Reproductive ecology of Baer's Pochard *Aythya baeri* in south China

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Abstract

Baer's Pochard *Aythya baeri* is an IUCN Critically Endangered diving duck, but our lack of knowledge of its reproductive ecology impedes implementation of effective conservation actions. We therefore report on the results of studies of the birds' breeding biology at a subtropical site in south China, well south of the traditionally recognised breeding range of this species. Here the Baer's Pochard depended on undisturbed wetlands with emergent vegetation as breeding habitat, where they nested in shallow water or on platforms above local water levels. Egg laying occurred between late April and mid-July. Clutch size averaged 9.7 eggs (range: 5–14), with evidence of conspecific parasitism being found in 29% of 31 nests. Incubation lasted for 24 days (range: 23–26), after which at least one fledged young was recorded for 38% of 45 nesting attempts (41% estimated by the Mayfield method), a success level comparable with several less endangered *Aythya* species. Nesting failure was attributed to nest desertion, possibly associated with warm weather, nest predation by Siberian Weasels *Mustela sibirica* and flooding. Based on these results, we propose that the protection of at least 120 ha of continuous wetland as breeding habitat, with management of emergent vegetation adjacent to open water, and provision of artificial nest-site microhabitats (*e.g.* nesting platforms), will all potentially enhance the breeding success of this species.

Key words: Breeding biology, conservation, life history, nest success.

Baer's Pochard *Aythya baeri* is a diving duck endemic to eastern Asia. The species breeds in southeast Russia and northeast China, and winters in south China, along with scattered wintering sites in Japan, South Korea, Myanmar, Thailand, Bangladesh and India. Historically, Baer's Pochard was considered relatively abundant throughout its range, but since 1988 it has repeatedly been up-listed by the International Union for Conservation of Nature (IUCN), initially from Threatened, via Vulnerable and Endangered, to its current listing as Critically Endangered following dramatic population declines over the last three decades (IUCN 2019). The global population is now estimated to number < 700 adult individuals (IUCN 2019), making it one of the world's most threatened waterfowl species. In response to the species' current status, a Single Species Action Plan (SSAP) has been developed under the East Asian-Australasian Flyway Partnership (EAAFP), coordinated by the EAAFP Baer's Pochard Task Force (BPTF). In China, now thought to constitute the core of the pochard's remaining breeding and wintering areas, a working group has been established to monitor and protect the species.

As an initial step towards conservation policy-making, since 2010 the species' distribution, habitat and population size in both summer and winter have been the subject of surveys throughout its range, especially in China (Hearn *et al.* 2013). This activity has made notable progress in finding Baer's Pochard breeding and summering (*i.e.* present during the breeding season but with no evidence of nesting) at several sites south of their traditionally recognised breeding range. These include Hengshui Lake (37°36'N, 115°36'E), Xinxiang Yellow River (35°24'N, 114°29'E), Zoucheng (35°20'N, 116°35'E), Minquan (34°34'N, 115°12'E), Chuzhou (32°23'N, 118°42'E), Fu River (30°41'N, 114°18'E) and East Lake (29°42'N, 115°45'E) (Hearn *et al.* 2013; Hearn 2015; Wu *et al.* 2018; Xu *et al.* 2019; Fig. 1). At the same time, efforts to rediscover the species in areas thought to be their breeding strongholds in northeast China and eastern Russia have found no evidence of nesting since the 1990s (Heim *et al.* 2013; Fig. 1).

Despite the fact that we need to be able to assess contemporary annual breeding success, to gain a better understanding of the causes of recent population declines, there have been no recent attempts made to quantify the reproductive ecology of Baer's Pochard nesting in these regions. Three recent studies provided information on breeding of Baer's Pochard based on data from only 2–7 nests (Lu *et al.* 2015; Wang *et al.* 2019; Li *et al.* 2020). A relatively extensive study of the species' reproductive ecology was also conducted 30 years ago in Xianghai (45°02'N, 122°18'E) of northeast China (Gao *et al.* 1992), the traditionally recognised breeding range where the species is likely no longer present.

In this paper, we report on the reproductive ecology of Baer's Pochard at Fu River, in the middle of the Yangtze River floodplain, which is one of the recently found, southernmost breeding sites (Lu *et al.* 2015), and also a traditional wintering resort. Based on data from 45 Baer's Pochard nests recorded during 2018–2019, we provide information on the timing of the breeding season, nesting habitat, breeding behaviour and nest site location, clutch size, incubation period and nest success. The information will serve to provide base-line knowledge on the natural history of this species, and also aid future effective implementation of sound conservation measures for this Critically Endangered species.

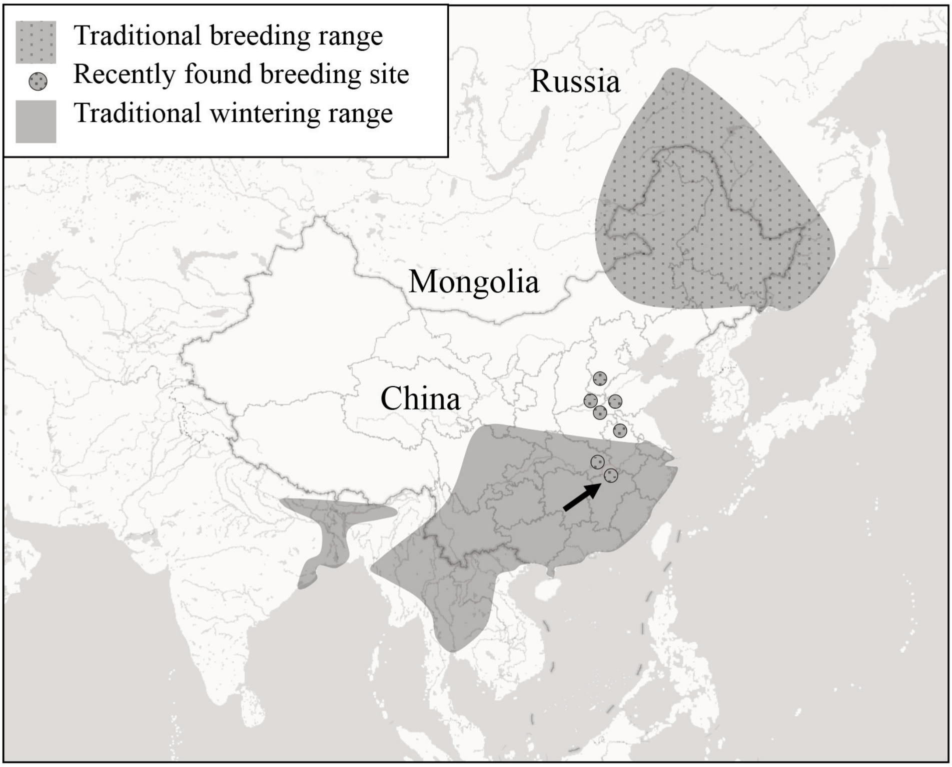

Figure 1. The distribution currently described for Baer's Pochard. Stippled grey (upper) and uniform grey (lower) shaded areas represent the traditional breeding and wintering ranges, respectively, with breeding sites discovered since 2012 marked by the stippled circles. The arrow indicates the site at which the current study was conducted.

Study site and methods

Observations were made at the Fu River wetland, which is located 25 km from Wuhan, the largest city in central China (Fig. 1). We chose a study plot where breeding Baer's Pochard had been observed (Lu *et al*. 2015; Fig. 2), within a 154 ha wetland (the wetland area being estimated from Google Maps) covered by emergent vegetation, surrounded by largely agricultural land. The emergent vegetation consists of sedges *Carex* sp. and *Scirpus* sp., Soft Rush *Juncus effusus*, Reed *Phragmites communis*, Bulrush *Typha orientalis*, Wild Rice *Zizania caduciflora* and Lotus *Nelumbo nucifera*. Although the wetland is suffering from the effects of intensive aquaculture, the existing emergent vegetation around standing water generally remains undisturbed by grazing and harvesting, at least during the Baer's Pochard breeding period.

Field investigations were undertaken between mid-May and early August of 2018

Figure 2. View of the study plot, showing nesting habitats used by Baer's Pochard, by Qun Lu.

and 2019. We searched systematically for Baer's Pochard nests throughout the extent of the emergent vegetation growing at an 83 ha pond within the wetland. When a nest was firstly found, we numbered each nest located, recorded its spatial coordinates by global position system (GPS), described the nest site characteristics (water depth within 1 m of the nest, dominant vegetation type, and maximum vegetation height above the water surface using a tape measure), and also took measurements of the nest dimensions. Clutch size was recorded, the eggs were weighed to the nearest 0.01 g using an electronic balance, and egg length and breadth were measured to the nearest 0.1 mm using a digital calliper. Subsequent visits were conducted to monitor the outcome of the breeding attempt, at least once per week for most nests (n = 39), of which a few (n = 7) where the female was still laying, or the eggs were close to hatching, were visited every 1–2 days to determine when these events occurred and to estimate the duration of incubation. A few nests (n = 6) were checked only once during the study period, mainly because the nests had already been deserted when they were first found, but data from these nests were used in describing nest site characteristics, egg size or clutch size where possible. To reduce the influence of research activities on the birds' breeding success, we were careful to restore vegetation around the nest after nest inspections.

Nine randomly chosen Baer's Pochard nests were monitored via video cameras (Forsafe H801) to obtain the information on breeding behaviour. The camera was fixed to a post inserted into the pond substrate 2–3 m from the nests during the period of egg-laying (one nest) or incubation (eight nests). Each recording bout lasted for at least a full day (the 24 h day-night cycle), and the total recording time for the nine nests averaged 5.6 days (s.d. ± 6.0, range = 1–20 days). Egg-laying or incubating females were relaxed on the nest even during the initial minutes after deployment of the cameras. Information extracted from the video recordings mainly described the occurrence of typical behavioural events, including the on- and off-nest time of incubating females, maintaining nest structure, intraspecific nest parasitism and nest predation. Unfortunately, we were unable to save the large amount of video data generated, and were only able to extract information regarding the on- and off-nest schedule for two out of the nine nests monitored.

Nest density was estimated by dividing the number of all nests located within the extent of emergent vegetation growing at the pond by the area of the emergent vegetation surveyed, which was determined from a Google map of the study plot. The range of emergent vegetation available for the Baer's Pochard to nest varied yearly, becoming reduced when flooded due to heavy rainfall or aquaculture water management. Nearest neighbour distances between nests were calculated from the spatial coordinates of nest sites. Egg volume was measured as egg length × egg breadth^2 (following Lu 2011). We estimated the approximate date of onset of laying (*i.e.* when the first egg was laid) by counting the number of eggs (assuming that one egg was laid per day) and determining the developmental stage of the eggs from fresh egg mass and egg dimensions in relation to daily mass loss rate (Hoyt 1979). The incubation period was defined as the time from the laying of the last egg to the hatching of the last young.

Intraspecific nest parasitism was considered to occur in a nest if more than one egg was laid per day, or new eggs were added a few days after incubation was initiated (Post & Seals 2000). These two criteria were confirmed by video recordings in two different nests. Interspecific nest parasitism by Spot-billed Ducks *Anas poecilorhyncha* – the only other waterfowl species nesting in the study plot, where they have a much lower nest density (1/20) than that of Baer's Pochard – may potentially occur. Parasitism by Spot-billed Ducks would have been easy to detect because their large eggs are clearly distinguishable from those of Baer's Pochard, but no Baer's Pochard nest was found to have been parasitised by Spot-billed Ducks during our 2-year study. Although Mallards *Anas platyrhynchos* also breed in the study area, they have never been found to nest in the wetland used by Baer's Pochard.

A nest was considered to have been abandoned if the female was absent from the nest with cold eggs left for more than four hours (the longest off-nest bout recorded), and there was no evidence that she had returned again. A nest was considered to have been destroyed by predators if the nest bowl contained broken egg fragments with yolk remains on the ground. Nests were considered successful if there was evidence that at least one young had fledged. Nest success was calculated as the percentage of successful nests among all nests located. We also evaluated nest success with the probability of nest survival from egg-laying to fledging based on the Mayfield method (Mayfield 1975; Johnson 1979). Nest exposure time was the number of days that a nest was known to be active, assuming that changes in nest status occurred on the midpoint date between two nest checks.

All statistical analyses were performed using Program R (R Core Team 2018). Descriptive statistics are expressed as means ± s.d. and the level of significance was set at $P < 0.05$.

Results

Nesting habitat and nest-site selection

All Baer's Pochard used emergent vegetation dominated by sedges (n = 43 nests) or reeds (n = 2 nests) growing in the pond as nesting habitats. Vegetation height ranged between 0.3–1.8 m in the sedge community and 1.9–2.1 m in the reed community. Densities of nests located within the potentially available emergent vegetation were 0.58 nests ha^{-1} in 66 ha of emergent vegetation in 2018 and 0.50 nests ha^{-1} in 14 ha of emergent vegetation in 2019. The decrease in nesting habitat in 2019 was because pond water was artificially maintained to a higher level for aquaculture, so flooding the emergent vegetation. Mean nearest neighbour distances between nests in 2018 (53.8 ± 54.2 m, range = 4.3–269.9 m, n = 38) did not differ from those recorded in 2019 (50.3 ± 82.9 m, range = 8.4–235.5 m, n = 7. Independent-samples test: t_{43} = 1.44, P = 0.89, n.s.).

Nests were located among emergent vegetation, usually in shallow water (< 1 m, n = 24), or on small islands or ridges higher than pond water level (n = 21). Water depths around the nests were typically 30–90 cm, but up to 150 cm after heavy rainfall. The distance of a nest to the nearest pond bank varied between 1–50 m. Nests were circular cylindrical structures, made of sedges collected from the immediate vicinity, lined with a layer of down. For 39 nests, the external diameter was on average 32.9 ± 4.0 cm (range = 26–40 cm), internal diameter was 17.9 ± 1.5 cm (range = 12–20 cm), depth (from the bottom to the highest point of the nest inner wall) was 8.7 ± 1.9 cm (range = 2–12 cm), and height (from the bottom to the highest point of the nest outer wall) was 26.0 ± 14.9 cm (range = 4–55 cm).

Breeding parameters

Baer's Pochard began to lay eggs in late April and had ceased by mid-July (Fig. 3). Over this period of 80 days, most clutches (64% of 44) were initiated during May and no new clutches were recorded after 14 July. The probability of a female producing a second clutch was very low, given that a full breeding cycle (including nest building, egg laying, incubation and rearing of ducklings) took *c.* 70 days to complete. A few late-initiated clutches could have been due to re-nesting after failure of the first attempt.

Baer's Pochard eggs were whitish without spots (Fig. 4a). The average length of 394 eggs was 51.4 ± 1.7 mm (range = 46.5–57.0 mm) and width 38.5 ± 1.1 mm (range = 35.0–41.0 mm), with an average egg volume being 76,508 ± 6,149 mm^3 (range = 56,963–95,817 mm^3). Fresh Baer's Pochard eggs (those found during the laying period) weighed 42.6 ± 2.5 g (range = 37.8–47.7 g, n = 118). Clutch size, excluding clutches involved in intraspecific nest parasitism (see below), ranged from 5–14 eggs, averaging 9.7 ± 2.4 eggs (n = 29). Clutch size declined significantly during the breeding season (clutch size against the number of

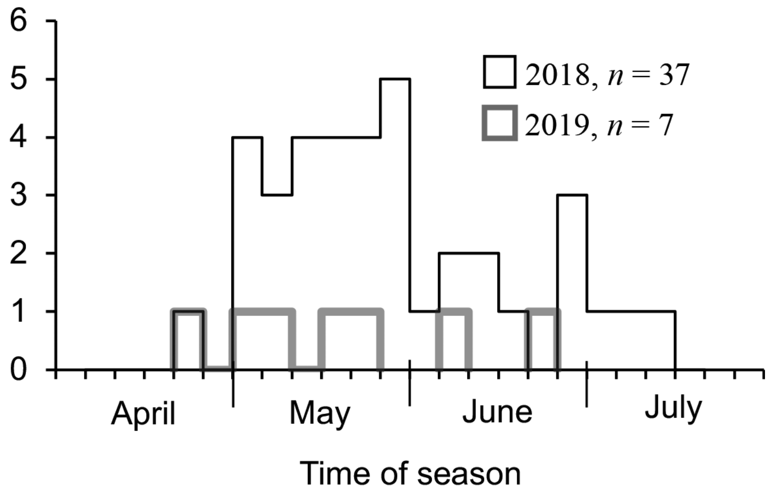

Figure 3. Frequency distribution of first-egg dates of Baer's Pochard in 2018 and 2019.

days of clutch initiation date relative to 1 April for 2018 data, Pearson correlation: r_{25} = –0.40, P = 0.04). There was no correlation between average total egg volume within a clutch and clutch size (both 2018 and 2019 data: r_{32} = 0.17, P = 0.35, n.s.), even after controlling for clutch initiation date (partial correlation for 2018 data: r_{24} = 0.32, P = 0.11, n.s.).

There was evidence for intraspecific nest parasitism in 9 (29.0%) out of 31 clutches of known size. The number of parasitic eggs within a host clutch varied between 1–7 eggs (2.9 ± 2.3 eggs, n = 9). There was no difference in the frequency of intraspecific nest parasitism between 2018 (29.2%, 7 of 24 nests) and 2019 (28.6%, 2 of 7 nests; χ^2_1 = 0.001, P = 0.98, n.s.). Clutch size of nine host nests was 12.1 ± 2.1 eggs (range = 9–15) and 9.2 ± 3.5 eggs (range = 3–14) including and excluding parasitic eggs, respectively (Paired-samples test: t_8 = 3.74, P = 0.01). The former was significantly greater than that of non-parasitised nests (Independent-samples test: t_{36} = 2.66, P = 0.01) and the latter was not (t_{36} = 0.14, P = 0.89, n.s.). The pattern was not a consequence of parasitism being more likely to occur early in the season when clutch size tended to be large, because hosts did not initiate breeding significantly earlier than non-hosts (number of days of clutch initiation date relative to 1 April: 60 ± 18, n = 9 and 55 ± 20, n = 29, respectively; t_{36} = 0.71, P = 0.48, n.s.).

Females began incubation when the last egg was laid (Fig. 4b). Incubation lasted for 24.3 ± 1.2 days (range = 23–26 days, n = 6 clutches) on average. It took 1–3 days for hatchlings to finally emerge from all eggs within a clutch (n = 4 clutches; Fig. 4c).

Breeding behaviour

Baer's Pochard appeared to have a monogamous mating system, at least within a breeding season. Pairs consisting of one

Figure 4. Baer's Pochard nest with (a) eggs, (b) incubating females (in hot conditions, and (c) female and ducklings. Note, in (c), the tall emergent plants around the nest had been removed by the female to lift the nest when the pond water level increased due to continuous rainfall. Photographs by Qun Lu.

female and one male were frequently seen from mid-April. Field observations at one nest showed that the pair bond remained intact during the egg-laying period. No males were found nearby the nests on which females were incubating among the 50-day video recordings for nine nests. Also, males were absent from post-hatching family groups (n = 5 sightings). Video recordings from nests showed that female Baer's Pochard left the nest to forage 2–3 times (2.5 ± 0.6 times, n = 4 days) in a 24 h day-night cycle, which occurred between 05:47–20:03 h (13:53 ± 4.3 h, n = 11 records) and lasted for 27–240 min (88 ± 71 min, n = 7 records). At almost every departure, they covered the eggs with nest material; when sitting on the nest, they often placed plant material onto their back, perhaps a strategy to reduce conspicuousness to predators. Heavy rainfall or manipulation for aquaculture can elevate water levels and threaten to submerge the nest. In response to the potential risk of flooding, females increased the height of the nest. This was recorded at two nests during the incubation stage, with the females gathering emergent plants from around their nests, which although increasing nest height potentially reduced concealment of the nest (Fig. 4c).

During the highest temperatures, at around midday, female Baer's Pochard often stood on the nest and sheltered eggs from the strong sunlight, whilst allowing circulation of air around them. Video cameras set on two nests recorded that the female frequently left the nest to take water into her plumage, and then immediately returned to the nest to cool the eggs.

Two intraspecific nest parasitism events were captured by video cameras from two different Baer's Pochard nests. One took place when the host female was laying and the other when the host female was incubating, both in the morning (at around 09:00 h). In the former event, both the parasitic female and a male (probably her mate) fought or kept confronting the host female for 13 min, during which the parasitic females laid successfully by sitting on the nest together with the host female for 4 min. In the latter event, only the parasitic female was videoed; she stood by the host who was sitting on the nest for 2–3 min and then took a chance to deposit her egg.

Reproductive success

Among 346 eggs recorded in 2018, 107 (30.9%) hatched successfully, compared to 19.2% among 52 eggs recorded in 2019. On average, 7.3 ± 3.8 young (range = 3–16, n = 16) fledged per nest. Partial egg loss occurred in 14 (87.5%) of the 16 successful clutches, with each clutch losing an average 4.1 ± 1.9 eggs (range = 1–9 eggs, n = 14), amounting to 40.0 ± 17.5% (range = 7.1–75.0%) of all eggs from these clutches.

Of the 38 nests found in 2018, 16 fledged at least one young, with an apparent nest survival rate of 42.1%. Only one of the seven nests found in 2019 was successful, giving a nest survival rate of 14.3%. Combined data from the two years produced an overall apparent nest success rate of 37.8%. The Mayfield estimate of nest success was 45.4% in 2018 and 22.6% in 2019, with an overall success rate of 41.2%. There were three major reasons contributing to complete nest failure, namely nest desertion, nest predation (mainly by Siberian Weasels *Mustela sibirica* on the basis of remains in the nest, confirmed by video recordings at two nests) and flooding. These causes of complete nest failure differed between years, being 63.6%, 22.7% and 13.6%, respectively in 2018 (n = 22 nests), but 0%, 66.7% and 33.3% in 2019 (n = 6 nests). Nests with parasitic eggs tended to be more successful (55.6% of 9) than those without parasitic eggs (37.8% of 29), although the difference was not statistically significant (χ^2_1 = 0.88, P = 0.35, n.s.).

Discussion

Breeding biology

The current study provides information on the breeding biology of a diving duck species in the subtropics, which is poorly known to ornithologists (Xiao *et al.* 2017). In these regions, the warm climates facilitate an extended breeding season for birds. Indeed, Baer's Pochard in our study area have a breeding season twice as long as the same species in northeast China where breeding is initiated in late May (Table 1). The long breeding season does not necessarily mean that a female can raise two broods per year. Nevertheless, the extended breeding period may allow Baer's Pochard to lay a

Table 1. A comparison of reproductive parameters among diving duck *Aythya* species. Nest success was calculated with either traditional or Mayfield method (marked with the superscript M).

Species	Locality	Latitude (°N)	Clutch initiation	Clutch size	Incubation period (d)	Nest parasitism (%)	Nest success (%)	Sources
Baer's Pochard *A. baeri*	S China	29.7	Late April	9.7	24	29.0	37.8	1
	CE China	35.1	1–15 May	9.9			57.1	2
	NE China	45.0	15–25 May	11.9	24	22.2	27.8	3
Common Pochard *A. ferina*	W France	47.1	1–15 April				39.5	4
	S Czech	49.2	10–15 May	8.1	25		83.3	5, 6
Tufted Duck *A. fuligula*	S Czech	49.2	9–26 May	9.0	25		55.6	5, 7, 8
	Latvia	57.3		9.2			91.7	9
Ferruginous Duck *A. nyroca*	N Iran	35.6	29 April	8.3				10
	NE Algeria	36.8	15 April	9.5	28	9.7	37.0	11
	N Algeria	36.9	14 April	13.3		39.0	44.0	12
Ring-necked Duck *A. collaris*	S Canada	50.5					32.0	13
Canvasback *A. valisineria*	E USA	40.2		6.9			62.8M	14
	NE USA	42.3	1–10 May	7.5			60.0	15
	S Canada	50.2	? April		25	41.0	40.7	16
Redhead *A. americana*	E USA	40.2		8.9			70.0M	14
	NE USA	42.3	1–10 May	7.0			75.0	15
	NE USA	47.4				36.0	15.2	17
Lesser Scaup *A. affinis*	NE USA	42.3	9–19 June	8.0				15
	S Canada	50.5					11.0	18
	NW Canada	62.5		9.0		15.4	57.0M	19
Greater Scaup *A. marila*	SE Canada	45.5		8.8	27		41.0M	20
	NW USA	61.2		8.5	26		25.1M	21
	NW Canada	62.5		8.9		12.1	75.0M	19

Sources: 1) This study; 2) Li *et al.* 2019; 3) Gao *et al.* 1992; 4) Folliot *et al.* 2017; 5) Neužilová & Musil 2010; 6) Musil *et al.* 2017; 7) Liordos & Lauder 2015; 8) Čehovská *et al.* 2019; 9) Dugger & Blums 2001; 10) Barati & Ataii 2008; 11) Fouzari *et al.* 2015; 12) Djelailia *et al.* 2017; 13) Koons & Rotella 2003; 14) Bouffard 1983; 15) Austin & Pyle 2004; 16) Sorenson 1997; 17) Lokemoen 1966; 18) Koons & Rotella 2003; 19) Fournier & Hines 2001; 20) Tatman *et al.* 2009; and 21) Flint *et al.* 2006.

replacement clutch if the first clutch failed, as often observed in other waterfowl species (Arnold *et al.* 2010).

While passerines with extensive ranges often exhibit a latitudinal increase in clutch size (Lack 1954), waterfowl species tend to show the opposite tendency (Owen 1980; Dunn & MacInnes 1987; but see Rubolini & Fasola 2008). Although we should be prudent about small sample sizes from relatively few sites, our study population on average had smaller clutches than two populations of Baer's Pochard breeding further north in China (Table 1). Meanwhile, Baer's Pochard at our study site produced eggs of relatively large volume compared to those breeding further north on the Yellow River in Xinxiang (69,169 mm^3, Li *et al.* 2020), but eggs smaller in volume than these were found yet further north in Xianghai (78,223 mm^3, Gao *et al.* 1992). When facing energy constraints, organisms tend to make a trade-off between offspring size and number (Smith & Fretwell 1974). There is a negative relationship between egg size and clutch size, confirmed across several waterfowl clades, but the relationship often is absent at the intraspecific level (Rohwer 1988; Christians 2000; Blums *et al.* 2002). The latter case is true for the Baer's Pochard studied here. Seasonal decline in clutch size has been reported in many single-brooded birds (Rowe *et al.* 1994), including waterfowl (Dalhaug *et al.* 1996; Samraoui & Samraoui 2007), presumably in response to food limitation. The pattern was also found in the current study in Baer's Pochard.

Intraspecific nest parasitism is widespread among waterfowl, typically including pochards (Yom-Tov 2001; Andersson *et al.* 2019). In this study, we found that the phenomenon occurred in 29% of Baer's Pochard nests, similar to levels of parasitism reported for other *Aythya* species (Table 1). Adaptive mechanisms underlying the intraspecific nest parasitism in Baer's Pochard remains unclear. Future studies should investigate the relatedness between parasites and hosts, to assess the evolutionary significance of social parasitism from a perspective of inclusive fitness (Hamilton 1964; Wang & Lu 2018).

Reproductive success

Baer's Pochard at this subtropical site had a higher apparent nest success than their counterparts breeding in northeast China where information was obtained during the 1980s (Gao *et al.* 1992). The nest success recorded by the current study was intermediate in the range of values reported for several diving duck species that are less endangered (Table 1). This fact rather suggests that reproductive success at the nesting stage is unlikely to be the major cause of the population decline in Baer's Pochard, assuming our results to be typical for other areas.

The major causes of complete nest failure in studied Baer's Pochard differed between the two study years, with nest desertion being predominant in 2018, but nest predation in 2019. Nest desertion could potentially be associated with excessive high ambient temperatures. Avian eggs are usually incubated at 36°–40°C and extraordinarily high temperatures can incur energy costs to incubating females; the developing embryos are also highly sensitive to even brief exposure to lethal temperatures of 40.5°C and above (Conway & Martin 2000). The central Yangtze River floodplain frequently experiences maximum daily ambient temperatures > 35°C during the peak incubation period of Baer's Pochard (mid-May to mid-July). Temperatures around nests could be higher because dense vegetation limits ventilation of warm water vapour from open water surfaces, potentially leading to overheating stress on Baer's Pochard. In 2018, there were nine days with a maximum daily ambient temperature of > 35°C during the peak incubating period, compared to one day in 2019, which could have contributed to the observed between-year differences in the rate of nest desertion.

More frequent nest predation in 2019 was likely due to the extensive activity of 60–70 Water Buffalo *Bubalus bubalis* grazing in the study area in that year (compared to very few in 2018), which removed emergent vegetation and potentially provided access for weasels to nests. During the peak incubation period, rainfall was higher in 2019 (804 mm) than in 2018 (716 mm), a fact that may explain high nest failure rate due to flooding in 2019 compared to 2018. Nest predation can be related to rainfall in an indirect manner, when dry years make nests more accessible to the mammalian predators.

Waterfowl nests subjected to intraspecific or interspecific parasitism are more likely to be deserted by host females, presumably because of the increased fitness costs to hosts or the limited ability for host females to incubate exceptionally large clutches (Giroux 1981; Amat 1985). However, in our study, Baer's Pochard nests containing eggs parasitised by conspecifics were more successful than those unparasitised.

Nest visits by researchers is not thought to have increased the possibility of nest desertion or predation in this study. Among 39 nests that were visited more than once, 33 were still active or successful at the second visit, two were flooded and the remaining four deserted or predated. All four nests monitored every 1–2 days during the egg-laying stage survived at least until incubation began, and of four nests monitored intensively during the late incubation period, two hatched successfully, one was flooded and only one was predated. Among the six nests whose fates had been known when found for the first time, one was judged successful, two were flooded and the remaining three deserted or preyed. The nine nests monitored by video cameras did not experience a reduction in success rate (55.6%) compared to the overall level. There were five nests that had failed when first found, one due to flooding and the four others due to nest desertion or predation.

Implications for conservation

The current study, which reveals reproductive habitat requirements and factors limiting nest success of Baer's Pochard, may provide evidence-based advice on conservation of the Critically Endangered species. Habitats are the first priority for species conservation. The two sites so far confirmed to be reproductive habitats of the species around Wuhan city have continuous wetlands of 120 ha (Wang *et al.* 2019) and 154 ha (this study), respectively. Our study shows that Baer's Pochard depended on breeding ponds with emergent vegetation and water depth of > 1.5 m in which to dive for food. Therefore, we consider that at least 120 ha of continuous wetlands with emergent vegetation and sufficient supply of unpolluted open water are fundamentally important to sustain a breeding population.

Unfortunately, wetland habitats suitable for Baer's Pochard to nest are currently rare and fragmented in the middle parts of the Yangtze River floodplain, where wetland ecosystems were historically far more widespread. It is a fundamentally important issue to promote the restoration of wetland ecosystems by using Baer's Pochard as the flagship species, which may be possible given that the Chinese government has made protection of the Yangtze River a national policy priority. There is a pressing need to undertake a large-scale assessment of wetland units that can potentially be used by breeding Baer's Pochard, but for some reason are not currently available or occupied. Such a survey will allow us to identify wetlands that qualify for protected areas. Much current conservation policy has focused on large, mostly intact wetland landscapes, but our study shows that Baer's Pochard can aggregate and breed successfully in high densities in relatively small, isolated patches of suitable habitats. Protection of such productive areas is more urgent for conservation because they tend to contribute to local biodiversity and to be disproportionately susceptible to small scale local human activities, as argued in a recent study (Wintle *et al.* 2019).

In terms of habitat management, we suggest that the creation of optimised wetland mosaics that contain both emergent vegetation and open deeper water would be effective measures to improve breeding habitat for Baer's Pochard. Complete nest failure of Baer's Pochard can be caused by flooding due to either heavy rainfall or manipulation of pond water levels for aquaculture. Mandatory regulation of suitable water levels in ponds with the potential to support breeding Baer's Pochard would ensure optimal breeding habitats and reduce the risks of flooding. The 2019 observations revealed that Water Buffalo activity was a potential factor leading to nest failure, so cooperation with local communities should be undertaken to prevent the livestock from entering the ponds where Baer's Pochard are breeding.

Conservation measures at the scale of nest site microhabitat are needed. Baer's Pochard prefer nesting on small isolated platforms. Such microhabitats occur randomly in breeding ponds, but are frequently absent despite other nesting requirements being satisfied within a site. We therefore suggest artificial nesting platforms in deep water areas as a potentially useful method to increase Baer's Pochard breeding densities, and at the same time to prevent mammalian predators from accessing duck nests. Our study suggests that high temperatures during incubation in the subtropics are potentially responsible for nesting failure in Baer's Pochard. A recent study also revealed that heat waves may cause mortality to developing avian embryos (Griffith *et al.* 2016). Planting lotus among emergent vegetation or establishing artificial shelters around Baer's Pochard nests may improve nest thermal conditions and avoid the risk of overheating during periods of high ambient temperatures. Nevertheless, we should be aware that, in the long run, reproduction of Baer's Pochard in the subtropics will make the species susceptible to increasing global warming.

It is worth noting that any management measures suggested above should be considered as "hypothetical" (Austin *et al.* 2014). Follow-up monitoring and assessment should be performed to determine the effectiveness of different measures; if they are demonstrated to be less effective than expected, modifications will need to be made. Baer's Pochard have been present at this subtropical site year-round at least since 2015, but it is unknown whether breeding and wintering individuals are the same. To provide a better understanding of the causes of Baer's Pochard population declines, we should be able to identify whether the individuals that breed and winter in this study area in southern China are the same. The most effective approach to answering such a question is the deployment of individual marks or better still telemetry devices, which will allow us to monitor the movement and habitat use of individuals throughout the annual cycle. Such methods would also make it possible to pin-point currently unknown important areas for the species and enlighten our knowledge of habitat requirements along migratory pathways, which in turn would provide a basis for establishment of the species-specific protected area network (Beatty *et al.* 2014).

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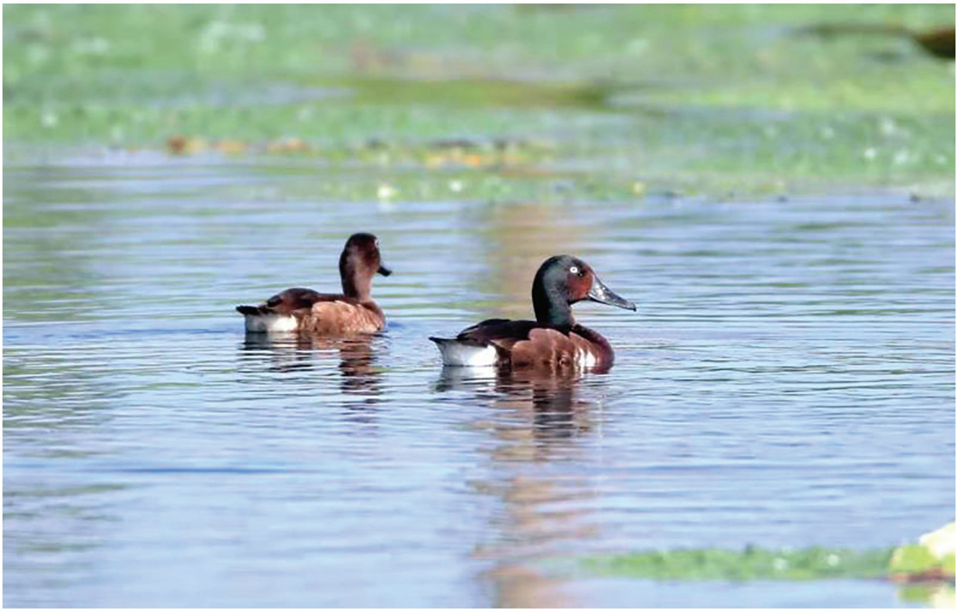

Photograph: Baer's Pochard and their breeding habitats in south China, by Huigong Yu.