Biodiversity changes in the lakes of the Central Yangtze

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The Central Yangtze ecoregion in China includes a number of lakes, but these have been greatly affected by human activities over the past several decades, resulting in severe loss of biodiversity. In this paper, we document the present distribution of the major lakes and the changes in size that have taken place over the past 50 years, using remote sensing data and historical observations of land cover in the region. We also provide an overview of the changes in species richness, community composition, population size and age structure, and individual body size of aquatic plants, fishes, and waterfowl in these lakes. The overall species richness of aquatic plants found in eight major lakes has decreased substantially during the study period. Community composition has also been greatly altered, as have population size and age and individual body size in some species. These changes are largely attributed to the integrated effects of lake degradation, the construction of large hydroelectric dams, the establishment of nature reserves, and lake restoration practices.

摘 要：长江中游是中国湖泊湿地最为集中、湿地退化也最为严重的区域。在过去的几十年里，湖泊退化导致该地区水生生物多样性发生了显著的变化。本文利用过去的土地利用资料和遥感数据，分析了该地区主要湖泊的现代分布和过去 50 年的面积变化；从物种丰富度、群落组成、种群数量和个体大小以及年龄组成等方面，综述了该地区过去 50 年来水生植物、鱼类和鸟类的生物多样性变化。结果显示，该地区主要湖泊的水生植物多样性总体上呈显著的减少趋势；一些植物群落的组成发生了变化；某些种群的数量、年龄结构和个体大小呈退化趋势。这些变化主要是由栖息地退化、大型水利工程建设以及保护区建设和退田还湖实践等因素综合作用的结果。

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Global biodiversity is decreasing at an unprecedented rate, in parallel with the rapid growth of the human population (DeFries *et al.* 2004). Among ecosystems that support high biodiversity, wetlands occupy only about 1% of the Earth's surface, but provide habitat for about 20% of the world's species (Dugan 1993), especially endangered and endemic species. For example, approximately 50% of the endangered bird species in China inhabit wetland ecosystems (Wetland International [China] 1998). However, these biologically rich ecosystems have undergone dramatic reductions. The ecological consequences of these changes to wetlands, and the resulting loss of biodiversity, have elicited considerable concern (Gibbs 2000).

In a nutshell:

- The large collection of lakes in the Central Yangtze region of China has decreased substantially in size and number over the past 50 years
- An increasing human population, greater food production, and overfishing are the major causes of lake degradation
- Biodiversity losses have also been observed among aquatic plants, fish, and waterfowl, at community, population, and species levels
- Lake degradation, the construction of large dams, the establishment of nature reserves, and lake restoration practices are the primary forces driving these changes in biodiversity

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The Central Yangtze refers to the section of the Yangtze River Basin that extends from Yichang in Hubei province to Hukou in Jiangxi province (Figure 1), and includes a number of ecologically and economically valuable lakes and wetlands. Dongting Lake, Poyang Lake, and the lakes in the Jianghan Plain and Anqing region, together with the Yangtze River and its tributaries, provide important habitats for aquatic animals and plants. This area is also an important stopover and breeding ground for birds migrating through Eurasia (Kanai *et al.* 2002). More than 300 species of waterfowl, about 200 fish species, and approximately 95% of the world's wintering Siberian crane (*Grus leucogeranus*) depend on these wetlands (Wu and Ji 2002). It is also an important habitat for the endangered Baiji (or Chinese river) dolphin (*Lipotes vexillifer*), a freshwater cetacean that inhabits the Yangtze River. Because of its many vital ecological functions and unique biodiversity, the Central Yangtze has been designated by WWF as one of the Global

中國的環境

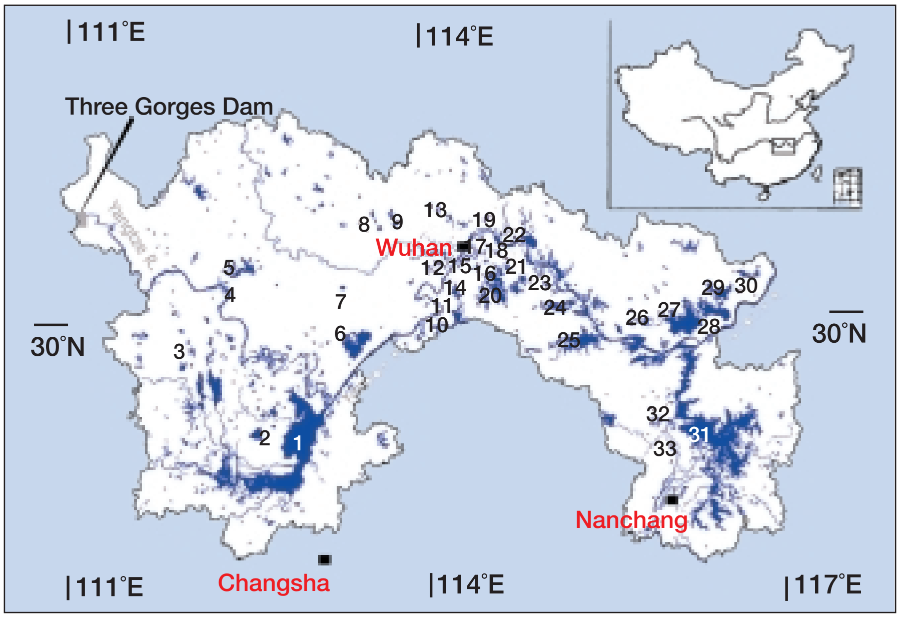

***Figure 1.** Distribution of lakes in the Central Yangtze region in 1998, produced from eight non-cloudy Landsat Thermatic Mapper (TM) images in the dry season of 1998 (~October to December). Numbers 1 to 33 represent major lakes, where detailed information on lake size (water surface area) was documented in the 1950s and the late 1990s (most for the year of 1998). 1. Dongtinghu (Dongting Lake); 2. Datonghu; 3. Niulanghu; 4. Guhu; 5. Changhu; 6. Honghu; 7. Paihu; 8. Laoguanhu; 9. Diaochahu; 10. Futouhu; 11. Luhu; 12. Guanlianhu; 13. Wangmuhu; 14. Qinglinghu; 15. Huangjiahu; 16. Nanhu; 17. Donghu; 18. Beihu; 19. Wuhu; 20. Liangzihu; 21. Yaerhu; 22. Zhangduhu; 23. Huamahu; 24. Dayehu; 25. Wanghu; 26. Taibaihu; 27. Longganhu; 28. Huangdahu; 29. Pohu; 30. Wuchanghu; 31. Poyanghu; 32. Banghu; and 33. Dahuchi.*

200 priority ecoregions for conservation (Olson and Dinerstein 1998).

Nevertheless, intensive land reclamation over the past several decades has replaced floodplains and lakes with agricultural areas and urban settlements. For example, in the 1930s, the surface area of Dongting Lake covered 4955 km^2, but had decreased to ~2500 km^2 by the late 1990s, and the lake was divided into three sublakes (East, West, and South Dongting Lake; Zhao *et al*. 2005). In the 1950s, there were 414 lakes with surface areas greater than 1 km^2 in the Jianghan Plain, but by 1998 this number had fallen to 258 (Fang *et al*. 2005). Wetland degradation has resulted in serious negative ecological consequences, including increased flooding, a decline of biodiversity, and extinction of a number of endemic species (Zhao *et al*. 2005).

Several studies have documented the changes in aquatic biodiversity patterns and community structures in various rivers and lakes in the Central Yangtze at different periods since the 1950s (eg Fu *et al*. 2003); however, an integrated analysis on the status of biodiversity changes is not yet available. Here, we review biodiversity changes at the community, population, and species level for aquatic plants, fish, and waterfowl in the Central Yangtze. The objectives of this review are to: (1) provide basic information on the changes in the lakes over the past 50 years using historical land cover information and remote sensing data; (2) review the changes in biodiversity based on analyses found in the literature; and (3) summarize major factors that have led to the changes in biodiversity.

Although our review focuses on a period beginning in the 1950s, some of the biodiversity data were available only from the 1960s, as a result of changes in China's policy on restriction of information and investigation methods during that period. In addition, we did not perform statistical analyses on some aspects of biodiversity changes because of insufficient data. The data sources used in this review were gathered from different publications and reports and are listed in WebTable 1.

Changes in lake size

In order to understand the effects of the changes in lake size on biodiversity, we documented the current distribution of lakes in the Central Yangtze, using Landsat Thematic Mapper (TM) remote sensing data (Figure 1). Figure 1 was generated from eight non-cloudy Landsat TM images in the dry season of 1998 (mostly from October to December). The satellite images were classified into six land-cover types (settlement, cropland, shrub, forest, water body, and barren land) on the basis of the multispectral classification algorithm (maximum likelihood), using Erdas Imagine 8.4. Only data on water body type was exported to ArcView GIS software for data analysis (Zhao *et al*. 2005).

Figure 2 illustrates changes in water surface area (lake size) for some of the major lakes in the study area between the 1950s and the late 1990s. Information on the size of the lakes in the late 1990s was taken from Figure 1, and data for the 1950s was obtained from land-cover maps made during that period (scale of 1:200 000). For further details on the data and on data processing, see Fang *et al*. (2005).

The results showed that the surface area of most of the lakes shrank dramatically in the late 1990s, as compared to the 1950s: 31 of 33 lakes experienced a marked decline in size, while only two (Changhu Lake and Huamahu Lake) showed an increase (Figure 2). The term "changing rate of lake size" was used to evaluate the magnitude of lake degradation, and was obtained by dividing the difference in lake size in the 1990s and in the 1950s by the lake size in the 1950s. This revealed that 14 lakes had decreased in size by 50–100%, another 10 lakes had been reduced by 25–50%, and a further seven by 0–25% (Figure 2 inset).

These reductions in surface area were mainly the result of the practice of impoldering (a type of land reclamation that encroaches on lakes and their associated wetlands for agricultural purposes, through the construction of dikes and drainage structures; Zhao *et al.* 2005). Natural processes, such as sedimentation and interannual changes in climate may also cause reductions in lake surface area (Du *et al.* 2001), but the contribution of natural silt deposition to the decrease in water surface of Dongting Lake, the second largest lake in the region, was estimated as < 7% over the past 70 years (Zhao *et al.* 2005). According to Fang *et al.* (2005), variations in annual rainfall were also not a major factor in the size decreases of lakes in the Jianghan Plain area.

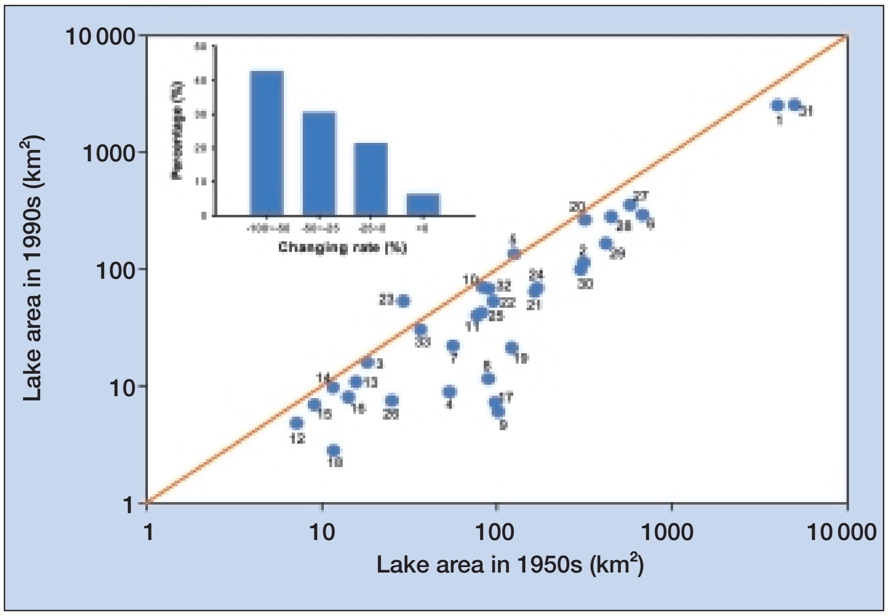

Figure 2. *Comparison of the surface area of 33 major lakes in the Central Yangtze region between the 1950s and the late 1990s. Lake sizes were much smaller in the late 1990s than in the 1950s for most lakes. Among the 33 major lakes, the size of 14 lakes decreased by 50–100%, that of 10 lakes by 25–50%, and of seven lakes by 0–25%. Only two lakes (Changhu and Huamahu) increased due to aquaculture (inset). The numbers 1–33 represent major lakes and correspond to those listed in Figure 1.*

■ Changes in biodiversity

Aquatic vascular plants

Over the course of many decades, the number of aquatic vascular species has tended to decrease in six of the eight major lakes in which species were well documented (Figure 3). This was mainly due to loss of certain species which are sensitive to environmental pollution and other habitat changes. For example, at Donghu Lake, formerly dominant species, such as sago pondweeds (*Potamogeton maackianus* and *Potamogeton cristatus*), Indian fern (*Ceratopteris thalictroides*), duck lettuce (*Ottelia alismoides*), ivy leaf duckweed (*Lemna trisulca*), *Eriocaulon buergerianum*, water celery (*Oenanthe javanica*), Asian marshweed (*Limnophila sessiliflora*), and dwarf bladderwort (*Utricularia exoleta*), have mostly disappeared since the 1970s, primarily as a result of increasing pollution (Liu 1995; Yu 1995). Eight plant species have disappeared from Honghu Lake during the past 50 years (Peng *et al.* 2004). At Liangzi Lake, which suffers less human disturbance, plant richness did not show any significant change and has fluctuated between 87 and 92 species over the past 30 years, while the number of species at Poyang Lake (the largest lake in this area) has tended to increase since the 1980s, most likely due to the establishment in 1983 of the Poyang Lake National Nature Reserve (Poyang Lake National Nature Reserve 1993).

In order to look for an overall trend in the changes to plant species in these lakes, we standardized species richness data for each decade and for each lake by defining the data in the 1990s as a baseline (100), and obtained relative species richness for each decade and for each lake through the calculation

$$(100/N_{1990}) \times N_i$$

where N_{1990} is a lake's species richness in the 1990s and N_i represents the species richness for a particular decade. (The level of species richness of the 1990s was used as the basis for this standardization because richness data for that decade was available for all eight lakes.) We then averaged the values of the relative species richness of all the lakes for each decade, and obtained an overall trend of species richness change from the 1960s to the 2000s. The results suggested a significant decrease ($r^2 = 0.93$, $P = 0.007$) in species richness for these eight lakes during the study period (Figure 3 inset).

Not only did the number of species change, but so to was species composition within aquatic plant communities altered (Table 1). The dominant aquatic vegetation species at Donghu Lake were common reeds (*Phragmites communis*), wild rice (*Zizania latifolia*), and sago pondweed (*P maackianus*) in the 1950s (Zhou *et al.* 1963), but these were replaced by *P maackianus*, holly-leaved naiad (*Najas marina*), and *Hydrilla verticillata* in the 1960s (Chen and He 1975). *P maackianus* disappeared during the 1970s–1980s, and *N marina* became predominant (Yao *et al.* 1990). Submersed plants, such as *N marina*, spiked water-milfoil (*Myriophyllum spicatum*), and American eelgrass (*Vallisneria spiralis*), were dominant in the 1990s (Yan *et al.* 1997), but were supplanted by emergent plants such as bulrushes (*Typha orientalis*) and Indian lotus (*Nelumbo nucifera*) by 2001 (Wu *et al.* 2003).

The dominant species at Honghu Lake in the 1960s included floating-leaved plants such as water chestnut (*Trapa bispinosa*) and submersed ones such as *P malaianus*, *V spiralis*, and *H verticillata*), but these were replaced by other submersed plants (*P maackianus*, *M spicatum*, and *Ceratophyllum demersum*) and emergent plants (*Hydrilla*

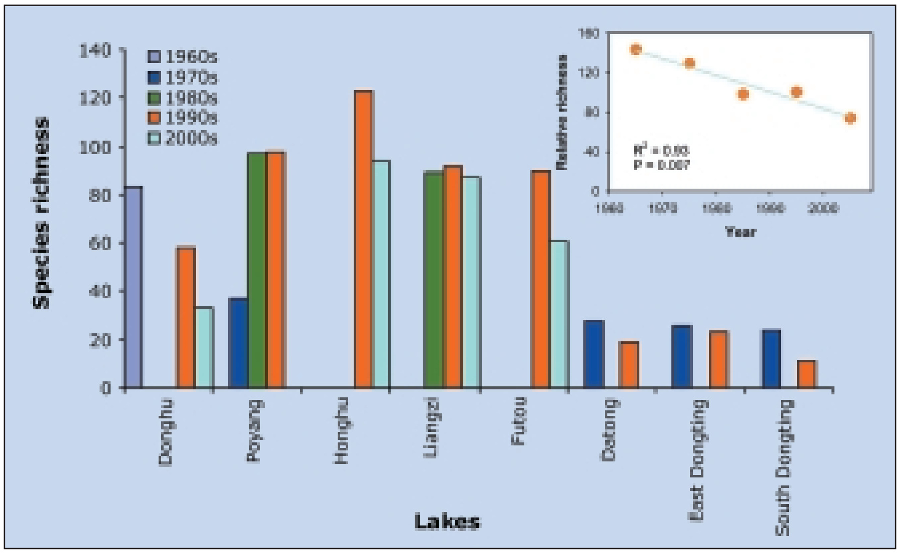

Figure 3. *Changes in species richness of aquatic vascular plants in eight large lakes in the Central Yangtze. The inset figure illustrates averaged relative species richness of all the lakes for each decade; they show a significant decrease ($r^2 = 0.93$, $P = 0.007$) over the study period. (See text for inset details.)*

and *Zizania latifolia*) in the 1980s (Li 1982). By the 1990s, they were further replaced by submersed plants, such as *P maackianus*, and hornwort (*C demersum*; Li 1997).

The dominant species of aquatic vegetation at Liangzi Lake also underwent major changes. The original vegetation consisted primarily of *V spiralis*, *H verticillata*, *N marina*, and brittle naiad (*Najas minor*) in the 1950s, but had changed to *P malaianus*, *P maackianus*, *Potamogeton crispus*, and *C demersum* by the 1980s (Jin 1992). In the 1990s, areas covered by *P malaianus* were greatly reduced and largely replaced by *P maackianus* (Jin 1999).

Fish

During the study period, substantial changes were also seen in fish diversity at community, population, and species levels (Figure 4). The species richness of fishes in Donghu, Honghu, and Liangzi lakes has tended to decline since the 1960s (Figure 4a). In Donghu Lake in the 1960s, for example, there were 67 species of fish, but this number had fallen to 38 by the 1990s; nearly half the fish had disappeared, including some rare species, such as Reeve's shad (*Tenualosa reevesi*), Chinese banded shark (*Myxocyprinus asiaticus*), the Yangtze grenadier anchovy (*Coilia brachygnathus*), and bream (*Megalobrama skolkovii*; Fang 1991; Huang *et al.* 1995). The number of fish species in Honghu Lake declined from 74 in the 1960s to 57 in the 1990s (Chang *et al.* 1995; Song *et al.* 1999). Similarly, fish species in Liangzi Lake dropped from 75 in the 1970s to 54 in the 1980s.

An important characteristic of the changes in fish species composition is that the proportion of migratory and semi-migrant species decreased, while that of resident species increased in the fishing yield. Most importantly, the percentage of typical migrant species, such as Chinese sturgeon (*Acipenser sinensis*), Yangtze sturgeon (*Acipenser dabryanus*), *Tenualosa reevesi*, Japanese eel (*Anguilla japonica*), and *Myxocyprinus asiaticus*, declined dramatically, and some have not been observed at all in recent years (Qiu *et al.* 1998; Yi *et al.* 1999;

Table 1. Dominant species of aquatic vegetation in Central Yangtze lakes at different periods

Periods	*Donghu Lake*	*Honghu Lake*	*Liangzihu Lake*
1950s	*Phragmites communis*, *Zizania latifolia*, *Potamogeton maackianus*, and *Azollaim imbricate*		*Vallisneria spiralis*, *Hydrilla verticillata*, *Najas marina*, and *Najas minor*
1960s	*Potamogeton maackianus*, *Najas marina*, *Hydrilla verticillata*, *Myriophyllum spicatum*, and *Ceratophyllum demersum*	*Trapa bispinosa*, *Potamogeton malaianus*, *Vallisneria spiralis*, and *Hydrilla verticillata*	
1970s	*Najas marina*		
1980s	*Najas marina*	*Potamogeton maackianus*, *Myriophyllum spicatum*, *Zizania latifolia*, and *Ceratophyllum demersum*	*Potamogeton malaianus*, *Potamogeton maackianus*, *Potamogeton crispus*, and *Ceratophyllum demersum*
1990s	*Najas marina*, *Myriophyllum spicatum*, and *Vallisneria spiralis*	*Potamogeton maackianus*, *Myriophyllum spicatum*, and *Ceratophyllum demersum*	*Potamogeton malaianus*, *Potamogeton maackianus*, and *Trapa quadrispinosa*
Present	*Typha orientalis* and *Nelumbo nucifera*		*Potamogeton maackianus*, *Ceratophyllum demersum*, *Myriophyllum spicatum*, and *Vallisneria spiralis*

References: Zhou *et al.* 1963; Chen 1975, 1980; Li 1982; Yao *et al.* 1990; Jin 1992, 1999; Wang *et al.* 1994; Li 1997; Yan *et al.* 1997; Wu *et al.* 2003

Zhang *et al.* 2000). At Dongting Lake, the yield of four carps (well-known migrant and semi-migrant species in China) – black carp (*Mylopharyn-godon piceus*), grass carp (*Ctenopharyngodon idellus*), silver carp (*Hypophthalmichthys molitrix*), and bighead carp (*Aristichthys nobilis) – declined* steadily from 21% of the total fishing yield in 1963 to 14.1% in 1981, and to 9.3% in 1999. At the same time, the yield of resident fish species, such as common carp (*Cyprinus carpio*), goldfish (*Carassius auratus*), and catfish (*Silurus asotus*), have increased from 63% in the 1960s to 86.1% in 1999 (Liao *et al.* 2002). At Honghu Lake, the yield of semi-migrant species represented approximately 50% of the total yield in the 1950s, but fell to only 0.5% in the 1980s (Chang *et al.* 1995; Song *et al.* 1999). The greatest changes seen in these fish populations have been in body size and age structure of some species. For example, for *T reevesii*, a very important migrant fish in the Yangtze River, fishing yield statistics showed that in 1962, 2–3-year-old individuals represented only 31% in weight of the total yield of this species, while the remainder was composed of older fishes (4–7 years old). However, in 1986, the percentage of 2–3-year-old fish increased to 92%, while no individuals of 5 years or older were seen at all (Figure 4b). In addition to this decrease in numbers of older fish, mean individual size (weight per individual) also decreased greatly; in 1962, the majority caught weighed 1–2 kg (63%), with a very small number of < 1.0 kg (1%), while in 1986 individuals of < 1.0 kg made up 41% of the total yield, and there were no individuals > 3.0kg (Qiu *et al.* 1998; Figure 4c).

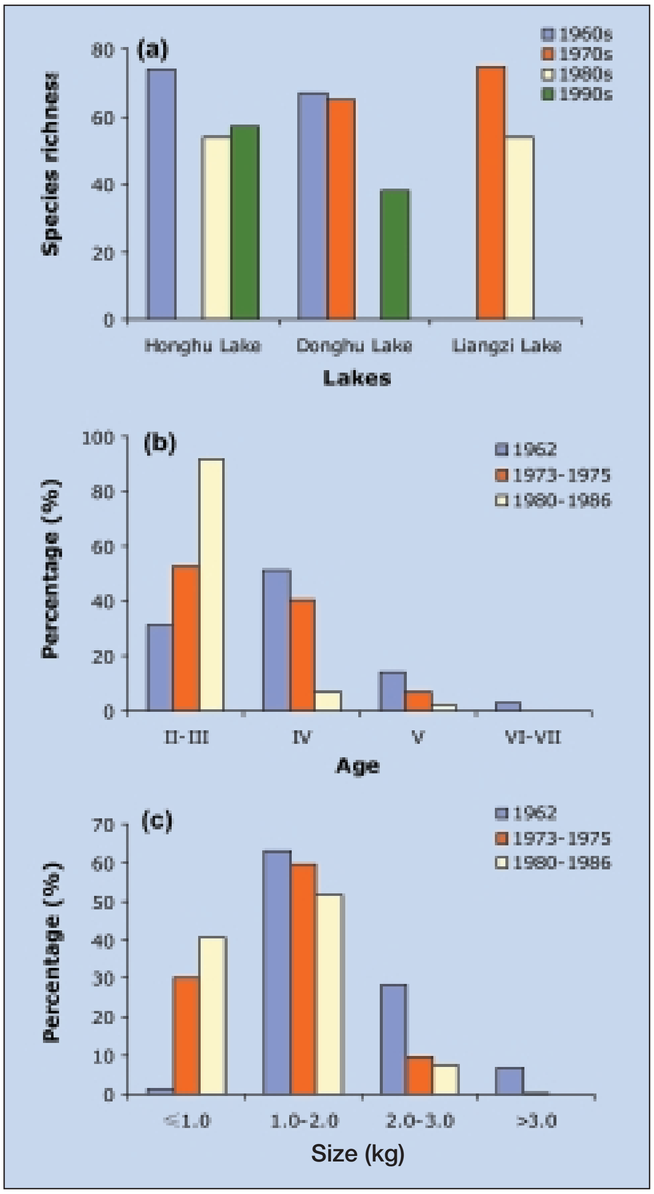

Figure 4. *Changes in species richness and population structures of fish in some lakes in the Central Yangtze. (a) Changes in species richness in three large lakes (Donghu, Honghu, and Liangzi). (b) Frequency distribution of mean age of* T reevesii. *(c) Frequency distribution of mean individual size (weights) of* T reevesii.

Waterfowl

Lakes in the Central Yangtze region are important stopover and breeding sites for migrant birds in Eurasia (Kanai *et al.* 2002). Figure 5 shows the changes seen in the waterfowl species at Honghu Lake, Dongting Lake, and Chenhu Lake, where interannual changes in bird populations have been well documented. Wintering waterfowl at Honghu Lake decreased from 36 species in the 1960s to 28 species in the 1990s (Figure 5a). Of these, geese and duck species (Anatidae) declined from 25 to 20 (Figure 5b), while in Chenhu Lake 9 species disappeared between the 1980s and the 1990s (Figure 5a). Geese and ducks at Dongting Lake declined from 31 species at the end of the 1950s to 20 species in 1991–92, and then increased again, to 28 in the period 2000–02 (Figure 5b; Zhao 2002). The increase seen over the past 10 years was most likely due to the establishment of the East Dongting Lake nature reserve in 1992 (Zhao 2002). However, seven rare species, including red-breasted geese (*Branta ruficollis*), whooper swans (*Cygnus cygnus*), and lesser whistling ducks (*Dendrocygna javanica*), which were present in 1963, were not observed in 2000–02. Instead, four new bird species appeared: snow geese (*Anser caerulescens*), pochard (*Aythya ferina*), scaup (*Aythya marila*), and goldeneye ducks (*Bucephala clangula) (*Zhao 2002).

The changes in waterfowl populations in the Central Yangtze lakes are clearly seen in the variations in populations of Siberian cranes (*Grus leucogeranus*) at Poyang Lake and the lesser white-fronted goose (*Anser erythropus*) at Dongting Lake (Figure 6). These were chosen as representative species for these two lakes, respectively, because approximately 95% of the critically endangered Siberian crane winter at Poyang Lake (Meine and Archibald 1996) and about half of the world population of the globally threatened lesser white-fronted geese winter at Dongting Lake (Lei 2000). Furthermore, relatively long-term monitoring data on waterfowl is available for these two lakes.

The population of Siberian cranes at Poyang Lake increased steadily from 730 in the wintering period of

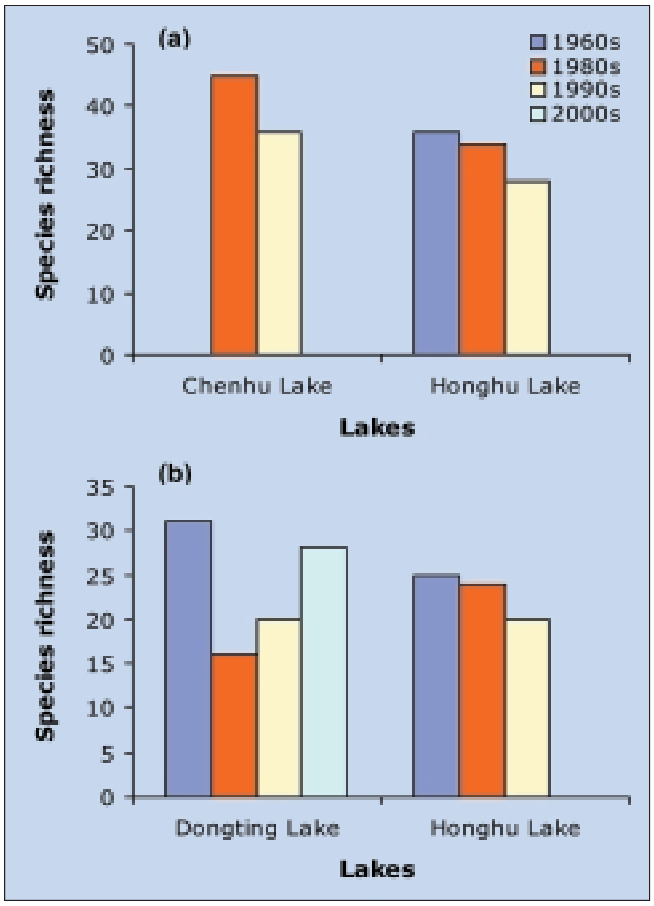

Figure 5. *Changes in species richness of (a) overwintering waterfowl and (b) Anatidae (geese and ducks) in three lakes (Honghu, Dongting, and Chenhu) in the Central Yangtze.*

1983–84 to 2653 during 1988–89, and then remained relatively constant from 1989 to 1995, after which the population began to decrease. The much smaller numbers for the wintering periods of 1992–93 (725 individuals), 1997–98 (960) and 1998–99 (762) (Figure 6a) were probably caused by flooding in these years (Zhao 2002).

At Dongting Lake, the population of lesser white-fronted geese increased between the wintering period of 1992–93 and 2001–02 ($P = 0.057$), and peaked in 1998–99, with a total of 16 500 (Figure 6b). The total extant population of white-fronted geese is estimated to be around 25 000–30 000 individuals (Lorentsen *et al.* 1999).

Baiji dolphin

The Baiji dolphin, also known as the Chinese river dolphin, is endemic to the Yangtze River, and is considered to be a "living fossil" whose evolutionary history can be traced back more than 20 million years. However, its numbers have declined rapidly over the past several decades (Liu *et al.* 1996). Historically, it was often observed in the Yangtze River and in Poyang and Dongting lakes. However, population size fell sharply over the past 50 years or so, from 6000 in the 1950s to 400 in 1984, then to 60 in 1998. Most strikingly, it has not been observed at Poyang Lake and Dongting Lake since 1978, suggesting that it may now be locally extinct (Yang *et al.* 2000).

Major factors affecting biodiversity changes

Land-use and land-cover change

Land-use and land-cover change affects habitat availability and consequently leads to alterations in biodiversity (DeFries *et al.* 2004). Over the past 50 years, the Central Yangtze region has experienced extensive land-use and land-cover changes. For example, impoldering land reclamation through drainage techniques in this region resulted in a decline in biodiversity and even extinction of some endemic species (Zhao *et al.* 2005). Increased levels of impoldering have caused a substantial loss of spawning areas for the common carp at Poyang Lake, from 5.2×10^4 ha in 1961 to 2.6×10^4 ha in 1984, thereby greatly decreasing population size (Zhang 1988). Urbanization has rapidly encroached on most wild habitats, including forests and lake areas, leading to declines in lake size, deterioration of water and air quality, and loss of biodiversity (Li *et al.* 2006).

Environmental pollution

Environmental pollution is one of the principal threats to biodiversity in the Central Yangtze region (Xie and Chen 1999). The strategy used to stop the expansion of schistosomiasis in the Yangtze River essentially comprised the mass release of chemicals between 1955 and the 1980s designed to control the vectors of the disease, and while successful, this approach led to a serious deterioration in water quality and severely impacted biodiversity (Yuan *et al.* 2002). For example, at Poyang Lake, waterfowl numbers fell sharply between 1971 and 1978, when the schistosomiasis control program was being implemented (Poyang Lake National Nature Reserve 1993).

Donghu Lake, a shallow urban lake, was classified as mesotrophic (narrow range of nutrients and intermediate in water quality) in the 1950s, but deteriorated to become hypereutrophic (nutrient-rich, characterized by major algal blooms and poor water quality) by the 1980s, due to accelerated levels of eutrophication. Consequently, phytoplankton proliferated rapidly, greatly reducing light penetration through the water column. This is one of the major reasons why aquatic vascular vegetation, particularly submersed macrophytes, declined or disappeared altogether (Yan *et al.* 1997; Wu *et al.* 2003).

Noise pollution can also be classified as a form of environmental pollution. Intensive shipping noise has greatly disturbed the growth and development of the Baiji dolphin, and may be a factor in the decline of its population size (Hua *et al.* 1995).

Overexploitation

The increasing amount of aquaculture being carried out in the Central Yangtze floodplain has also had serious negative effects on biodiversity. Peng *et al.* (2004) argued that fish being bred in Honghu Lake grazed on aquatic vegetation, especially submersed macrophytes, thereby decreasing aquatic vascular plants and vegetation coverage. At Donghu Lake, the loss of *P maackianus*, a dominant submersed vascular plant, was closely associated with overstocking of grass carp (*C idellus*; Chen 1980).

Overexploitation of fish resources is another major cause of the dramatic fall in the number of wild fish species in most lakes in this area. The use of certain fishing techniques, such as dense-aperture nets, bombing, poisoning, and electric shocks, has severely affected breeding and regeneration of fish species in some lakes (Zhang 1988).

Large hydroelectric projects

Large dams cause habitat loss, alter the reproductive environments of some species, and block migration routes, leading to a substantial decline in biodiversity (Stanley and Doyle 2003; Wu *et al.* 2004). The construction of the Gezhou Dam in the upper-Central Yangtze River in 1981 led to a sharp decline in the populations of three endangered and endemic ancient fish species, Chinese sturgeon (*A sinensis*), Yangtze sturgeon (*A dabryanus*), and Chinese paddlefish (*Psephurus gladius*), which are being prevented from reaching their traditional spawning areas in the Jinsha River (in the upper reaches of the Yangtze River) by the dam (Wei *et al.* 1997). The ongoing Three Gorges Dam Project, the largest hydroelectric dam in the world (38 km upstream from Gezhou Dam), will have catastrophic consequence for fish, most especially to the migrant species in the middle and lower reaches of Yangtze River, by damaging the new spawning sites already formed below and above the Gezhou Dam and completely blocking the upstream migration routes of fish (Xie 2003). These large dams impact not only fish, but many other aquatic and terrestrial species as well (Wu *et al.* 2004).

The Central Yangtze is characterized by an interconnected network of water systems, including the river and its tributaries, and a large number of shallow lakes. The dams and dikes built to control flooding from the early 1950s through to the end of the 1970s caused almost all of the shallow lakes to become separated from the Yangtze River; only Poyang Lake and Dongting Lake remain connected. The separation of the lakes from the river and its tributaries has cut off the traditional migratory route of many fish and restricts the species exchange between the lakes and the river, which is another cause of the decline in fish species in the lakes (Huang *et al.* 1995; Song *et al.* 1999).

Establishment of nature reserves and lake restoration projects

The implementation of China's sustainable development strategy and a growing awareness of environmental protection and biodiversity conservation in the Central Yangtze, a biodiversity hotspot, have raised considerable concern. Mostly within the past 20 years, 16 national and local nature reserves have been established in this area and are playing an important role in protecting biodiversity (Fang *et al.* 2006). For example, since the establishment of the nature reserves, Poyang Lake and East Dongting Lake have become the most important overwintering sites for the Siberian crane and lesser white-fronted goose, respectively (Figure 6).

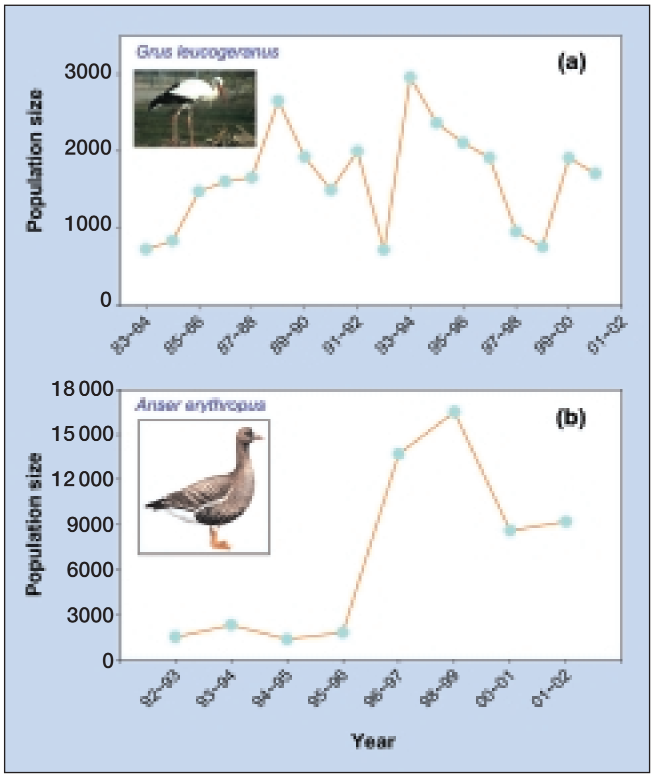

***Figure 6**. Changes in population size of two waterbirds: (a) Siberian crane (*Grus leucogeranus*) from 1983 to 2001 at Poyang Lake, and (b) lesser white-fronted goose (*Anser erythropus*) from 1992 to 2002 at Dongting Lake.*

Historically, impoldering was carried out in the Central Yangtze to support a growing human population, and instances of this land reclamation practice increased from the early 1950s to the late 1970s (Shi 1989). The negative impacts, together with a growing awareness of the importance of wetlands, have lead to the establishment of policies to protect and restore lakes and associated wetlands. The Chinese government enacted a policy to prohibit impoldering from the end of the 1970s. Local people have allowed some inundated lands to be rejoined to the original lakes because they are unwilling to repair breached dikes (Wang 1998). After unprecedented flooding in 1998, the Chinese government implemented a lake restoration project in the Central Yangtze floodplain, which reversed the impoldering and controlled degradation of the lakes to some degree. For example, the area covered by Honghu Lake, the largest lake in the Jianghan Plain, increased in size between 1987 and 1998 (Zhao *et al.* 2003).

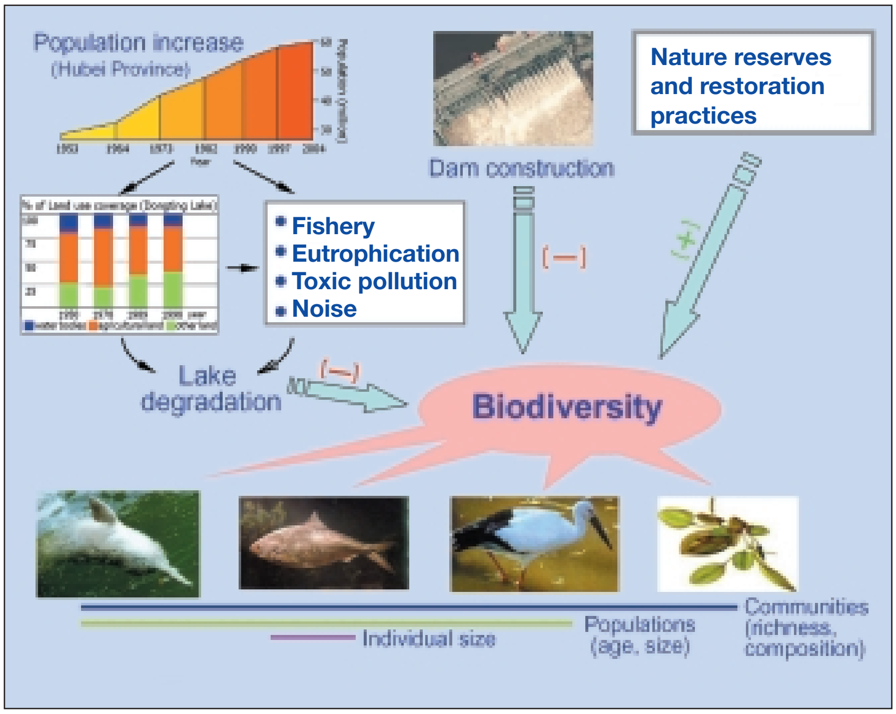

Figure 7. *Biodiversity changes and their relationship with human impacts in the Central Yangtze lakes. Increases in human population result in land-use and land-cover changes and environmental pollution, which lead to degradation of lakes (eg loss of wetlands, water pollution and eutrophication, and overfishing). These, together with the construction of large hydroelectric dams, establishment of nature reserves, and lake restoration practices, are the major causes of changes in aquatic biodiversity in the Central Yangtze. Such human-induced biodiversity changes take place at multiple levels (species richness, community composition, population size and age structure, and individual body size).*

■ Conclusions

Substantial changes have been observed in aquatic biodiversity in most of the Central Yangtze lakes. These changes are the result of the impacts of three kinds of human-induced activities, as illustrated in Figure 7: (1) lake degradation (eg loss of wetlands, water pollution and eutrophication, and overfishing), caused by a growing human population and increased food production; (2) the construction of large hydroelectric projects, primarily aiming at exploiting water resources for power generation; and (3) the establishment of nature reserves and lake restoration practices to restore habitats for plants and animals. Natural processes (such as lake sedimentation and climate change) are also factors for the changes in lake structure and biodiversity in this region, but these were not included here because their influences are likely much smaller than those induced by rapid, intensive human disturbances (Zhao *et al.* 2005).

As stated above and shown in Figure 7, lake degradation and the construction of large dams have led to a substantial decrease in species richness within inhabitant plant and animal communities, as well as changes in population size, age structure, and individual size of fish species. On the other hand, the establishment of a number of nature reserves and lake restoration projects since the late 1980s and early 1990s has restored habitats and biodiversity to some degree. One example of this is seen in the increase in the numbers of overwintering waterfowl at some lakes (Figure 6). A concerted effort by ecologists, hydrologists, policy makers, and local residents will be required to minimize negative human impacts, maximize the effectiveness of nature reserves and lake restoration, and to protect and ultimately restore the wetland biodiversity of this area.

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