large lakes in this basin became mesotrophic to eutrophic with the beginning of blue-green algae blooms.

Lakes Tai and Cao have now become hypereutrophic. Lake Cao has 192 and 3,035 μg L^{-1} of TP and TN, respectively, while Lake Tai's TP and TN are 108 and 1,771 μg L^{-1} based on the survey conducted in 2001–2003. Aquatic ecosystems in these lakes have undergone a major change in which systems dominated by macrophytes have been replaced by algal-dominated systems. Blue-green algae blooms in the great lakes in this basin are becoming annual occurrences, threatening water supplies and the sustainability of freshwater ecosystems.

These lakes have changed from oligotrophic to hypereutrophic in the last 40 years. Continuing disposal of untreated domestic and industrial wastes contributed significantly to this change. Lake management practices, such as dams and weirs for flood control and extensive use of littoral area and wetland for farming, aquaculture, and home construction, have also contributed to the acceleration of this process.

With its enormous population and increasing use of its great lakes, China needs to integrate its lake management programs and to plan for sustainable use of its aquatic resources. The management plan should take into consideration the environmental costs of development and the ecological service that these lakes provide. The reduction or recycling of wastes by industries needs to be closely controlled. Continued encouragement and promotion of environmental consciousness is necessary, and promotion of sustainable uses of inland waters and involvement of average citizens to contribute to the joint decision in environmental planning and lake management are a key to the success of managing these important water bodies.

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