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Plant Diversity and Black-Necked Crane Distribution in Caohai Wetland, Southwestern China

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Abstract: The Caohai Wetland is an important habitat for many rare birds, such as black-necked cranes. This study focused on the species composition and diversity of plants in the seven main habitats of black-necked cranes in the Caohai Wetland, and on the distribution characteristics of black-necked cranes in these habitats in the winter season from November in 2022 to March in 2023. A total of 138 species belonging to 111 genera, 40 families, 23 orders and 4 classes and 2 phyla were recorded during field investigations involving 31 investigated plots, which comprised 112 quadrats. Among the different investigated plots in the seven habitats of black-necked cranes, the Shannon-Wiener index values ranged from 0.1125 to 2.4800. Notably, plant species diversity decreased in almost all habitats from the terrestrial zone to the water-land transitional zone and from the water-land transitional zone to the shallow water zone. The water level, habitat area, microcirculation heterogeneity and grazing activities are critical factors related to plant species diversity. In this winter, about 2,469 black-necked cranes overwintered in the seven main habitats. Black-necked cranes inhabiting in Huyelin (HYL) and Wenjiatun (WJT) are of absolute advantage in terms of population among the seven major habitats. To better protect the habitat of black necked cranes, we need to control the spread of tall plants, scientifically regulate the plant community structure of the habitat in combining with black necked crane feeding habits, and to regulate the water level of Caohai Lake reasonably to ensure sufficient water-land transitional zone and shallow water zone for black-necked cranes to inhabit.

Key words: Caihai Lake, black-necked crane, plants, biodiversity, wetland, habitat.

1. Introduction

The black-necked crane (*Grus nigricollis*) is a unique species among 15 crane species worldwide that lives and reproduces on high-altitude plateaus (2,500-5,000 m above sea level) [1, 2]. It is a globally vulnerable species and the only one found on plateaus [3]. The life history of black-necked cranes is closely related to that of wetlands [4]. At present, there are approximately 17,389-17,610 black-necked cranes worldwide [5]. Black-necked cranes occur mainly in India, Nepal, Bhutan, Vietnam, China, and Myanmar [6, 7]. In China, black-necked cranes are a key protected and vulnerable species, and they occur primarily in Gansu, Guizhou, Qinghai, Yunnan, Xinjiang, western Sichuan, Xizang, and Inner Mongolia [8]. In recent years, climate change has occurred, and the habitats and foraging grounds of black-necked cranes have been severely damaged under the influence of human activities. Urgent measures are needed for protecting black-necked crane populations, such as establishing nature reserves, maintaining habitats, regulating tourism and agricultural activities, and reducing swamp drainage and pesticide use [9].

Three relatively independent overwintering populations have been found on the Qinghai-Tibet Plateau, Yunnan-Guizhou Plateau and Bhutan. The eastern population of black-necked cranes comprises approximately 4,300 individuals, which overwinter in northeastern Yunnan and northwestern Guizhou. Most

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black-necked cranes occurring in the three national nature reserves on the Yunnan-Guizhou Plateau, namely, the Dashanbao (Zhaotong County in Yunnan Province), Huize (Huize County in Yunnan Province), and Caohai Wetlands (Weining of Hui Yi Miao Autonomous County in Guizhou Province), spend most of the winter there, and they largely migrate from the Dashanbao and Caohai Wetlands to Ruoergai for breeding. The central population, which comprises 232-300 black-necked cranes, overwinters in northwest Yunnan. There are approximately 8,700 black-necked cranes in the west, overwintering in central and southern Xizang and Bhutan, while a few black-necked cranes regularly overwinter in Arunachal Pradesh, India. The key bird migration sites include the wetlands on the Zoige Plateau (China), which is used as a stopover site and for breeding, and in Gaza (Bhutan), which is used as a stopover site in autumn and spring [10].

Caohai Lake is the largest natural freshwater lake on the Yunnan-Guizhou Plateau and is a typical subtropical plateau wetland ecosystem in China. It is an integrated ecological system with high biodiversity [8]. It is referred to as a "highland pearl", bird paradise, underwater forest, species gene bank and open-air museum [11]. The Caohai Wetland is an important habitat for many rare birds, such as the black-necked crane, and is an important node in the western passage, which is one of the three major bird migration routes in China [12-15]. More than 70,000 waterbirds overwinter each year, and approximately 2,000 black-necked cranes overwinter in the Caohai Wetland [16]. Black-necked cranes overwinter in Caohai wetland from late October to mid-November each year, and migrate back to their breeding grounds in spring from late March to early April of the following year. The average number of days they spend overwintering in Caohai is 162.6 days [17]. From November 2022 to March 2023, approximately 2,469 black-necked cranes overwintered in the Caohai Wetland. The Caohai National Nature Reserve is the main overwintering area for migrating black-necked cranes, and stable and high-quality roosting-sites are crucial for the survival of migratory wading birds in winter [4, 18].

Studying the plant diversity and composition of various habitats of black-necked cranes can help explain the distribution and behaviour of black-necked cranes during their overwintering period and provide a basis for the effective protection and systematic management of black-necked crane overwintering areas.

2. Experiments

2.1 Study Area

The Caohai Wetland (26°45′ N-27°00′ N, 104°10′ E-104°25′ E) is located at the foot of Wumeng Mountain east of the Yunnan-Guizhou Plateau, at an altitude of 2,171.7 m. Caohai Lake covers an area of 23.25 km^2, and it exhibits an average water depth of 2-3 m. Caohai belongs to the Yangtze River system and is an upstream lake of the Hengjiang River, a tributary of the Jinsha River. Its water supply mainly comes from atmospheric precipitation, followed by groundwater supply [19]. Its ecological structure and function are integral, and it is a representative subtropical plateau wetland ecosystem in China. The Caohai region is dominated by an Indian summer monsoon climate. The Caohai wetland and its watershed ecosystem is an extremely important high-altitude wetland ecosystem in southwestern China. The fragility, typicality, importance, biodiversity, climate specificity, and species richness of its ecological environment have typical representative significance in the world. It is of great importance to climate change, regional ecological security and social and economic development in the southwest region of China. It is an important site for the overwintering and stopover of migratory birds [20]. The mean annual precipitation in this catchment is approximately 951 mm, 88% of which occurs between May and October [21, 22]. The average temperature is 10.5 ℃, the average annual rainfall is 1,000 mm, the average annual sunshine duration is 1,805.4 h, and the average annual relative humidity is 79% [23]. Owing to its unique geographical location

and natural conditions, the Caohai Basin exhibits a wide variety of flora and fauna [24].

2.2 Field Investigation

Field investigations regarding plant diversity in habitats were conducted from 3 to 27 August 2022. A total of 30 plots across seven habitats, namely, Wujiayantou (WJYT), Yangguanshan (YGS), Wenjiatun (WJT), Huyelin (HYL), Wangjiayuanzi (WJYZ), Zhujiawan (ZJW), and Liujiaxiang (LJX), were investigated via the ArcGIS system on the basis of the habitat size and shape (Fig. 1), and 3 to 5 quadrats (1 m×1 m) (112 in total) were arranged randomly in each investigated plot. For each quadrat, the Latin name, coverage (%), individual number and average height of each species were recorded. Plants were identified according to the description features provided by the Flora Reipubicae Popularis Sinicae (https://www.iplant.cn/frps2019/) and the Plant Photo Bank of China (https://ppbc.iplant.cn/).

Observation of black-necked crane was carried out from October 25, 2022 to March 25, 2023. The investigation team consists of 7 groups, with 2 people in each group. Arrive at the observation place before 6:40 am every day (most black-necked cranes leave their habitat and fly to foraging areas between 7:00 and 7:35), wait for the black-necked cranes take off for observation and counting. Observe the number of black-necked cranes left from 7:40 to 8:30 am.

To evaluate the richness and evenness of plants in the seven habitats, three widely used diversity indices, namely, the Shannon-Wiener index (*H*), Simpson diversity index (*D*), and Pielou index (*J*), were considered in this study [25, 26]. All data were managed, processed and analyzed with WPS Office and Origin 2021.Ink, and the investigation plots were designed with the aid of ArcGIS 10.3.

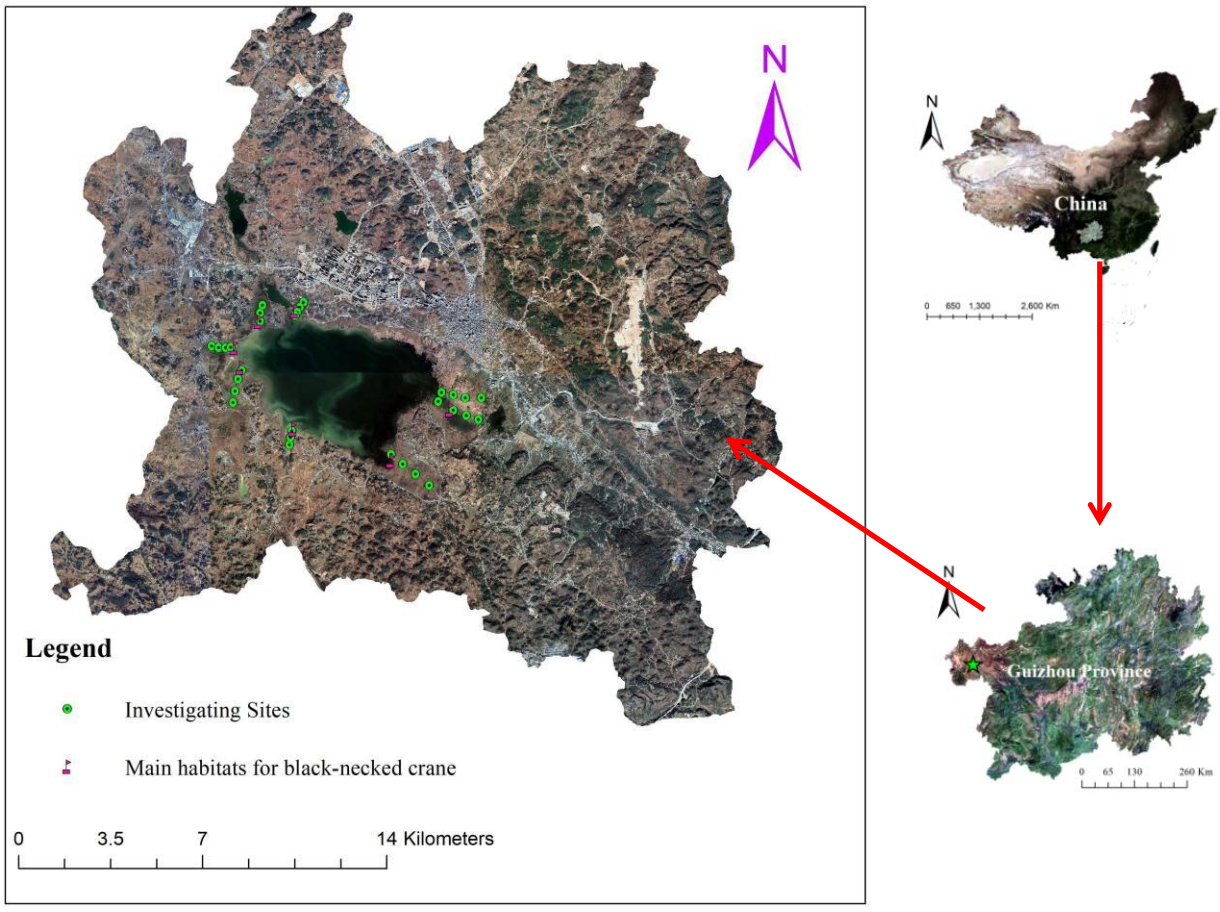

Fig. 1 Diagram of the black-necked crane habitats and investigated plots.

3. Results

3.1 General Information on the Plants in the Different Habitats

As listed in Table S1, a total of 138 species belonging to 111 genera, 40 families, 23 orders and 4 classes (*Dicotyledoneae*, *Monocotyledoneae*, *Filicopsida* and *Equisetinae*) and 2 phyla (*Angiospermae* and *Pteridophyta*) were recorded in this investigation. In the WJYT, YGS, WJT, HYL, WJYZ, ZJW and LJX habitats, a total of 58, 45, 63, 68, 55, 72 and 76 plant species, respectively, were recorded.

Table S1 Plant species in the seven habits around Caohai Lake.

No.	Orders	Families	Genera	Species
1	*Campanulales*	*Compositae*	*Artemisia*	*Artemisia annua* L.
2				*Artemisia carvifolia* Buch.-Ham. ex Roxb.
3			*Aster*	*Aster subulatus* Michx.
4			*Bidens*	*Bidens pilosa* L.
5			*Carduus*	*Carduus nutans* L.
6			*Carpesium*	*Carpesium abrotanoides* L.
7			*Cirsium*	*Cirsium japonicum* Fisch. ex DC.
8				*Cirsium setosum* (Willd.) MB.
9			*Conyza*	*Conyza canadensis* (L.) Cronq.
10			*Dichrocephala*	*Dichrocephala auriculata* (Thunb.) Druce
11			*Erigeron*	*Erigeron acer* L.
12			*Eupatorium*	*Eupatorium fortunei* Turcz.
13			*Galinsoga*	*Galinsoga parviflora* Cav.
14			*Pseudognaphalium*	*Pseudognaphalium* affine (D. Don) Anderb.
15			*Inula*	*Inula japonica* Thunb.
16			*Kalimeris*	*Kalimeris indica* (L.) Sch. -Bip.
17			*Lactuca*	*Lactuca seriola* Torner
18			*Lapsana*	*Lapsana apogonoides* Maxim.
19			*Ixeris*	*Ixeris polycephala* Cass.
20			*Senecio*	*Senecio scandens* Buch.-Ham. ex D. Don
21			*Siegesbeckia*	*Siegesbeckia orientalis* L.
22			*Sonchus*	*Sonchus asper* (L.) Hill
23				*Sonchus oleraceus* L.
24			*Synurus*	*Synurus deltoides* (Ait.) Nakai
25			*Taraxacum*	*Taraxacum mongolicum* Hand.-Mazz.
26			*Xanthium*	*Xanthium sibiricum* Patrin ex Widder
27	*Centrospermae*	*Amaranthaceae*	*Alternanthera*	*Alternanthera philoxeroides* (Mart.) Griseb.
28		*Caryophyllaceae*	*Stellaria*	*Stellaria vestita* Kurz
29		*Chenopodiaceae*	*Chenopodium*	*Chenopodium album* L.
30		*Phytolaccaceae*	*Phytolacca*	*Phytolacca acinosa* Roxb.
31	*Contortae*	*Gentianaceae*	*Nymphoides*	*Nymphoides peltatum* (Gmel.) O. Kuntze
32	*Euphorbiales*	*Euphorbiaceae*	*Acalypha*	*Acalypha australis* L.
33			*Pedilanthus*	*Pedilanthus tithymaloides (Linn.)* Poit.
34	*Geraniales*	*Geraniaceae*	*Geranium*	*Geranium sibiricum* L.
35				*Geranium wilfordii* Maxim.
36		*Linaceae*	*Linum*	*Linum usitatissimum* L.
37	*Liliflorae*	*Juncaceae*	*Juncus*	*Juncus effusus* L.
38	*Myrtiflorae*	*Haloragidaceae*	*Myriophyllum*	*Myriophyllum verticillatum* L.
39		*Lythraceae*	*Lythrum*	*Lythrum salicaria* L.
40		*Onagraceae*	*Epilobium*	*Epilobium hirsutum* L.

Table 1 to be continued

41	*Parietales*	*Guttiferae*	*Hypericum*	*Hypericum patulum* Thunb. ex Murray
42	*Plantaginales*	*Plantaginaceae*	*Plantago*	*Plantago depressa* Willd.
43	*Polygonales*	*Polygonaceae*	*Fagopyrum*	*Fagopyrum dibotrys* (D. Don) Hara
44				*Fagopyrum esculentum* Moench
45			*Polygonum*	*Polygonum amphibium* L.
46				*Polygonum aviculare* L.
47				*Polygonum hydropiper* L.
48				*Polygonum lapathifolium* L.
49				*Polygonum nepalense* Meisn.
50				*Polygonum orientale* L.
51				*Polygonum persicaria* L.
52				*Polygonum viscosum* Buch.-Ham. ex D. Don
53			*Rumex*	*Rumex crispus* L.
54				*Rumex dentatus* L.
55	*Ranales*	*Ceratophyllaceae*	*Ceratophyllum*	*Ceratophyllum demersum* L.
56		*Ranunculaceae*	*Anemone*	*Anemone vitifolia* Buch.-Ham.
57			*Ranunculus*	*Ranunculus chinensis* Bunge
58				*Ranunculus japonicus* Thunb.
59	*Rosales*	*Leguminosae*	*Medicago*	*Medicago sativa* L.
60			*Trifolium*	*Trifolium pratense* L.
61				*Trifolium repens* L.
62			*Vicia*	*Vicia sepium* L.
63		*Rosaceae*	*Agrimonia*	*Agrimonia pilosa* Ldb.
64			*Duchesnea*	*Duchesnea indica* (Andr.) Focke
65			*Potentilla*	*Potentilla kleiniana* Wight et Arn.
66			*Rubus*	*Rubus parvifolius* L.
67			*Sanguisorba*	*Sanguisorba officinalis* L.
68	*Tubiflorae*	*Boraginaceae*	*Cynoglossum*	*Cynoglossum zeylanicum* (Vahl) Thunb.
69		*Convolvulaceae*	*Dichondra*	*Dichondra repens* Forst.
70			*Pharbitis*	*Pharbitis purpurea* (L.) Voisgt
71		*Labiatae*	*Clinopodium*	*Clinopodium chinense* (Benth.) O. Ktze.
72			*Lycopus*	*Lycopus lucidus* Turcz.
73			*Prunella*	*Prunella vulgaris* L.
74			*Rosmarinus*	*Rosmarinus officinalis* L.
75			*Salvia*	*Salvia plebeia* R. Br.
76			*Stachys*	*Stachys japonica* Miq.
77				*Stachys sieboldii* Miq.
78			*Teucrium*	*Teucrium viscidum* Bl.
79		*Solanaceae*	*Datura*	*Datura stramonium* Linn.
80			*Physalis*	*Physalis alkekengi* L.
81		*Verbenaceae*	*Verbena*	*Verbena officinalis* L.
82	*Umbelliflorae*	*Umbelliferae*	*Centella*	*Centella asiatica* (L.) Urban
83			*Daucus*	*Daucus carota* L. var. sativa Hoffm.
84				*Daucus carota* L.
85			*Hydrocotyle*	*Hydrocotyle sibthorpioides* Lam.
86			*Oenanthe*	*Oenanthe javanica* (Bl.) DC.
87				*Oenanthe linearis* Wall. ex DC.
88				*Oenanthe rivularis* Dunn
89			*Torilis*	*Torilis scabra* (Thunb.) DC.
90	*Urticales*	*Moraceae*	*Humulus*	*Humulus scandens* (Lour.) Merr. in Trans

Table 1 to be continued

91		*Urticaceae*	*Urtica*	*Urtica fissa* E. Pritz.
92	*Arales*	*Araceae*	*Acorus*	*Acorus calamus* L.
93			*Lemna*	*Lemna minor* L.
94	*Cyperales*	*Cyperaceae*	*Carex*	*Carex neurocarpa* Maxim.
95			*Cyperus*	*Cyperus fuscus* L.
96			*Juncellus*	*Juncellus serotinus* (Rottb.) C. B. Clarke
97			*Heleocharis*	*Heleocharis dulcis* (Burm. f.) Trin.
98			*Scirpus*	*Scirpus triangulatus Roxb.*
99			*Schoenoplectus*	*Schoenoplectus triqueter* (L.) Palla
100				*Schoenoplectus tabernaemontani* (C. C. Gmel.) Palla
101	*Farinosae*	*Commelinaceae*	*Commelina*	*Commelina diffusa* Burm. f.
102	*Graminales*	*Gramineae*	*Arthraxon*	*Arthraxon hispidus* (Thunb.) Makino
103			*Beckmannia*	*Beckmannia syzigachne* (Steud.) Fern.
104			*Calamagrostis*	*Calamagrostis epigeios* (L.) Roth
105			*Catabrosa*	*Catabrosa aquatica* (L.) Beauv.
106			*Cynodon*	*Cynodon dactylon* (L.) Pers.
107			*Echinochloa*	*Echinochloa crusgalli* (L.) Beauv.
108				*Echinochloa frumentacea* (Roxb.) Link
109			*Eleusine*	*Eleusine indica* (L.) Gaertn.
110			*Eragrostis*	*Eragrostis ferruginea* (Thunb.) Beauv.
111			*Imperata*	*Imperata cylindrica* (L.) P. Beauv.
112			*Leersia*	*Leersia hexandra* Swartz.
113				*Leersia japonica* (Makino) Honda
114			*Leptochloa*	*Leptochloa chinensis* (L.) Nees
115			*Lolium*	*Lolium perenne* L.
116			*Miscanthus*	*Miscanthus sinensis* Anderss.
117			*Panicum*	*Panicum virgatum* L.
118			*Paspalum*	*Paspalum paspaloides* (Michx.) Scribn.
119			*Phragmites*	*Phragmites australis* (Cav.) Trin. ex Steud.
120			*Polypogon*	*Polypogon fugax* Nees ex Steud.
121			*Rhynchelytrum*	*Rhynchelytrum repens* (Willd.) Hubb.
122			*Setaria*	*Setaria viridis* (L.) Beauv.
123			*Zizania*	*Zizania latifolia* (Griseb.) Stapf
124			*Zoysia*	*Zoysia japonica* Steud.
125	*Helobiae*	*Alismataceae*	*Alisma*	*lisma orientale* (Samuel.) Juz.
126				*Alisma plantago-aquatica* Linn.
127			*Sagittaria*	*Sagittaria trifolia L.* var. sinensis (Sims.) Makino
128				*Sagittaria trifolia* L.
129		*Najadaceae*	*Najas*	*Najas marina* L.
130		*Hydrocharitaceae*	*Hydrilla*	*Hydrilla verticillata* L.
131		*Potamogetonaceae*	*Potamogeton*	*Potamogeton lucens* L.
132				*Potamogeton pectinatus* L.
133				*Potamogeton malaianus* Miq.
134	*Pandanales*	*Sparganiaceae*	*Sparganium*	*Sparganium stoloniferum* (Graebn.) Buch.
135		*Typhaceae*	*Typha*	*Typha angustifolia* Linn. Sp.
136	*Eufilicales*	*Pteridaceae*	*Pteris*	*Pteris cretica* L.
137	*Equisetales*	*Equisetaceae*	*Equisetum*	*Equisetum arvense* L.
138				*Equisetum diffusum* D. Don

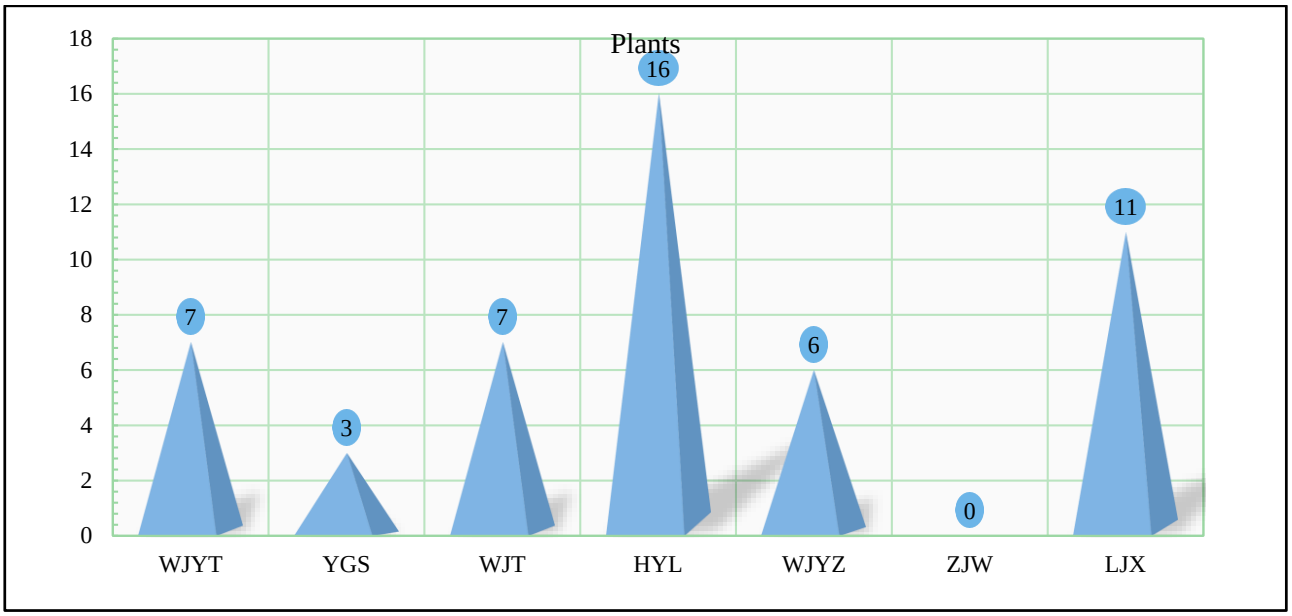

Fig. 2 Rare plants in each habitat.

Twelve species of plants (*Artemisia annua* L., *Taraxacum mongolicum* Hand.-Mazz., *Alternanthera philoxeroides* (Mart.) Griseb., *Juncus effusus* L., *Trifolium repens* L., *Verbena officinalis* L., *Oenanthe javanica* (Bl.) DC., *Schoenoplectus tabernaemontani* C.C. Gmel., *Leersia hexandra* Swartz., *Paspalum paspaloides* (Michx.), *Phragmites australis* (Cav.) Trin. ex Steud., and *Equisetum diffusum* D. Don) are widely distributed in the study area, and these plants were found in the 7 habitats considered. Fifty rare plants, which were found in only one habitat, were recorded in this investigation, and the number of rare plants in each habitat is shown in Fig. 2. The rare plants in the WJYT habitat include *Trifolium pratense* L., *Sanguisorba officinalis* L., *Cynoglossum zeylanicum* (Vahl) Thunb., *Centella asiatica* (L.) Urban, *Daucus carota* L. var. sativa Hoffm., *Daucus carota* L., and Arthraxon hispidus (Thunb.) Makino; those in the YGS habitat include *Carpesium abrotanoides* L., *Xanthium sibiricum* Patrin ex Widder, and *Cyperus fuscus* L.; and those in the WJT habitat include *Gnaphalium affine* D. Don, *Lapsana apogonoides* Maxim., *Acalypha australis* L., *Acalypha australis* L., *Stachys sieboldii* Miq., *Hydrilla verticillata* L., and Potamogeton malaianus Miq. The rare plants in the HYL habitat include *Cirsium japonicum* Fisch. ex DC., *Eupatorium fortunei* Turcz., *Sonchus asper* (L.) Hill, *Synurus deltoides* (Ait.) Nakai, *Stellaria vestita* Kurz, *Phytolacca acinosa* Roxb., *Hypericum patulum* Thunb. ex Murray, *Dichondra repens* Forst., *Lycopus lucidus* Turcz., *Stachys japonica* Miq., *Cynodon dactylon* (L.) Pers., *Leersia japonica* (Makino) Honda, *Leptochloa chinensis* (L.) Nees, *Panicum virgatum* L., *Sagittaria trifolia* L., and *Pteris cretica* L.; those in the WJYZ habitat include *Pedilanthus tithymaloides* (Linn.) Poit., *Linum usitatissimum* L., *Anemone vitifolia* Buch.-Ham., *Ranunculus chinensis* Bunge, *Vicia sepium* L., and *Rubus parvifolius* L.; and those in the LJX habitat include *Artemisia carvifolia* Buch.-Ham. ex Roxb., *Polygonum aviculare* L., *Potentilla kleiniana* Wight et Arn., *Pharbitis purpurea* (L.) Voisgt, *Rosmarinus officinalis* L., *Humulus scandens* (Lour.) Merr. in Trans, *Urtica fissa* E. Pritz., *Miscanthus sinensis* Anderss., *Zizania latifolia* (Griseb.) Stapf., *Alisma plantago-aquatica* L., and *Sparganium stoloniferum* (Graebn.) Buch.

3.2 Diversity of Plant Species in the Different Habitats

The Shannon-Wiener index values of the different habitats are provided in Table 1. The species diversity clearly decreased from the terrestrial zone to the water-land transitional zone and from the water-land

transitional zone to the shallow water zone. Across all 31 investigated plots, the Shannon-Wiener index values ranged from 0.1125 to 2.4800. In the WJYT habitat, a total of 58 species were recorded, and the Shannon-Wiener index value decreased from 1.9298 for WJYT-1 to 0.2749 for WJYT-4. In the YGS habitat, a total of 45 species were recorded, and the Shannon-Wiener index value decreased from 1.4167 for YGS-1 to 0.5508 for YGS-3. In the WJT habitat, a total of 63 species were recorded, and the Shannon-Wiener index value decreased from 1.4311 for WJT-1 to 0.5042 for WJT-4. In the HYL habitat, a total of 68 species were recorded, and the Shannon-Wiener index value decreased from 1.7053 for HYL-1 to 0.6931 for FYL-4. In the WJYZ habitat, 58 species were recorded, and the Shannon-Wiener index value decreased from 1.4315 for WJYZ-1 to 0.1125 for WJYZ-3. In the ZJW habitat, a total of 72 species were recorded, and the Shannon-Wiener index value decreased from 1.8539 for ZJW-1 to 0.4968 for ZJW-4. As the LJX habitat is obviously larger than the other habitats, two lines of investigation were employed. A total of 76 species were recorded in this habitat, and the Shannon-Wiener index value decreased from 1.7196 to 0.7338.

Table 1 Diversity of plants in the habitats of black-necked cranes in the Caohai Wetland (mean ± standard error).

Investigated plot	Shannon-Wiener index	Pielou index	Simpson diversity index
WJYT-1	1.9298 ± 0.1075	0.3494 ± 0.0174	0.8005 ± 0.0101
WJYT-2	1.8902 ± 0.3109	0.3745 ± 0.0713	0.7403 ± 0.1085
WJYT-3	1.3082 ± 0.1237	0.1822 ± 0.0216	0.6348 ± 0.0444
WJYT-4	0.2749 ± 0.2114	0.0699 ± 0.0057	0.1446 ± 0.0213
YGS-1	1.4167 ± 0.2429	0.2551 ± 0.0499	0.6100 ± 0.1003
YGS-2	1.1659 ± 0.1466	0.1926 ± 0.0326	0.5762 ± 0.0944
YGS-3	0.5508 ± 0.0128	0.1747 ± 0.0071	0.3705 ± 0.0125
WJT-1	1.4311 ± 0.1675	0.2677 ± 0.0393	0.5270 ± 0.0609
WJT-2	1.0390 ± 0.1661	0.1726 ± 0.0356	0.4892 ± 0.0975
WJT-3	1.3299 ± 0.1052	0.2140 ± 0.0251	0.6661 ± 0.0370
WJT-4	0.5042 ± 0.0941	0.2314 ± 0.0760	0.3265 ± 0.0817
HYL-1	1.7053 ± 0.1975	0.3421 ± 0.0462	0.7670 ± 0.0520
HYL-2	1.1533 ± 0.2448	0.1769 ± 0.0404	0.4802 ± 0.1190
HYL-3	0.7530 ± 0.1371	0.2264 ± 0.0338	0.4901 ± 0.0654
HYL-4	0.6931 ± 0.0325	0.2242 ± 0.0152	0.5000 ± 0.0478
WJYZ-1	1.4315 ± 0.1684	0.2491 ± 0.0445	0.6814 ± 0.0529
WJYZ-2	0.5465 ± 0.0485	0.1513 ± 0.0121	0.2834 ± 0.1956
WJYZ-3	0.1125 ± 0.0102	0.0301 ± 0.0021	0.0465 ± 0.0029
ZJW-1	1.8539 ± 0.3467	0.3386 ± 0.0668	0.7719 ± 0.0802
ZJW-2	1.3634 ± 0.0596	0.2477 ± 0.0166	0.6619 ± 0.0040
ZJW-3	1.2026 ± 0.1991	0.2237 ± 0.0156	0.6240 ± 0.0524
ZJW-4	0.4968 ± 0.0421	0.1475 ± 0.0138	0.2473 ± 0.02091
LJX-1	1.0276 ± 0.0474	0.1810 ± 0.0126	0.4972 ± 0.0403
LJX-2	1.3348 ± 0.4414	0.1825 ± 0.0609	0.5916 ± 0.1983
LJX-3	0.8850 ± 0.1200	0.1167 ± 0.0183	0.4573 ± 0.0501
LJX-4	0.7326 ± 0.2680	0.1703 ± 0.0103	0.5378 ± 0.1130
LJX-5	1.7196 ± 0.1074	0.3370 ± 0.0337	0.7512 ± 0.0388
LJX-6	1.5367 ± 0.2460	0.3006 ± 0.0547	0.7053 ± 0.0672
LJX-7	1.4032 ± 0.3107	0.2933 ± 0.0636	0.6308 ± 0.1085
LJX-8	0.7338 ± 0.0723	0.2174 ± 0.0567	0.4307 ± 0.0610

On the basis of the investigation results, the diversity of plants in these habitats exhibited a similar trend. The Shannon-Wiener index generally decreased from the terrestrial zone to the water-land transitional zone and from the water-land transitional zone to the shallow water zone (investigation line). This likely indicates that the plant diversity decreased along this line. However, the Shannon-Wiener index values of the WJT and LJX habitats did not decrease along the investigation line.

3.3 Evenness and Richness of Plant Species in the Different Habitats of Black-Necked Cranes

The Pielou index values of the different investigated plots ranged from 0.0301 (WJYZ-3) to 0.3745 (WJYT-2). In the WJYT habitat, the Pielou index values ranged from 0.0699 (WJYT-4) to 0.3745 (WJYT-2). In the YGS habitat, the Pielou index values ranged from 0.1747 (YGS-3) to 0.2552 (YGS-1). In the WJT habitat, the Pilou index values ranged from 0.1726 (WJT-2) to 0.2314 (WJT-4). In the HYL habitat, the Pilou index values ranged from 0.1769 (HYL-2) to 0.3421 (HYL-1). In the WJYZ, ZJW and LJX habitats, the Pielou index values ranged from 0.0301 (WJYZ-3) to 0.2491 (WJYZ-1), from 0.1475 (ZJW-4) to 0.3386 (ZJW-1), and from 0.1167 (LJX-3) to 0.3370 (LJX-5), respectively. In four habitats, namely, WJYT, YGS, WJYZ and ZJW habitats, the evenness of plant species decreased along the investigation line, i.e., from the terrestrial zone to the water-land transitional zone and from the water-land transitional zone to the shallow water zone. In the WJT, HYL and LJX habitats, the Pielou index values showed no obvious tendency.

The Simpson diversity index values of the different investigated plots ranged from 0.0465 (WJYZ-3) to 0.8005 (WJYT-1). In the WJYT habitat, the Simpson diversity index values ranged from 0.1446 (WJT-4) to 0.8005 (WJYT-1). In the YGS habitat, the Simpson diversity index values ranged from 0.3705 (YGS-3) to 0.6100 (YGS-1). In the WJT habitat, the Simpson diversity index values ranged from 0.3265 (WJT-4) to 0.6661 (WJT-3). In the HYL habitat, the Simpson diversity index values ranged from 0.4802 (HYL-2) to 0.7670 (HYL-1). In the WJYZ habitat, the Simpson diversity index values ranged from 0.0465 (WJYZ-3) to 0.6814 (WJYZ-1); in the ZJW habitat, the Simpson diversity index values ranged from 0.2473 (ZJW-4) to 0.7719 (ZJW-1); and in the LJX habitat, the Simpson diversity index values ranged from 0.4307 (LJX-9) to 0.7512 (LJX-5). In some habitats (WJYT, YGS, WJYZ and ZJW), the Simpson diversity index decreased with increasing Shannon-Wiener index.

3.4 Black-Necked Cranes in These Habitats in 2022-2023

Twenty six black-necked cranes arrived at Caohai wetland on November 2, 2022; On March 24, 2023, the last 39 black-necked cranes left Caohai wetland (as shown in Figs. S1 and S2). The maximum number of observed black-necked cranes in 2022-2023 is 2,469, which was appeared on January 25, 2023. The number of black-necked cranes in LJX habitat and ZJW habitat showed a relatively stable trend, while the number of black-necked cranes in the other five habitats showed some fluctuations. Overall, black-necked cranes inhabiting in HYL habitat and WJT habitat were of absolute advantage in terms of population among the seven habitats. During certain periods, the number of black necked cranes inhabiting in these two habitats are over 1,300, which occupied more than 50% of the total number. The number of black necked cranes in WJYT was relatively small, and the greatest number of black-necked crane did not exceed 100.

3.5 Night Rest and Foraging Activities of Black-Necked Cranes in Caohai Wetland in 2022-2023

The night resting space of black-necked crane in 2022-2023 is shown in Fig. 3. The main areas of the black-necked crane resting areas are water-land transitional zone and shallow water zone (less than 15 cm). At present, the night resting space of black-necked cranes in different habitats (December 1, 2022) is: 0.23 km^2 in

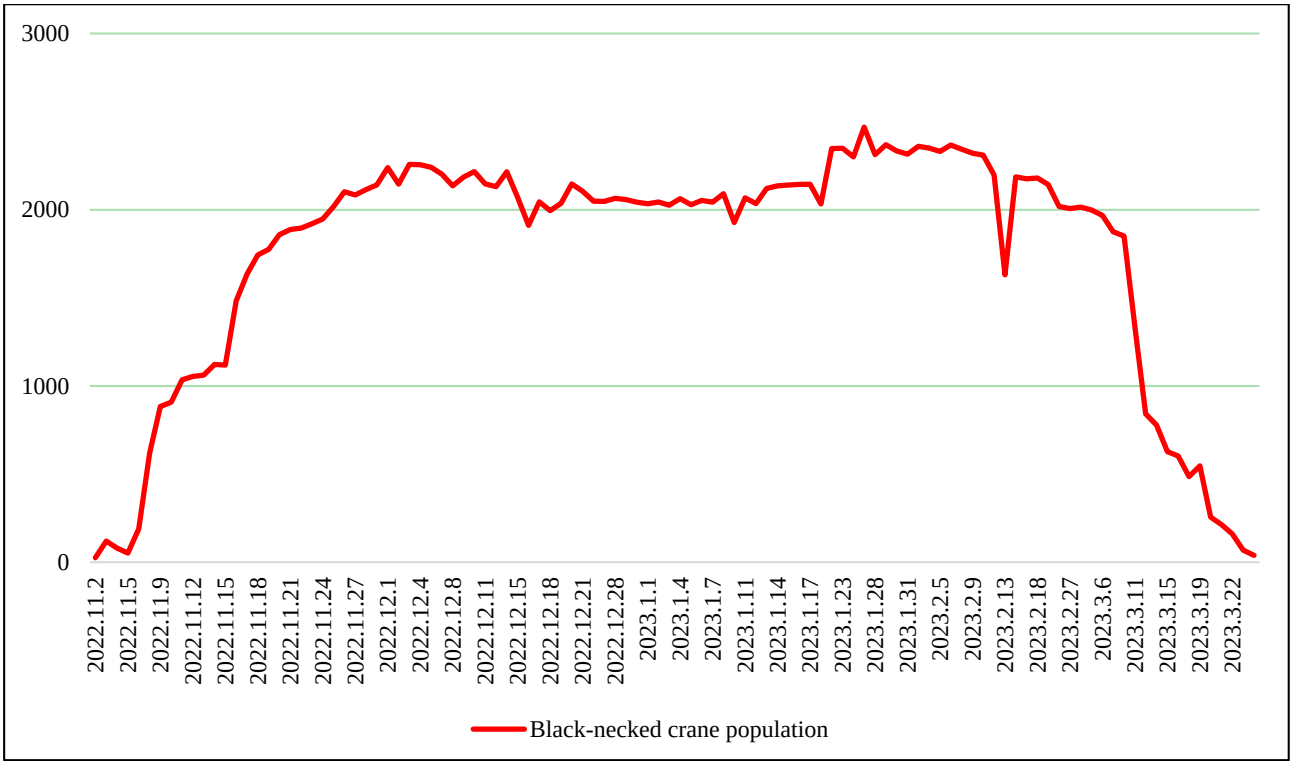

Fig. S1 Total number of black-necked crane in the Seven Habitats in Caohai from 2022 to 2023.

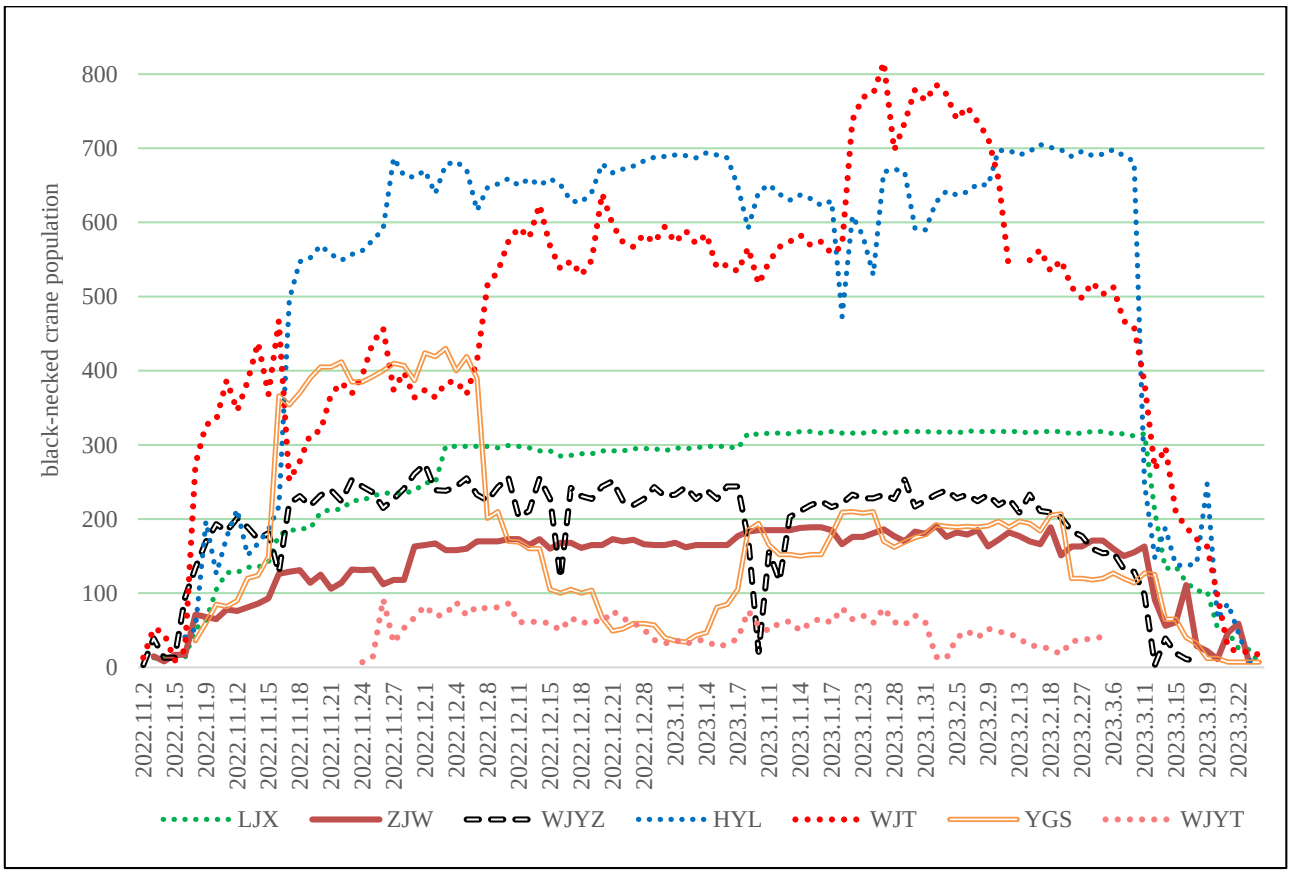

Fig. S2 Changes in black-necked crane population in the Seven Habitats in Caohai from 2022 to 2023.

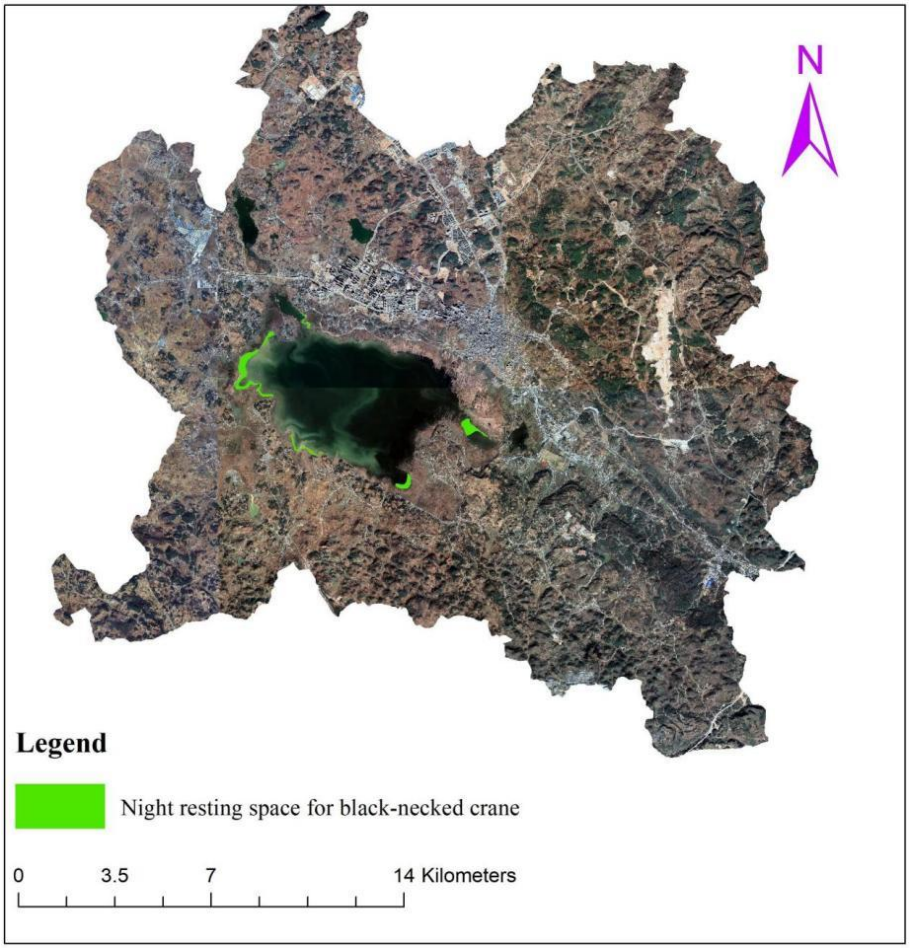

Fig. 3 The night resting space of black-necked crane in 2022-2023.

LJX habitat, 0.126 km^2 in ZJW habitat, 0.089 km^2 in WJYZ habitat, 0.226 km^2 in HYL habitat, 0.24 km^2 in WJT habitat, 0.067 km^2 in YGS habitat, and 0.042 km^2 in WJYT habitat. If the water level of Caohai Lake decreased, the space for the night rest of the black-necked crane in LJX habitat and HYL habitat will be compressed, while the space in WJYZ habitat, ZJW habitat, WJT habitat and YGS habitat will not be significantly affected. The space for the night rest of the black-necked crane in WJYT habitat will increase. If the water level of Caohai Lake increased, the night resting space for the black-necked crane in LJX habitat and HYL habitat will increase, but the night resting space for the black-necked crane at WJYT habitat will further decrease.

The foraging activities of black-necked cranes in Caohai watershed in 2022-2023 are presented in Fig. 4. The foraging activities of black-necked cranes in 2022-2023 were mainly concentrated in the southern, southwestern, western, and northwestern parts of the Caohai watershed, while no foraging activity distribution of black necked cranes was found in the northern, northeastern, and eastern parts.

4. Discussion

4.1 Main Factors Influencing Plant Species in the Seven Habitats of Black-Necked Crane

The species distribution and diversity indices indicated that the species richness, diversity and evenness of the seven habitats differed, with variations within individual habitats. First, flooding is the main factor determining the diversity of habitat plants. The Shannon-Wiener index values indicated that species diversity exhibits a decreasing trend in almost all habitats from the

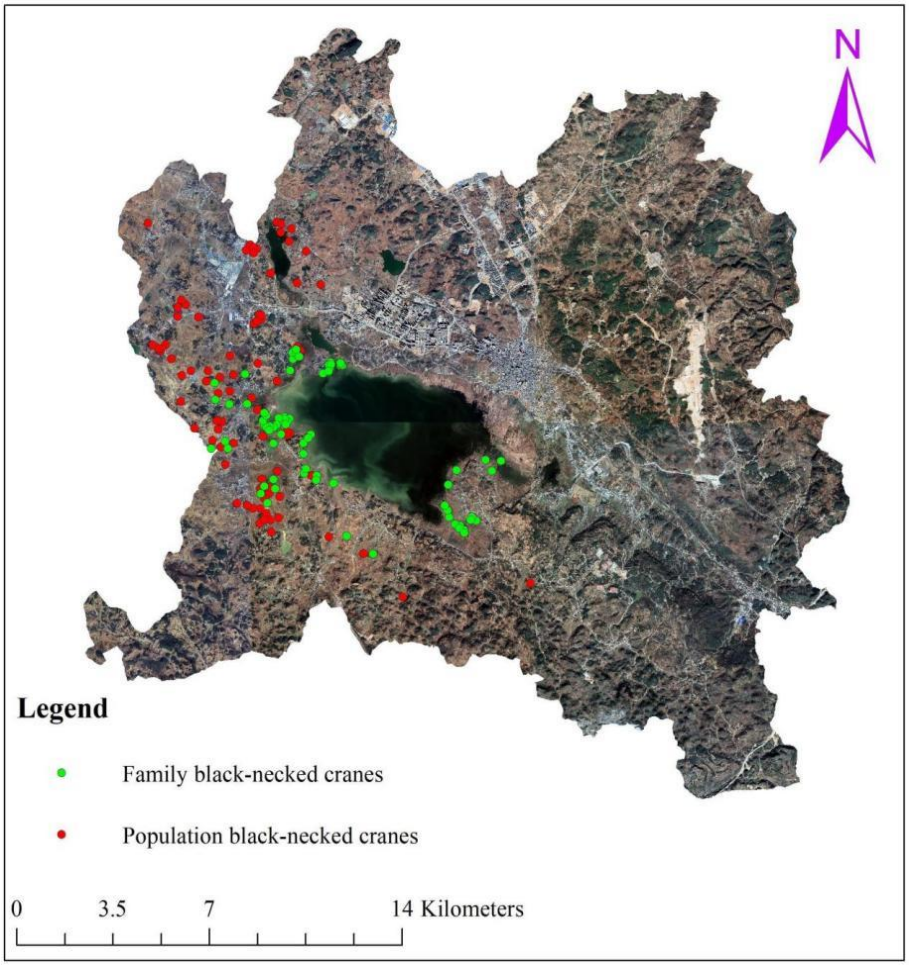

Fig. 4 The foraging activities of black-necked cranes in Caohai watershed in 2022-2023.

terrestrial zone to the water-land transitional zone and from the water-land transitional zone to the shallow water zone. For example, both the WJYT habitat (0.45 km^2) and WJYZ habitat (0.46 km^2) are smaller than the YGS habitat (0.76 km^2). However, the number of plant species in these two habitats is greater than that in the YGS habitat, mainly because most areas in the YGS habitat are submerged under the influence of annual water level changes. Second, there are relationships between the number of plant species and the habitat area. The areas of both the ZJW habitat (2.99 km^2) and LJX habitat (2.51 km^2) are greater than 2 km^2, with the number of species in these habitats exceeding 70. The WJYT, YGS, and WJYZ habitats are all smaller than 1 km^2, and the number of plant species is less than 60. The WJT habitat (1.01 km^2) and HYL habitat (1.76 km^2) exhibit areas of 1-2 km^2, while the number of plant species ranges from 60 to 70. Third, the spatial heterogeneity in microcirculation affects the diversity of plant species. The LJX habitat is smaller than the ZJW habitat, but the number of plant species in the LJX habitat (76) is greater than that in the ZJW habitat. Field investigations have demonstrated that the spatial heterogeneity in the LJX habitat is greater than that in the ZJW habitat because of factors such as artificial wetlands and the distribution of natural streams. Finally, human activities are important factors influencing species diversity. Grazing occurs in some areas of the ZJW, LJX, WJT, HYL, and YGS habitats. To a degree, grazing activities suppress the competitive advantage of some dominant species, thereby enhancing species diversity.

(a) (b)

(c)

Fig. 5 Black-necked crane in Caohai Wetland (Picture (a) was photographed by Dr. Xianfei Huang; pictures (b) and (c) were photographed by Mr Guanghui Liu).

4.2 Factors Affecting Black-Necked Crane Inhabitation

In this winter, about 2,469 black-necked cranes overwintered in the seven habitats. Based on our field investigation and observation, no direct relationship between plant diversity and black-necked crane population size was observed. The following two factors may be the primary factors for black-necked crane in choosing their habitat. First, black-necked cranes are of high vigilance, and they tend to choose the water-land transitional zone and shallow water zone (with a depth of water less than 15 cm) with better visibility as their resting place at night (Fig. 5). Therefore, waters and tall plants (taller than 60 cm) are primary factors in their choice. Habitats of HYL, WJT, YGS and WJYZ have relative long shores characterized with a greater area of water-land transitional zone and shallow water zone. The populations of black-necked crane in this habitats were relatively large, especially for HYL and WJT habitats. The total area of LJX habitat is the greatest one among the seven habitats in Caohai Wetland. But a large part of this habitat was occupied by tall stemmed plant, such as *Phragmites australis* (Cav.) Trin. ex Steud. (up to 300 cm), *Scirpus triqueter* L. (up to 190 cm), etc. Only a small area is suitable for black-necked cranes to inhabit (Fig. 3). Secondly, human disturbance (mainly the distance from residential buildings and busy ways) is also an important factor. YGS and WJYZ habitats are relatively suitable for black-necked crane inhabit based on circumstance, but both habitats are

close to residential buildings and are greatly affected by residents' activities. Among the seven habitats, WJYT habitat is the last choice for black-necked crane inhabiting. The number of black-necked cranes that inhabit here is the smallest, and the latest to arrive, and the earliest to leave. This may be related to the fact that WJYT habitat is closer to the road around the Caohai Lake, and the entire habitat is relatively small (0.45 km^2) and most areas near shore, which used to be quite suitable for black-necked cranes to inhabiting, were occupied by tall stem plants.

4.3 Factors Affecting Black-Necked Crane Foraging Activities

In Caohai watershed, the number of black-necked cranes was about 80 in 1983 [27], and this number has increased to 2,469 in 2023. During the period of eighties and nineties of last century, the foraging activities of black-necked cranes were mainly around the Caohai Lake (Fig. S3) [28]. After 2010, the foraging activities of black-neck cracks gradually shifted towards the west, southwest, and northwest of Caohai Lake [28]. By 2023, there were no foraging activities for black-necked cranes in the north and east of Caohai Lake. In addition, the foraging region expanded yearly. The following factors may contribute to these phenomena. (a) Human disturbance. With the development of Weining County, most areas in north and east of Caohai Lake were occupied by buildings, and are not suitable for black-necked crane foraging anymore; (b) Vegetation change. Before 2010, most areas around the Caohai Lake were meadows or swamps, and the main plants include *Juncus effusus* L., *Polygonum hydropiper* L., *Juncellus serotinus* (Rottb.) C. B. Clarke, *Commelina diffusa* Burm. f., *Schoenoplectus triqueter* (L.) Palla, *Schoenoplectus tabernaemontani* (C. C. Gmel.) Palla, etc. Next to meadows or swamps, a large amount areas were farmlands for plantation of corn, potato, carrot, cabbage, etc. Black-necked cranes could find enough foods around the Caohai Lake. However, during the past decade, farmlands around the Caohai Lake were reclaimed for wetlands. Consequently, black-necked

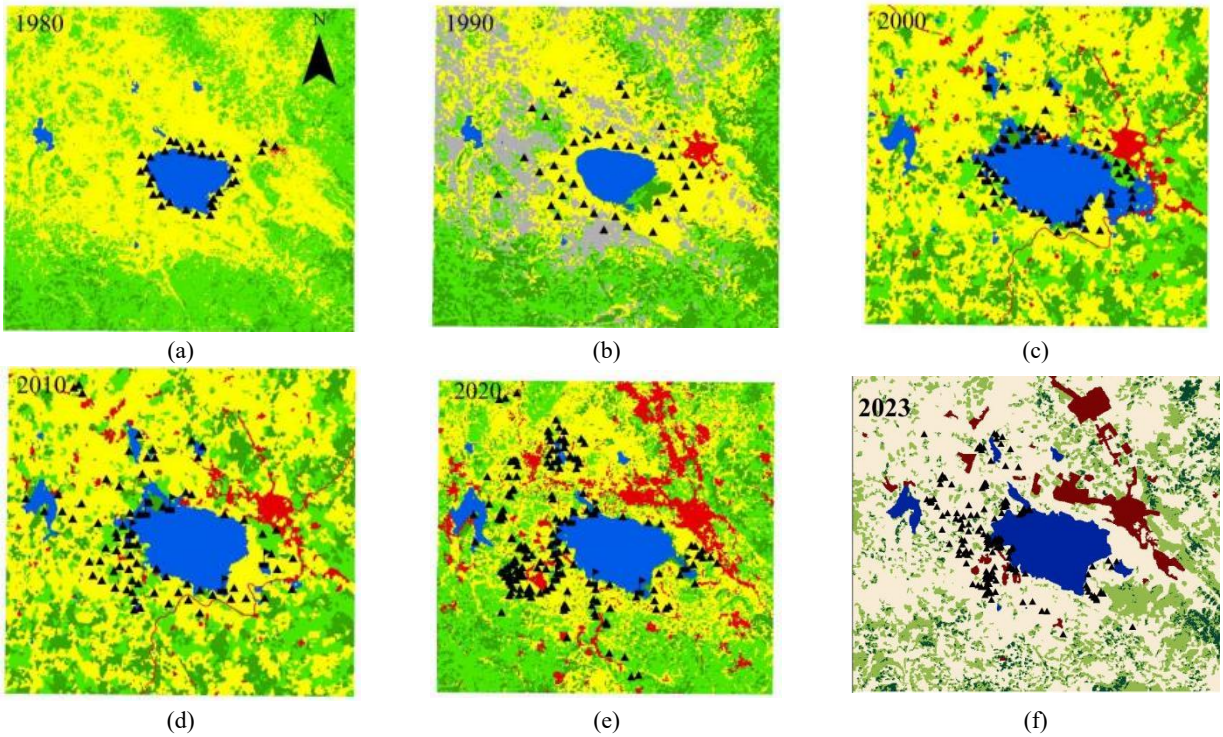

Fig. S3 Changes in black-necked crane distribution in Caohai watershed from 1980 to 2023 (Figures (a) to (e) reported by Wu (2021), Figure (f) is based on present study).

cranes cannot find enough foods around the Caohai Lake, and their foraging distances became further. (c) Spread of tall plants. During the past years, *Phragmites australis* (Cav.) Trin. ex Steud., which average height reaches 2.3 m, has occupied the northern shore of Caohai Lake, and no black-necked cranes distribute in this region anymore (Fig. S3). In addition, after returning farmland to wetlands, some tall dominant species rapidly expanded, compressing the foraging space of black necked cranes. For example, the ZJW habitat used to have a large number of clustered black necked cranes foraging here. After returning farmland to wetlands, *Bidens pilosa* L. (with an average height of 2.1 m) rapidly spread. At present, there is no foraging phenomenon of clustered black-necked cranes, and only some family cranes are engaged in foraging activities by the ditch.

5. Conservation Suggestions

In the Caohai Wetland, *Alternanthera philoxeroides* (Mart.) Griseb., *Carduus nutans* L. and *Phragmites australis* (Cav.) Trin. ex Steud. are the main species with severe ecological impacts. In the shallow water zone of Caohai, due to rapid growth, *Alternanthera philoxeroides* (Mart.) Griseb competes with other submerged plants and phytoplankton for sunlight and air, leading to hypoxia and death of aquatic organisms, fish and shrimp, seriously causing damage to the biodiversity in the Caohai Wetland. *Carduus nutans* L. is a biennial or perennial herb with a height of 30-100 cm. The stem wings are continuous, with triangular serrations of varying sizes along the edges and yellow white or brown needles at the tooth tips and edges. Field investigations have revealed that there is no bird activity in the area where *Carduus nutans* L. is distributed in patches (WJT). *Phragmites australis* (Cav.) Trin. ex Steud. is a perennial plant with well-developed rhizomes. The stem is upright, 1-3 m high, 1-4 cm in diameter, and encompasses more than 20 nodes. *Phragmites australis* (Cav.) Trin. ex Steud. preferentially grows in environments such as swamps, river floodplains, and shallow lakes. Under suitable conditions, seeds, rhizomes, and above-ground stems can be produced rapidly. At present, *Phragmites australis* (Cav.) Trin. ex Steud. is distributed in all the seven habitats of black-necked cranes. In the LJX, ZJW, and WJYT habitats, *Phragmites australis* (Cav.) Trin. occurs in patches and poses a notable threat to the habitats of black-necked cranes, one of the main protected birds in the Guizhou Caohai National Nature Reserve.

6. Conclusions

The Caohai Wetland is an important overwintering habitat for migratory birds in China. The conservation of plant species diversity is important for maintaining bird diversity, consequently ensuring the sustainable development of the regional natural ecology. The systematic and reasonable maintenance of the water level of Caohai Lake is important for ensuring the diversity of habitat plants. Necessary landscape modification and appropriate grazing activities can improve the diversity of plant habitats. In addition, increased attention should be given to the invasive species of *Alternanthera philoxeroides* (Mart.) Griseb., *Carduus nutans* L. and *Phragmites australis* (Cav.) Trin. ex Steud.

Black-necked cranes are of high vigilance, and they tend to choose the water-land transitional zone and shallow water zone with better visibility as their resting place at night. In order to better protect the habitat of black necked cranes, on the one hand, we need to reasonably control the high stem plants in the habitat, and scientifically regulate the plant community structure of the habitat in combining with the feeding habits of black necked cranes; On the other hand, it is necessary to regulate the water level of Caohai Lake reasonably to ensure sufficient water-land transitional zone and shallow water zone for black-necked cranes to inhabit.

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Conflict Interests

The authors have no relevant financial or non-financial interests to disclose.

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