Human-Induced Long-Term Changes in the Lakes of the Jianghan Plain, Central Yangtze
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Human-induced long-term changes in the lakes of the Jianghan Plain, Central Yangtze

Jingyun Fang, Sheng Rao, and Shuqing Zhao

The Jianghan Plain, located in the Central Yangtze area of China, is famous for its freshwater lakes, but these have undergone dramatic changes in area and number as a result of increasing human activity. We analyze the changes in lakes with an area ≥1 km^2 from the 1950s to 1998, using historical land-cover information and remote sensing data. The changes showed two distinct periods: the 1950s–1978 and 1978–1998. During the former period, the number of lakes fell from 414 to 250 (–39.6%) and total area decreased from 3885.4 km^2 to 1839.1 km^2 (–52.7%). During the latter period, the number of lakes rose, from 250 to 258 (+3.2%), while the area covered increased from 1839.1 km^2 to 2144.4 km^2 (+16.6%). The rapid fall in numbers of lakes from the 1950s to 1978 was largely attributed to extensive impoldering (land reclamation through draining techniques), resulting in substantial negative ecological consequences, such as increased flooding and a decline in biodiversity. In contrast, the increase in lake numbers and area from 1978 to 1998 was mainly due to the implementation of government policy prohibiting impoldering along the Yangtze River, and the return of inundated arable lands for aquaculture by local people.

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Freshwater lakes store renewable freshwater for human use and provide habitats for aquatic fauna and flora (Johnson *et al.* 2001). Despite their value, freshwater lakes have been greatly modified and degraded by human activities (Beeton 2002; Bronmark and Hansson 2002). How freshwater lakes change as a result of human activities, and the ecological consequences of those changes, has received increasing attention (Richter *et al.* 1997; Wilcove *et al.* 1998), but there have been surprisingly few studies conducted at the decadal time scale in heavily populated regions.

Central Yangtze (China) is an ideal place to study human-induced changes in freshwater lakes and their ecological consequences. As the human population grew, impoldering, a type of land conversion that encroaches on lakes and their associated wetlands for agricultural purposes, through the construction of dikes for agricultural purposes, became a major human activity in the region. This land reclamation practice was accelerated from the early 1950s to the late 1970s (Shi 1989), resulting in substantial negative consequences including increased flooding, decreased lake and wetland area, and a decline in biodiversity (Zhao *et al.* 2005).

The Jianghan Plain was the site of a historically famous swamp, *Yun-meng Ze* (cloud-dream swamp), which experienced extensive impoldering before the end of the 1970s, resulting in rapid loss of lake area. In the early 1950s, there were 1332 lakes greater than approximately 0.07 km^2 in size (roughly equal to 100 *mu*, the Chinese unit of area) and 322 lakes greater than about 3.5 km^2 (Hydroelectric Bureau of Hubei Province 1991). However, there are now fewer than 300 lakes covering an area of more than 1 km^2. Although some studies have investigated shrinkage of lakes in some parts of the Jianghan Plain (Li and Zhang 1997), no integrated analysis on the changes in size and number of lakes, and the possible causes, has been conducted for the Plain as a whole on a decadal scale.

In this study, we used five decades of historical land-cover information and remote sensing data to (1) estimate changes in the size and number of the lakes in the Jianghan Plain from the 1950s to 1998, and (2) explore the causes of these changes and their ecological consequences.

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■ Study site and methods

Site description

The Jianghan Plain is located in the northern part of the Central Yangtze River drainage basin, Hubei Province, China, and ranges from 28° 08' to 30° 08' N in latitude and from 111°12' to 114°47' E in longitude, with an altitude of <40 m in most parts (Figure 1). It is the largest plain in south China, encompassing a total area of 55 456 km^2 and 25 counties/cities. Geologically, it stems from the lower Yangtze and Hunan-Hubei-Guizhou platform and the old Jianghan basin of the late Paleozoic, and was formed in the past several hundred years by depositions from the Yangtze River and Han River (Liu 1994). The climate is subtropical, with an annual precipitation of 1000–1500 mm, and a mean annual temperature of 16.5°C (Cai and Du 2000). The zonal vegetation formerly consisted mainly of evergreen broadleaf forests and deciduous and evergreen broadleaf mixed forests, but almost all of these natural forests were logged. Currently, only small fragments of the zonal vegetation remain in hilly areas and the dominant natural vegetation in the plain consists of meadow and marsh communities. The zonal soil types include yellow-brown soil and red soil, but have been replaced with cropland and paddy soils in most areas (Liu 1994).

The Jianghan Plain contains a large number of lakes, most of which are dammed and fluvial lakes. Prior to impoldering, these lakes played an important role in flood mitigation, as well as providing water for drinking, irrigation, and aquaculture. Because this area supports a large and continuously growing human population, however, many lakes have been reclaimed for agricultural and aquaculture use. Consequently, the regional environment has been greatly altered over the past 50 years.

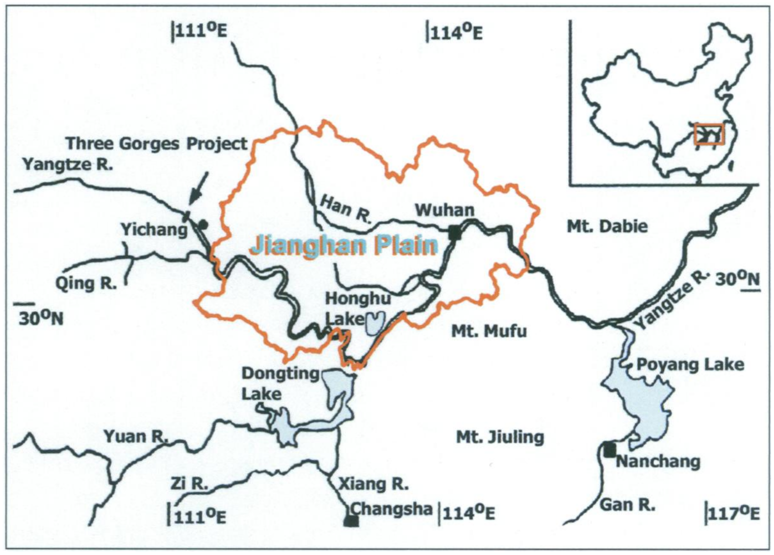

Figure 1. *The Jianghan Plain is situated in the northern part of the Central Yangtze River basin, Hubei Province, China.*

Data and data processing

In this study, we focused on Jianghan Plain lakes greater than 1 km^2 in size, since smaller lakes could not be effectively quantified using remote sensing imagery. The numbers and surface area measurements of these lakes from the 1950s to 1998 were acquired from historical land-cover information and remote-sensing data. The data used in this study spanned approximately 50 years, divided into three periods: the 1950s, 1978, and 1998. The land-cover data for the 1950s were obtained from 17 land-cover maps with topography information (scale 1:200 000, spanning from 1955 to 1959, with a mean of year 1957), which was surveyed from November-February by the China Army General Consultation. Land-cover information from the 1970s onwards was acquired from cloud-free Landsat remote-sensing images: Landsat Multispectral Scanner (MSS) data for 1978 and Landsat Thematic Mapper (TM) data for 1998. Both Landsat MSS and TM data were obtained from China's Satellite Ground Station and the Center of Remote Sensing, the Institute of Petroleum Survey and Design, China (further details available from the corresponding author).

Because the time of year (eg dry or rainy season) significantly affects topographies and remote sensing imagery, every effort was made to collect data on lake surface area during specific periods. As a result, most of the images used in this study were from the dry season (October–December), and a few from September; historical land-cover maps with topography information were also from the dry season (November–February). Therefore, the different data sources used were consistent within specific seasons.

Each of the 17 historical maps from the 1950s was scanned into digital images at 600 dots per inch, giving a ground resolution of approximately 10 m. The land-cover maps showing topography for the 1950s contained 40–55 land-cover types with clear boundaries. Because we focused on the changes in surface area of the original lakes, the final classification consisted of only two categories, water and non-water. We reclassified these 40–55 land-cover types into water and non-water types, first through visual interpretation, then by tracing the boundary of each water body using GIS software (Founder drawing 5.5). Vector maps of the land-cover maps were transferred to ArcView GIS software, and resampled to a resolution of 90 m x 90 m, making them comparable with those obtained by remote sensing. The image processing software ERDAS 8.4 was then used to classify the land-cover types, in order to acquire information about the Jianghan Plain lakes. To provide consistency of band spectrums for different sensors of MSS and TM, the Landsat data were interpreted using similar band combinations with RGB (MSS bands 6, 7, 5, and TM bands 4, 5, 3). All images were geo-referenced according to 1:50 000 topographical maps, and the TM images (30 m x 30 m) were degraded and resampled to a resolution of 90 m x 90 m.

The quality of the classified products is critical to the analyses of the lake changes over time. We used the method of Jensen (1996) to assess the accuracy of the classified imagery products, based on field surveys and existing lake and reservoir distribution maps of Hubei Province. The resulting classification accuracy of water bodies for 1978 and 1998 was 82% and 86%, respectively, suggesting that the classified imagery products were of high quality. Land cover information for the 1950s was obtained directly from the land-cover maps and our classification consisted of only water and non-water categories; classified products for the 1950s were therefore very precise.

The classified water-body maps (Figure 2) were exported to the ArcView GIS software. We eliminated areas occupied by rivers, and retained only information on the lakes by referencing existing lakes, water body shape, and the lake and reservoir distribution map of Hubei Province. The

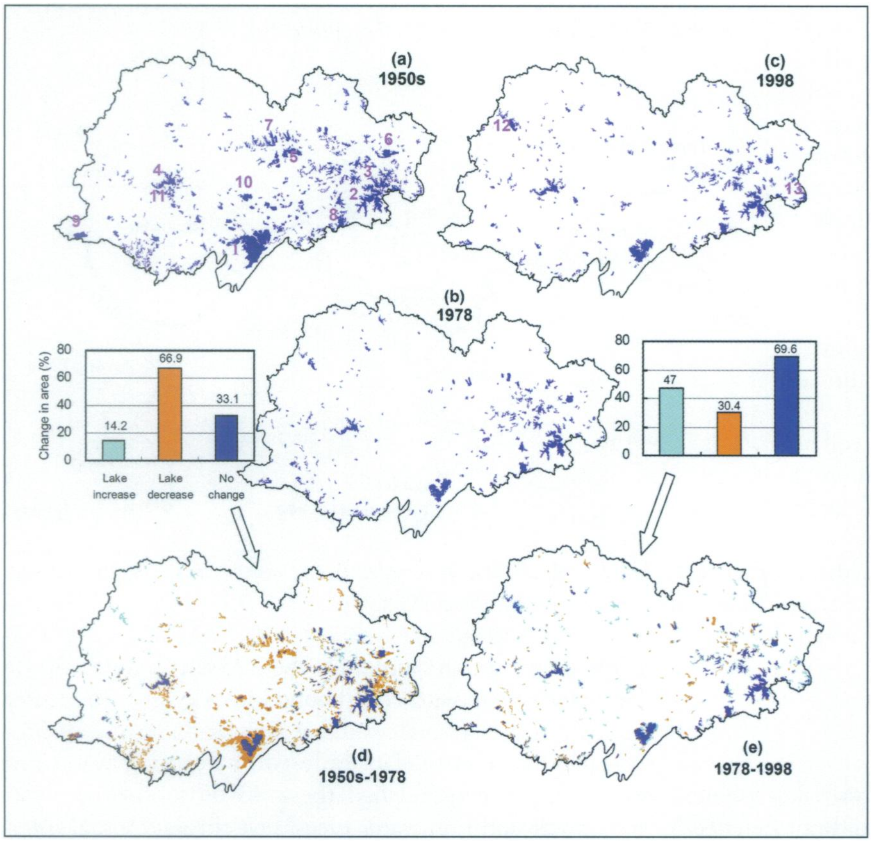

Figure 2. *Distribution of lakes in the Jianghan Plain for three periods, (a) the 1950s, (b) 1978, and (c) 1998, and overlaps of (d) the 1950s–1978, and (e) 1978–1998. The overlaps illustrate spatial distribution of lake-size decreases, increases, and areas where no change has occurred between the two periods. Insets indicate change in area (%) for the 1950s–1978 and 1978–1998. During the 1950s–1978, there was a net loss of 52.7% (inset of Figure 2d), while between 1978 and 1998, the lake area showed a net increase of 16.6% (inset of Figure 2e). The figures show major lakes that correspond to the number in Table 2: 1, Honghu Lake; 2, Liangzihu Lake; 3, Yaerhu Lake; 4, Changhu Lake; 5, Diaochahu Lake; 6, Zhangduhu Lake; 7, Laoguanhu Lake; 8, Futouhu Lake; 9, Wei River Reservoir; 10, Paihu Lake; 11, Guhu Lake; 12, Zhang River Reservoir; and 13, Huamahu Lake.*

area and perimeter of each lake were calculated for the 1950s, 1978, and 1998. The lakes were grouped into eight area size classes: 1–5, 5–10, 10–25, 25–50, 50–100, 100–200, 200–500, and 500–1000 km^2. We then calculated corresponding total surface area of lakes and number of lakes for each of the area size classes, including 13 major lakes that were larger than 50 km^2 in area (see Figures 2a and 2c).

■ Results

Figure 2 shows the distribution of lakes in the Jianghan Plain for the 1950s, 1978, and 1998, and changes in area (%) for two periods, from the 1950s to 1978 and from 1978–1998 (see Figure 2d, e insets). The changes were grouped into three categories: lake size increase, decrease, and no change for these two periods. These results were obtained by overlapping the distribution of lakes between the 1950s and 1978 and between 1978 and 1998. Both size and number of lakes decreased rapidly from the 1950s to 1978 (Figures 2a, 2b, and 2d), but did not show any apparent change between 1978 and 1998 (Figures 2b, 2c, and 2e), implying an inconsistent pattern for these two periods. During the first period, the total surface area of the lakes decreased by 52.7% from 3885.4 km^2 in the 1950s to 1839.1 km^2 in 1978 (Table 1 and inset of Figure 2d). This decrease in lake size also occurred in most of the lake size classes for this period. For example, the total area of the lakes in the size classes 1–5 km^2, 25–50 km^2, and 500–1000 km^2 decreased by 38.2%, 36.7%, and 100%, respectively (Table 1). Only in the size class 200–500 km^2 did lake area increase, by 53.8%, due to degradation of Honghu Lake (the largest lake in the Plain) from 678.9 km^2 (size class 500–1000 km^2) in the 1950s to 223 km^2 (size class 200–500 km^2) in 1978 (Tables 1 and 2). During this period, the number of lakes decreased by 39.6%, from 414 to 250. The number of lakes within each size class also declined sharply. For example, the number of lakes of 1–5 km^2 declined from 297 in the 1950s to 188 in 1978. Lakes of 50–100 km^2 declined from six in the 1950s to one in 1978 (Table 1). The largest lake, Honghu, switched size class from, 500–1000 km^2 in the 1950s to 200–500 km^2 in 1978, resulting in an increase in the number of lakes in the size class 200–500 km^2 from one in the 1950s to two in 1978 (Table 1).

In contrast to the changes seen between the 1950s and 1978, both the area and number of lakes tended to increase between 1978 and 1998. The total surface area of the lakes increased by 16.6%, from 1839.1 km^2 in 1978 to 2144.4 km^2 in 1998 (Figure 2e and inset). The only exception was shown by lakes in the size class 1–5 km^2, which decreased slightly in size, by 1.2%. The sizes of lakes in all other size classes increased. The total area of the lakes increased by 18.4% (5–10 km^2), 11.8% (10–25 km^2), 10.4% (25–50 km^2), 173.1% (50–100 km^2), 18.9% (100–200 km^2), and 13.3% (200–500 km^2), respectively (Table 1). The total number of lakes increased slightly, from 250 in 1978 to 258 in 1998 (3.2%), but this change differed from that seen in the lake size classes. For example, the number of lakes in the size class 1–5 km^2 continued to decline from 188 in 1978 to 182 in 1998, while those of 5–10 km^2 increased from 29 in 1978 to 36 in 1998, and those of 10–25 km^2 from 23 to 28 (Table 1). The number of lakes in the size classes 25–50 km^2,

Table 1. Changes in the area and number of lakes and changing percentages for different size classes in the Jianghan Plain, Central Yangtze

Area classes (km^2)	Lake area (km^2)			Change in area (%)		Number of lakes			Change in number (%)	
	1950s	1978	1998	1950s-1978	1978-1998	1950s	1978	1998	1950s-1978	1978-1998
1–5	626.3	387.2	382.5	-38.2	-1.2	297	188	182	-36.7	-3.2
5–10	367.4	207.5	245.6	-43.5	18.4	50	29	36	-42.0	24.1
10–25	727.3	360.3	402.9	-50.5	11.8	47	23	28	-51.1	21.7
25–50	335.1	212.0	234.1	-36.7	10.4	9	6	6	-33.3	0.0
50–100	439.7	69.7	190.5	-84.1	173.3	6	1	3	-83.3	200.0
100–200	392.4	112.9	134.2	-71.2	18.9	3	1	1	-66.7	0.0
200–500	318.3	489.5	554.7	53.8	13.3	1	2	2	100.0	0.0
500–1000	678.9	0	0	-100.0	NA	1	0	0	-100.0	NA
Total	3885.4	1839.1	2144.4	-52.7	16.6	414	250	258	-39.6	**3.2**

100–200 km^2, and 200–500 km^2 remained constant during this period.

The changes in each lake greater than 50 km^2 in size were investigated further (Figure 2a and 2c; Table 2). Between the 1950s and 1978, each of these lakes decreased in size, or was separated into several smaller lakes (termed a sublake), but then expanded slightly or showed no significant variation between 1978 and 1998. For example, Honghu Lake decreased from 679.8 km^2 in the 1950s to 223 km^2 in 1978, but then increased to 290.3 km^2 by 1998. Changhu Lake decreased from 125.9 km^2 in the 1950s to 112.9 km^2 in 1978, but increased to 134.2 km^2 by 1998. The second largest lake, Liangzihu, as well as Futou Lake and Wei River Reservoir, declined from the 1950s to 1978, then showed no significant change between 1978 and 1998. Yaerhu Lake, Diaochahu Lake, Zhangduhu Lake, and Laoguanhu Lake were divided into a number of sublakes. Interestingly, Paihu Lake and Guhu Lake shrank considerably between the 1950s and 1978, but several sublakes reappeared in 1998. The Zhang River Reservoir was established between the 1950s and 1978, and its size increased from 36.6 km^2 in 1978 to 67.4 km^2 in 1998. Three separate sublakes became linked during the 1950s to form Huamahu Lake, which covered an area of 53.2 km^2 by 1998.

By overlaying the lake distribution maps from each of the study periods (1950s–1978 and 1978–1998), the spatial distributions and data on the three lake change categories (decrease, increase, and no change) were obtained (Figures 2d and 2e). Only 33.1% of lakes could be categorized as "no change" between the 1950s and 1978, suggesting that 66.9% of lakes disappeared during this period. The net decrease in lake surface area was calculated as the difference between the decrease in water surface area (66.9%) and the surface area covered by the newly established reservoir (14.2%). The net loss of lake surface area between the 1950s and 1978 was therefore 52.7% (Figure

Table 2. Size of lakes larger than 50 km^2 for three periods: 1950s, 1978, and 1998 in the Jianghan Plain, Central Yangtze

No.	Lake name	Location: Centroid latitude	Location: Centroid longitude	1950s	Lake size (km^2) and notes: 1978	Lake size (km^2) and notes: 1998
1	Honghu Lake	28°35'	113°	678.9	223.0	290.3
2	Liangzihu Lake	28°58'	114°02'	318.3	266.4	264.3
3	Yaerhu Lake	29°08'	114°08'	164.8	Separated into five sublakes: 25.1, 9.8, 6.6, 5.0, and 1.0 km^2	Separated into five sublakes: 23.3, 14.2, 8.0, 6.2, and 1.2 km^2
4	Changhu Lake	29°07'	112°16'	125.9	112.9	134.2
5	Diaochahu Lake	29°21'	113°20'	101.7	4.5, 3.6	2.9, 1.6, 1.3
6	Zhangduhu Lake	29°21'	114°12'	95.4	40.4, 4.5, 3.0, 2.7	42.3, 5.3, 2.9, 1.5
7	Laoguanhu Lake	29°27'	113°06'	89.5	8.5, 2.1, 1.8	9.6, 1.9
8	Futouhu Lake	28°47'	113°47'	83.3	69.7	69.9
9	Wei River Reservoir	28°43'	111°28'	61.6	32.5	31.4
10	Paihu Lake	28°59'	112°55'	56.3	10.8	11.5, 6.7, 2.3, 1.2
11	Guhu Lake	29°02'	112°13'	53.6	2.1	2.9, 2.0, 1.7, 1.2, 1.0
12	Zhang River Reservoir	29°39'	111°53'	No	36.6	67.4
13	Huamahu Lake	29°04'	114°31'	17.1, 9.1, 3.1	8.2, 5.3, 2.1	53.2

Figure 3. *A number of lakes and associated wetlands have been reclaimed for agricultural and aquacultural use in the Jianghan Plain: (a) rice field; (b) radish field; (c) cotton field; and (d) mussel cultivation for the production of pearls.*

2d inset). The net increase in lake size between 1978 and 1998 was 16.6% (difference between 47% and 30.4%), with 69.6% of the lake area remaining unchanged (Figure 2e inset).

■ Discussion

The rapid decrease in size and number of lakes in the Jianghan Plain resulted largely from accelerated impoldering practices in the Central Yangtze between the early 1950s and the late 1970s. Three unprecedented periods of impoldering occurred in the Jianghan Plain between 1957 and 1976 (Huang 2001). As a result, the amount of arable land increased by 2704 km^2 (Committee for Agricultural Division of Hubei Province 1995). This represents 1.3 times the total area lost from lakes ≥1 km^2 between the 1950s and 1978. In other words, 76% of the arable land gained during this period was due to reclamation of land from lakes ≥1 km^2 in size; the remaining 24% probably resulted from the reclamation of land from lakes of less than 1 km^2 in size.

This accelerated impoldering activity was caused primarily by the increasing demands on ecosystem services imposed by the rising human population. The population in the Jianghan Plain was estimated as 1127.8×10^4 in 1953, increasing to 2021.5×10^4 in 1982, 2119.5×10^4 in 1991, and 2352.4×10^4 by 1998 (Sun 1994; Hubei Statistical Year Book 1992, 1999). A rapid rate of increase, 29.8×10^4/year, occurred between 1953 and 1982, coinciding with the period of lake disappearance. This period of reclamation from lakes to arable land was necessary to satisfy the increasing need for crop production and aquaculture (Figures 3 and 4). This human-induced long-term shift was also seen in Dongting Lake, a large lake in the Central Yangtze (Zhao *et al.* 2005).

Natural processes, such as interannual variability in climate and lake sediment, may also influence changes in lake size. Variations in precipitation are strongly associated with water body area (Yin and Li 2001). We therefore used 50-year time series records of annual mean precipitation from 1951 to 2000 from all 10 climatic stations over the Jianghan Plain to examine the effects of the interannual variations in precipitation on changes in lake size (Figure 5). No significant trends were identified over the 50 years of the study period, with the exception of a much greater rainfall for the years 1954 (1802 mm) and 1991 (1761.2 mm). The 50-year average annual precipitation was 1115.6 mm, and annual precipitation for the years 1957, 1978, and 1998 was 1129.9 mm, 1032.1 mm, and 1171.6 mm, respectively. This suggests that the interannual variability in precipitation may not be a significant factor in lake size change in this study area.

In addition, the natural accumulation of silt from the Yangtze River may also be a contributing factor in the

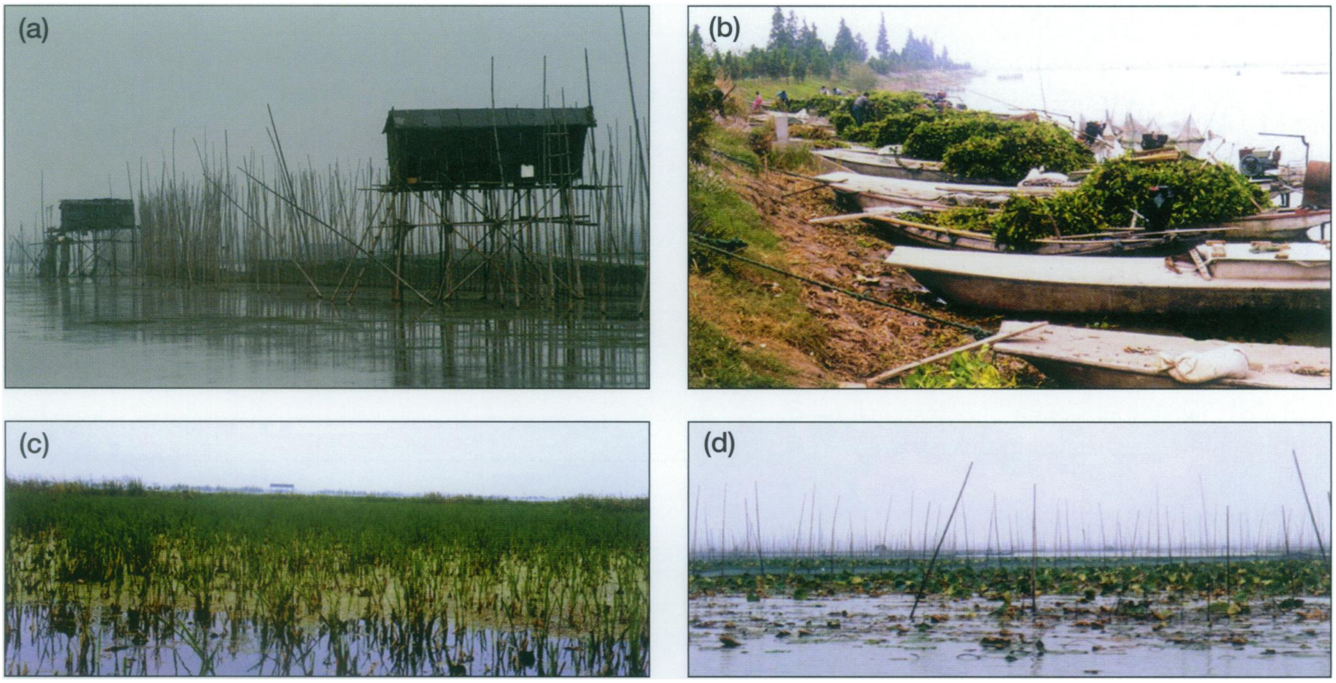

Figure 4. *An increasing human population has led to an overuse of water surface in lakes of the Jianghan Plain: (a) fish aquaculture with retiary boxes; (b) collecting aquatic plants for fish food; (c) cultivation of water bamboo (*Zizania caduciflora*), a persistent perennial root plant; and (d) lotus cultivation.*

shrinkage of lakes in the Jianghan Plain; however, this was much less important than the effects of reclamation practices, because the Yangtze River has been blocked off from this area since the early 1950s (Hydroelectric Bureau of Hunan Province 1989). For this reason, the sedimentation rate from lakes is very low. For example, the sediment deposition rate of Honghu Lake was 0.72–1.9 mm per year for a number of decades (Pu *et al.* 1994).

We therefore believe that increased impoldering has been a major driver in the decrease in number and area of lakes in the Jianghan Plain between the 1950s and 1978, while the slight increase in lake numbers and area between 1978 and 1998 can be attributed to changes in government policy restricting impoldering and requiring local people to return arable lands to the lakes.

The rapid decline in the size and number of lakes in Jianghan Plain appears to have significantly restricted hydrological and ecological services, such as flood retention and provision of support for biodiversity. The frequency of floods in the Plain increased considerably; the average interval between unusual floods in Hubei Province had been as long as 10 years in the 1950s, but the interval declined to 3.3 years during the 1970s, and to only 2.5 years during the 1990s (Yin and Li 2001). Biodiversity decreased at an alarming rate. For example, the number of fish species in the Plain decreased from 101 in the early 1950s to 82 in 1982, and the number of vascular plants and indigenous fishes in the largest lake (Honghu Lake) decreased from 92 and 74 species in the 1960s to 68 and 54 species, respectively, in the1980s (Liu and Cao 1998).

These impacts, and an awareness of the importance of wetlands, motivated the Chinese Government to prohibit impoldering along the Central Yangtze since the late 1990s (Wang 1998). Meanwhile, local people are willing to return inundated arable lands to the lake, or even to convert these lands to lakes/ponds for aquaculture (including lotus root cultivation and fish production), responding to changing market demands and thereby improving their financial income. For example, the area used for fish cultivation increased from 58.9 km^2 in 1990 to 100 km^2 in 1999 in Honghu City, an increase of 69.8% (Statistical Bureau of Hubei Province 1991, 2000). Consequently, the total area and number of lakes in the Jianghan Plain increased between 1978 and 1998. A study of land conversion in the Honghu Lake area between 1987 and 1998 showed similar results to our own, with the area covered by water nearly doubling, from 457.5 km^2 in 1987 to 854.1 km^2 in 1998 (Zhao *et al.* 2003).

In conclusion, changes in surface area and numbers of lakes in the Jianghan Plain over a 50-year period, quantified by historical land-cover maps and remote sensing imagery, show two distinct periods: the 1950s–1978 and 1978–1998. During the earlier period, the total surface area and number of lakes decreased rapidly, resulting in significant negative ecological consequences; during the latter period, the trend reversed and lake number and area increased slightly. Such changes are generally consistent with those from a field survey of the middle and large lakes and reservoirs in Hubei Province, conducted by the Committee for Agricultural Division of Hubei Province (1995). They reported that the size/number of lakes ≥0.07 km^2 in the Province decreased from 8528 km^2/1332 in 1949 to 2373 km^2/310 in 1977, then increased to 2983

km^2/843 (including sublakes separated from major lakes) in 1988, respectively.

However, the restored or newly established lakes and aquaculture ponds may not function in the same way as the original, natural lakes, because these are human-dominated systems. For instance, six species of aquatic plants disappeared from Changhu Lake between 1981 and 2001 (Peng *et al.* 2003), although lake size increased during this period, suggesting that natural habitats cannot simply be replaced by human-made ecosystems. Further studies are needed in this area.

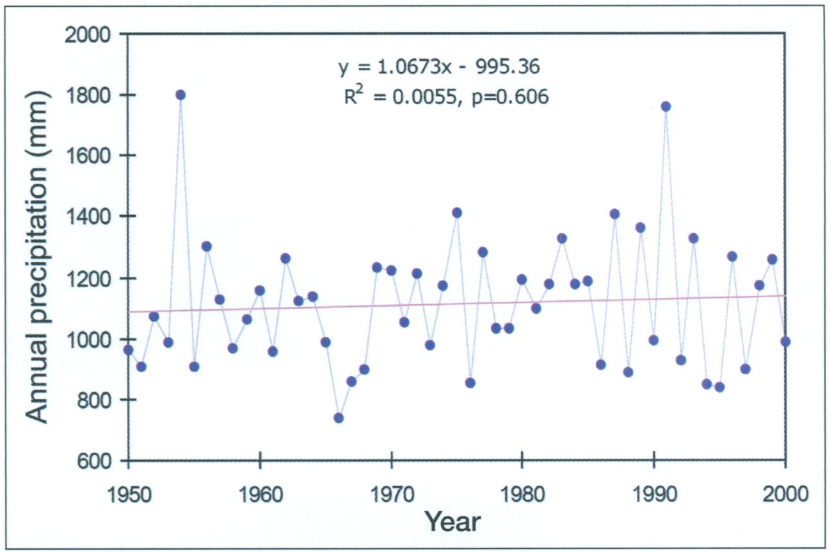

Figure 5. *Interannual change in annual precipitation of the Jianghan Plain between 1951 and 2000. The precipitation data are from an average of 10 climatic stations situated across the Plain. No significant trend in precipitation can be seen over the 50 year period.*

■ Acknowledgment

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