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REPORT

Decline of traditional rice farming constrains the recovery of the endangered Asian crested ibis (*Nipponia nippon*)

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Abstract Traditional agriculture benefits a rich diversity of plants and animals. The winter-flooded rice fields in the Qinling Mountains, China, are the last refuge for the endangered Asian crested ibis (*Nipponia nippon*), and intensive efforts have been made to protect this anthropogenic habitat. Analyses of multi-temporal satellite data indicate that winter-flooded rice fields have been continuously reduced across the current range of crested ibis during the past two decades. The rate of loss of these fields in the core-protected areas has unexpectedly increased to a higher level than that in non-protected areas in the past decade. The best fit ($R^2 = 0.87$) numerical response model of the crested ibis population shows that a reduction of winter-flooded rice fields decreases population growth and predicts that the population growth will be constrained by the decline of traditional winter-flooded rice fields in the coming decades. Our findings suggest that the decline of traditional rice farming is likely to continue to pose a threat to the long-term survival and recovery of the crested ibis population in China.

Keywords Crested ibis · GIS expert system · Land cover/use change · Population growth · Remote sensing · Traditional agriculture

INTRODUCTION

Traditional agriculture incorporating biodiversity-friendly farming practices benefits a rich diversity of plant and animal species in many parts of the world (Czech and Parsons 2002; Wright et al. 2012). Winter-flooded rice farming is a traditional agricultural method that involves single cropping and then flooding the fallow field during winter to ensure the water supply for the next year. Conservation scientists and practitioners have widely recognized that these flooded rice fields provide alternative or complementary foraging habitats for waterbirds during the winter and breeding seasons (Elphick 2000; Wood et al. 2010; Toral et al. 2011).

The crested ibis (*Nipponia nippon*) was once widespread across East Asia, including Japan, China, Russia, and the Korean peninsula, but it is now extinct over almost all of its former range (BirdLife International 2012). The last seven individuals were discovered in 1981, in a remote village on the southern slopes of the Qinling Mountains in China (Liu 1981). Their refuge comprised several ancient oaks for nesting and nearby winter-flooded rice fields for foraging (Schaller 1994). Apart from a few records of the historical distribution of this species, previous studies on reproduction (Yu et al. 2006), foraging and breeding habitat selection (Ma et al. 2001; Liu et al. 2003), population dynamics and demography (Wang and Li 2008), and conservation strategies (Xi et al. 2002; Su 2008) in wild crested ibis have been conducted based on this rediscovered and recovering population. Scientists attributed the dramatic decline of the crested ibis population in the mid-twentieth century to the combined influence of habitat loss (due to changing farming practices) and the high risk of human-induced mortality (due to hunting and use of toxic pesticides) (Li et al. 2009; Ding 2010). Consequently, intensive conservation efforts have been made to prohibit hunting and deforestation, to monitor the nesting habitats, to prevent predation, and to limit or prohibit the use of agrochemicals over the past 30 years (Xi et al. 2002; Su 2008). It is commonly believed that the strict conservation measures combined with a higher public awareness contributed to increased breeding population size and reduced anthropogenic disturbances,

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which have contributed to the rapid recovery of the crested ibis population (Wang and Li 2008). Given such strict conservation, food availability has been identified as the primary limiting factor to the population growth of the ibis (Xi et al. 2002; Yu et al. 2006).

Although semi-natural or natural wetlands in the floodplain may function as alternative habitats for the crested ibis during the post-breeding season (July to October), adult birds in the montane areas exclusively forage in the winter-flooded rice fields during the winter and breeding seasons (Ma et al. 2001; Liu et al. 2003). Additionally, a principal component analysis by Wang et al. (2000) and a resource selection analysis by Li et al. (2001) indicated that the proximity as well as area of winter-flooded rice fields was an important factor in selecting nest sites by crested ibis. The winter-flooded rice fields have served as essential habitats for the survival and recovery of the crested ibis population over the past 30 years (Ding 2004). Loss of these habitats may lead to food shortages for the crested ibis population, particularly in the winter and breeding seasons. Therefore, considerable efforts have also been made to maintain and restore the winter-flooded rice fields for the conservation of this endangered species, especially in the core-protected areas. For example, the Chinese conservation management agency signed agreements with local farmers to maintain the traditional farming practice and promoted ecological compensation to offset the incurred losses (Ding 2004). Since 2001, the birds have dispersed and established more and more nest sites outside the protected areas; their distribution area is now 30 times larger than the 100 km^2 in the 1980s and early 1990s (Ding 2010). However, this means that limited financial and human resources have to be shared across a much larger area, so that effective conservation management of the winter-flooded rice fields is likely to become more difficult.

Traditional farming in China is becoming obsolete with the development of modern agricultural technologies as well as the change in land-use policies (Liu et al. 2008). For example, since 1960, the construction of reservoirs has led to better agriculture and irrigation conditions and has addressed the problem of supplying enough water for rice production. With the introduction of double cropping, the winter flooding of rice fields has been increasingly replaced by dryland farming of rapeseed or winter wheat. This change in farming practice was further stimulated by the rapid growth in demand for grain under the pressure of an increasing human population. Between the 1950s and 1980s, the winter-flooded rice fields in the floodplain of the Han River decreased by almost 90 % (Dong et al. 1992).

For most endangered species, their chance of recovery depends on whether their critical habitat is identified and protected and/or restored. Thus, monitoring the spatiotemporal change of winter-flooded rice fields plays a fundamental role in both agriculture and conservation. Unfortunately, it is unclear whether the remaining winter-flooded rice fields in the distribution area of the crested ibis have been protected or to what extent they have changed in the past two decades, as well as the ecological impact of these changes. Scientists, conservation managers, and agencies are unable to conduct these studies because of a lack of appropriate technology, methodology, and funding. This is where remote sensing methods can be a time- and cost-effective alternative. A number of studies have demonstrated the use of multi-temporal remotely sensed data for monitoring changes in rice agriculture on a large scale (Gumma et al. 2011; Moré et al. 2011), as well as for assessing the dynamics of flooded rice fields available to waterbirds in flat and homogenous landscapes (Fleskes et al. 2005; Toral et al. 2011). Integrated remote sensing and GIS techniques can yield precise spatial information on the distribution of scattered winter-flooded rice fields and any subtle changes (Sun et al. 2014).

Taking the current range of the crested ibis as an example, we assessed the changes of winter-flooded rice fields in protected and non-protected areas over the last two decades, and examined the potential impact of these changes on the population growth of crested ibis. Our specific objectives were to (1) identify the changes that have taken place to winter-flooded rice fields, (2) compare the magnitude of changes in these fields between the core-protected and non-protected areas, and (3) investigate the mechanism for the population growth of crested ibis under the change of winter-flooded rice fields and forecast future population trends.

MATERIALS AND METHODS

Study area

The study area is located on the southern slopes of the Qinling Mountains in the central area of Yang County, Shaanxi Province, China (Fig. 1). It encompasses 1080 km^2, centered at 33°19′N and 107°33′E, and covers an elevation range between 425 m and 1909 m. In 2009 about 80 % of all known nest sites of the crested ibis were established in this area. Major land cover/use (hereafter called simply land use) types in the study area include forest, shrub, grass, cropland, open water, built-up areas, and waste land. The cropland can be divided into rain-fed fields with dryland crop cultivation, summer-irrigated rice fields with a dry fallow period or rotational dryland cultivation in winter (winter-dry rice fields), and rice fields with an intentionally or naturally flooded fallow period from October to May (winter-flooded rice fields).

Special attention was paid to three areas when we considered the distribution of both the crested ibis nest sites and winter-flooded rice fields (Fig. 1). The first area is centered at the original nest site that was discovered in 1981. The second area had the highest density of nest sites. The local authority claims both

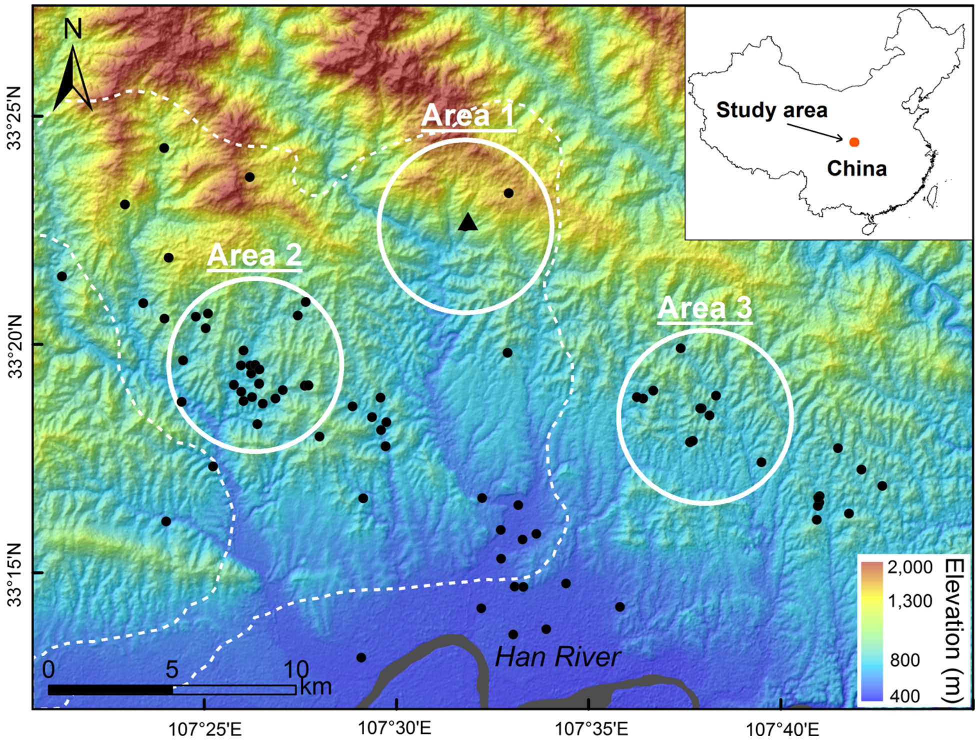

Fig. 1 Map of the study area. The locations of nest sites in 1981 (*triangle*) and 2009 (*dots*) are marked. Three specific study areas with a radius of 3.5 km are located at the original nest site in 1981 (Area 1), the area with the highest nest site density (Area 2), and the new location of nest dispersion outside the core-protected area in 2001 (Area 3). The boundary of the protected area is outlined with a *white dotted line*

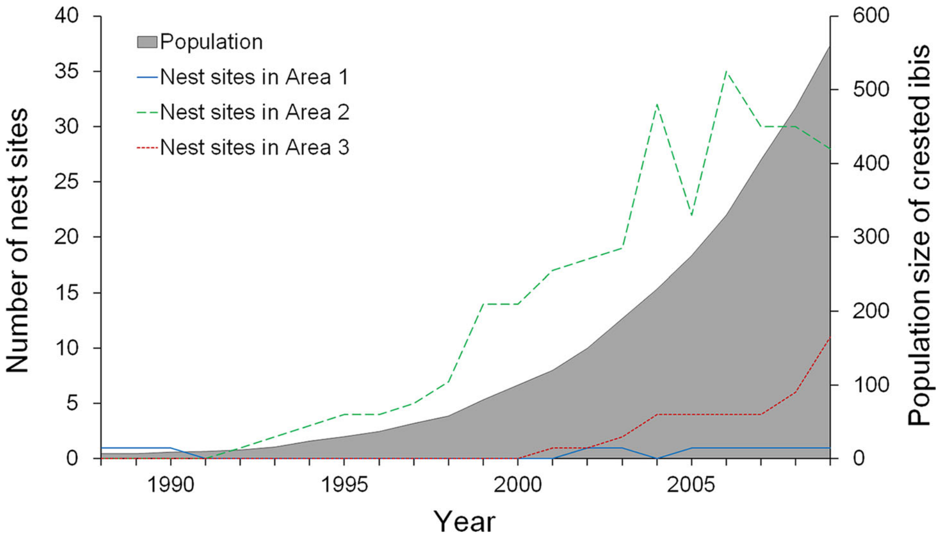

Fig. 2 Temporal changes of the crested ibis population in the whole study area and number of the nest sites in three specific areas from 1988 to 2009

are in the core area and are under strict protection. The third area was centered around the first nest site that was established outside the core-protected areas. Long-distance dispersal to non-protected areas first took place in 1999 (Ding 2010), and more nest sites have been established around the third area since 2001. Temporal changes of the crested ibis population in the whole study area and the number of nest sites in the three specific areas are presented in Fig. 2. Previous studies found that the foraging distance of the crested ibis in winter and breeding seasons rarely exceeds 3 km on average (Liu et al. 2003). We therefore chose a radius of 3.5 km for our study areas. The elevations of the three areas decrease successively, while the human population density increases from Area 1 to Area 3.

Classification of winter-flooded rice fields and associated major land-use types

Preparation of satellite images and ancillary topographic data

We used Landsat images to map the distribution of winter-flooded rice fields and the associated major land-use types at a spatial resolution of 30 m. Six orthorectified Landsat images were downloaded from the U.S. Geological Survey Earth Explorer site (http://earthexplorer.usgs.gov/), namely Landsat Thematic Mapper (TM) (28/08/1987, 20/12/1988, 30/07/2000, 12/01/2009, and 05/06/2009) and Enhanced Thematic Mapper Plus (ETM+) (14/11/2001). The multi-season cloud- and snow-free images were needed to identify the flooded areas in winter and the mixture of surface water and rice plants during the growing season around 1988, 2001, and 2009, respectively. The Landsat images were geometrically rectified using 1:50 000 topographic maps, and the processing utilized a second-order polynomial and nearest-neighbor interpolation with an accuracy of less than 0.5 pixels (15 m) root-mean-square error. The TM/ETM+ bands 1–5 and band 7 (thermal band 6 was excluded) in two scenes in three time phases were stacked and reprojected to UTM zone 48 N, datum WGS84. All image pre-processing was executed using ENVI 4.8.

Topographic information, including elevation and terrain position (i.e., gully, lower mid-slope, mid-slope, upper mid-slope, and ridge), was derived from 30-m ASTER Global Digital Elevation Model (DEM) with vertical accuracies between 10 m and 25 m RMSE (https://lpdaac.usgs.gov/). The DEM data were geometrically co-registered with the Landsat images using a second-order polynomial and nearest-neighbor interpolation. Five terrain position classes were calculated using the algorithm (Skidmore 1990) implemented in Interactive Data Language.

Land-use field data collection

The land-use data for image classification and verification were collected in the field during April 2012, based on stratified random sampling. Seven strata (winter-flooded rice fields, winter-dry rice fields, rain-fed fields, open water, forest, shrub/grass, and other) were identified. The size of the sample plots was 50 × 50 m. The geographical coordinates of the plots' centers were recorded using a GPS receiver with a positional accuracy from 5 to 10 m. Precise observation confirmation of historical land use was impossible as the study period stretches over two decades, and neither historical maps nor high-resolution images were available. Instead, historical land use of each sample plot was recorded from personal interviews with local farmers. Different actors were interviewed for the same plot to reduce potential bias. In total, 272 sample plots with constant land use throughout the study period were described and randomly divided into two equal groups for training and testing our classification.

Hybrid image classification approach

The satellite images were initially classified using a non-parametric supervised classification algorithm called support vector machine (SVM). The SVM algorithm locates the optimal hyperplane decision boundary that separates classes (Brown et al. 1999). The classifier produced a land-use map as well as seven rule maps each containing the probability that a pixel belonged to one of the seven classes.

A GIS-based expert system was constructed to perform post-classification sorting of the initial land-use classification using additional topographic data (i.e., elevation and slope position). The expert system was described in detail by Skidmore (1989). The key mechanism of the expert system is Bayes' theorem (see the text and Table S1 in Electronic Supplementary Material for detail). The land-use map and the associated probability rule maps were presented to the expert system as input. Elevation and terrain position data acted as items of evidence to infer the most probable land-use type that would occur in a given grid cell. The expert system algorithm worked forward from the topographic data (item of evidence) to the hypothesis (the most probable land-use type), and the search terminated only after all the evidence had been evaluated. The land-use class, which had the highest posterior probability of occurring at a grid cell location, was assigned. We expected that the expert system would correct misclassifications generated by the SVM classifier.

Accuracy assessment

The accuracy of the land-use map was assessed using a confusion matrix of the field observations against the classification result. The overall accuracy and Kappa coefficient (Cohen 1960) were calculated. The McNemar's test for related samples (Foody 2004; De Leeuw et al. 2006) was used to evaluate the statistical significance of differences in accuracies achieved by the classifications for 1988, 2001, and 2009, to ensure the comparability of the outputs in different time phases.

Change detection of winter-flooded rice fields

Post-classification comparison identified changes pixel by pixel by overlaying the three independently produced land-use maps and generated the conversion matrices (1988–2001 and 2001–2009). In providing important clues to the changes, the conversion matrix can become too complicated to analyze when the number of classes being considered is high. In this study, we focused on the changes in the target class (winter-flooded rice fields).

In addition to the absolute change in area of the winter-flooded rice fields, we analyzed the magnitude of the rate of change, because the same amount of habitat loss (e.g. 10 %) in different areas with varied habitat availability (e.g., 10 ha versus 1000 ha) will have distinct effects on crested ibis population. Due to the different lengths of two periods, we calculated the annual rate of change as a normalized index in order to make appropriate comparisons using the compound interest rate (Puyravaud 2003) (Eq. 1):

$$\text{Annual rate of change} = \frac{100\,\%}{t_2 - t_1} \times \ln\left(\frac{A_2}{A_1}\right), \qquad (1)$$

where A_1 and A_2 are the areas of winter-flooded rice fields at time t_1 and t_2, respectively.

Prediction of population responses to the changes of winter-flooded rice fields

Population growth rate is the summary parameter of trends in population density or abundance. It can be estimated using census data since the population size of crested ibis has been measured at the same time each year. Here, we interpreted the instantaneous growth rate of birth-pulse populations $r = N_{t+1}/N_t - 1$, where N_{t+1} and N_t are population sizes in the year $t + 1$ and t, which was suggested by Eberhardt and Simmons (1992). We adopted the general discrete-time population model of Dennis and Otten (2000) that incorporates a priori models of geometric growth, logistic growth, and numerical response. First, the population growth rates were regressed against population abundance to verify whether there was evidence of density dependence supporting logistic growth. The effects of population density on population growth rate may act through their effects on food availability and associated effects on somatic growth, fecundity, and survival of the species, according to a 'numerical response' (Sibly and Hone 2002). Therefore, we adopted the mechanistic paradigm and regressed the population growth rates against food availability to explain the population growth of the crested ibis. This type of numerical response was reviewed by Sibly and Hone (2002). The population's food supply is shared between its members through a process of resource competition, thus we assessed food availability by per capita availability of winter-flooded rice fields. We also verified the additive effects of population density on the instantaneous growth rate (r). Model fit was assessed firstly by statistical significance and then by the coefficient of determination (R^2). We simulated the population trends from 2001 to 2050 with the best fitted model in two scenarios that (1) the area of winter-flooded rice fields is constant after 2009; and (2) the area of winter-flooded rice fields continues to decrease/increase based on the change detection results of the present study.

RESULTS

Land-use classification

The classification maps for the years 1988, 2001, and 2009 in the three areas are presented in Fig. 3 (see Electronic Supplementary Material, Fig. S1 for the maps of the whole study area). The overall map accuracies ranging between 89.3 and 90.8 %, and the high Kappa statistics between 0.87 and 0.89, indicate that the classification results are good. The McNemar's test for related samples showed no significant differences between the accuracies of the three classifications (Table 1), which confirmed that the three classification maps were comparable for use in further analyses.

Changes to winter-flooded rice fields

The total area covered by the winter-flooded rice fields in the whole study area decreased from 4643.19 ha in 1988 to 2806.11 ha in 2009 at an annual loss rate of 0.4 and 5.5 % in the two periods, respectively. A decline in the winter-flooded rice fields was also observed from 1988 to 2009 in all three areas (Fig. 4). Land-use types converted from and to winter-flooded rice fields in the three areas are shown in Fig. 5, respectively. In all three areas and two periods, very small proportions of the winter-flooded rice fields were converted to open water for human use, such as aquaculture ponds and reservoirs, which may offer an alternative habitat. Area 1 experienced different processes of land-use change to winter-flooded rice fields during the two periods. From 1988 to 2001, winter-flooded rice fields in Area 1 covered more or less the same total area, with a very small net loss of less than 2 ha. However, the winter-flooded rice fields were then drastically reduced (by 47.61 ha, accounting for almost 40 %) until 2009, owing to an extensive conversion to non-agricultural uses, such as shrub/grass (Fig. 5b). In Area 2, despite the gain of 41.40 ha in winter-flooded rice fields chiefly from winter-dry rice fields between 1988 and 2001 (Fig. 5a), the winter-flooded rice fields shrank from 291.15 to 239.67 ha during the first period with a loss rate of 1.5 %

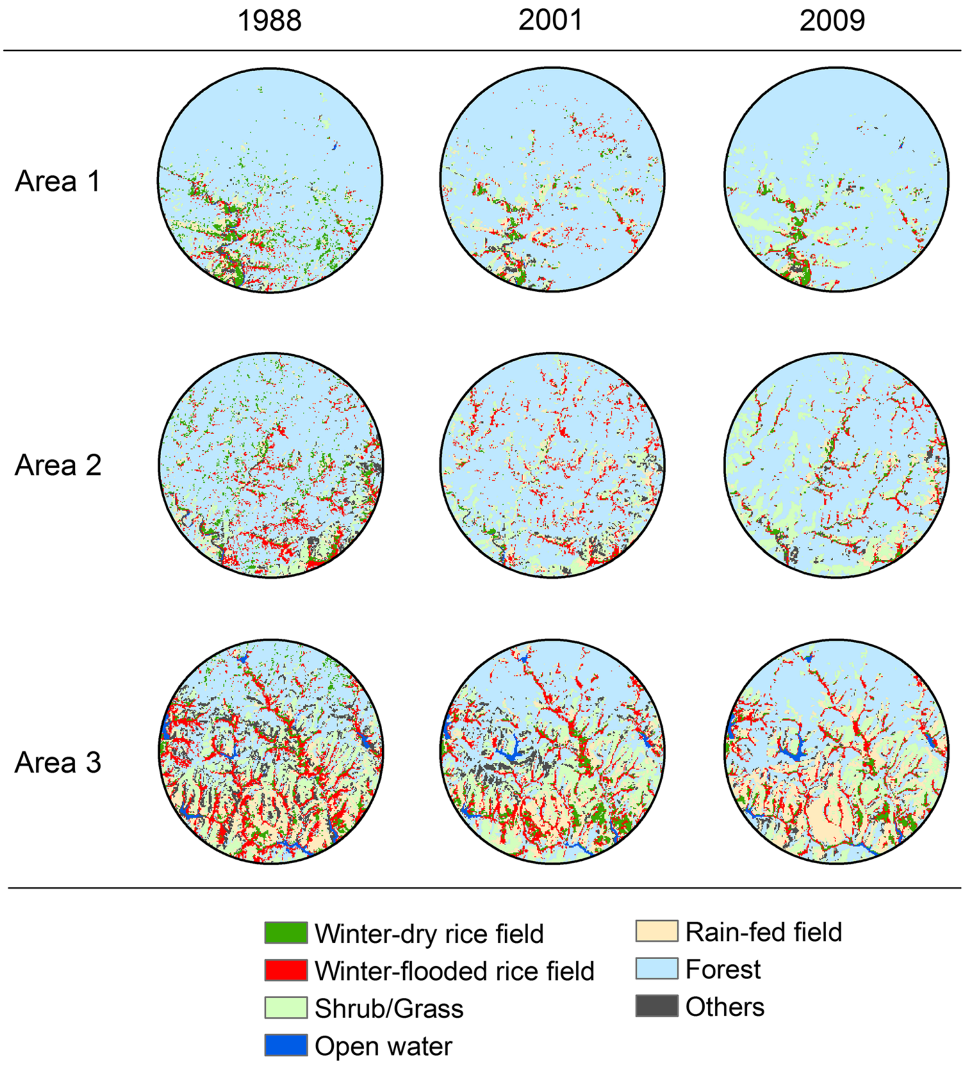

Fig. 3 Land cover/use maps in Areas 1, 2, and 3 for the years 1988, 2001, and 2009

per year. They continued to decline by 63.63 ha with an annual rate more than double of that during the second period. Large proportions of the lost winter-flooded rice fields were converted to other arable land, accounting for 69 and 59 % of the lost area in each period, respectively (Fig. 5b). The remainder was lost to shrub/grass or other non-agricultural uses. In Area 3, the non-protected area, a net loss of 103.68 and 91.53 ha of winter-flooded rice fields, was observed during the two periods. The loss rate here was similar to that in Area 2 from 1988 to 2001. During the second period, the rate of loss was higher, but still lower than that seen in the core-protected areas (Fig. 4). The continuous reduction of winter-flooded rice fields in Area 3 was due mainly to conversion to winter-dry rice fields and rain-fed fields, which accounted for 80 and 78 % of the loss in each period, respectively (Fig. 5b).

Population dynamics in response to the changes of winter-flooded rice fields

There was no evidence of density dependence in the first period (i.e., before 2001) of population increase ($F = 0.07$, $p = 0.79$, $R^2 = 0.01$), whereas the population exhibited density-dependent growth in the second period (i.e., after 2001) ($F = 23.40$, $p < 0.001$, $R^2 = 0.77$). In the second period, the numerical response of the population growth rate (r) to the per capita availability of winter-flooded rice fields was highly significant ($F = 62.43$, $p < 0.001$, $R^2 = 0.87$). There was no additive effect on r of population density ($p = 0.44$), which indicates that the effect of density dependence arises through competition for food resources. The fitted regression was $r = -0.041 + 0.09 * \ln(\text{per capita food availability})$. The regression

Table 1 Land-use classification accuracy assessed by overall accuracy and Kappa coefficient. The *p* value for the McNemar's test greater than 0.05 indicates no significant difference between the accuracies of two compared classifications

Classification	Overall accuracy (%)	Kappa coefficient	McNemar's test		
			Compared classification	χ^2	*p* value
1988	89.8	0.88	2001	0.50	0.480
2001	89.3	0.87	2009	3.13	0.077
2009	90.8	0.89	1988	2.25	0.134

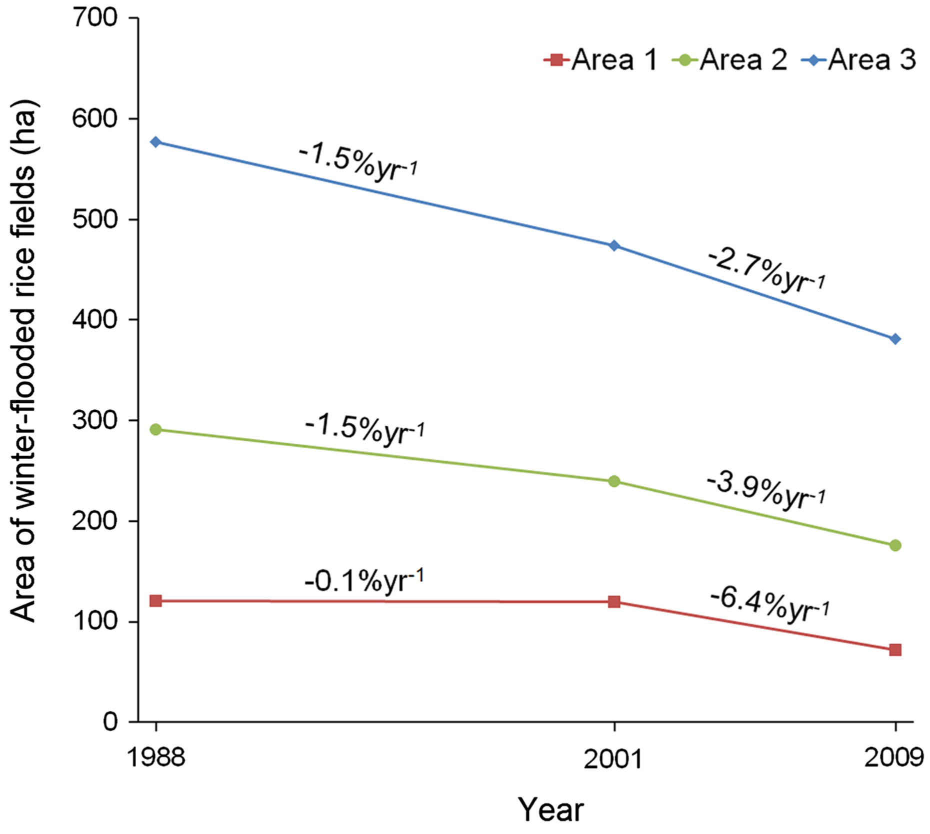

Fig. 4 Change in the area of the winter-flooded rice fields in Areas 1, 2, and 3 from 1988 to 2009. The annual rate of change for each period in each area is given above the lines

estimates that crested ibis abundance declines when the availability of winter-flooded rice fields per ibis drops below 1.56 ha. The population trends in 50 years were simulated based on this numerical response (Fig. 6). In both scenarios, the population growth rate increased at first, but then declined at a faster rate. If the area of winter-flooded rice fields would stop declining, the population size increased to 1757 in 2050. In the second scenario, however, the population size approached 940 individuals at the tipping point in 2021, after which it declined due to a continuous reduction of the winter-flooded rice fields.

DISCUSSION

Potential impact of reduction in winter-flooded rice fields on crested ibis population

A population that is rebounding from a catastrophic decline in numbers may grow geometrically for a while when resources are abundant, and predators, pathogens, and competitors are absent. We found that the population of crested ibis exhibited geometric growth in the early stage of recovery, which was also confirmed by Wang and Li (2008).

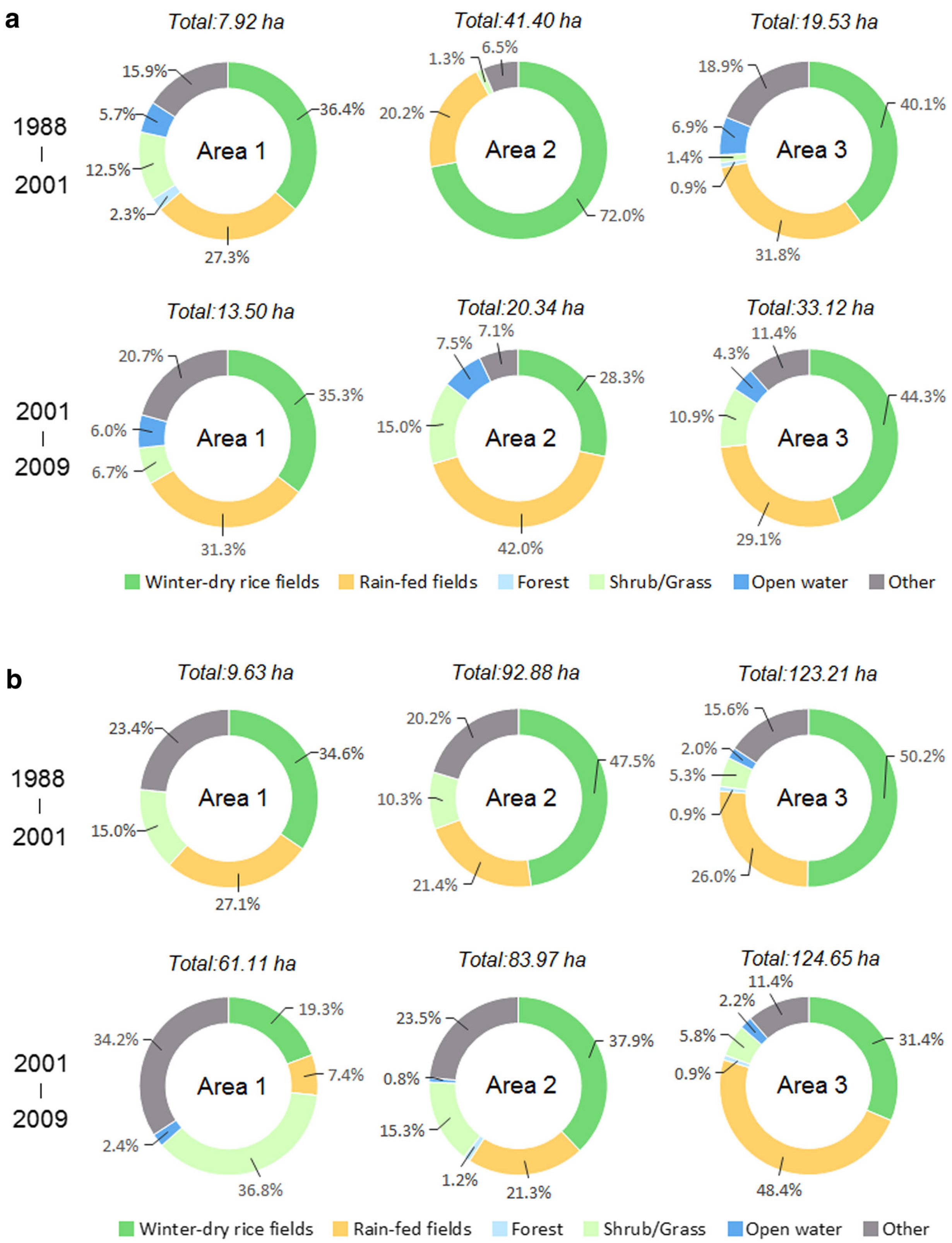

Fig. 5 Conversions of **a** land cover/use types to winter-flooded rice fields and **b** winter-flooded rice fields to other land cover/use types during 1988–2001 and 2001–2009

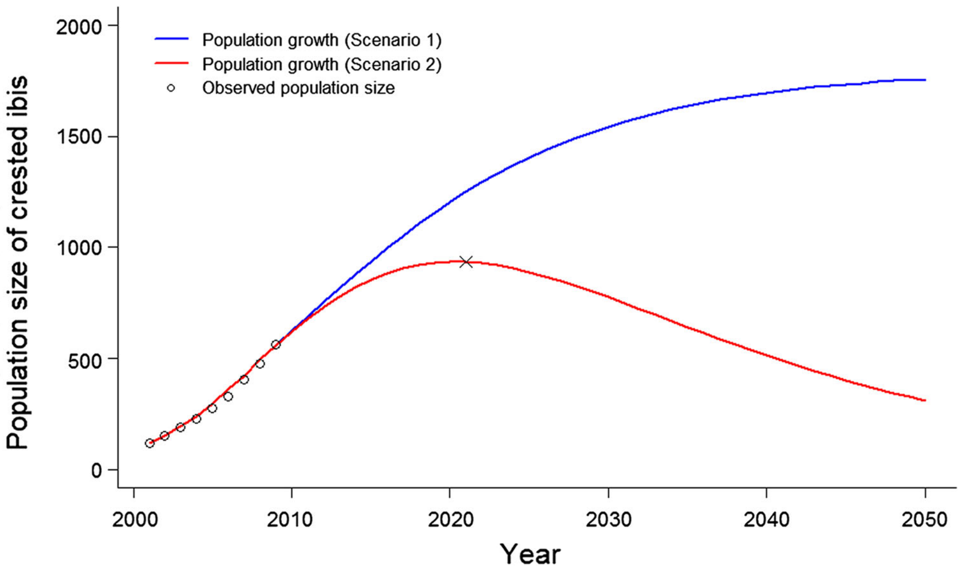

Fig. 6 Numerical response of the crested ibis population to the constant amount of winter-flooded rice fields after 2009 (Scenario 1) and to the continuous reduction of winter-flooded rice fields (Scenario 2) predicting the population trends in 50 years. The *cross symbol* represents the tipping point in the year 2021 with the maximum population of 940

In this period, the reduction of winter-flooded rice fields was relatively less and some winter-flooded rice fields were restored, especially in the core-protected areas (Fig. 5a). The crested ibis population behaved as if food resources were unlimited when it was small. The rapid growth of the crested ibis population and the recovery from the brink of extinction achieved through the conservation management that greatly reduced the risks of hunting, poisoning, and predation (Xi et al. 2002; Wang and Li 2008). Consequently, the average survival rate of nestlings for crested ibis in the 1980s and 1990s was reported to be much higher than other endangered ibis species (Wang and Li 2008). However, we found a negative effect on the population growth rate of the reduction of winter-flooded rice fields resulting in population regulation after 2001. This relationship accounted for 87 % of the variation in population growth rate, indicating the critical role of winter-flooded rice fields in the restoration of crested ibis population. The ongoing conversion of winter-flooded rice fields to dryland farming in winter or non-agricultural uses is rapidly reducing the availability of foraging habitats for the crested ibis. Food shortage has decreased the number of fledglings in some areas despite its increased breeding population size (Su 2008). The continuous reduction of winter-flooded rice fields is shown here to eventually constrain its population growth in the coming decades (Fig. 6). Habitat loss may further increase interspecific competition in the crested ibis and conspecific competition with other waterbirds, such as egrets. As the ibis population approaches the habitat's carrying capacity, competition will become more intense, leading to increasing death rates and decreasing birth rates, thereby threatening further restoration of the crested ibis population.

The numerical response may also be influenced by other mechanistic factors, such as the availability of suitable nesting trees, anthropogenic disturbance, and pesticide exposure (Newton 1998), which may be related to the unexplained remaining variation in the population growth rate. The results reported here indicate the population change within the specific study area (Fig. 1). The crested ibis may emigrate from the focal study area and scatter over a wider area allowing the total population to continuously increase. Unfortunately, the fate of the emigrants is not known and due to data availability, spatial population dynamics was not considered in this study. Although it is unlikely to give exactly the same result as a model incorporating every detail, the parsimonious model described here is likely to provide useful approximations. In order to investigate density-dependent mechanisms adequately in wild populations subject to changing environmental conditions, management of endangered species, such as crested ibis, requires ongoing and quantitative assessment of trends involving demographic parameters, by following populations over time from very low population abundances to equilibrium (Sutherland and Norris 2002).

Ground truth data were assumed to be 100 % accurate for the land-use classification procedure, but data collection is potentially subject to bias, when no other independent sources of information (e.g., high-resolution aerial photos) are used to determine historical land use. Farmer surveys may introduce errors due to memory lapse or concern about the consequences of providing a truthful answer (Morra-

Imas and Rist 2009). For instance, farmers may exaggerate the size of the winter-flooded rice fields or distort positional information in order to gain government compensation. In addition, selection bias may also exist, as farmers who volunteer participate in interviews may be systematically different from those who do not (Morra-Imas and Rist 2009). The errors in ground truth data are usually unknown and the uncertainties cannot be quantified, but they produce errors of omission (false negative) and commission (false positive) in the classification. When omission error is more than commission error, the land-use category is underestimated, and vice versa (Joseph 2005). In either case, the numerical response model may be subject to the bias arising from the misclassification of the winter-flooded rice fields.

Causes of reduction in winter-flooded rice fields

Farmers have long been dependent on exploiting existing resources in underdeveloped, mountainous areas. Winter-flooded rice fields are created or extensively modified and maintained by humans, and they cannot be protected by completely prohibiting human use within the protected area or by restricting the type of use made of natural resources. With continuing agricultural growth and economic development, local farmers are unlikely to put a high value on winter-flooded rice fields in their own interests, due to the low yields and difficult conditions of this type of farming. According to a socio-economic survey of local communities in the distribution area of the crested ibis during 2012–2013 (Ding et al. 2013), the average annual income of 645 households was around US$2090. Most of them derived their income from farming and egress laboring, accounting for 52.9 and 36.3 % of total income, respectively. However, the average annual income from winter-flooded rice cultivation was only about US$65 per household, thus contributing extremely little to the total income. As long as natural conditions and labor capacity permit, local farmers would rather increase their incomes by changing farming practice to crop rotations, involving higher-yield and income-generating crops on limited land (Sai et al. 2013). Consequently, the conservation management of traditional and biodiversity-friendly farming practice is facing more obstacles and challenges.

In addition to the decline in winter-flooded rice fields across the current range of crested ibis, we found different patterns of land-use conversion for the winter-flooded rice fields in the core-protected areas and non-protected areas. The rate of loss of winter-flooded rice fields in the core-protected areas was lower than or similar to that in the non-protected areas during 1988–2001. More recently, winter-flooded rice fields disappeared at a much higher rate in the protected areas. It is generally perceived that habitats in protected areas will be better protected from human activities (Liu et al. 2001; Nagendra 2008). Demographic and socio-economic pressures as well as national policies were likely responsible for the reduction of winter-flooded rice fields in the core-protected areas. As the mountain areas have been opened up and the educational level of farmers increases, more and more of the labor force and farmers in the remote mountain areas have given up their farming income and become migrant workers or self-employed to earn more money outside the poor villages (Duan et al. 2013; Sai et al. 2013). Alternatively, local residents are also being relocated from their remote mountain homes, which have been deemed unsuitable for sustaining human life, to regions with better economic prospects. This migration is a major measure to alleviate poverty and sustainably manage the ecosystem in two national policy programs, China's Western Development policy launched in 2000, and the new socialist countryside construction (Rogers and Wang 2006; Li et al. 2011). Labor migration and urbanization may reduce the use of agrochemicals and fuel wood and thereby reduce environmental stress (Duan et al. 2013), which is beneficial to the recovery of crested ibis population. However, these changes in both economic and lifestyle activities may have resulted in winter-flooded rice fields as well as other arable land being abandoned and turning into shrub/grass or waste land. In addition, China's Grain for Green Program, to return steep slopes of cultivated land to forest and grassland, also contributed to the conversion of winter-flooded rice fields to shrub/grass during the second period (The program was initiated in 1999 and implemented in 2002 (Liu et al. 2008)). In comparison, winter-flooded rice fields in the non-protected areas at lower elevations were exposed to more intensive disturbance due to the higher human population density and less conservation management. The lost winter-flooded rice fields were mainly converted to winter-dry rice fields and rain-fed fields due to changes in farming practice.

Higher rates of habitat loss within protected areas are uncommon, but other cases have been found (Nagendra 2008). For instance, forest in the Monarch Butterfly Reserve in Mexico (Brower et al. 2002) and in the Wolong Giant Panda Nature Reserve in China (Liu et al. 2001) both experienced a higher rate of clearing than the surrounding areas. This was mainly attributed to uncontrolled tree felling by local communities, which resulted from pitting local economic needs against the ecological needs of wildlife. Sai et al. (2013) found that local residents were not satisfied with the current compensation for conserving the crested ibis habitat and could still easily obtain more benefits from the existing resources and thereby maximize their interests. Given the dissemination of information, the unexpected reduction of winter-flooded rice fields in protected areas hints at a conflict between conservation and local communities.

Conservation efforts have to deal with a two-pronged situation: managers have few resources to invest in the protected area, and local communities live in poverty (Nagendra 2008). Such situations are common in Asia. The protection will not achieve the desired outcome simply by forcing the farmers to participate in conservation efforts, and the conflicts between conservation and local socio-economic development will be aggravated further. Maintenance and restoration of winter-flooded rice fields require the understanding and cooperation of local residents with the promotion of reforms to organic and ecological farming practices (Su 2008). Supporting or mimicking traditional agriculture is a conservation paradigm in Europe and other developed countries (Wright et al. 2012). By contrast, such agri-environmental schemes have rarely been applied in the developing world due to the more challenging social and political conditions. Legislation may need to propose incentives for biodiversity-friendly and lower-impact farming practice, thereby trying to eliminate the threats of agricultural intensification and abandonment.

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