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INVITED ARTICLE

Captive propagation, habitat restoration, and reintroduction of Oriental White Storks (*Ciconia boyciana*) extirpated in South Korea

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Abstract Reintroduction of wildlife that is extinct or extirpated in its ecological range becomes a new conservation tool to restore the status of historic biodiversity in ecosystems. However, reintroduction projects often meet the uncertainty of successful results due to a lack of scientific knowledge on how the system previously worked. To minimize the reintroduction failure, successful captive propagation should be followed by a series of assessing habitat quality for the target species in reintroduction sites before and after releases. The purpose of the present paper is to describe the past, present, and future efforts of Oriental White Stork (*Ciconia boyciana*) reintroduction in South Korea. The species is listed as a globally endangered bird species currently breeding only in Russia and partially in China, and it has been extirpated in Japan and South Korea more than a decade ago. Reintroduction of a stork population was recommended in Japan and the Korea peninsula. The last stork individual was translocated and died in a zoo in 1994 so that Korea Institute of Oriental White Stork Reintroduction Research Center (KIOWSRRC) was launched in 1996. Our captive breeding effort tightly linked with veterinary management yielded near one hundred captive storks in the facility up to dates. Prior to reintroduction, a wide range of GIS-related analyses using past breeding habitat information determined reintroduction sites, which habitat quality for future releases began to be managed and restored. The pre-release training program is also scheduled prior to the first reintroduction of 2013. The significance of the reintroduction projects in South Korea is to not only restore the extinct population in their historic breeding ranges but also augment the total size of the endangered metapopulation of storks in one of its historic regions.

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Introduction

Reintroduction is an intended movement of wildlife into a part of its innate range to restore the status of the historically extirpated population (Seddon et al. 2007; Armstrong and Seddon 2008). Ecologists and wildlife managers, in several decades, have not only sought to conserve currently viable populations but also attempted to reintroduce individuals to previously damaged populations. However, the restoration projects often lack scientifically manageable knowledge on how the system worked previously with the interesting species and how a population after releases will self-sustain in a given ecosystem (McNab 1983). Successful reintroduction requires a series of careful pre-release studies that include successful captive breeding tightly linked with veterinary management, habitat management of reintroduction sites, pre-release training programs, and future demography studies (Armstrong and Seddon 2008). The Oriental White Stork (*Ciconia boyciana*; hereafter stork), one of the large and long-lived stork family Ciconiidae, is listed as *Endangered*, which status became deteriorated even from a *Threatened* species in IUCN Red List of Threatened Species in 1994 (BirdLife International 2008). Now the four-related countries in East Asia began to recognize the fast need of conservation acts on the remaining stork population.

Historically the breeding stork populations were ranged from Russia, northern China to Japan and the Korea peninsula (Luthin 1987). The last remaining breeding area for the majority of the globally decreasing stork populations currently become limited to the Amur-Heilong basin floodplains along the border of Russia (Simonov and Dahmer 2008). In the mean time, the sizes of stork populations both breeding in Russia (V. Andronov, personal communication) and wintering in China (L. Z. Zhou, personal communication) have been critically decreasing, which was intensively discussed in the International Symposium on Conservation of Oriental White Stork's Habitat and Population held in Hefei, Anhui, China of 2010. Nevertheless, the status of this species in the Korea peninsula was described as *not uncommon* prior to Korea War in 1950–1953 (Campbell 1892) where Austin (1948) also depicted that individual stork nests were at least 100 m apart at the rate of one nest to one village (i.e., fairly high breeding densities as a non-colonial breeder; Fig. 1). Although it became listed as *Natural Monument No. 199* by Cultural Heritage Administration of Korea as well as *Endangered Species Level 1* by Korea Ministry of Environment, the last breeding pair remained in South Korea until the male was killed by a careless hunter in 1971, and then the widowed female was translocated to and lived in Seoul Zoo until 1994. To our knowledge, the population of breeding storks ranged in the Korea peninsula has become extirpated more than a decade ago presumably due to Korea War and elongated habitat loss. Similarly, the latest breeding status of the North Korea population has been reported as very scarce and sporadic until 1977 (Tomek 1999). Finally, the significance of the reintroduction project has been strongly recommended in Japan and South Korea (Luthin 1987). Since the last breeding stork pair was lost in South Korea in 1971, the small number of storks (i.e., approximately 10 to 20 individuals) presumably after breeding in Russia still visit the west coast of the Korea peninsula for wintering (Tomek 1999; Park and Cheong 2002; see Fig. 1). Korea Institute of Oriental White Stork Reintroduction Research Center (KIOWSRRC) was established in 1996 to restore the extirpated stork population in South Korea, starting with a series of stork imports from foreign countries for captive propagation and currently planning on the reintroduction of storks into the wild. The purpose of the present manuscript is to describe 1) captive breeding effort and 2) habitat management of reintroduction sites, and 3) reintroduction plans, followed by 4) future directions in the stork reintroduction project conduced in South Korea.

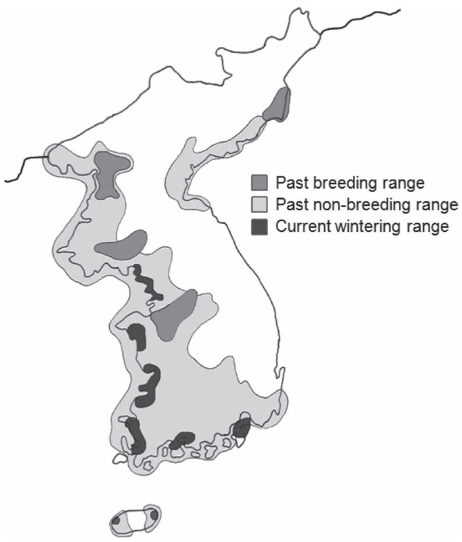

Fig. 1. The approximate distribution of breeding and non-breeding oriental white storks (*Ciconia boyciana*) prior to the extirpation in the Korea peninsula with its current wintering range only in South Korea (S. K. Kim, unpublished data).

Captive propagation and veterinary management

We have run the captive breeding project with importing a total of 38 storks periodically from Russia, Germany, and Japan since 1996 (i.e., 26 individuals from Russia, four individuals from Germany, and eight individuals from Japan), resulting in a total of 96 viable storks in the facility up to dates (Fig. 2). Three types of enclosures were maintained in the stork Reintroduction facility: 1) large public enclosures, 2) breeding enclosures, and 3) large semi-natural habitat enclosures. First, to establish breeding pairs, individuals were naturally induced to interact with each other in two larger enclosures. Second, breeding pairs were translocated to each nesting area with nesting materials and a nesting pole prior to reproduction

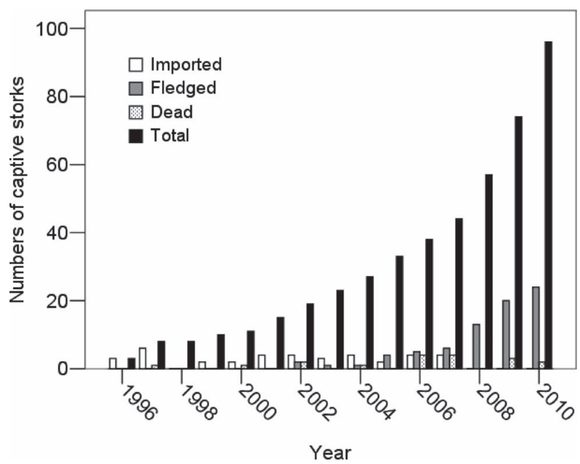

Fig. 2. The progress of the captive propagation made by Korea Institute of Oriental White Stork (*Ciconia boyciana*) Reintroduction Research Center in South Korea. Bars denote numbers of captive storks imported from Russia, German, and Japan, fledged successfully, and dead in 1996–2010.

Table 1. Reproductive rates of captive oriental white storks (*Ciconia boyciana*)' nests in Korea Institute of Oriental White Stork Reintroduction Research Center, South Korea in 1996−2010. Data are limited only to the first breeding attempts and rates without assisted parental care in captivity. Fledging success indicates the success that a nest produces at least one fledgling.

Reproductive rates	Clutch size	Incubation period (days)	Hatching success	Nestling period (days)	Fledge numbers	Fledging success
Mean	4.27	29.92	0.90	55.91	2.08	0.92
±1·SE (n)	0.17 (30)	2.15 (26)	0.07 (21)	3.93 (11)	0.31 (13)	0.08 (13)

(i.e., total 25 breeding cages) when they exhibited courtship displays among socially interacting individuals. Here, storks with other member of Family Ciconiidae are not sexually dimorphic, resulting in a common misidentification for sexing while establishing pairs due to a false sign of courtship (King 1990). To identify correct sexes in captivity, a non-invasive method for sexing was developed using bill morphology from high-resolution photography (Cheong et al. 2007); another simple and universal sexing method was found using a multiplex polymerase chain reaction (PCR) for storks as well as other avian species (Han et al. 2009a, 2009b). In captivity, both males and females contributed for reproduction including nest building, egg incubation, and post-hatching nestling care (Cheong et al. 2006). Artificial incubation, cross-fostering, or hand-rearing chicks were also applied when parents did not exhibit appropriate parental behaviors on occasion during the incubation or nestling period (Cheong 2005). Since the first captive breeding in 1996, storks pairs have produced a total of 76 viable fledges up to dates (Table 1, see also Fig. 2). During the period of captive propagation, diagnosis and treatment of disease in captive storks have been monitored by the veterinary medical center in Chungbuk National University since 2005. The team of the veterinary medical center established a diagnosis method for abnormal health conditions in captive storks (Han et al. 2009c; Han et al. in prep.). Third, one large top-open enclosure provided a semi-natural habitat where a flock of captive storks after being clipped their primary flight feathers were allowed to compete for supplied food resource and experience a variety of foraging areas that differed in vegetation and water depth as a part of prelease training for future reintroduction.

Pre-release habitat management of reintroduction sites

The ecological evaluation of reintroduction sites is one of crucial issues in reintroduction biology. First, we surveyed the past breeding sites through intensive literature and face-to-face interviews with local people to find potential reintroduction sites (Kim 2009a; Park et al. 2010), which was intended to be close to the originality of its historic range for reintroduction (Armstrong and Seddon 2008). A total of 26 past breeding sites were found in Chungcheong-do and Gyeonggi-do (Fig. 3). Contrasting the landcover characteristics of the used breeding sites in the past to the randomly selected unused sites using remote-sensing data with a GIS-based tool, the potential reintroduction sites that exhibited higher percentages of paddy fields, grasslands, and closed to urbanized area were narrowed down (Kim et al. 2008; Kim 2009a). The selection of the first reintroduction sites (Dae-ri, Kwangsimeyon; 36°32′42.35″N, 126°47′05.77″E) did not also occur

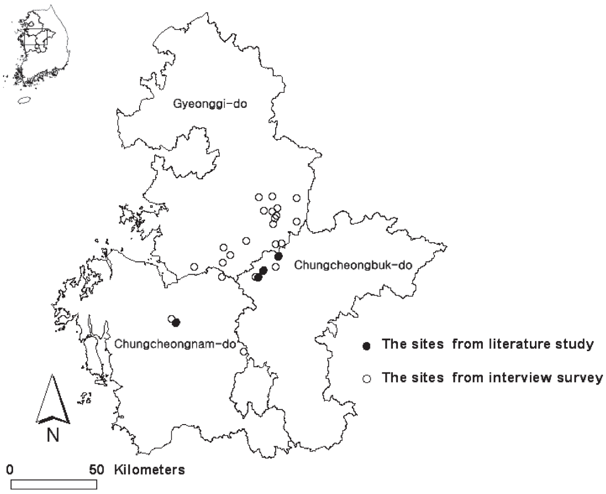

Fig. 3. Historic breeding sites of oriental white storks (*Ciconia boyciana*) in Gyeonggi-do, Chungcheongbuk-do, and Chungcheongnam-do, South Korea. Dots indicate locations of breeding sites, based on literature surveys (filled dots) and face-to-face interviews (opened dots; Kim 2009b).

without the financial and political supports of Yesan Province and Cultural Heritage Administration of Korea in 2009. The selected habitats in the reintroduction region were re-examined by a series of ecological evaluations, including the assessment of wetland biodiversity, agricultural types (i.e., pesticide-used vs. ecologically friendly agriculture), hydrology with pollution level, topography, distance to rivers, and total available area for reintroduced storks.

Storks in South Korea are known to be a representative of wetland species foraging in primarily paddy fields, riparian areas, and various types of wetlands in the past (Park et al. 2010). The reintroduction sites occupy mainly large and connected patches of paddy fields where food availability is anticipated to one of the major habitat requirements for breeding storks. However, the current project lacks sufficient knowledge on the breeding ecology of storks due to the historically early extirpation in South Korea. Instead, we have attempted to investigate and manage food availability in association with agricultural methods and habitat types for future reintroduction sites. For example, more mudfish (*Misgrnus* and *Channa* species), potential food sources for breeding storks in reintroduction sites, and higher biodiversity were found in the paddy fields with the mixed characteristics of shallow ponds, water flows for the movements of fresh-water fish, and ecologically friendly agricultural methods without the history of pesticide use (Cho 2010; Ra 2010). In addition, shallow-water paddy fields appeared to contain more tadpoles and mudfish compared to other types of wetlands in the reintroduction sites (Sung et al. 2008; Kim 2009b).

In addition to the assessment of food availability, we also plans to monitor the foraging ecology of other existing members of the order Ciconiiformes such as the genera of *Egretta* and *Ardea* that exhibit a similar foraging preference to storks in relation to differences in the structure of paddy fields and agricultural methods in a large scale throughout the year. Other studies paid attention to egrets and herons as an indicator species for predicting habitat-specific food availability of storks in Japan (Nakajima et al. 2006). It was found that major foraging habitats of egrets and herons tended to be paddy fields during the breeding season and riparian areas near rivers during the non-breeding season presumably due to changes in the aquatic fauna throughout the year in Japan. Similarly, the habitat use of herons and egrets varied throughout the year, depending upon food availability in paddy fields and riparian areas in South Korea (Choi et al. 2007, 2008). However, more data on food availability and habitat quality on reintroduction sites are critically needed prior to stork releases.

Pre-release behavioral training and reintroduction plan

We established a pre-release behavioral training and reintroduction plan for captive storks in addition to habitat management. Here, captive-bred animal training prior to releases is known to play a crucial role in survival rate of reintroduced animals (Sutherland 1998; Griffin et al. 2000). An experimental pre-release of captive storks into a large bird cage containing various habitat types with natural prey items supplied from the reintroduction sites is anticipated to facilitate the flying and foraging ability of captive storks prior to reintroduction (K. Naito, personal communication). Subsequently, small numbers of captive pairs (i.e., less than ten individuals) are scheduled to be released into the reintroduction sites in 2013, based on the progress of the current habitat restoration effort. These release sizes should be carefully considered because storks generally maintain large home ranges during the breeding season (Jiguet and Villarubias 2004), and elevated numbers of breeding pairs per area can also elicit a negative density dependent feedback effect on reproductive rates (Denac 2006). To minimize this likelihood, we still try to find an optimal level of how establishment probability will be improved by a combined effect of release sizes and habitat quality during the breeding and non-breeding seasons. A survey of historical breeding sites was evidence for an approximate range of 50 and 100 breeding stork pairs in South Korea (Kim 2009b), which is ideally aimed for the self-sustainable number of the reintroduced stork population close to its historical originality. Nevertheless, numbers of releases in consecutive reintroductions should be determined after monitoring habitat-specific densities and vital rates of previously released individuals along with the current status of habitat quality.

Future directions

What ecological conditions for wildlife reintroduction are needed for the future persistence of a newly established population would be a key question in reintroduction biology. First, the reintroduction incidence of stork individuals will be followed by an intensive monitoring for population demography to project its growth rate (Schaub et al. 2004) as well as a satellite-tracking effort to estimate home range sizes and study habitat selection. Second, an adaptive management strategy after reintroduction will be also applied to assess how the system after reintroduction will work in the current ecological condition (Sarrazin and Barbault 1996; Schreiber et al. 2004). It is because a preliminary failure of reintroduction tends to provide useful information on habitat requirements (e.g., food availability) for reproduction and survival of newly established wildlife (Armstrong et al. 2007; see also Armstrong and Seddon 2008). For example, this management strategy will be also allowed to estimate proper habitat compositions through a series of food supplementation experiments at reintroduction sites. Third, the extension of ecologically friendly agriculture in paddy fields for storks' major foraging sites will be continued not only at our reintroduction sites but also in potential areas after the dispersion of releases during the breeding and non-breeding seasons. Currently, a group of rice farmers chose an eco-friendly agricultural method in a core part of reintroduction sites (i.e., approximately 39,000 m^2) with a full support of Rural Development Administration in South Korea. This method involves no use of chemicals, the year-around maintenance of shallow water depth (e.g., above 8 cm), and biotope establishment connected by water flows for maintaining a wide range of aquatic fauna in paddy fields. This agricultural movement through nurturing young farmers with new intellectuals is expected to attract more local rice farmers and also landlords in the region of reintroduction sites. Lastly, we have offered a wide range of environmental education programs for the significance of wildlife conservation and reintroduction biology to local students in the reintroduction sites to improve their fundamental knowledge and attitudes towards future stork reintroduction. It was even found that a short-term environmental education program with the topic of biodiversity and wildlife conservation for a group of elementary and middle school students significantly yielded a positive attitude moving towards the significance of wildlife conservation (Kim et al. 2010).

Conclusively, our reintroduction effort of the extirpated stork population that previously bred in South Korea along with the breeding population newly being established in Japan is likely to expand the total metapopulation size of globally endangered storks in the world. Based on the historical prediction of a directional stork migration from the Korea peninsula to Japan (Y. Ohsako, personal communication), the released stork population from South Korea may also interbreed with the stork population in Japan and facilitate the genetic diversity of storks in Japan in the near future.

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