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The population structure and habitat use of resident of Mandarin Duck (*Aix galericulata*) in Wu River (Southwest China)

Canshi Hu[1,2*]

Abstract

Background The Mandarin Duck (*Aix galericulata*) has recently been recognized as a partial migrant in China. The resident population of this species is primarily recorded in southern China, which is not only the traditional wintering range, but also the southernmost breeding sites. However, little information is known about their abundance and habitat requirements during breeding periods. This study provided the first report on the structure of the resident population and the habitat used during the post-breeding period at a tributary of the Wu River in Guizhou Province, Southwest China, which was one of the recently identified breeding sites within the traditional wintering range.

Results A total of 36 Mandarin ducks were recorded among 15 sites, and the mean population density was estimated to be 3.51 ± 3.06 ind./km. The observed adults sex ratio of males to females was 0.44:1. At the microhabitat scale, the results of logistic regression models indicated that the key habitat variables included the distance to the nearest forest edge (dist.forest), opening extent of valley (deg.valley) and distance to the nearest human settlement (dist.settlement). The Mandarin Duck preferred to use foraging sites near forest edges, where dense marginal growth of woodland and shrubs was present.

Conclusion These findings suggested that dense vegetation along rivers could play a positive, important role in habitat use by the resident population of Mandarin ducks. Compared to traditional breeding ranges, both adults and ducklings of this species were more likely to experience human-related disturbances due to the limited availability of ancient trees outside villages. This information will contribute to provide baseline knowledge on the resident population of Mandarin ducks, and enhance understanding of the causes and consequences of breeding partial migration.

Keywords Habitat requirements, Logistic regression models, Observed sex ratio, Partial migration, Post-breeding period, Resident population

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Background

The Mandarin Duck (*Aix galericulata*) belongs to the family Anatidae and the order Anseriformes [6]. This species is a typical Palearctic wildfowl and has an extremely large range [3]. In China, it historically bred primarily in the Hulun Buir Meng of Inner Mongolia, the Changbai Mountains, the Wusuli River, the Heilong River, the Tumen River, the Songhua River, and the upper reaches of the Yalu River in northeastern China [6]. The wintering grounds of Mandarin Duck are located in the middle and lower reaches of the Yangtze River and the provinces of South China, westward to Yunnan Province [30] (Fig. 1). The species has also been recorded in Russia, Korea, and Japan, and it is occasionally found in India [6].

The Mandarin Duck is a shy and secretive species and prefers to swim in narrow and tranquil rivers [31]. Beginning in late April, the breeder of this species nests in natural cavities of ancient trees in large forests along the banks of small streams with dense marginal growth of woodland and shrubs [8, 25, 28, 31]. Following incubation, the ducklings of the Mandarin Duck are dependent upon parental care in shallow waters close to nests [22, 28]. The overall population trend of the Mandarin Duck appears to have decreased recently as a result of the felling of trees, which are used by them as nests [2, 21].

Through observations in recent decades, the migration pattern of the Mandarin Duck has been recognized as partial migration. Several breeding records of resident population of Mandarin Duck have been found in southern China (Table 1; Fig. 1). The southern China is not only the traditionally recognized wintering range of Mandarin Duck, but also the southernmost breeding sites. Like the Baer's Pochard (*Aythya baeri*), the newly breeding range in southern China was referred to as 'the traditional wintering ranges' [26]. In China, some wintering Mandarin ducks migrate to traditional breeding sites during the breeding period, and others reside in traditional wintering sites to reproduce in the summer. Following Chapman et al. [5], the migration pattern of the Mandarin Duck was classified as 'Breeding Partial Migration', a less common form of partial migration patterns.

In Guizhou Province, one of the traditional wintering ranges, several stable breeding populations of Mandarin Duck have gradually been recorded in the ranges of

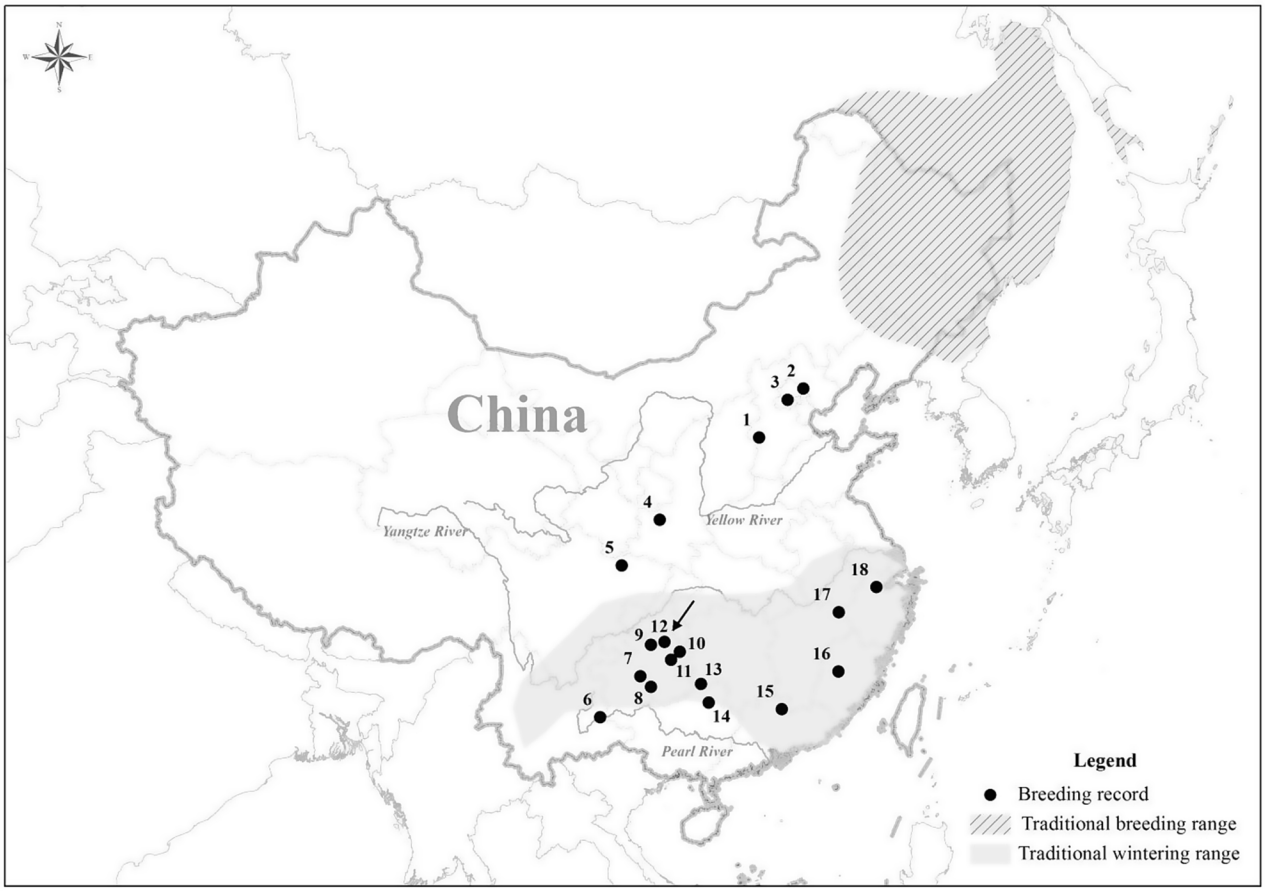

Fig. 1 The main distribution currently described for Mandarin Duck (*Aix galericulata*) in China. The traditional breeding and wintering ranges were imitated from BirdLife International [3]. Abbreviations of breeding records refer to Table 1. The arrow indicates the site at which the current study was conducted

Table 1 The breeding records of resident Mandarin Duck (*Aix galericulata*) at the sites south of traditionally recognized breeding range in China

Extant	Province	Records	Elevation (m)	Status[a]	Citation
South of traditional breeding range	Hebei	(1) Jiaotanzhuang-Hehekou of Pingshan	605–968	Breeding	Li et al. [15]
		(2) Xinglong	-	Breeding	Cheng [6]
	Beijing	(3) Haidian	46	Breeding	Cui et al. [7]
	Shaanxi	(4) Jingdang of Qishan	800	Breeding	Lei [14]
	Sichuan	(5) Shuinianhe of Jiange	580	Breeding	Li et al. [16]
Traditional wintering range	Yunnan	(6) Wuluohe of Shizong	920	Breeding	Wang et al. [25]
	Guizhou	(7) Baihuahu of Qingzhen	1100	Breeding	Wu et al. [27]
		(8) Baiha of Guiding	750	Breeding	Wu et al. [27]
		(9) Qinggangtang of Suiyang	650	Summering	Wu et al. [27]
		(10) Fanjingshan of Jiangkou	560	Breeding	Wu et al. [27], Yang et al. [28]
		(11) Yuanyanghu of Shiqian	550	Breeding	Fang et al. [9]
		(12) Dejiang	600–700	Breeding	The current study
	Hunan	(13) Yudaihe of Tongdao	440	Breeding	Liu et al. [17]
	Guangxi	(14) Guilin	150	Breeding	Jiang and Cai [13]
	Guangdong	(15) Chebaling of Shaoguan	340	Breeding	Shu et al. [20]
	Fujian	(16) Middle part of Fujian	-	Breeding	Cheng [6]
	Jiangxi	(17) Wuyuan	-	Breeding	He et al. [11]
	Zhejiang	(18) Xihu of Hangzhou	30	Breeding	Yu et al. [29]

[a]summering: present during the breeding period but with no evidence of nesting

breeding: nests or ducklings observed in breeding or post-breeding periods

the Dalou Mountains and Wuling Mountains, including Jiangkou [27, 28], Shiqian [9], and Dejiang (current study) (Table 1; Fig. 1). During periods of nesting, laying, incubation and post-hatching, resident Mandarin ducks were found in intermountain streams, ponds and paddy fields surrounded by dense deciduous forest [27, 28].

Despite the need to understand the population dynamics of resident Mandarin ducks and their habitat characteristics during breeding and post-breeding periods within traditional wintering ranges, little information is known about the resident population of this species. Especially during the post-breeding period, the habitat quality of the nesting territory was the key factor affecting the resident population of Mandarin ducks due to breeding ducks foraging in nearby nesting trees [22]. Understanding the habitat requirements of Mandarin ducks is of fundamental importance to the accrual distribution of individuals. Furthermore, compared to the traditional breeding range in northeast China, adaptive changes seemingly occurred in breeding behaviors and habitats. Resident Mandarin ducks occasionally use caves on the face of steep cliffs or ducts in city buildings as nests [13, 14, 27], and nesting habitats are close to human disturbances such as settlements, roads and paddy fields [15].

Thus, the objectives of this study were (i) to describe the population structure and sex ratio of Mandarin ducks in newly breeding grounds (the tributary of the Wu River in Dejiang County, China), providing a reference for future research. Moreover, (ii) the characteristics of microhabitat utilization were analyzed in order to better protecting the resident population of this species. This information will contribute to provide baseline knowledge on the resident population of Mandarin ducks, and enhance understanding of the causes and consequences of breeding partial migration.

Materials and methods

Study area

This study was conducted along a tributary of the Wu River in Dejiang County, Guizhou Province, Southwest China, including the Fengle River, Xueji River and Yemao River (28°21′-28°23′N, 107°53′-107°57′E). These rivers, with elevations ranging from 600 to 700 m, are located in the transition zone between the Dalou Mountains and Wuling Mountains and are bordered by steep cliffs. On both sides of the rivers, the vegetation with high canopy density is characterized by middle subtropical evergreen broad-leaf forest and shrub forest. Human settlements and paddy fields are dispersed throughout the surrounding area.

The Mandarin ducks breed annually between April and June [25, 31] and nest in the cavities of tall trees close to paddy fields and human settlements. During the post-breeding period, both adults and ducklings of the Mandarin Duck forage along the river surrounding the nest trees [22, 28].

Population survey

Field surveys were conducted during the post-breeding period of the Mandarin Duck in late May 2020 along the Fengle River, Xueji River, and Yemao River using an

ornithological telescope (Swarovski 10 × 42). Mandarin ducks were directly counted from a raft on mountain rivers under favorable weather conditions [18]. When ducks were encountered, the number of ducks, life stage (adult/duckling) and sex (male/female) were recorded. Sex was determined based on feather and bill color (gray in females and dark red in males) [21]. To avoid recounting birds, flocks flying overhead were excluded from the count. A total of 7 line transects were carried out, with a total length of 10.26 km.

Microhabitat use variables

Habitat use was assessed with a used-versus-available sampling design [24]. Upon encountering the Mandarin Duck in the field surveys, the spatial coordinates were recorded with a global positioning system (GPS), and the habitat site characteristics were described.

According to the behavioral traits of the Mandarin Duck, seven habitat variables were measured at both used and available sites (Table 2). Considering the species' shy and secretive nature, and its preference for narrow, tranquil rivers [31], habitat variables were identified including the opening extent of the valley (deg.valley), width of the river (width.river) and distance to the nearest road (dist.road). The distance between the habitat site and the nearest forest edge (dist.forest) was measured, as the Mandarin ducks with ducklings were often found in areas covered by shrub or wood forest on either side of the river during the post-breeding period [28]. Additionally, the nesting trees selected by the Mandarin ducks appeared to be near villages, and there are suitable foraging habitats for Mandarin ducks after a period of incubation [15]. Therefore, the distance from the habitat site to the nearest human settlement (dist.settlement) and paddy field (dist.paddy) were considered. Available sites were randomly selected within the study area's rivers using the Create Random Points Tool in GIS (ArcGIS software, version 10.0). The random site was excluded when the distance to any used site was shorter than 100 m.

Statistical analyses

The mean population density of Mandarin Duck was estimated by counting the number of individuals observed per unit length of river. The observed sex ratio was compared using a binomial test. To compare the differences in habitat structure between used and available sites, a Kolmogorov-Smirnov Z test was performed to test for normality. Student's t-test was then used for normal data, while Mann-Whitney U-test was used when data were not normally distributed. The binomial test and t/U test were conducted using 'stats' package in R (version 4.3.2; [19]). Data were expressed as 'Mean ± SD'.

The post-breeding habitat use of the Mandarin Duck was modeled using logistic regression analysis, a method commonly employed in avian studies to predict the presence or absence of species. The dependent variable in the models was a binomial variable indicating used (1) and available (0) sites. Prior to performing multiple regression, Spearman's test was used to examine correlations between all habitat variables to avoid issues of multicollinearity. If the correlation coefficient (r) was higher than 0.7, the variable deemed to be less biologically significant was removed [10]. A correlation matrix was examined and none of habitat variables were removed ($r < 0.7$). Subsequently, logistic regression analysis was conducted to test the relative importance of the remaining habitat variables, using the 'stats' package in R (version 4.3.2; [19]). The models representing all possible combinations of habitat variables were guided by the information-theoretic approach based on Akaike information criterion value, corrected for small samples (AICc) [4]. These models were then ranked according to their difference from the AICc of the best model (Δi). In the case of nearly equivalent support for models (Δi < 2), the model-averaging approach was applied using the 'MuMIn' package in R to compare with the selected best model and to assess the importance of various explanatory variables, guided by standardized beta coefficients [1].

Table 2 Description of habitat variables used in the habitat utilization study during post-breeding period

Habitat variables	Description
elev	The elevation (m)
deg.valley	The opening extent of the valley (degrees)
width.river	The width of the river (m)
dist.forest	The distance to the nearest forest edge (m)
dist.road	The distance to the nearest road (m)
dist.settlement	The distance to the nearest human settlement (m)
dist.paddy	The distance to the nearest paddy field (m)

Results

Population survey

A total of 36 Mandarin ducks (13 adults and 23 ducklings) were recorded among 15 sites in the study area during the post-breeding period. The mean population density was 3.51 ± 3.06 ind./km. In the study area, 13 adults were recorded, and the adults sex ratio of males to females was 0.44:1 (binomial test, $P = 0.27$). All the observed adult males retained breeding plumage rather than eclipse plumage, although two of them had shed one or two sail-shaped tertiary feathers. Twenty-three ducklings were recorded, and most of them (78%) gregariously followed adult females on the rivers.

Microhabitat use

Habitat data from both used and available sites were analyzed during the post-breeding period. The results showed that there were significant differences in the

Table 3 Habitat variables of Mandarin Duck (*Aix galericulata*) between used and available sites during post-breeding period

Habitat variables[a]	Used ($n=15$)		Available ($n=15$)	
	Mean ± SD	Range	Mean ± SD	Range
elev (m)	634.73 ± 11.55	619.00-660.00	631.53 ± 21.08	610.00-694.00
deg.valley (degrees)	129.00 ± 17.65	105.00-160.00	134.67 ± 15.17	110.00-170.00
width.river (m) •	58.20 ± 26.30	28.00-130.00	79.67 ± 37.28	30.00-143.00
dist.forest (m)*	11.53 ± 11.68	1.00–41.00	23.67 ± 12.02	5.00–45.00
dist.road (m)*	186.33 ± 107.31	60.00-460.00	316.93 ± 150.63	75.00-495.00
dist.settlement (m)	334.00 ± 176.29	100.00-720.00	427.80 ± 200.49	120.00-800.00
dist.paddy (m)	204.73 ± 96.68	50.00-360.00	242.13 ± 109.63	115.00-560.00

[a]Abbreviations refer to Table 2

*$P < 0.05$

•$0.05 < P < 0.10$

Table 4 Logistic regression results for the final set of habitat models of Mandarin Duck (*Aix galericulata*) during post-breeding period. Used sites were coded as 1 and available sites as 0. K is the number of parameters in the model, logLik is the log-likelihood estimator, AICc is akaike information criterion for small sample sizes, Δi is the difference in AICc value from that of the best model (i.e. the lowest AICc), and ωi is AICc weight. Except for the global model and null model, only models with Δi < 2 are shown

Model structure[a]	K	logLik	Δ_i	ω_i
deg.valley + dist.forest + dist.settlement	4	-12.49	0.00[b]	0.506
deg.valley + dist.forest + dist.settlement + dist.road	5	-11.77	1.47	0.243
deg.valley + dist.forest + dist.settlement + dist.paddy	5	-11.78	1.49	0.240
Global[c]	8	-10.35	8.99	0.006
Null	1	-20.79	9.16	0.005

[a]Abbreviations refer to Table 2

[b]Lowest value of AICc = 34.58

[c]Global model structure: elev + deg.valley + width.river + dist.forest + dist.road + dist.settlement + dist.paddy

habitat variables of width.river, dist.forest and dist.road (Table 3). It seemed that the Mandarin ducks were distributed along narrow mountain rivers (width.river), and they were close to the edge of shrub or wood forests (dist.forest) and roads (dist.road).

Logistic regression analysis identified the habitat variables of the opening extent of the valley (deg.valley), distance to the nearest forest edge (dist.forest), and distance to the nearest human settlement (dist.settlement) as the most important explanatory variables in the best candidate model (Table 4). However, no single model best explained the patterns of habitat use during the post-breeding period. Additional strongly competing models

Table 5 Beta coefficients (β) and standard errors (SE) for the averaged model (Δi < 2) of the habitat use by Mandarin Duck (*Aix galericulata*) during post-breeding period. Used sites were coded as 1 and available sites as 0

Variables[a]	*β*	SE	*Z*	*P*
Intercept	23.063	10.494	2.094	0.036*
dist.forest	-0.118	0.051	2.209	0.027*
dis.settlement	-0.011	0.006	1.884	0.060•
deg.valley	-0.123	0.063	1.868	0.062•
dist.road	-0.001	0.003	0.396	0.692
dist.paddy	-0.002	0.005	0.379	0.705

[a]Abbreviations refer to Table 2

*$P < 0.05$

•$0.05 < P < 0.10$

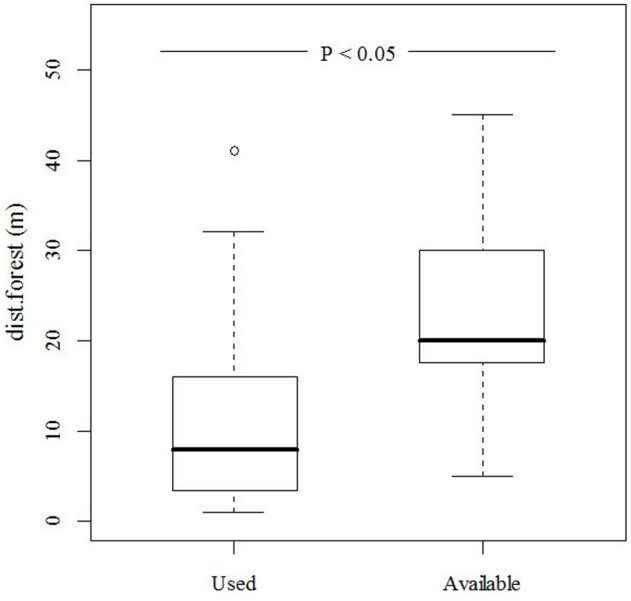

Fig. 2 Comparison of distance to the nearest forest edge (dist.forest) of Mandarin Duck (*Aix galericulata*) between used and available sites during post-breeding period

(Δi < 2) included the effects of distance to the nearest road (dist.road) or paddy fields (dist.paddy) (Table 4). The addition of each variable did not improve the fits of these models because of the slight increase in log-likelihood values over that of the best-supported model.

The differences between AICc values were less than 2 for the top three models, which were averaged to obtain the best explained estimate. The results of the averaged model showed that distance to the nearest forest edge (dist.forest) was significant ($P = 0.027$, Table 5). Comparisons between used and available sites revealed that Mandarin ducks preferentially used foraging sites near the forest edge ($t = 2.804$, $P = 0.009$, Table 3; Fig. 2). They were likely to be found on either side of the river surrounded by dense shrubs and wood forests. Moreover, Mandarin ducks seemed to prefer a narrow extent valley (deg.

valley) ($P = 0.062$) close to human settlements (dist.settlement) ($P = 0.060$, Table 5).

Discussion

The partially migratory population of the Mandarin Duck bred within the traditional wintering range, mainly south of the middle and lower reaches of the Yangtze River. In this research, a newly breeding ground was reported in the tributary of the Wu River in Dejiang County, Guizhou Province of China. The expansion of their breeding grounds is likely driven by population growth and the deterioration of former suitable breeding habitats within traditional breeding ranges [15]. Although breeding Mandarin ducks have been recorded in many southern provinces of China during both the breeding and post-breeding periods, their distribution pattern was discontinuous (Fig. 1). In these regions, the resident Mandarin ducks required rivers, freshwater pools, or lakes surrounded by dense evergreen broad-leaf woodland and shrubs in mountain areas [17, 25, 28]. The increasing breeding grounds at the sites south of the traditional breeding range indicated that there were suitable wetland habitats for Mandarin Duck nesting and foraging near their nesting cavities.

The sex ratio results from this study indicated that the Mandarin ducks underwent a complete molt during the post-breeding period. Male Mandarin ducks molted their flight feathers simultaneously earlier than the females, and both males and females thus successively became flightless for a while [21]. Male Mandarin ducks first shed a pair of sail-shaped tertiary feathers, causing them to adopt eclipse plumage and closely resemble females. The radio-tracking data showed that flightless males of Mandarin ducks hid in ponds with dense vegetation in small flocks, whereas late-molting females were typically solitary [21]. Consequently, male Mandarin ducks were observed less frequently than females in current study (the adults sex ratio of males to females was 0.44:1).

Consistent with previous studies on breeding habitats [12, 15], dense vegetation along rivers could play an important positive role in habitat use by resident Mandarin ducks during both breeding and post-breeding periods. Particularly during the post-breeding period, when human-related disturbances posed significant risks to the survival of ducklings, the results of current study showed that Mandarin ducks tended to use foraging sites near the forest edge ($P = 0.009$, Table 3). Furthermore, at the microhabitat scale, Mandarin ducks that were nearing complete molt foraged in a narrow extent valley, which was surrounded by dense marginal growth of deciduous woodland and shrubs, because of safety concerns (Table 5; Fig. 2).

The resident population of Mandarin ducks is currently facing multiple potential threats as the distribution of breeding grounds dispersed to the traditional wintering ranges. Wetland and large-scale forest habitats suitable for the Mandarin Duck are currently rare and fragmented, and the overall population trend has recently appeared to be decreasing [21]. In the traditional wintering range, taking Guizhou Province as an example, many trees with natural cavities suitable for nesting disappeared because the large-scale forest was cut down historically. The remnants of ancient trees were generally distributed in villages or nearby geomantic woods, and their availability limited nesting sites in the breeding period and foraging sites in the post-breeding period. The radio-tracking results of Sun et al. [22] showed that the breeding Mandarin ducks did not forage more than 4 km from their nest trees during the post-breeding period. Hence, the home range of resident Mandarin ducks was seemingly close to human disturbances during the post-breeding period, which was a potential risk for their increasing population [13, 15, 28]. However, compared to sites within the traditional breeding range, human-related disturbances could be mitigated by dense vegetation, although the Mandarin ducks in this study were observed closer to such human disturbances (Table 3). Post-breeding habitat use characteristics appear to represent a trade-off between food availability and human-related disturbance avoidance [31].

Fortunately, the resident Mandarin ducks may be adaptable in terms of breeding behavior under a lack of suitable nesting cavities. The conventional cavities used by Mandarin ducks were holes caused by tree decay, mostly where a branch broke off [28]. The availability of such cavities likely increased with the maturity of the trees, and it was recognized that the breeders depended almost exclusively on tree holes in both traditional breeding and wintering ranges [25, 31]. Nevertheless, currently, enough rare ancient trees cannot be obtained for Mandarin Duck nesting. In this study area, no nest trees were found within 5 km of the rivers, either through interviews or field surveys. In contrast, previous reports have indicated that Mandarin ducks occasionally used caves on the face of steep cliffs or ducts in city buildings as nests [13, 14, 27]. Examples can also be found in other species, such as Oriental Pied-Hornbill (*Anthracoceros albirostris*), a typical secondary cavity-nesting bird, which was recorded to nest on a steep limestone cliff instead of in the cavity of a tree, just as the Mandarin Duck [23]. Since little information is known about the resident population of Mandarin ducks and their reproductive conditions, monitoring and following up on the population is urgent.

Conclusions

This study provided the first report on the resident population structure and habitat utilization of Mandarin ducks during the post-breeding period at one of the recently

found breeding sites within the traditional wintering range. The results emphasized the importance of distance to the nearest forest edge (dis.forest) as a potentially limiting factor for post-breeding habitat use by Mandarin ducks. Therefore, vegetation protection and management along the mountainous rivers in southern China can support the resident populations of Mandarin ducks. In addition, since the resident population of this species was located near human settlements in the post-breeding period, it is recommended to strengthen the publicity of protection in surrounding areas. This information could contribute to provide baseline knowledge on the resident population of Mandarin ducks and enhance understanding of the causes and consequences of breeding partial migration.

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Author contributions
Canshi Hu conceived, designed, and executed this study and wrote the manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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