

Review

Updated Global Population Estimates of Three Endemic Crane Species in Northeast Asia: Wintering Status and Conservation Implications in Korea and Japan

Hwasu Lee

Department of Agriculture, Forestry, and Bioresources, Seoul National University, Seoul 08826, Republic of Korea; wncrane@gmail.com

Abstract

Red-crowned (*Grus japonensis*, RCC), White-naped (*G. vipio*, WNC), and Hooded Cranes (*G. monacha*, HC) are threatened endemic species in Northeast Asia. Their continental populations comprise two subpopulations: an eastern subpopulation that winters in Korea and Japan and a western subpopulation wintering in China. Population figures cited from the IUCN Red List are outdated (assessed: RCC 2021; WNC 2018; HC 2016). Accordingly, this review synthesized official winter censuses from Korea and Japan (1998–2023), harmonized across countries, to assess wintering trends and site status of the eastern subpopulation. Recent Chinese literature was reviewed to update global crane population estimates. The updated global population sizes of RCC, WNC, and HC were estimated at approximately 4600, 13,100, and 19,300 individuals, respectively. The eastern subpopulations are increasing in proportion and comprise approximately 44.5%, 97.1%, and 96.2%, respectively, of the totals. However, accuracy of global population estimates was limited by heterogeneity in census protocols between Korea and Japan and by temporal lags between Chinese literature-based and Korea–Japan census data. Standardized survey protocols and transboundary data sharing are needed to obtain more accurate estimates of these populations. The standardized datasets provide baseline data for establishing wintering-site management strategies to ensure sustainable conservation of these species.



Academic Editor: Luc Legal

Received: 10 August 2025

Revised: 23 September 2025

Accepted: 28 September 2025

Published: 29 September 2025

Citation: Lee, H. Updated Global Population Estimates of Three Endemic Crane Species in Northeast Asia: Wintering Status and Conservation Implications in Korea and Japan. *Diversity* **2025**, *17*, 682. <https://doi.org/10.3390/d17100682>

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Keywords: red-crowned crane (*Grus japonensis*); white-naped crane (*Grus vipio*); hooded crane (*Grus monacha*); global population estimate; eastern subpopulation; wintering population dispersal

1. Introduction

Within the family Gruidae, three migratory species—the Red-crowned (*Grus japonensis*, RCC), White-naped (*Grus vipio*, WNC), and Hooded Cranes (*Grus monacha*, HC)—are ecologically and conservationally important in Northeast Asia because of their limited distribution and declining populations [1]. These species are all listed as “Vulnerable” (VU) on the IUCN Red List, and breed in northeastern China, Mongolia, and the Russian Far East, as well as primarily winter in Korea, Japan, and southeastern China [2–4]. National legal protection policies differ among countries. China, Mongolia, and Russia protect both these species and most of their key habitats, primarily through protected-area designation of core breeding, stopover, and wintering sites [5–12]. Korea protects all three species, but the protected area designation for wintering sites is only partial [13,14]. By contrast, Japan applies different protection regimes by species: species protection primarily concerns the

Red-crowned Crane, whereas protected-area designation for White-naped and Hooded Cranes focuses on the primary wintering grounds at Izumi and Yashiro [15–17].

Cranes generally breed at low densities across extensive wetland areas, making accurate population counting during the breeding season challenging, even when helicopter surveys are employed [10,18–20]. In contrast, during the migration and wintering periods, cranes form conspicuous flocks and concentrate at a limited number of key stopovers and wintering sites, resulting in most population assessments being conducted in these areas [11,21–25]. During the Cold War era, international collaboration among the range states for cranes was limited owing to divergent political systems [26–29]. In addition, owing to insufficient information on the timing of migration and stopovers, accurately estimating the total population size of each species was challenging [29].

Satellite tracking studies aimed at elucidating the migration patterns of the Northeast Asian cranes began in 1991. The first study was conducted on White-naped and Hooded Cranes, tracking individuals from a wintering site in Izumi, Japan, to their breeding grounds [30]. A subsequent study tracked the same two species from three breeding sites in Russia—Daursky, Khingansky, and Muraviovka, to their respective wintering areas, revealing two distinct migratory routes [9,31]. In 1993 and 1994, Red-crowned Cranes were tracked from breeding sites at Khingansky and Lake Khanka, and were observed to follow two distinct migratory routes. Although a similar dual-route pattern was observed in White-naped and Hooded Cranes, each species followed slightly different flyways, resulting in different wintering destinations [32]. Since then, satellite tracking has been extensively applied to various crane species, providing comprehensive insights into their migration schedules, travel distances, and stopover use patterns [16,26,33,34]. Based on these studies, the three crane species in Northeast Asia were classified into populations based on migratory behavior and further distinguished into subpopulations according to their flyways and wintering areas. First, Red-crowned Cranes are typically divided into migratory continental and resident island populations in Hokkaido, Japan, whereas the other two species occur exclusively in continental populations [35]. Second, continental populations were further categorized based on migratory routes and wintering grounds into the western flyway subpopulation (hereafter western subpopulation) that winters along the Chinese coast and in the Poyang Lake region and the eastern flyway subpopulation (hereafter eastern subpopulation) that winters on the Korean Peninsula and in Izumi, Japan [36,37].

Although limited studies have included long-term population data spanning over 20 years for the three crane species, these surveys were conducted only at major wintering sites, limiting the ability to accurately estimate overall population sizes and trends for each species [25,38–40]. According to the IUCN Red List, the global population estimates for the three crane species were approximately 3800 Red-crowned Cranes in 2021, 6750 White-naped Cranes in 2018, and 16,000 Hooded Cranes in 2016, based on synthesized data from various researchers [2–4]. However, the last assessment dates differed by species, and data availability varied in quality and completeness, indicating that these figures may not completely reflect the current population sizes. Population trends also differed among species. Hooded Cranes are believed to be increasing, whereas Red-crowned and White-naped Cranes are assumed to be decreasing. The eastern subpopulations of all three species were estimated to be larger than those of their western counterparts. However, trends within subpopulations varied by species. For Red-crowned Cranes, the western subpopulation has been reported to be declining, whereas the eastern subpopulation appears to be increasing. These estimates were supported by relatively detailed data collected from multiple sources [4,36,37]. In contrast, no comprehensive trend information has been provided for the subpopulations of White-naped and Hooded Cranes. However,

available data from the eastern breeding grounds in Mongolia and the wintering sites at Poyang Lake indicate that the western subpopulation of White-naped Cranes has declined significantly compared with past estimates [11,19]. Notably, no study has specifically addressed the current status of the eastern subpopulations of any of these three species.

This review aimed to (i) provide updated global population estimates for the Red-crowned, White-naped, and Hooded Cranes; (ii) assess trends and current status of the eastern subpopulations; and (iii) identify habitat management challenges at wintering sites and propose alternative conservation strategies. These objectives are important because this review updates widely cited but outdated global population estimates and provides an up-to-date population baseline across the eastern flyway, thereby informing wintering-site management.

2. Materials and Methods

To achieve these objectives, long-term official census data from Korea and Japan were compiled, and recent publications on wintering populations in China were reviewed. Additionally, a literature review of the major wintering sites in Korea and Japan was conducted to identify site-specific challenges.

2.1. Official Census Data Collection

2.1.1. Winter Waterbird Census of Korea (WWCK): Nationwide Winter Waterbird Monitoring Program

The Winter Waterbird Census of Korea (WWCK), organized by the Ministry of the Environment, is a comprehensive and systematic avian monitoring program in Korea. It aims to assess the species composition, population size, and distribution of endangered species by conducting synchronized surveys of waterbirds across rivers, reservoirs, rice paddies, and coastal wetlands throughout the country during winter. The results of these surveys support the development of conservation and habitat management strategies.

Since its inception in 1999 with 69 survey sites, the number of sites has undergone gradual expansion and restructuring, reaching 200 locations by 2014, a number that has remained consistent thereafter. Initially, surveys were conducted once yearly over a two- to three-day period on a weekend in mid-January, the coldest time of the year, with all regions surveyed simultaneously. However, since the 2014–2015 winter season, the number of surveys has been flexibly adjusted to two to four times per season, as required (to monitor population changes at different wintering stages or in response to avian influenza outbreaks). In addition to these mid-winter counts, monthly surveys (six in total) have been conducted at major migratory bird sites from October to March annually since 2014. All data are publicly accessible through the National Migratory Bird Geographic Information website (<https://species.nibr.go.kr/bird/home/geo/index.do>, accessed on 1 February 2025), and several studies based on these data have been published [40–44].

In WWCK, all crane wintering sites were incorporated into the survey area by 2005, with Yeoncheon being the last site to be added. Crane data were extracted and compiled for analysis. The mid-January period corresponds to a stable wintering phase for cranes in Korea, when migration from breeding grounds is complete and local populations have settled. This timing minimized the risk of double-counting individuals wintering in Izumi, Japan [45–47]. However, this dataset does not include detailed information relating to the proportion of juveniles and the ratio of family to non-family groups.

2.1.2. Crane Census Data in Japan: Long-Term Site-Based Monitoring in Hokkaido, Yashiro, and Izumi

Although cranes have been recorded at various locations in Japan, most observations are incidental or temporary [48]. Currently, regular population monitoring is conducted at

three sites: Hokkaido, Yashiro, and Izumi [38]. Municipal governments collect long-term census data at these sites.

In the Hokkaido region, Red-crowned Crane population data have been collected independently by both the municipal government (<https://www.pref.hokkaido.lg.jp/ks/skn/tantyou.html>, accessed on 1 February 2025) and the Red-crowned Crane Protection Group (<https://www6.marimo.or.jp/tancho1213/2024kauntosuu.pdf>, accessed on 1 February 2025). Although both surveys began in 1952, discrepancies emerged in 1958 with the Protection Group reporting slightly higher counts. These data have been cited in previous studies [35,38] and include the number of juvenile individuals. Accordingly, we used data from the Red-crowned Crane Protection Group.

In Yashiro, a wintering site for Hooded Cranes, population data are posted on the Shunan City website (<https://www.city.shunan.lg.jp/site/turu-yasiro/12774.html>, accessed on 1 February 2025). Population counts have been recorded continuously since 1877, beginning with 10 individuals, and this dataset has been cited in previous studies [17,49]. The data include the total number of individuals, as well as relatively detailed information such as the number of juveniles, dates of arrival and northward departure, and records of other observed species.

Izumi is the largest wintering site for cranes in Northeast Asia and supports substantial populations of White-naped and Hooded Cranes. Population monitoring began in 1927 and continues to date. Population data and related information are publicly available on the official website of Crane Park Izumi, managed by the Izumi City municipal government (<https://www.city.kagoshima-izumi.lg.jp/cranepark/>, accessed on 1 February 2025), and have been cited in a previous study [38]. In this region, population counts follow a distinctive protocol. Between November and mid-January, four to six single-day official surveys are conducted. The official population figure for each crane species is designated as the species-specific count recorded on the single survey day when the site-wide total across crane species is highest, such that the official figures for all species are derived from the same survey. To mitigate potential bias arising from mismatches between survey timing and the true seasonal peak, if a different official survey round within the same winter records a higher value for a given species, this value is reported as the species-specific seasonal maximum; since 2008, seasonal maxima have been reported alongside the corresponding official figures.

2.1.3. Literature Search for Wintering Population Counts in China

To compile recent estimates of wintering population size for each species in China, peer-reviewed journal articles reporting site- and year-specific wintering counts in tables or figures were identified. A search was conducted on Google Scholar on 10 July 2025, using combinations of the scientific names of the species with “China” or names of known wintering sites. Results were screened in date-descending order; eligible studies were retained, and data were extracted and summarized until sufficient coverage was obtained for each species; no meta-analysis was attempted.

2.2. Data Harmonization and Selection

A discrepancy in year-labeling conventions was identified between countries. The Japanese dataset was organized by arrival year, whereas the Korean dataset was indexed by survey year. To harmonize this difference, Korean records were relabeled one year earlier so that the year index(t) was defined as

$$t := t_{JP} = t_{KR} - 1$$

where t denotes the aligned winter season labeled by the Japanese arrival year (e.g., the 2012–2013 winter is labeled $t = 2012$, corresponding to Korea’s survey year 2013). This relabeling step did not alter observed counts or their assignment to a given winter season. Because the Korean dataset was available for a shorter span, the analysis window was restricted to 1998–2023, the period with overlapping coverage.

Because the Korean and Japanese datasets were curated independently by national programs, cross-country duplication was absent. In view of the flocking behavior of cranes during winter, records were compiled at the level of major wintering sites. Within the Winter Waterbird Census of Korea (WWCK), which surveys many localities, counts from non-focal sites were aggregated into an “Other” category and were summarized separately. For Izumi, from 2008 onward, the annual species value was defined as the larger of the official single-day mid-winter count and the seasonal maximum recorded during the official surveys within the same winter; for years prior to 2008, only the official count was available and was used. For each species, the counts for Korea and Japan are presented in the Supplementary Materials.

Site-level representative values for wintering sites in China were selected according to a hierarchical procedure. When only a single publication was available for a given site, the population count reported in that source was adopted as the representative value. Where multiple publications were available, those containing data for the most recent year were prioritized; if multiple publications reported the same most recent year, population counts were arithmetically averaged across those publications and the mean was adopted as the representative value.

Although parts of the wintering range may extend into the Democratic People’s Republic of Korea (DPRK), that region was excluded owing to a lack of recent, verifiable site-year data.

2.3. Aggregation Formulas

This review first derived eastern subpopulation totals and then global population estimates. Because the Korean and Japanese inputs are annual time series, all terms are indexed by year t (see Section 2.2). By contrast, the Chinese inputs lack a comparable annual series and are therefore treated as time-invariant constants.

2.3.1. Eastern Subpopulation Totals

For species s , the eastern subpopulation total is obtained by adding the Korea-wide total to the species-specific counts from Japanese wintering sites:

$$E_{s,t} = K_{s,t} + \sum_{r \in R_s^{\text{JP}}} J_{s,t}^{(r)}, \quad s \in \{\text{RCC}, \text{WNC}, \text{HC}\}$$

where $K_{s,t}$ is the Korea-wide winter count in year t ; $J_{s,t}^{(r)}$ is the count at Japanese wintering site r in year t . and $R_{\text{RCC}}^{\text{JP}}$, $R_{\text{WNC}}^{\text{JP}}$, $R_{\text{HC}}^{\text{JP}}$ equal $\emptyset$, $\{\text{IZ}\}$, $\{\text{IZ}, \text{YA}\}$, respectively.

2.3.2. Global Population Estimates

For each species, the global population estimate was obtained by adding the eastern subpopulation total to the species-specific China constant; the island term included only for RCC:

$$G_{s,t} = E_{s,t} + C_s + 1_{\{s=\text{RCC}\}} J_{\text{RCC},t}^{\text{island}}$$

where C_s is the time-invariant China winter total for species s ; $J_{\text{RCC},t}^{\text{island}}$ is the island (Hokkaido) winter counts in year t ; and $1_{\{s=\text{RCC}\}}$ is the indicator (1 if $s = \text{RCC}$, 0 otherwise).

2.4. Sensitivity and Uncertainty Analysis

During data compilation for this review, multiple records were identified for two wintering sites—Izumi (Japan) and Poyang Lake (China). Since 2008 at Izumi, to prevent underestimation of official species-specific counts, whenever a value higher than the official count is recorded in another official survey round within the same wintering season, that value is designated as the seasonal maximum and is listed alongside the official count. Meanwhile, at Poyang Lake, discrepancies in counts across sources have been identified even for the same time period. Furthermore, based on the collected literature, disparities in the availability of literature-derived count data among Chinese wintering sites have been identified.

To evaluate the impact of these differences on population estimation, (A) the effect of choosing between the official count and the seasonal maximum at Izumi on the estimate for eastern subpopulation was defined as ‘method-assumption uncertainty’, and (B) the effect of selecting alternative scenarios {LOW/BASE/HIGH} for China’s species-specific constants on the global population estimate was defined as ‘input-selection uncertainty’; these two sources were quantified separately. All results are provided in the Supplementary Materials.

2.4.1. Sensitivity of the Eastern Subpopulation Based on Izumi Data

To evaluate the method-assumption sensitivity of the eastern subpopulation total, only years for which both the official count (OFF) and the seasonal maximum (MAX) were reported ($t \geq 2008$) were included. Because MAX was always greater than or equal to OFF across the analysis set, the reference was set to MAX, and OFF was treated as the alternative. The reference is defined as follows:

$$J_{s,t}^{IZ} = \max(\text{OFF}_{s,t}, \text{MAX}_{s,t}) \quad s \in \{\text{WNC}, \text{HC}\}$$

where $\text{OFF}_{s,t}$ is the official count, $\text{MAX}_{s,t}$ is the seasonal maximum, $J_{s,t}^{IZ}$ is the Izumi term adopted as the reference, and s indexes the species under analysis. In this dataset, this rule reduces to:

$$J_{s,t}^{IZ} = \text{MAX}_{s,t}$$

Hence, the alternative can only induce a downward change via the official count. Applying the above to the summation formula for the species-specific eastern subpopulation total yields

$$E_{s,t} = \begin{cases} K_{\text{WNC},t} + J_{\text{WNC},t}^{IZ} \\ K_{\text{HC},t} + J_{\text{HC},t}^{IZ} + J_{\text{HC},t}^{\text{YA}} \end{cases}$$

where $E_{s,t}$ denotes the species-specific eastern subpopulation total; see Section 2.3 for definitions of $K_{s,t}$ and $J_{\text{HC},t}^{\text{YA}}$. Because alternative values exist only for Izumi in this dataset, the Izumi-specific change term was derived as follows:

$$J_{s,t}^{(IZ,x)} \in \{\text{OFF}_{s,t}, \text{MAX}_{s,t}\} \quad \Delta J_{s,t}^{(IZ,x)} = J_{s,t}^{(IZ,x)} - J_{s,t}^{IZ}$$

$$E_{s,t}^{(x)} = E_{s,t} + \Delta J_{s,t}^{(IZ,x)} \quad x \in \{\text{OFF}, \text{MAX}\}$$

where $J_{s,t}^{(IZ,x)}$ denotes the Izumi term substituted by x , $\Delta J_{s,t}^{(IZ,x)}$ is the change from the reference, and $E_{s,t}^{(x)}$ is the alternative eastern subpopulation total with that change applied.

In this dataset, because the reference equals MAX, only the OFF alternative was computed. Sensitivity (percent change) is computed as

$$\delta_{s,t}^{(IZ,x)} = 100 \frac{E_{s,t}^{(x)} - E_{s,t}}{E_{s,t}} \quad x \in \{\text{OFF}, \text{MAX}\} \quad E_{s,t} > 0$$

where $\delta_{s,t}^{(IZ,x)}$ is the sensitivity (%) relative to the reference $E_{s,t}$. The absolute difference between the seasonal maximum and the official count for the same species–year is defined as

$$d_{s,t} = |\text{MAX}_{s,t} - \text{OFF}_{s,t}|$$

where $d_{s,t}$ is the absolute discrepancy for the Izumi term. Finally, the summary measure of the impact of the Izumi method-assumption choice on the results is defined as

$$w_{s,t} = 100 \frac{d_{s,t}}{E_{s,t}} \quad E_{s,t} > 0$$

where $w_{s,t}$ is the relative width (%) normalized by $E_{s,t}$.

2.4.2. Uncertainty in Global Population Estimates Based on Chinese Data

Because the site-level Chinese data did not form a continuous time series, for each wintering site, we set the most recent available count as a representative, time-invariant constant. Heterogeneity across literature sources was summarized into three scenario levels—LOW/BASE/HIGH, with BASE denoting the baseline scenario. These scenario values were summed across sites to obtain species-level constants and were then incorporated into the global population estimates to quantify uncertainty. At this stage, the eastern subpopulation input was fixed in accordance with this review’s data-selection rule (see Section 2.2), which selects the larger of the two values, to isolate variation attributable to the Chinese data. For robustness, the scenario construction was repeated for the three most recent years in reverse-chronological order: in each iteration the BASE value was taken as the single-year literature count. When a given year had a missing value for a wintering site, a last-observation-carried-forward (LOCF) rule was applied using the value from the immediately preceding iteration.

Data were classified into wintering sites with multiple literature sources and those with a single literature source. (i) Multiple-source sites. The lower and upper scenarios were defined as the minimum and maximum, respectively, of the most recent-year counts from sources $i \in \{A, B\}$, and the BASE was defined as their arithmetic mean; defined as follows:

$$\begin{aligned} c_{s,r}^{\text{LOW}} &= \min(y_{A,s,r}, y_{B,s,r}) \\ c_{s,r}^{\text{BASE}} &= (y_{A,s,r} + y_{B,s,r})/2 \\ c_{s,r}^{\text{HIGH}} &= \max(y_{A,s,r}, y_{B,s,r}) \end{aligned}$$

where $y_{i,s,r}$ is the most recent available count from source i , and $c_{s,r}^x$ is the time-invariant constant for species s at wintering site r under scenario x .

(ii) Single-source sites. The most recent available count was taken as BASE, sites were graded (A, B) by data characteristics, and grade-specific uncertainty coefficients $\varepsilon_{s,r} \in \{0.10, 0.20\}$ were applied to construct the lower/upper scenarios. The definitions are:

$$c_{s,r}^{\text{LOW}} = (1 - \varepsilon_{s,r}) y_{s,r} \quad c_{s,r}^{\text{BASE}} = y_{s,r} \quad c_{s,r}^{\text{HIGH}} = (1 + \varepsilon_{s,r}) y_{s,r}$$

Species-level Chinese constants were then obtained by summing across wintering sites as:

$$C_s^x = \sum_{r \in R_s} c_{s,r}^x \quad x \in \{\text{LOW}, \text{BASE}, \text{HIGH}\}$$

where R_s is the set of Chinese wintering sites for species s , and C_s^x is the species-level constant obtained by summing site-level constants. These species-level constants were applied in the global population formula to compute species-specific global population estimates:

$$G_{s,t}^x = E_{s,t} + C_s^x + 1_{\{s=\text{RCC}\}} J_{\text{RCC},t}^{\text{island}}$$

where $G_{s,t}^x$ is the global population estimate under scenario x ; see Section 2.3 for definitions of $E_{s,t}$, $1_{\{s=\text{RCC}\}}$, and $J_{\text{RCC},t}^{\text{island}}$. The percent change in the global population estimate relative to BASE is computed as:

$$\delta_{s,t}^{(\text{CHN},x)} = 100 \frac{G_{s,t}^x - G_{s,t}^{\text{BASE}}}{G_{s,t}^{\text{BASE}}} \quad x \in \{\text{LOW}, \text{HIGH}\} \quad G_{s,t}^{\text{BASE}} > 0$$

where $\delta_{s,t}^{(\text{CHN},x)}$ denotes the relative change (%) of the global population estimate compared with BASE. Finally, the scenario range width for China is defined as

$$w_{s,t}^{\text{CHN}} = 100 \frac{C_s^{\text{HIGH}} - C_s^{\text{LOW}}}{G_{s,t}^{\text{BASE}}} (\%) \quad G_{s,t}^{\text{BASE}} > 0$$

where $w_{s,t}^{\text{CHN}}$ is the relative width (%) of the Chinese scenarios. Because the numerator $C_s^{\text{HIGH}} - C_s^{\text{LOW}}$ is time-invariant, interannual variation in the relative width arises from changes in the denominator $G_{s,t}^{\text{BASE}}$.

2.5. Identifying Site-Specific Challenges at Wintering Sites

A targeted literature review was conducted, with priority given to principal wintering sites for each species along the eastern flyway. Searches were conducted in July 2025 across Google Scholar and national indices (KCI/KISS/RISS/DBpia for Korean literature; J-STAGE for Japanese literature), using combinations of the scientific names of the species and threat- and management-related terms. Records reporting site-level issues, management actions, or outcomes for Red-crowned, White-naped, or Hooded Cranes at the priority sites were included. Findings were synthesized qualitatively, and no meta-analysis was performed.

2.6. Statistical Analysis

Two complementary approaches were used to estimate annual rates of change and time-series trends for the three crane species in Korea, Japan, and their combined total. First, annual percent change (APC) was estimated by fitting log-link generalized linear models (GLMs) with year as a covariate. Poisson GLMs were used as the default; when overdispersion (Pearson $\chi^2/\text{df} > 1$) was detected, models were refitted as negative binomial GLMs. The year coefficient $\hat{\beta}$ was transformed to APC as $\text{APC} = 100(\exp(\hat{\beta}) - 1)$ (% per year), and 95% confidence intervals (CI) were obtained as Wald intervals $100(\exp(\hat{\beta} \pm 1.96 \text{SE}(\hat{\beta})) - 1)$. Second, the presence of a monotonic time-series trend was evaluated using the nonparametric Mann–Kendall (MK) test with a two-sided significance level of $\alpha = 0.05$.

3. Global Population Estimates and Trends of Three Crane Species in Korea and Japan

The combined wintering populations of the three crane species observed in Korea and Japan increased steadily from 12,205 individuals in 1998 to 35,125 individuals in 2023 (Figure 1). All three species exhibited increasing trends, with the highest growth rate observed in White-naped Cranes (318%), followed by Red-crowned Cranes (268%), and Hooded Cranes (220%). Previously, most wintering individuals were concentrated in Japan, resulting in a large disparity in population size between the two countries. However, this gap has gradually decreased over time, and the crane population in Korea has increased sharply since 2010. By 2022, the number of cranes wintering in Korea exceeded those wintering in Japan. Detailed annual counts by country and wintering site for each species are provided in Supplementary Materials (Tables S1–S3).

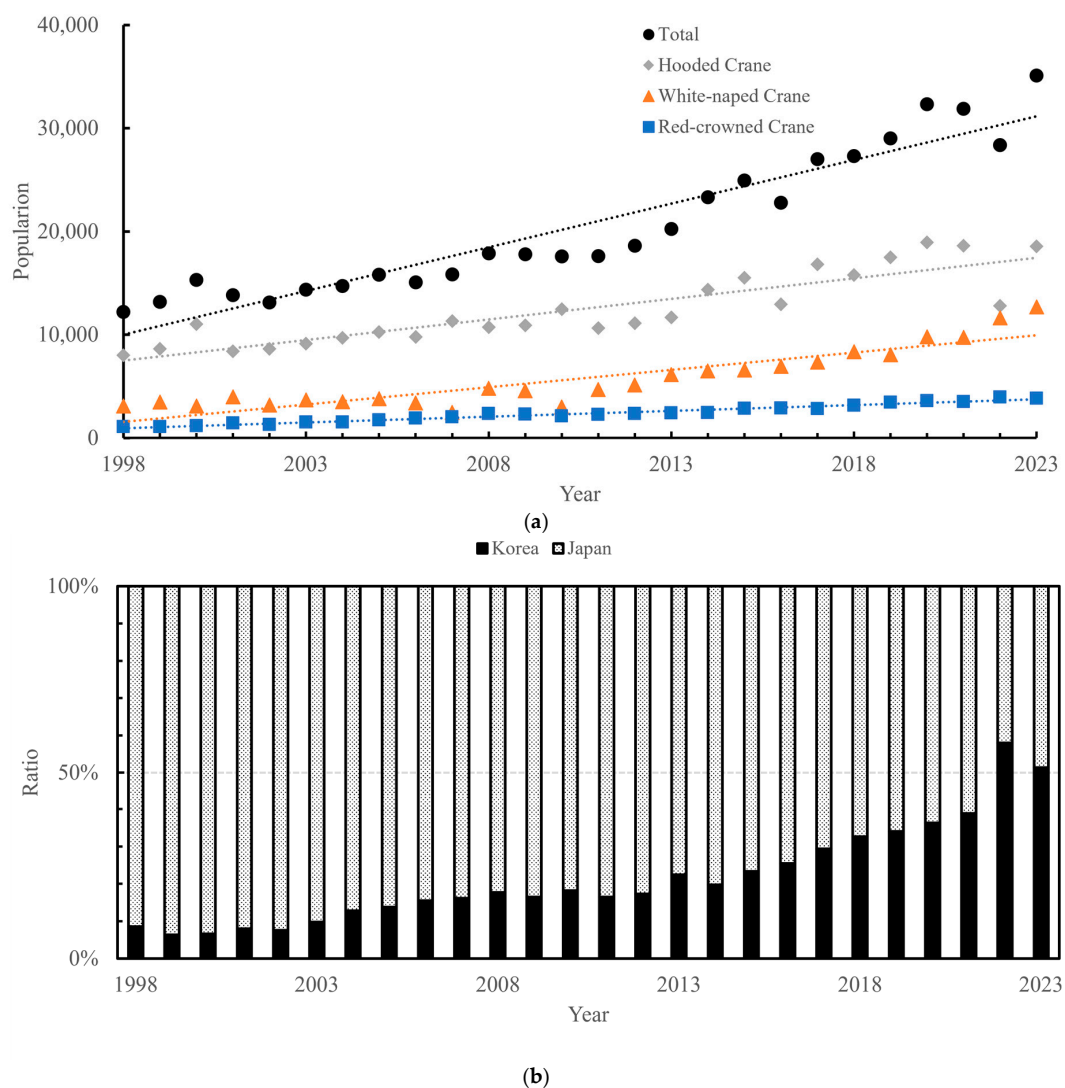


Figure 1. Population size and trends by (a) species and (b) national wintering proportions in Korea and Japan, 1998–2023.

3.1. Red-Crowned Crane

The combined wintering population of Red-crowned Cranes in Korea and Japan increased from 1088 individuals in 1998 to 3848 in 2023 (Figure 2a; APC 5.16% year⁻¹; 95% CI: 4.77–5.56; MK test, $p < 0.001$), which closely aligns with the current global population estimate. In terms of subpopulation classification, the eastern subpopulation wintering

in Korea increased from 382 to 2048 individuals (APC 6.86% year⁻¹; 95% CI: 6.12–7.61; MK test, $p < 0.001$), whereas the island population in Japan increased from 706 to 1800 (APC 3.96% year⁻¹; 95% CI: 3.52–4.41; MK test, $p < 0.001$). Notably, the Korean population has increased since 2016, reaching over 2000 individuals by 2022, and exhibiting a higher growth rate than that of the island population.

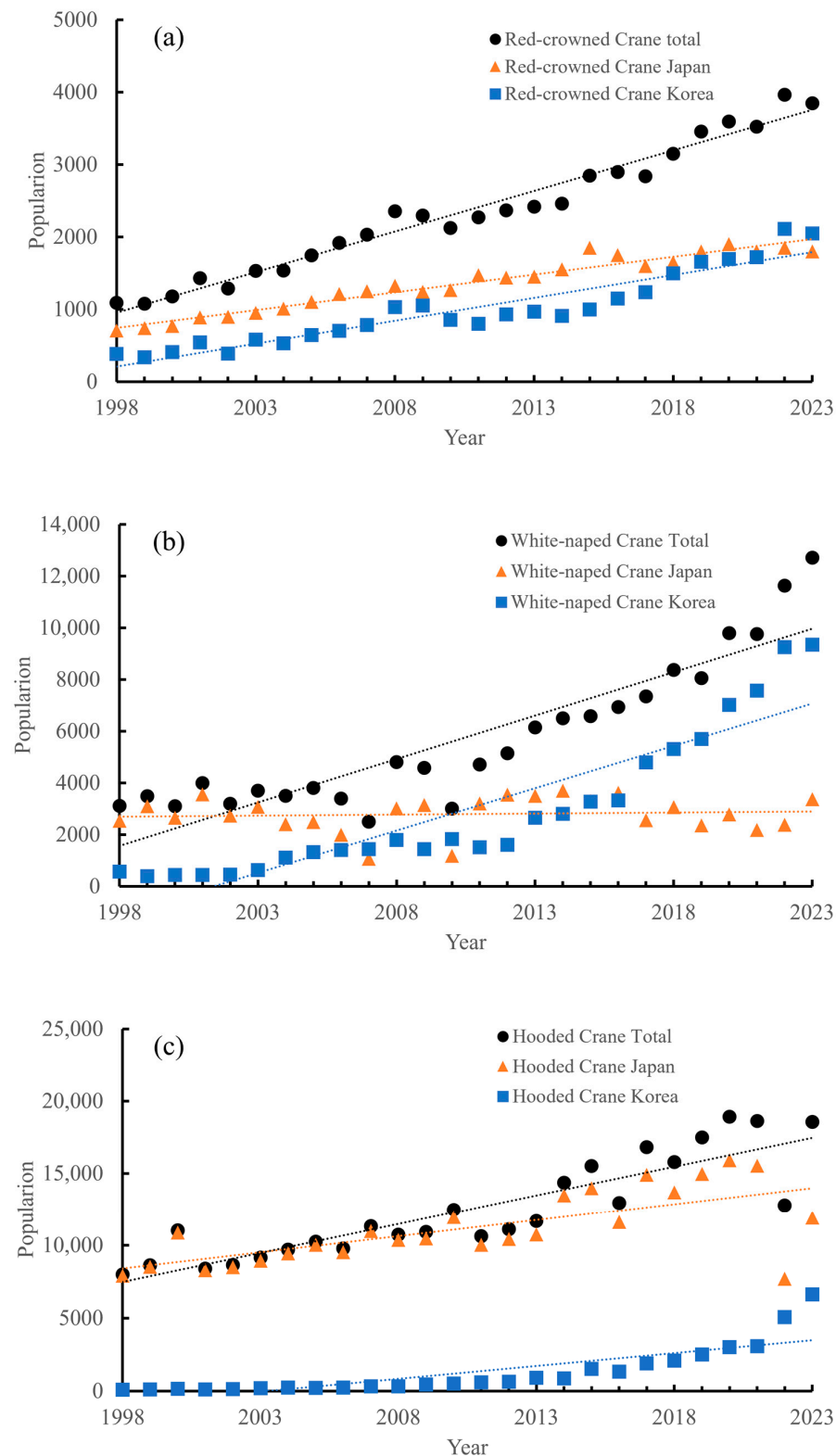


Figure 2. Numbers and trends of wintering individuals by country for each species: (a) Red-crowned, (b) White-naped, and (c) Hooded Cranes.

Currently, the three main wintering sites in China are located in coastal areas. The Yancheng Nature Reserve (33°35' N), historically the largest and southernmost wintering site, has shown a declining trend, with approximately 355 individuals in 2022. The Yellow River Delta Nature Reserve (37°45' N) has shown a consistent increase since the early 2000s, with 318 individuals observed in the spring of 2023. The Liaohe estuary Nature Reserve (40°50' N) was previously classified as a breeding area; however, wintering individuals were first recorded in 2010. The population has steadily increased, reaching 95 individuals by 2022 [50]. Based on these data, the Chinese wintering population was estimated to be 768 individuals. Combined with the eastern subpopulation in Korea and island population in Japan, the global population is currently estimated to reach 4600 individuals. Robustness checks indicate that, even when accounting for variation in Chinese numbers, effects on global totals were minimal across all scenarios (Base, R-1, R-2) (Tables S5–S7).

3.2. White-Naped Crane

The eastern subpopulation of White-naped Cranes increased from 3104 individuals in 1998 to 12,714 in 2023 (Figure 2b; APC 5.67% year⁻¹; 95% CI: 4.72–6.63; MK test, $p < 0.001$), which is approximately twice the current global population estimate. In Korea, the population increased from 569 to 9341 (APC 13.46% year⁻¹; 95% CI: 12.31–14.62; MK test, $p < 0.001$), whereas in Japan it increased from 2535 to 3373 (APC 0.29% year⁻¹; 95% CI: –1.11–1.71; MK test, $p = 0.758$). The Korean population has increased sharply since 2016, exceeding that of Japan, and continues to increase rapidly. In contrast, Japan's highest count was recorded in 2014 with 3700 individuals, followed by annual fluctuations. Sensitivity analysis contrasting Izumi's official counts (OFF) with maximum counts (MAX) showed very large year-to-year differences (Table S4). Using OFF instead of MAX markedly alters annual wintering totals for Japan and structurally reduces estimates for the eastern subpopulation ($\Delta\text{OFF}\% \leq 0$). This likely reflects Izumi's OFF methodology, which is strongly influenced by the numerically dominant Hooded Crane. Weekly monitoring in the lower Han River in Korea showed that White-naped Crane numbers fluctuated continuously until late December and stabilized after January [46]. Because the lower Han River functions both as a stopover along the eastern subpopulation's flyway and as a wintering site, these fluctuations indicate that migration had not concluded. Consequently, some OFF values likely precede the full arrival of White-naped Cranes at Izumi, and use of MAX is therefore more appropriate for estimating wintering population size.

The western subpopulation of White-naped Cranes appears to be predominantly concentrated in the Poyang Lake region of China. This wintering population exhibited a continuous declining trend, with 412 individuals recorded in 2019 and a three-year average of approximately 472 individuals, including that year [51,52]. Combined with the eastern subpopulation, the estimated global population reached up to 13,100 individuals. Robustness checks show that the influence of Chinese counts on global totals varied by year but was $\leq 7.31\%$ (Tables S5–S7). However, given the large discrepancy between the two cited sources, confidence in this figure is limited; excluding those values reduces variability to a minimal level.

3.3. Hooded Crane

The eastern subpopulation of Hooded Cranes increased from 8013 individuals in 1998 to 18,563 in 2023 (Figure 2c; APC 3.24% year⁻¹; 95% CI: 2.67–3.82; MK test, $p < 0.001$), exceeding the previously reported global population estimate of approximately 2500 individuals. In Korea, the wintering population increased from 92 to 6645 (APC 17.84% year⁻¹; 95% CI: 16.85–18.84; MK test, $p < 0.001$), whereas in Japan, it increased from 7921 to 11,918 (APC 2.08% year⁻¹; 95% CI: 1.31–2.86; MK test, $p < 0.001$). The Korean population has

increased significantly since 2019, whereas the Japanese population peaked at 15,923 individuals in 2020 and has declined slightly since then. A notable decrease in 2022 was primarily due to a highly pathogenic avian influenza (hereafter HPAI) outbreak shortly after cranes arrived in Izumi, Japan, resulting in a mass mortality of approximately 1500 individuals [53]. This outbreak disrupted population monitoring efforts, and thousands of cranes reportedly shifted their wintering locations to the southern coastal areas of Korea, including Suncheon Bay, contributing to uncertainty in the 2022 data. Sensitivity analysis comparing OFF and MAX from Izumi showed limited year-to-year differences (Table S4). However, in 2023 the OFF–MAX gap was notably larger than in other years, plausibly due to HPAI, underscoring the need for continued detailed monitoring.

Currently, China has four major wintering sites for Hooded Cranes. Three of these—Poyang Lake, Shenjin Lake, and Caizi Lake—are wetlands located in the Yangtze River Basin, whereas the fourth site is Chongming Dongtan in the Yangtze River Estuary. At Poyang Lake, 196 individuals were recorded in 2019, and the three-year average population, including that year, was 268 individuals. Although the wintering population in this region fluctuated, a slight increasing trend was observed [51,52]. During the 2021–2022 wintering period, a maximum of 244 and 174 individuals were observed in Shenjin and Caizi lakes, respectively [54]. In Chongming Dongtan, long-term monitoring since 2000 revealed a stable wintering population of approximately 100 individuals by 2021 [25]. Accordingly, the wintering population of China was estimated to be approximately 715 individuals. Combined with the eastern subpopulation, the estimated global population reached up to 19,300 individuals. Robustness checks indicate that variation in Chinese numbers was limited under all scenarios, with minimal impact on global totals (Tables S5–S7).

4. Site-Specific Recent Population Status and Trends Along the Eastern Flyway

The wintering distributions of the eastern subpopulations of the three crane species varied latitudinally (Figure 3). Red-crowned Cranes winter in the northernmost sites, White-naped Cranes exhibit the broadest latitudinal range among the three species, and Hooded Cranes are concentrated in the southernmost sites. In total, 10 major wintering sites were identified: eight in Korea and two in Japan. These sites were further classified into single and mixed species.

Cheorwon Basin (A), Yeoncheon (B), and Imjin River (C) were mixed-species wintering sites for both Red-crowned and White-naped Cranes (Table 1). In 2023, Red-crowned Cranes recorded at these sites were 1291, 614, and 79, respectively, whereas the corresponding counts of White-naped Cranes were 5022, 2113, and 635, respectively. Both species exhibited progressively increasing populations at these locations, including an increase in the number of juveniles [40]. These wintering sites are located near the border of the Democratic People's Republic of Korea within the Civilian Control Zone (CCZ). Established in 1967, the CCZ is a buffer area surrounding the Demilitarized Zone (DMZ), which lies approximately 2 km south of the inter-Korean border, where civilian settlement and agriculture are prohibited. The CCZ spans 5–20 km and is strictly controlled by military authorities, resulting in restricted access for the general public [55,56]. Inside the CCZ, the human population density is lower, and human activity is less frequent than in areas outside the zone. The area predominantly consists of agricultural land that provides a relatively stable wintering habitat for cranes, many of which overwinter [57,58]. Cheorwon Basin has the largest area of rice paddies in Gangwon Province. In contrast to Yeoncheon and the Imjin River, the Cheorwon Basin has more extensive flat terrain, numerous reservoirs, and ice-free streams, supporting the largest numbers of Red-crowned and White-naped Cranes in Korea. The area has been designated as a protected site for migratory birds, although

legal protection is limited to specific locations [14,59]. In contrast, the Yeoncheon and Imjin River regions are predominantly mountainous, with fewer rice paddies, which may limit the availability of foraging habitats for cranes. Notably, in Yeoncheon, cranes are frequently observed foraging in job's tears (*Coix lacryma-jobi*) fields on mountain slopes, a behavior that is not commonly observed at other sites.

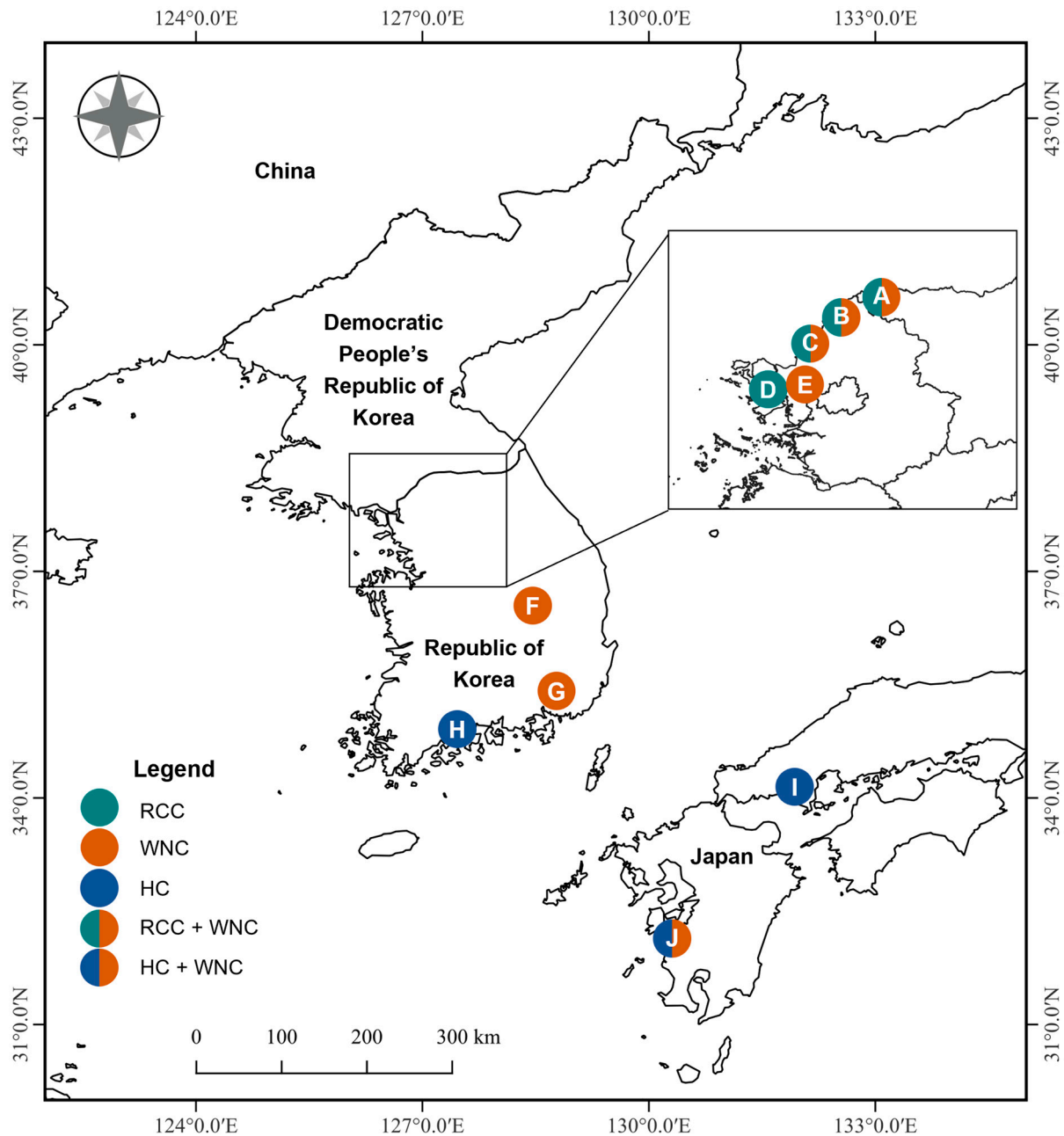


Figure 3. Spatial distribution of major wintering sites for the eastern subpopulations of Red-crowned (RCC), White-naped (WNC), and Hooded Cranes (HC).

Ganghwa Island (D) is a coastal wintering site of Red-crowned Cranes. In 2023, 63 individuals were recorded at this location, representing the smallest population among the wintering sites of this species, although the numbers have been consistently increasing. Most cranes that foraged in family groups dispersed across tidal flats, and nearby uninhabited islets were used for resting during high tide or as roosting sites [60]. In addition to being important for cranes, the area is a critical breeding site for Black-faced Spoonbills (*Platalea minor*) in the spring and is protected as a nature reserve [14].

Table 1. Summary of the wintering areas of cranes on the eastern flyway.

	Wintering Site	Habitat	Red-Crowned Crane		White-Naped Crane		Hooded Crane		Control ²
			Pop. Size in 2023 (Avg. 19–23)	Trend ¹	Pop. Size in 2023 (Avg. 19–23)	Trend	Pop. Size in 2023 (Avg. 19–23)	Trend	
A	Cheorwon Basin	Reservoir, River, Paddy	1291 (1245)	Inc	5022 (5108)	Inc			NR, CCZ, AF
B	Yeoncheon	River, Paddy, Field	614 (493)	Inc	2113 (1173)	Inc			CCZ, AF
C	Imjin River	River Paddy	79 (71)	Inc	635 (415)	Inc			CCZ, AF
D	Ganghwa Island	Mud flat	63 (36)	Inc					NR
E	Han River Estuary	River Paddy			8 (21)	Dec			-
F	Gumi Haepyeong	River Paddy			52 (15)	Dec			-
G	Junam Reservoir	Reservoir, Paddy			1116 (930)	Inc			AF
H	Suncheon Bay	Mud flat, Paddy					5619 (3466)	Inc	NG, AF
I	Yashiro	Paddy					7 (15)	Sta	NR
J	Izumi	Paddy			3373 (2613)	Sta	12,972 (13,197)	Inc	NR, AF

¹ Population trends: declining (Dec), increasing (Inc), stable (Sta). ² Control: artificial feeding (AF), civilian control zone (CCZ), national garden (NG), and national reserve (NR). Detailed data on the annual crane counts at each wintering site are provided in the Supplementary Materials.

The Han River Estuary (E) and Gumi Haepyeong (F) are wintering sites for White-naped Cranes, with eight and 52 individuals recorded, respectively, in 2023; both populations are declining. Cranes at these sites roost or rest along the riverbanks and forage in nearby rice fields. As the wintering site is closest to Seoul, the Han River Estuary experiences habitat fragmentation and loss of agricultural foraging grounds owing to urban development, resulting in rapidly deteriorating wintering conditions [46]. Gumi Haepyeong experienced a notable decline in crane numbers following large-scale environmental changes resulting from artificial weir construction in the main stream of the Nakdong River in the late 2000s [61]. In contrast to other wintering sites, both locations lack formal management, and their future prospects as crane wintering grounds are limited.

Junam Reservoir (G) is a wintering site for White-naped Cranes, with 1116 individuals recorded in 2023, and the population has been steadily increasing. Cranes roost or rest within the reservoir and forage on adjacent farmland. Habitat management is conducted by the municipal government, which regularly provides supplemental food. However, weak conservation policies have occasionally resulted in conflicts with local residents.

Suncheon Bay (H) is the main wintering site for Hooded Cranes in Korea, with 5619 individuals recorded in 2023, and the population continues to grow. The cranes move freely between nearby agricultural fields and tidal flats to forage. The site is designated as a national garden and is intensively managed by the municipal government with the implementation of strong conservation policies. Access to wintering areas is strictly regulated, and cranes are consistently provided with supplemental food and a stable roosting environment.

Yashiro (I) is a wintering site for Hooded Cranes, with seven individuals recorded in 2023. Although the number is small, the wintering population has been consistently maintained. The population peaked at 355 individuals in 1940, but gradually declined, with approximately 100 individuals wintering annually until the late 1970s. Following habitat degradation and the loss of roosting sites, the population has continued to decline, and recently, fewer than 20 individuals have wintered yearly [17,49]. Despite protection and various restoration efforts, the population is yet to recover.

Izumi (J) is a mixed-species wintering site for White-naped and Hooded Cranes, with 3373 and 12,972 individuals recorded in 2023, respectively. The number of White-naped Cranes has remained stable, whereas the Hooded Crane population has continued to increase, although at a slower rate than that observed in Suncheon Bay in Korea. Izumi remains the largest wintering site for Hooded Cranes and is designated as a protected area where intensive habitat management practices include regular supplemental feeding.

5. Current Issues and Wintering Site Management Recommendations Toward Sustainable Conservation of Populations on the Eastern Flyway

Primary threats to crane populations include habitat loss and degradation, poaching, poisoning, and collisions with power lines or buildings [1,36,62–64]. Korea, China, and Japan have implemented a range of conservation policies, including the designation of breeding and wintering sites as protected areas, to increase populations and ensure their protection. In recent decades, these countries have undertaken proactive habitat management, supplemental feeding, public campaigns, and environmental education initiatives [8,17,65–69]. Consequently, direct mortality from human activities such as poaching and mass poisoning has notably decreased.

5.1. The Necessity of Dispersal Due to Population Aggregation

During the early 2000s, the wintering of 83–85% of the global Hooded Crane population in Izumi, Japan [48], highlighted the necessity of population dispersal. At that time, other wintering sites along the eastern flyway, such as Suncheon Bay in Korea and Yashiro in Japan, supported only approximately 150 and 20 individuals, respectively, in contrast to the approximately 10,800 cranes at Izumi. Additionally, approximately 2600 White-naped Cranes overwinter in the Izumi area, which covers only 8.16 km², resulting in high wintering densities and increased vulnerability to infectious diseases [70]. In these conditions, a worst-case scenario could have pushed the species toward extinction. To mitigate this risk, international cooperation has been initiated to encourage the dispersal of wintering populations to new sites [2,48].

HPAI is a widespread disease among waterbirds in East Asia during the winter, with the H5 subtype causing high mortality. The first H5N1 outbreak in the region was reported in Hong Kong in 1997, followed by additional outbreaks in Hong Kong and Korea in 2003, and Vietnam in 2004 [71]. In Izumi, outbreaks of HPAI occurred in 2010–11 (H5N1), 2014–15 (H5N8), 2016–17 (H5N6), 2020–21 (H5N8), and 2021–22 (H5N1/H5N8), but did not result in substantial losses. However, in the winter of 2022–23, a severe H5N1 outbreak led to the mass mortality of approximately 10% of the wintering crane population, presenting a considerable threat to their survival [53,72–74]. Unlike previously recognized threats, disease outbreaks may result in rapid and severe consequences with limited opportunity for mitigation, underscoring the importance of population dispersal.

Suncheon Bay in Korea comprises 7.54 km² of agricultural land and 6.4 km² of tidal flats. Although the farmland area is smaller than that of Izumi, the combination of farmland and tidal flats provides a larger effective habitat for cranes [47]. Over the past two decades, Suncheon City has removed all utility poles and power lines from a 3 km² area surrounding the wintering site and implemented a biodiversity management contract scheme that compensates farmers for habitat management, thus providing a stable wintering environment for cranes. Continuous supplemental feeding and other initiatives have contributed to the habitat quality [69]. Consequently, the number of wintering cranes has steadily increased, reaching 5619 individuals in 2023, accounting for approximately 32% of the eastern sub-population. Several factors may explain this successful population influx: (1) reduced migration distance and avoidance of risky sea crossings, (2) provision of high-quality roosting and feeding habitats with ample food supply, and (3) availability of extensive adjacent farmlands. Tracking studies have shown that after departing from Izumi in early March, Hooded Cranes stop for approximately nine days each in multiple staging areas, including the west coast of Korea, Songnen Plain, and Muraviovka Park, before arriving at breeding grounds in the Russian Far East by late April [16]. Prolonged stopovers at each site are likely to help maintain optimal body conditions for breeding [75]. Consequently, cranes wintering in Suncheon Bay may benefit from reduced migration distances and better

physical conditions, potentially resulting in improved breeding performance compared to those wintering at Izumi.

The Cheonsu Bay area ($36^{\circ}37' \text{ N}$, $126^{\circ}27' \text{ E}$) along the west coast of Korea is one of the largest agricultural regions within the migratory flyway, covering 36.9 km^2 , and is an important stopover site for Hooded Cranes. Large flocks feeding on farmland are observed during the northward migration in March. Although large concentrations are not observed during autumn migration, cranes are regularly observed in the area through mid-December, and some remain throughout winter. During the 2014–15 winter, up to 240 individuals were recorded, although the numbers declined as winter progressed, with only a few remaining by mid-January [47]. In January 2016, a severe cold spell led to the abandonment of the site by the remaining wintering flock. These observations indicate that Cheonsu Bay has considerable potential as a wintering site for Hooded Cranes. Notably, the site is approximately 600 km from Izumi, allowing cranes, which typically migrate up to 3800 km in one direction, to reduce their journey by approximately 15% [30]. If further population dispersal is required, long-term habitat management and tailored conservation strategies should be implemented in Cheonsu Bay to facilitate crane wintering.

The Cheorwon Basin along the inter-Korean border is the principal wintering site for both Red-crowned and White-naped Cranes, supporting approximately 65% of Red-crowned Cranes and 40% of White-naped Cranes within the eastern subpopulation, with approximately 6300 individuals concentrated in this area. Although the population density in this area has increased sharply, concerns about aggregation have been alleviated by the availability of extensive habitats. The Cheorwon Basin covers 82.5 km^2 of farmland, with 61.5 km^2 within the CCZ and 21.0 km^2 outside, approximately 10 times greater than that of Izumi. Moreover, unlike in Izumi, only limited supplemental feeding is provided in the Cheorwon Basin, with most cranes foraging independently in different zones, resulting in a more dispersed wintering pattern [23]. Farmland area and crane distribution in the Yeoncheon and Imjin River regions have not yet been accurately determined, but similar management in these areas suggests that concerns regarding population aggregation are currently less critical.

5.2. Revising Habitat Management Strategies for Wintering Cranes

Thomas [76] proposed empirical minimum viable population (MVP) thresholds, suggesting that species with normal variability require populations of at least 1000 individuals, whereas birds and mammals experiencing high population fluctuations require a minimum of 10,000 individuals. Based on the 2023 census, the eastern subpopulation had 2048 Red-crowned Cranes, 12,714 White-naped Cranes, and 18,563 Hooded Cranes. Considering that cranes undertake long-distance migration and aggregate in relatively small wintering areas, rendering them vulnerable to disease outbreaks, these species can be classified as highly fluctuating populations. Thus, both the White-naped and Hooded Cranes in the eastern subpopulation met the MVP threshold, whereas the Red-crowned Cranes did not meet this threshold. A population viability analysis (PVA) of the island population of Red-crowned Cranes in Hokkaido, Japan, was conducted using census data from 1991 to 2004. During this period, the population size ranged from 453 to 950 individuals and showed an increasing trend, but still did not meet the MVP criterion. However, the PVA results indicated that regardless of varying mortality rates or carrying capacities, the risk of extinction within 100 years was negligible. In Hokkaido, the harsh winter climate frequently makes it challenging for cranes to secure food naturally, and some individuals approach human settlements to search for food. Continuous supplemental feed was provided to ensure population persistence. Consequently, the population continued to increase, reaching 1850 individuals in 2023, and the breeding range expanded [35,77]. In contrast, the population

growth rate of the eastern subpopulation wintering in the inter-Korean border area was steeper than that in Hokkaido, and the population size remained large. Additionally, the breeding and wintering habitats of these cranes are either designated protected areas or are unlikely to be degraded, making the prospects for population persistence highly favorable. Therefore, all three eastern subpopulations, the Red-crowned, White-naped, and Hooded Cranes, are currently regarded as stable and are no longer at an imminent risk of extinction.

The Izumi case, in which decades of intensive habitat management and supplemental feeding resulted in a notable population increase, prompted the adaptation of these management strategies to other wintering sites in Korea, adjusted to local conditions. Over the past 25 years, the wintering populations of all three crane species examined in this review, including island populations of Red-crowned Cranes, have more than doubled in Korea and Japan. Although Red-crowned and White-naped Cranes are dispersed across multiple wintering sites, Hooded Cranes remain concentrated in the Izumi and Suncheon Bays. High-density wintering conditions characterize both sites; Izumi has maintained a high-density crane population for decades [38,78], whereas Suncheon Bay has recently experienced a rapid increase in wintering numbers, resulting in higher densities. In contrast to other wintering sites, both Izumi and Suncheon Bays are major ecotourism destinations, and local policies have highlighted population growth as well as visitor attractions [48]. Substantial quantities of supplemental food are provided in certain areas and are expected to maintain these high-density conditions in the future. Although concerns have been raised about the risks associated with such aggregations, priority has been given to increasing numbers and dispersal, as most of the global population is concentrated in only a few wintering sites under the threat of extinction. Moreover, owing to the limited knowledge of actual population sizes, management strategies have focused on population growth and dispersal rather than the maintenance of optimal densities.

Recent census data and population trends in Korea and Japan suggest that sufficient population growth has occurred. However, the dispersal of the population remains limited, and, as observed in the case of Yashiro, the recovery of diminished wintering populations is challenging. Additionally, studies on Northeast Asian cranes have historically focused on population conservation and species biology, resulting in a lack of data on site-specific carrying capacities and wintering statuses. Therefore, conducting long-term studies on the appropriate population sizes and carrying capacities of wintering sites is necessary. Based on these findings, a gradual reduction in artificial feeding should be considered to decrease dependence on humans and to maintain appropriate densities at each wintering site as the subsequent step in population management.

5.3. The Need for Long-Term Habitat Conservation Strategies in Inter-Korean Border Regions

Satellite tracking studies since the 1990s have highlighted the critical importance of the DMZ and CCZ as wintering and stopover sites for cranes in Northeast Asia [79]. The DMZ, which has remained inaccessible to civilians for over 70 years since the armistice, is now internationally recognized for its well-preserved natural ecosystems, attracting the interest of biologists worldwide. This region supports cranes, as well as a diversity of threatened species, natural monuments, and cultural sites. The Korean government has attempted several times to designate the DMZ and surrounding areas as biosphere reserves in efforts to conserve these unique habitats; however, these attempts have been repeatedly unsuccessful owing to a lack of engagement with local farming communities [56]. Subsequently, municipal governments established boundaries for protected areas, and following thorough consultations with residents, successfully achieved UNESCO Biosphere Reserve designations for two regions in June 2019: the Gangwon Eco-Peace Biosphere Reserve (GWBR), which includes the Cheorwon Basin wintering site, and the Yeoncheon

Imjin River Biosphere Reserve (YIBR), which includes the Yeoncheon and Imjin River wintering sites. Currently, four major crane wintering sites in Northeast Asia are designated UNESCO Biosphere Reserves: Yancheng in China; and, in Korea, Suncheon Bay, the GWBR, and the YIBR. The Yancheng Biosphere Reserve (YBR), designated a protected area in 1983 and named a UNESCO Biosphere Reserve in 1992, is China's southernmost wintering site for Red-crowned Crane [50,78,80]. The UNESCO Suncheon Biosphere Reserve (USBR), a key wintering site for Hooded Cranes, was listed in July 2018.

The YBR was originally designed to protect the wetlands from cranes and other waterbird species [81]. Initially, cranes were evenly distributed across the core, buffer, and transitional zones of the reserve. However, increasing economic pressure for land use change has led to the expansion of aquaculture and reed fields, resulting in a reduction in natural wetlands and an increase in artificial wetlands and farmlands in all functional zones. Consequently, despite an overall increase in the number of cranes, their distribution has contracted and concentrated within the core zone, a trend that has recently intensified [78,82,83]. In particular, the proliferation of wind turbines along coastal buffers and transition zones has persistent negative effects on crane habitats. If wind energy development continues, the wintering distribution of cranes will likely become increasingly restricted to the core zone [83].

The two biosphere reserves in Korea's border region (GWBR and YIBR) have core zones aligned with mountain ranges and river systems, buffer zones that include agricultural land within the CCZ, and transitional zones primarily consisting of farmland and rural settlements outside the CCZ [84,85]. Consequently, the wintering habitats of cranes in these reserves are primarily located in the buffer and transition zones, in contrast to the YBR zoning scheme in China, in which the wintering grounds are established within the core zone. In Cheorwon County, changes in the CCZ boundaries and the expansion of artificial structures have led to shifts in crane distribution [57,59]. Since the designation of these Korean biosphere reserves, the wintering populations of Red-crowned Cranes and White-naped Cranes have increased by approximately 30% and 50%, respectively, indicating a concurrent expansion of their wintering ranges. Currently, activities within the CCZ remain highly restricted, resembling core zone conditions, except for the regulated agricultural use by local residents. However, because the CCZ was established for military purposes, its continued existence may depend on future political circumstances, although its timing remains uncertain. Evidently, abolishing the CCZ would result in considerable pressure for land use conversion and infrastructure development, likely leading to habitat fragmentation, increased human population density, and degraded crane wintering conditions. Considering the relatively small population size of the Red-crowned Crane compared to that of the other two species, developing long-term management plans is particularly important to ensure the continued conservation of wintering habitats in these transboundary areas.

6. Conclusions and Prospects

6.1. Limitation in Estimating Accurate Population Sizes

In this review, two major limitations were identified during the data collection and evaluation processes.

First, potential errors may result from differences in population survey methods between Korea and Japan. Each country conducts surveys during different periods and employs distinct methods to calculate official population counts. Specifically, Izumi in Japan currently provides both official population counts and maximum observed numbers for each species. However, detailed information regarding the survey timing for these maximum counts was not provided, which inevitably reduced the accuracy of the combined eastern subpopulation estimates.

Second, there are limitations regarding the accessibility and accuracy of data from China. Attempts have been made to acquire monitoring data for Chinese wintering sites comparable to those in Korea and Japan; however, no suitable datasets have been found. Consequently, the data were obtained from recently published literature, which is a method with apparent limitations. Owing to the considerable time required for manuscript preparation, peer review, and publication, such data inherently lag behind current monitoring records. The oldest dataset referenced for global population estimates in this review includes crane observations at Poyang Lake from 2001 to 2019. Moreover, discrepancies in the species-specific counts were observed between the two reviewed studies [51,52]. Accordingly, consistent with our data-selection criteria, the mean of the species-specific counts from the two references was cited. Liang et al. [51] used data obtained from the annual monitoring report of natural resources in the Poyang Lake Wetland Reserve of Jiangxi Province and suggested that similar monitoring systems might exist at other crane wintering sites in China. Employing such data can notably enhance the accuracy of future global population estimates. Together, these limitations and associated uncertainties are acknowledged when interpreting combined eastern subpopulation and global estimates, as well as their management implications.

6.2. Conclusions

In this review, updated global population estimates for three crane species endemic to Northeast Asia were obtained using reliable official census data and recent literature, confirming that current population sizes exceed previous estimates. In addition, the eastern subpopulations of these cranes exhibited consistently increasing trends, likely resulting from long-term localized conservation strategies focused primarily on artificial feeding at wintering sites in Korea and Japan. However, elevated population densities at primary wintering sites increase the vulnerability of cranes to infectious diseases, highlighting the need for population dispersal.

6.3. Prospects

Building on these conclusions, this review outlines directions for research and wintering-site management. To date, studies on cranes have primarily focused on understanding their ecological characteristics and implementing local conservation measures. Considering their broad geographical range across multiple countries, international collaboration and data sharing are essential for standardizing methods to accurately estimate global population size and facilitate effective population dispersal. Specific studies examining wintering site conditions, including habitat-carrying capacities, the effects of controlling artificial feeding, and identifying suitable alternative wintering sites, are currently insufficient and must be prioritized.

Meanwhile, Korea's CCZ provides stable wintering habitats for Red-crowned and White-naped Cranes owing to restricted public access. However, long-term habitat conservation in this area remains uncertain because political circumstances can alter accessibility and management practices. Although these areas are designated as UNESCO Biosphere Reserves, crane habitats in the CCZ are predominantly located within the buffer and transition zones rather than in the core areas, necessitating comprehensive long-term conservation strategies.

This review underscores the necessity of shifting habitat management strategies in response to increasing crane populations, the direction of future conservation efforts, and the importance of international cooperation. These findings serve as foundational data for the development of applicable conservation policies and wintering-site management

strategies, ultimately contributing significantly to the sustainable conservation of crane populations in Northeast Asia.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/d17100682/s1>, Table S1. Annual numbers of Red-crowned Cranes at each wintering sites in Korea and Japan (1998–2023). Table S2. Annual numbers of White-naped Cranes at each wintering sites in Korea and Japan (1998–2023). Table S3. Annual numbers of Hooded Cranes at each wintering sites in Korea and Japan (1998–2023). Table S4. Izumi MAX-OFF sensitivity by year and species (reference = MAX). Table S5. Input Data for Chinese Wintering Sites by Species under Baseline and Robustness Scenarios (Base, R-1, R-2). Table S6. Scenario-specific site-level constants for Chinese wintering sites. Table S7. Species-level Chinese constants and global population estimate under robustness scenarios (Base, R-1, R-2).

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: All data are available in the manuscript.

Conflicts of Interest: The author declares no conflicts of interest.

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