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Rapid loss of lakes on the Mongolian Plateau

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Lakes are widely distributed on the Mongolian Plateau and, as critical water sources, have sustained Mongolian pastures for hundreds of years. However, the plateau has experienced significant lake shrinkage and grassland degradation during the past several decades. To quantify the changes in all of the lakes on the plateau and the associated driving factors, we performed a satellite-based survey using multitemporal *Landsat* images from the 1970s to 2000s, combined with ground-based censuses. Our results document a rapid loss of lakes on the plateau in the past decades: the number of lakes with a water surface area >1 km^2 decreased from 785 in the late 1980s to 577 in 2010, with a greater rate of decrease (34.0%) in Inner Mongolia of China than in Mongolia (17.6%). This decrease has been particularly pronounced since the late 1990s in Inner Mongolia and the number of lakes >10 km^2 has declined by 30.0%. The statistical analyses suggested that in Mongolia precipitation was the dominant driver for the lake changes, and in Inner Mongolia coal mining was most important in its grassland area and irrigation was the leading factor in its cultivated area. The deterioration of lakes is expected to continue in the following decades not only because of changing climate but also increasing exploitation of underground mineral and groundwater resources on the plateau. To protect grasslands and the indigenous nomads, effective action is urgently required to save these valuable lakes from further deterioration.

Mongolia | lake shrinkage | mining | irrigation | climate change

The Mongolian Plateau, located in the hinterland of temperate Asia, sustains the eastern part of the Eurasian Steppe (1). The Inner Mongolia Autonomous Region of China (Inner Mongolia hereafter) and the entire territory of Mongolia (formerly the Mongolian People's Republic) constitute its core region, with an area of about 2.75 million km^2 and a population of about 28 million (2–4). The plateau is dotted with numerous lakes surrounded by vast grasslands (Fig. 1), which have nourished the Mongolian people and created a unique Mongolian nomadic civilization (5). Many of these lakes on the plateau are internationally important wetlands for threatened species and migratory waterfowls, 13 of which are designated to be protected by the Ramsar Convention (6) (*SI Appendix*, Text S1).

However, a number of lakes have shrunk remarkably in recent decades as a result of intensive human activities and climate change. The shrinkage and drying up of lakes have exacerbated the deterioration of regional environment, which has directly threatened the livelihood of local people. Because of the degradation of lakes and grasslands, the plateau has become one of the major sources of sand–dust storms in northern China (7, 8), and dust from this region was even detected in North America in 1998 (9). Although several previous works have examined the changes in some lakes on the plateau (10, 11), a collective study of changes in the lakes across the plateau has not been performed. Using 1,240 available scenes of multitemporal images of Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper (ETM+) from the late 1970s to 2010, combined with information on climate, topography, land use, human activity, and high-resolution Google Earth images, we established a database of Mongolian lakes (MONLAKE) for the entire plateau (for details see *Materials and Methods* and *SI Appendix*, Text S2 and Table S1). Using this database, we explored the changes in the lakes over the past three decades and investigated their possible driving forces.

Results and Discussion

Changes in Lakes >1 km^2 Between the late 1980s and 2010. We first investigated the changes in lakes with surface area >1 km^2 between the late 1980s and around 2010 using TM and ETM+ images. The images used were consistently obtained in the wet season (June to September). To better describe the changes in different-sized lakes, the lakes were categorized into three classes: small (1–10 km^2), medium (10–50 km^2), and large lakes (>50 km^2) (refs. 12, 13, *SI Appendix*, Text S2). A total of 785 lakes (427 in Inner Mongolia and 358 in Mongolia) with water surface area >1 km^2 were detected across the plateau in the late 1980s (around 1987) (Fig. 1), of which small, medium, and large lakes accounted for 88.4%, 7.1%, and 4.5%, respectively (Fig. 2*A* and Table 1) (For information on the locations and water surface area of all of the lakes, see *SI Appendix*, Table S1*A*). Over the past two decades, a large number of lakes have dried up. The number of lakes with an area >1 km^2 has decreased from 785 in the late 1980s to 577 in 2010 (Table 1), with the disappearance of 145 lakes in Inner Mongolia and 63 lakes in Mongolia (i.e., respective decreases of 34.0% and 17.6%), suggesting more severe conditions in the former than in the latter. Accompanying the decrease in the number of lakes, a rapid shrinkage of lake surface area has also occurred, especially in Inner Mongolia: the total water surface area of the lakes decreased from 4,160.2 km^2 in the late 1980s to 2,900.6 km^2 in 2010, a decrease of 30.3% (Fig. 2 *B* and *C*, Table 1).

Temporal Changes in Lakes >10 km^2 Between the late 1970s and 2010. To further understand the changes in lakes, the temporal changes in all of the 91 medium (10–50 km^2) and large lakes

Significance

The Mongolian Plateau, composed mainly of Inner Mongolia in China and the Republic of Mongolia, has been experiencing remarkable lake shrinkage during the recent decades because of intensive human activities and climate changes. This study provides a comprehensive satellite-based evaluation of lake shrinkage across the plateau, and finds a greater decreasing rate of the number of lakes in Inner Mongolia than in Mongolia (34.0% vs. 17.6%) between the late 1980s and 2010, due mainly to an unsustainable mining boom and agricultural irrigation in the former. Disastrous damages to the natural systems are threatening the livelihood of local people, and we thus call for an urgent action to prevent further deterioration.

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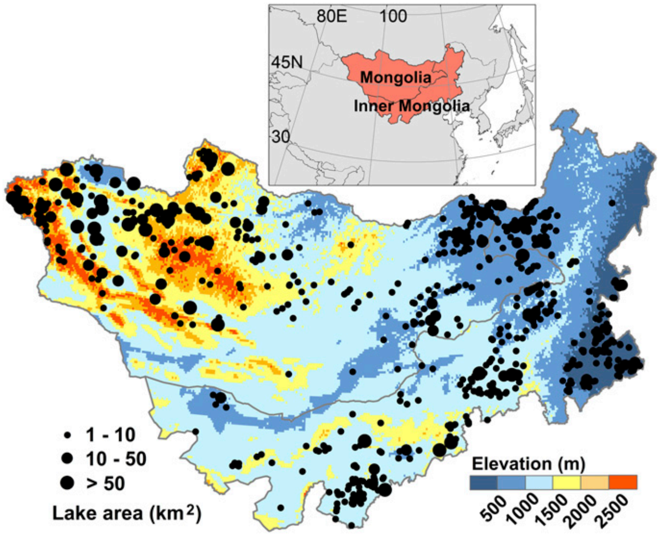

Fig. 1. Distribution of lakes with water surface area >1 km^2 on the Mongolian Plateau. *Inset* shows the study area.

(>50 km^2) between the late 1970s and 2010 were investigated using MSS data from the late 1970s and early 1980s and TM/ETM+ data from the late 1980s to 2010 (*SI Appendix*, Text S2, Fig. S1 and Table S1*B*). The water surface area of most medium and large lakes in Inner Mongolia significantly declined, dropping by 21.5% from a total area of 3,136.4 km^2 in the late 1980s to 2,461.6 km^2 in 2010. For instance, Hulun Lake (I20 in *SI Appendix*, Fig. S1 and Table S1), which is the largest lake in Inner Mongolia and one of China's five largest freshwater lakes, has shrunk by 357.2 km^2 (17%) since 2000. A similar decline was observed in Dalinor Lake (I22, decreased by 14%). Since the 1970s, Daihai Lake (I24) and Hongjian Nuur (I27) have shrunk by 78.8 km^2 (53%) and 21.3 km^2 (38%), respectively. Taolimiao-Alashan Nuur (I11), Naiman Xihu (I17), and Huangqihai Lake (I23) have all dried up (*SI Appendix*, Fig. S2). All these lakes are nationally or even internationally important wetlands. Compared with these shrunken lakes, the surface area of a few lakes in Inner Mongolia has increased because of anthropogenic management or intervention. Fox example, Tumuji Paozi (I16, a national nature reserve) was recharged from the Chuo'er River (14); East Juyan Lake (I19) was fed by the Heihe River (15); and Wuliangsuhai Lake (I26) received water diverted from the Yellow River (16). In contrast, the changes in the medium and large lakes in Mongolia showed geographical differences (*SI Appendix*, Fig. S1): a few lakes in the eastern arid region declined or dried up, whereas those in the western areas did not change significantly or even slightly increased because of the water recharge from accelerated melting of glaciers in the upper reaches of the mountains, e.g., Khyargas Lake (M54) and Uvs Lake (M62) (17).

To identify an overall trend in the changes in these medium and large lakes, we calculated the relative water area (RWA, in percent) of these lakes for nine periods from the late 1970s to 2010: 1976–1980, 1981–1985, 1986–1990, 1991–1993, 1994–1997, 1998–2000, 2001–2003, 2004–07, and 2008–2010, using the following equation (18):

$$RWA(\%) = \frac{1}{n}\sum_{i=1}^{n}\left(A_i/A_i^s\right) \times 100, \qquad [1]$$

where n is the number of lakes, A_i represents the averaged surface area of the ith lake in one of these nine periods, and A_i^s is the water surface area of the ith lake in the base period (1986–1990). The period 1986–1990 was used as the base period

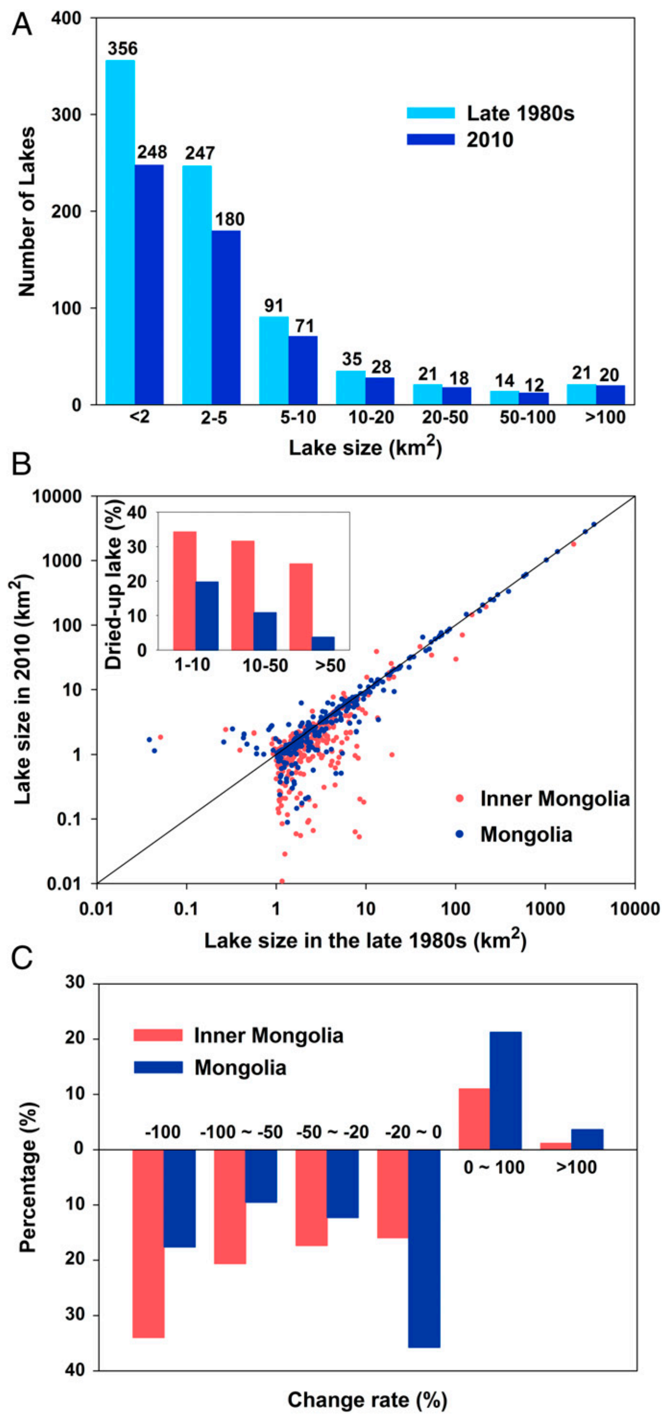

Fig. 2. Changes in lakes on the Mongolian Plateau between the late 1980s and 2010. (*A*) Frequency distribution of lake sizes in the late 1980s and 2010 over the plateau, revealing that the number of lakes of all sizes (especially small lakes, i.e., 1–10 km^2) had decreased significantly. (*B*) Comparison between water surface area of lakes in the late 1980s and 2010 for Inner Mongolia and Mongolia (on logarithmic scale); *Inset* shows the percentage of dried-up lakes for small, medium, and large lakes, suggesting that a large number of lakes had disappeared during the study period, especially in Inner Mongolia. (*C*) Frequency distribution of the rate of change in lake size between the late 1980s and 2010 for Inner Mongolia and Mongolia, showing that the water surface area of most lakes had declined, but that of a few lakes had increased. A change rate of −100% shows that the lakes had dried up.

Table 1. **Changes in number and total surface area of lakes on the Mongolian Plateau between the late 1980s (around 1987) and 2010**

	Lakes in 1987		Lakes in 2010		Lake changes			
Lake class	Number of lakes	Total area (km^2)	Number of lakes	Total area (km^2)	Number of dried-up lakes	Change in number of lakes (%)	Change in total area (km^2)	Change in total area (%)
Inner Mongolia								
1–10 km^2	400	1,023.8	263	439.0	137	−34.3	−584.8	−57.1
10–50 km^2	19	297.0	13	216.2	6	−31.6	−80.8	−27.3
>50 km^2	8	2,839.4	6	2245.4	2	−25.0	−594.0	−21.0
All lakes	427	4,160.2	282	2,900.6	145	−34.0	−1,259.6	−30.3
Mongolia								
1–10 km^2	294	789.4	236	569.2	58	−19.7	−220.2	−27.9
10–50 km^2	37	611.8	33	491.3	4	−10.8	−120.5	−19.7
>50 km^2	27	12,410.7	26	12,419.1	1	−3.7	8.4	0.07
All lakes	358	13,811.9	295	13,479.6	63	−17.6	−332.3	−2.4
Whole plateau								
1–10 km^2	694	1,813.2	499	1,008.2	195	−28.1	−805.0	−44.4
10–50 km^2	56	908.8	46	707.5	10	−17.9	−201.3	−22.2
>50 km^2	35	15,250.1	32	14,664.5	3	−8.6	−585.6	−3.8
All lakes	785	17,972.1	577	16,380.2	208	−26.5	−1,591.9	−8.9

because satellite images were available for all of the medium and large lakes.

The total water surface area of the lakes in Inner Mongolia showed an increasing trend before the mid-1990s, but then shrank rapidly (Fig. 3). In 2010, the total surface area of the lakes was only 60% of that in the late 1980s, with values of 57% and 61% for the medium and large lakes, respectively. Compared with this rapid loss of lakes, the total surface area of the medium and large lakes in Mongolia did not change significantly. Note that we present the respective changes in the RWA values in Inner Mongolia and Mongolia in Fig. 3 because of the different trends in the lake changes in these two regions.

Effects of Regional Climate and Human Activities on Lake Changes. We analyzed the effects of regional climate and human activities on the lake changes to explore the possible driving factors. We used annual mean temperature (AMT, in degrees Celsius),

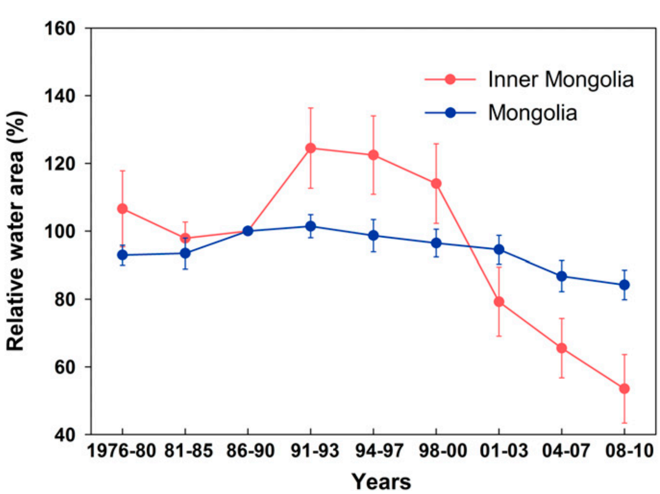

Fig. 3. Changes in relative water area (RWA, in percent) for medium (10–50 km^2) and large lakes (>50 km^2) in different periods (from the late 1970s to 2010) in Inner Mongolia and Mongolia, suggesting that RWA peaked in the period 1991–1993 and then declined for both Inner Mongolia and Mongolia, with the former showing greater decrease trend than the latter. The bars show SEs of RWA for each period. For details on the calculation of RWA, see the text and Eq. **1**.

annual precipitation (AP, in millimeters), and Thornthwaite's potential evapotranspiration (PET) (19) as measures of regional climate, and grazing, coal mining, and irrigation as indicators of human activities.

Over the past 30 y, a consistent increase in AMT and PET for both Inner Mongolia and Mongolia ($P < 0.001$) and a decreasing trend in AP after the 1990s have been observed ($P = 0.056$ for the former, and $P = 0.009$ for the latter) (Fig. 4 *A*–*C*). These may have aggravated aridification of the plateau after the 1990s, and become a possible cause of lake shrinkage.

During the study period, grazing intensity in both regions has increased, although the increasing trend slowed down after 2005 (Fig. 4*D*). Overgrazing leads to grassland degradation and subsequent reductions in soil function and water conservation of grasslands, and thus affects the lake water supply (17, 20). Coal mining has been widely operated across Inner Mongolia since the late 1990s, especially in the grassland area (*SI Appendix*, Fig. S3). The number of mining enterprises increased dramatically from 156 in 2000 to 865 in 2010, and the associated coal production increased from 72 to 789 Tg (1 Tg = 10^{12} g) (Fig. 4*E*) (3). Coal mining is an extremely water-intensive industry (refs. 21, 22; *SI Appendix*, Fig. S4), it cuts off rivers and destructs underground aquifer (23, 24), consuming 2.54 m^3 water for extracting every ton of coal (25). In the cropland area of Inner Mongolia (*SI Appendix*, Figs. S3 and S4), the exploitation of groundwater and rivers for agricultural irrigation might be another driving force of lake shrinkage. During the past decades, the area of irrigated croplands in Inner Mongolia has increased from 0.66 million hectare (ha) in the late 1970s to 3.03 million ha in 2010 (Fig. 4*F*) (3). In the southeastern areas of Inner Mongolia (traditionally, an agropastoral transitional zone with an annual precipitation of 300–400 mm), where grasslands have been largely reclaimed into croplands (26) (*SI Appendix*, Fig. S3), irrigation has caused a rapid depletion of both groundwater and river water. For example, the groundwater depth in Tongliao City in southeastern Inner Mongolia has dropped from 2.5 m in 1980 to 5.2 m in 2009 (*SI Appendix*, Fig. S5) (27). Compared with this rapid expansion in the cropland in Inner Mongolia, arable land in Mongolia is sparsely distributed in the northern areas where there are a few lakes (*SI Appendix*, Fig. S6*A*). In addition, the agricultural area in Mongolia decreased since the late 1990s (*SI Appendix*, Fig. S6*B*), suggesting a negligible effect of irrigation on the changes in lake.

To quantify the relative contribution of the aforementioned natural and human factors to the changes in lake area, we performed correlation analysis and multiple general linear model

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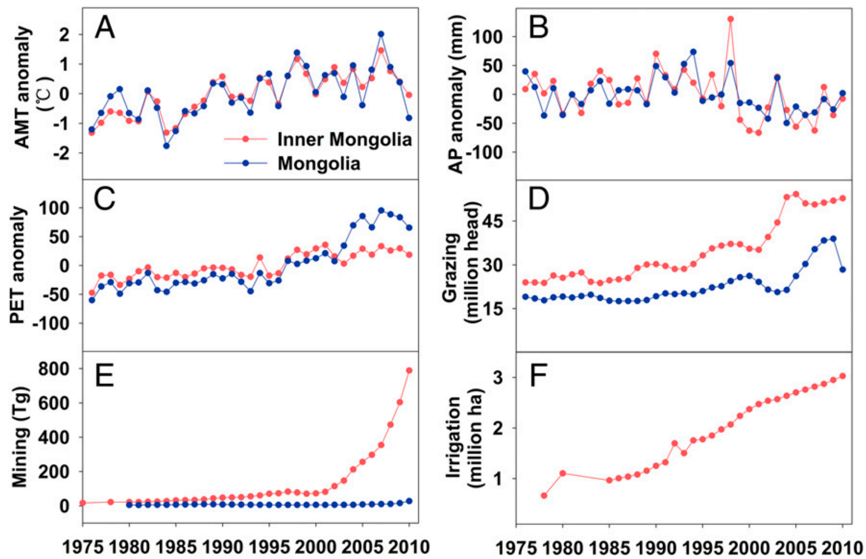

Fig. 4. Changes in climate and human activities in Inner Mongolia and Mongolia in the past decades. (*A*) AMT (annual mean temperature) anomaly, (*B*) AP (annual precipitation) anomaly, (*C*) PET (potential evapotranspiration) anomaly, (*D*) number of sheep and goats, (*E*) coal production, and (*F*) area of irrigated croplands in Inner Mongolia. These figures suggest that AMT and PET increased significantly over the study periods, and AP has decreased since the mid-1990s, and that the number of livestock and amount of coal production increased, especially for Inner Mongolia. Area of irrigated croplands in Inner Mongolia also increased dramatically.

(GLM) regression. As the dominant human activities are different between grassland and cropland areas in Inner Mongolia, with mining primarily occurring in the grassland area and irrigation generally applied in the cropland area (*SI Appendix*, Fig. S3), we further identified the major drivers of lake shrinkage in the grassland and cropland areas separately (Table 2). The GLM results showed that in Mongolia AP accounted for 70.4% of the variation of lake area, and grazing intensity explained additional 21.6%, and in the whole area of Inner Mongolia coal production accounted for 66.5% of the variation, and AP and grazing intensity explained additional 20.4% and 8.0%, respectively. Further analysis depicted that in the grassland area of Inner Mongolia mining had an explanatory power of 64.6% for the variation of lake area, followed by AP (18.3%) and grazing intensity (13.8%), but in the cropland area of Inner Mongolia, irrigation accounted for most of the variation (80.0%).

To verify the results by the GLM analysis (Table 2), we used the information–theoretic approach (28) to reduce model selection bias and further developed multiple GLM regressions to quantify the independent explanatory power of each selected

Table 2. Correlation and multiple GLM analyses on the relationships between overall changes in RWA of lakes >10 km^2 and climatic and human factors for Mongolia, Inner Mongolia, and grassland and cropland areas of Inner Mongolia, during the nine periods of 1976–1980, 1981–1985, 1986–1990, 1991–1993, 1994–1997, 1998–2000, 2001–2003, 2004–2007, and 2008–2010

						Inner Mongolia			
		Mongolia		Inner Mongolia		Grassland		Cropland	
Method	Variable	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Correlation analysis	AMT	−0.41	0.275	−0.38	0.312	−0.31	0.416	−0.68	0.043*
	AP	0.83	0.005*	0.80	0.009*	0.76	0.017*	0.70	0.035*
	PET	−0.84	0.004*	−0.60	0.091	−0.53	0.139	−0.80	0.009*
	Mining	−0.65	0.054	−0.81	0.008*	−0.80	0.009*	−0.59	0.100
	Grazing	−0.82	0.006*	−0.78	0.013*	−0.79	0.011*	−0.64	0.052
	Irrigation	—	—	−0.66	0.054	−0.66	0.053	−0.87	0.002*
Multiple GLM regression	Variable	MS	SS, %	MS	SS, %	MS	SS, %	MS	SS, %
	AMT	2.6	0.9	18.3	0.4	99.9	1.1	4.2	0.4
	AP	202.2	70.4*	974.3	20.4*	1725.7	18.3*	22.1	2.1
	PET	12.1	4.2	51.1	1.1	17.5	0.2	33.01	3.2
	Mining	4.6	1.6	3174.3	66.5*	6077.9	64.6*	0.03	0.0
	Grazing	62.0	21.6*	381.6	8.0	1296.6	13.8*	90.5	8.7
	Irrigation	—	—	60.2	1.3	38.2	0.4	830.0	80.0*
	Residuals	3.7	1.3	116.2	2.4	137.2	1.5	58.34	5.6

AMT (annual mean temperature), AP (annual precipitation), and PET (potential evapotranspiration) are used as the measures of regional climate. Mining indicated by coal production, grazing characterized by number of sheep and goats, and irrigation indicated by area of irrigated croplands are the measures of human activities.

*$P < 0.05$; MS, mean squares; SS, proportion of variances explained by the variable.

variable. The information–theoretic approach showed a full consistence with the multiple GLM analyses listed in Table 2 (*SI Appendix*, Text S3 and Tables S2 and S3). This confirms that driving forces of lake changes were different at different regions of the Mongolian Plateau: in Mongolia natural factor (precipitation) was the dominant driver, and in the whole region of Inner Mongolia mining was the most important factor. Further, in the grassland area of Inner Mongolia coal mining was most significant, but in its cultivated area, irrigation was responsible for the most of the lake area variation.

The human-induced lake changes in Inner Mongolia can be further supported by the difference in population density between Inner Mongolia (20.9 people/km^2) and Mongolia (1.9 people/km^2) (3, 4), which might lead to huge difference in human disturbances between these two regions. As a result, although the climate in both Inner Mongolia and Mongolia tended to be drier and warmer, the changing trend of lake area differed greatly (Fig. 3): a rapid decline occurred in the former, whereas there were not significant changes in the latter. Moreover, mining- and irrigation-induced lake shrinkage in Inner Mongolia was evidenced in many lakes. For example, in the grassland area, mining industries have caused rapid shrinkage of Ordos lake group and Dalinor lake group (29–31), and even drying up of Wulagai lake group (23) (for more details, see *SI Appendix*, Text S4). In the cropland area, increasing irrigation by the way of pumping groundwater and intercepting rivers has led to a remarkable degradation and even drying-up of Huangqihai Lake (32), Daihai Lake (33), East Juyan Lake (34), and Naiman Xihu (35). In contrast to Inner Mongolia, human activity intensity was relatively low in Mongolia (Fig. 4*E* and *SI Appendix*, Fig. S6), and only a few lakes were affected by overgrazing in the western Mongolia (17).

Conclusions and Perspective

Despite experiencing similar drying and warming climate (Fig. 4 *A–C*), the change of lake area in Mongolia and Inner Mongolia are markedly divergent (Fig. 3): the lake area decreased slightly in the former as a result of precipitation reduction but rapidly in the latter under intensive human activities. The Mongolian Plateau is rich in underground mineral resources such as coal, oil, copper, gold, and many other nonferrous metals (36). With increasing demands for energy and foods from China, Mongolia and other neighboring countries, exploitation of these mineral and groundwater resources will probably continue in the coming decades (37). For example, the governments of both China and Mongolia are strengthening their cooperation in coal mining (37). This, together with the expected drier and warmer climate (38, 39), will aggravate drought and thus cause further shrinkage of these lakes. Although both governments have made efforts to prevent ecological degradation, such as controlling grazing, returning farmland to grassland, and recharging some lakes through water diversion projects (40, 41), more effective action is urgently required to save these valuable lakes. Without it, the lake-loss–induced damages to the natural systems, nomadic culture, and plateau civilization will be disastrous. Therefore, the elimination of these devastating impacts is a great challenge that requires the wisdom of policy makers (21).

Materials and Methods

***Landsat* Images.** The remote sensing data used in this study were obtained from the United States Geological Survey website (www.usgs.gov/), including *Landsat* Multispectral Scanner for the late 1970s and early 1980s, and Thematic Mapper and Enhanced Thematic Mapper for the late 1980s to 2010. A total of 1,732 *Landsat* scenes were downloaded, of which 1,240 scenes with a cloud cover of about 10% or less, where the lakes were clearly visible, were used in the analysis. Because the survey time (e.g., dry or wet season) of the remote sensing images can affect the estimation of the lake surface area, we collected images with consistent survey dates (almost all from June to September) for each study period. For each lake, we used images taken in the same month for different study periods to document an accurate estimate of the surface area.

Interpretation of Images. The normalized difference water index (NDWI) was calculated to acquire information on the water surface area of lakes using well-qualified approaches (42–44). Because combinations of different bands of satellite images can generate different NDWI values, we evaluated the combinations of different bands, and found that the combination of band 2 (green band) and band 5 (midinfrared band) for the TM and ETM+ images, and that of band 5 (red) and 6 (near infrared) for the MSS images could provide the best performance for the study area. Thus, we used these band combinations to calculate the NDWIs using Eq. **2** for the TM and ETM+ images, and Eq. **3** for the MSS images. The NDWI values ranged from 0 to 1 (mostly around 0.5), and < 0 for water-free surface. The NDWI images were produced in ArcGIS 10.0 (ESRI, Inc.) using the raster calculator. Clear water body and nonwater areas were distinguished successfully. For those few MSS images that could not be processed using the NDWI method, manual vectorization was conducted by skilled operator to obtain the water area.

$$NDWI = \frac{band2 - band5}{band2 + band5} \quad [2]$$

$$NDWI = \frac{band5 - band6}{band5 + band6} \quad [3]$$

The detected lakes were then validated carefully using visual image interpretation and checked further against Google Earth images. Rivers, artificial ponds, and reservoirs were excluded by consulting lake experts, referring to the literature (e.g., refs. 13, 32) and checking against Google Earth images. The water surface area of these confirmed lakes was then calculated using ArcGIS 10.0 (ESRI, Inc.) based on the Albers equal-area projection.

Following the careful examinations described above, we established the Mongolian Lakes Database (*SI Appendix*, Table S1). Details about MONLAKE are described in *SI Appendix*, Text S2.

Data on Climate, Altitude, and Human Activities. Climate data were used for two analyses: general trends in climate change over the entire Mongolian Plateau, and climatic conditions for each medium and large lake in the MONLAKE database (*SI Appendix*, Table S1*B*). For the first analysis, AMT and AP were used to document the climatic trends over time across the plateau during the past three decades (Fig. 4 *A* and *B*). The monthly air temperatures and precipitations for Inner Mongolia were obtained from 50 meteorological stations (National Meteorological Information Center of China Meteorological Administration; www.nmic.gov.cn). Temperature and precipitation trends in Mongolia were derived from the University of East Anglia Climatic Research Unit Time Series 3.2 datasets (CRU TS3.2; www.cru.uea.ac.uk/cru/data/). For the second analysis, climate data from the WorldClim Database with a 30 arc-second (about 1 km^2) resolution (representative of 1950–2000; www.worldclim.org/download) (45) were used as data source to acquire mean annual temperature (MAT; in degrees Celsius) and mean annual precipitation (MAP; in millimeters) for each medium and large lake across the plateau (*SI Appendix*, Table S1*B*). In addition, data on altitude around each lake were documented from the same WorldClim Database (www.worldclim.org/current). Further, we calculated Thornthwaite's PET (19) for the corresponding meteorological stations and each site of the medium and large lakes using the AMT and AP data.

Grazing data (number of sheep and goats, 1970–2010), mining data (coal production by year, 1970–2010), and agricultural data (area of irrigated croplands from 1970 to 2010) in Inner Mongolia were documented from *Inner Mongolia Statistical Year Book* (3), and those in Mongolia were obtained from Food and Agriculture Organization of the United Nations database (faostat.fao.org) and the United States Energy Information Administration (www.indexmundi.com).

Statistical Analyses. We first performed correlation analysis to indicate the direction (negative or positive) and strength of the relationship between each of the six explanatory variables (i.e., AMT, AP, PET, mining, irrigation, and grazing intensity) and lake area changes (Table 2). We then conducted a multiple GLM analysis to quantify the relative contribution of each of the six variables to lake shrinkage (Table 2). We finally used the information–theoretic approach (28) to confirm the results by the multiple GLM analysis (*SI Appendix*, Text S3 and Tables S2 and S3). All statistical analyses were conducted in R Version 3.0.3 (46).

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