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Geographical variation, sex and age in Great Bittern *Botaurus stellaris* using coloration and morphometrics

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Biometrics, plumage and bare-part colour of 87 Great Bitterns *Botaurus stellaris* from the UK, France, Italy, Poland and Belarus, of known sex (sexed by behaviour, DNA or dissection), were analysed to provide reliable sexing and ageing criteria for this little-known species, and to investigate geographical variation in biometrics. Four parameters were analysed: bill length, tarsus, wing length and body weight. We found little (though significant) geographical variation across Europe, but this was not clinal and we cannot exclude variation in measurement technique among observers. Males were significantly larger than females for all biometric parameters: a discriminant function based on these parameters was able to sex correctly all individuals. Body weight varied with season, especially for males. During the breeding period, lore colour was also a reliable sex-criterion. Ageing proved more difficult and required a combination of iris colour (which darkens with age) and flight-feather moult. From this, the largest sample size of known-age Great Bitterns, we conclude that most previously published criteria for age determination of this species were wrong.

In studies that involve the capture of birds, it is often important to be able to determine the sex and age of individuals in the hand. Knowledge of this has progressed considerably over recent decades for most European species (e.g. Svensson 1992, Baker 1993, Jenni & Winkler 1994). However, sexing and ageing individuals in some monomorphic species remain problematic. Genetic sexing, though now widely employed (Fridolfsson & Ellegren 1999), may be difficult or expensive, and alternative methods, such as discriminant analyses of morphological measurements, are still widely used for sexing birds (e.g. Green & Theobald 1989, Gruys & Hannon 1993, Genevois & Bretagnolle 1995, Renner & Davis 1999). These have the additional advantage of allowing the investigation of geographical variation in size and shape.

The Great Bittern *Botaurus stellaris* remains a poorly known species because it is rare and difficult to catch. So far, published biometric data are based on skins (Cramp & Simmons 1977, Baker 1993), and even more recent work still relies on those old data (Hancock & Kushlan 1984, Voisin 1991). Knowledge of ageing and sexing Bitterns was reviewed by Baker (1993): the cap and moustachial stripe of juveniles are less contrasted than in adults, while the margin of greater coverts is whitish and outer primaries are pointed. Male and female Great Bittern plumages are alike, although males are larger (Cramp & Simmons 1977, Voisin 1991) and, during the reproductive period, undergo enlargement of the median part of their neck for call production (Puglisi *et al.* 2001). Owing to its decline in many European countries (Tyler *et al.* 1998, Kushlan & Hafner 2000, BirdLife International 2004), several study programmes have been conducted (UK, Italy, Belarus, France, Germany, Belgium, Poland) that included capture and ringing birds, some of which were of known sex and age. Here we summarize data from five European countries, and provide the first large sample (96 captures that

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involved 87 individuals of which 77 were of known sex) of measured and sexed individuals. Our aims were to investigate geographical variation in body size, to provide basic data on wing feather moult, to investigate head, iris and lore colours as an aid to determining age and sex, and to provide equations based on biometric parameters for sexing adults.

METHODS

Study sites

Great Bitterns (hereafter Bitterns) were studied at different sites in the UK, France, Italy, Poland and Belarus (Fig. 1). In the UK, Bitterns were caught at eight sites, especially on Leighton Moss and Minsmere, in 1987–2003. In France, Bitterns were caught on three main sites in 2003–04: Seine estuary, and Charnier-Scamandre and Vigueirat, the latter two both in the Camargue. In Italy, Bitterns were caught in 1997–2001 at Massaciuccoli and Colfiorito. In Poland, the study was carried out in 2003–05 in six sites located in the Lublin region in the southeast of the country. In Belarus, the study was carried out in 1999–2005 in the south of the country at Beloe fish-farm.

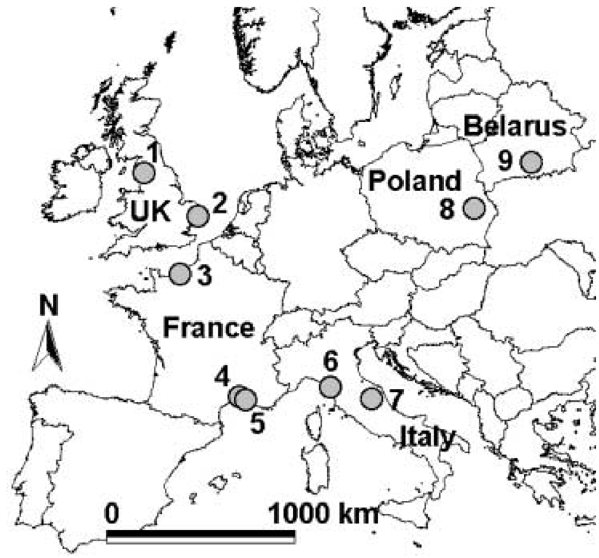

Figure 1. Map of the study area. From west to east – UK: 1 Leighton Moss, 2 Minsmere; France: 3 Baie de Seine, 4 Charnier-Scamandre, 5 Vigueirat; Italy: 6 Massaciuccoli, 7 Colfiorito; Poland: 8 Lublin; Belarus: 9 Beloe fish-farm.

Captures and measurements

Catching Bitterns is difficult, mainly because of their secretive habits, and (at least in Western Europe) the species' rarity. Different methods were used to catch males: vertical nets and playback of booms (UK: Gilbert *et al.* 2005), simply flushing males towards nets (Belarus), landing net after luring a male with playback or after approaching it while spontaneously booming (Italy: Puglisi *et al.* 2001), and using a mirror trap within the booming range of a male (France, following Huschle *et al.* (2002) for the American Bittern *B. lentiginosus*). Female catching required locating the nest, and was carried out in all countries but the UK. All but two females in Belarus and France were caught using vertical nets placed 3 m from the nest, with a further horizontal net overhanging the nest. Females returned quickly to their nests and were then flushed into the nets. In Italy and Poland, seven females were caught near their nests with vertical nets. Rarely, males did not fly when approached and could be caught by hand, and this also occurred for two females in France. Most captures ($n = 78$) took place during the breeding season, from March to June, but 18 were outside this period. In the UK and Poland, 11 freshly dead birds were sexed by dissection or DNA analysis. Other birds were sexed by behaviour, males being territorial and booming, while females alone attend the nest (Cramp & Simmons 1977, Géroudet 1978, Voisin 1991, del Hoyo *et al.* 1992). Measurements were taken according to Svensson (1992) and Baker (1993), and were wing length (±1 mm), bill length from the feathers to the tip of the bill (±0.1 mm), tarsus length (±0.1 mm) and body weight (±10 g). We could not check for consistency between observers, but these were always limited in number (generally, one or two by country), and were all trained in bird handling.

Coloration and moult

Photographs were taken of wing feather shape and wear, size and colour of cap and moustache, colour of the loral skin and iris colour in all countries but the UK, that permitted detailed *a posteriori* description. Iris colour was categorized into four types: uniformly dull pale olive-yellow (type 1); largely olive-yellow around the pupil, orange ring on outside, dark crescent under the pupil (type 2); orange-brown with a small yellow ring around the pupil, sometimes with the dark crescent under the pupil still visible (type 3); and uniformly maroon, dark orange-red or dark chestnut (type 4). Moult and wing-feathers were described according to the terms and methodology in Jenni and Winkler (1994). Except when specified, an 'adult' indicates a bird which is more than 1 year old in autumn and more than 2 years old in spring; immatures are younger birds.

Statistical analyses

Univariate statistical analysis (analysis of variance, ANOVA) was performed on each biometric character. Then, we used multiple analysis of variance (MANOVA) to obtain multivariate statistics (Wilks' lambda statistics), and carried out quadratic discriminant function analysis (DFA). We used quadratic DFA rather than linear DFA as the criterion of homoscedasticity was not met. DFA provides a quantitative check on the discriminatory power of the discriminant functions, by allocating single observations into the *a priori* group with the closest centroid in the multivariate space (Foottit & Mackauer 1980). Thus, the percentage of observations correctly classified into their *a priori* groups gives an indication of the extent of the separation. Following each analysis, two estimates of classification power were calculated. The first one, simply derived from resubstitution of all individuals, provides an apparent error rate (the error count), but has an optimistic bias. The second was obtained by a cross-validation technique (a jackknife procedure), and is probably more realistic (SAS 1989). The stepwise discriminant function was also used for detecting the biometric parameters that were the most informative with regard to sex discrimination, taking into account correlation between variables. Finally, canonical discriminant analysis (which differs from quadratic DFA) was used to derive scores of each individual and allow graphical representation. A principal component analysis was performed on the four biometric parameters (69 individuals) to summarize geographical variation (e.g. Bretagnolle 1995). We used original data and a correlation matrix, in which the first axis (PC1) is indicative of overall body size, and PC2 of shape (see discussion in Rising & Somers 1989). Non-parametric tests were used when sample size was low and/or when variables did not follow normal distributions. All statistical analyses were performed on SAS 8.0 software.

RESULTS

Biometrics and sexing of adult Bitterns

Table 1 summarizes the biometric measures of 77 different adults (86 measurements) of known sex, as well as those reported from the literature. All biometric measures differed significantly between sexes (see Table 1 for statistics), but partially overlapped (Fig. 2a & 2b). Discriminant analysis was able correctly to classify all 69 individuals for which the four biometric characters were available (Fig. 2c), and only two individuals (one of each sex) were misclassified when applying a cross-validation technique. Posterior probability of error rate was 0.008 with cross-validation indicating that an individual could be sexed with more than 99% confidence using the four biometric characters. A stepwise discriminant analysis revealed that body weight and wing length were the most sexually dimorphic parameters, and using just these, only two birds out of 74 were misclassified (canonical discrimination function: $8.62278 \times \text{weight (kg)} + 0.36924 \times \text{wing (cm)} - 23.02484$). However, as body weight varies between seasons (see below), we examined discriminant functions without weight, and found that wing and bill lengths had very high discrimination power, as only one of 79 birds was incorrectly sexed using resubstitution and two males when using cross-validation (canonical discrimination function: $2.95445 \times \text{bill (cm)} + 0.51973 \times \text{wing (cm)} - 37.96699$).

Tarsus and body weight varied geographically in females (Kruskal–Wallis test, $\chi^2 = 16.46$, $df = 4$, $P = 0.0025$ and $\chi^2 = 12.53$, $df = 4$, $P = 0.014$), as did bill length in males ($\chi^2 = 10.85$, $df = 4$, $P = 0.028$). Using only countries with at least eight individuals for a given sex, a MANOVA detected slight but significant geographical variation in both sexes: females, Wilks' lambda = 0.48, $F_{48,8} = 2.65$, $P = 0.017$; males, Wilks' lambda = 0.52, $F_{52,8} = 2.48$, $P = 0.023$. However, there was extensive overlap between countries, and no spatial pattern, such as a gradient, was revealed by a PCA performed on the data set of 69 measured birds (Fig. 2d).

Repeatability could be evaluated and tested (following methodology described in Lessels & Boag 1987) using eight birds recaptured once and one bird recaptured twice (though sample size was less in some cases because not all parameters were measured): high repeatability was found for wing length (0.664, $F = 89.38$, $P < 0.0001$), but it was only moderate for tarsus (0.208, $F = 51.77$, $P < 0.0001$) and body weight (0.132, $F = 32.25$, $P < 0.0001$), and low for bill length (0.113, $F = 3.18$, $P = 0.05$). Body weight did not vary much within season in males (the largest increase during the breeding season was 110 g for an Italian male, whose mid-neck circumference had enlarged from 162 to 184 mm), but it was particularly

Table 1. Summary statistics (mean ± sd, range (sample size)) for the four biometric parameters, according to sex (only birds of known sex are considered). Sample size refers to all the measurements obtained (i.e. include recaptures and recoveries). Immatures and adults are combined. Statistical significance in sexual dimorphism is tested using one-way ANOVA.

	Body weight (g)		Wing length (mm)		Bill from feathers (mm)		Tarsus (mm)	
	Male	Female	Male	Female	Male	Female	Male	Female
This study								
UK	1485 ± 366.14	1042 ± 83.86	350 ± 8.62	319 ± 8.64	70.3 ± 3.36	68.4 ± 1.92	107.8 ± 8.46	96.8 ± 4.79
	990–2060 (12)	955–1145 (5)	339–368 (11)	312–330 (5)	65.6–74.9 (10)	66.4–71.1 (5)	93.1–117.0 (8)	91.3–99.7 (3)
France	1598 ± 109.60	855 ± 84.08	352 ± 10.41	316 ± 7.92	70.2 ± 2.34	65.5 ± 2.94	99.9 ± 5.79	91.9 ± 2.32
	1520–1675 (2)	700–1010 (10)	340–360 (3)	303–324 (10)	68.7–72.9 (3)	61.0–69.6 (10)	94.5–106.0 (3)	88.4–95.3 (10)
Italy	1656 ± 135.52	770	344 ± 10.86	290	73.8 ± 2.75	63.5	102.0 ± 3.49	89.6
	1350–1870 (19)	(1)	318–361 (15)	(1)	65.5–78.0 (19)	(1)	95.6–106.5 (15)	(1)
Poland	1900	850 ± 70.71	364 ± 3.54	318 ± 6.25	74.1 ± 0.21	66.8 ± 4.33	117.2	95.1 ± 1.47
	(1)	750–950 (6)	361–366 (2)	310–331 (8)	73.9–74.2 (2)	59.6–75.1 (8)	(1)	93.4–98.1 (8)
Belarus	1510 ± 194.72	844 ± 57.25	351 ± 8.98	317 ± 5.98	72.4 ± 2.52	68.5 ± 1.76	103.5 ± 8.00	90.5 ± 2.77
	1195–1800 (10)	734–966 (14)	335–366 (10)	308–326 (13)	67.2–75.8 (10)	64.7–71.0 (14)	92.7–121.0 (10)	85.5–94.6 (14)
All countries	1582 ± 243.98	874 ± 97.23	349 ± 10.28	316 ± 8.05	72.5 ± 3.08	67.2 ± 3.03	103.9 ± 6.91	92.4 ± 3.33
	990–2060 (44)	700–1145 (36)	318–368 (41)	290–331 (37)	65.5–78.0 (44)	59.6–75.1 (38)	92.7–121.0 (37)	85.5–99.7 (36)
Test	$F_{79,1} = 277.4$		$F_{79,1} = 247.8$		$F_{83,1} = 65.5$		$F_{74,1} = 86.0$	
	$P < 0.0001$		$P < 0.0001$		$P < 0.0001$		$P < 0.0001$	
Previous studies								
Bauer and Glutz	1341 ± 384.60	1036 ± 118.75						
von Blotzheim (1966)	750–1940 (9)	867–1150 (5)	342–377 (3)		69–80 (3)		100–125 (3)	
Cramp and			346 ± 6.67	311 ± 7.34	69.1 ± 3.24	64.3 ± 2.10	102 ± 3.53	91.0 ± 2.63
Simmons (1977)			335–357 (21)	296–327 (16)	61–74 (20)	60–68 (16)	97–109 (11)	87–95 (9)
Baker (1993)			333.4	306	70.8	66.4	98	91.6
			310–347 (20)	278–336 (15)	66–75 (20)	60–71 (15)	88–105 (18)	83–98 (14)

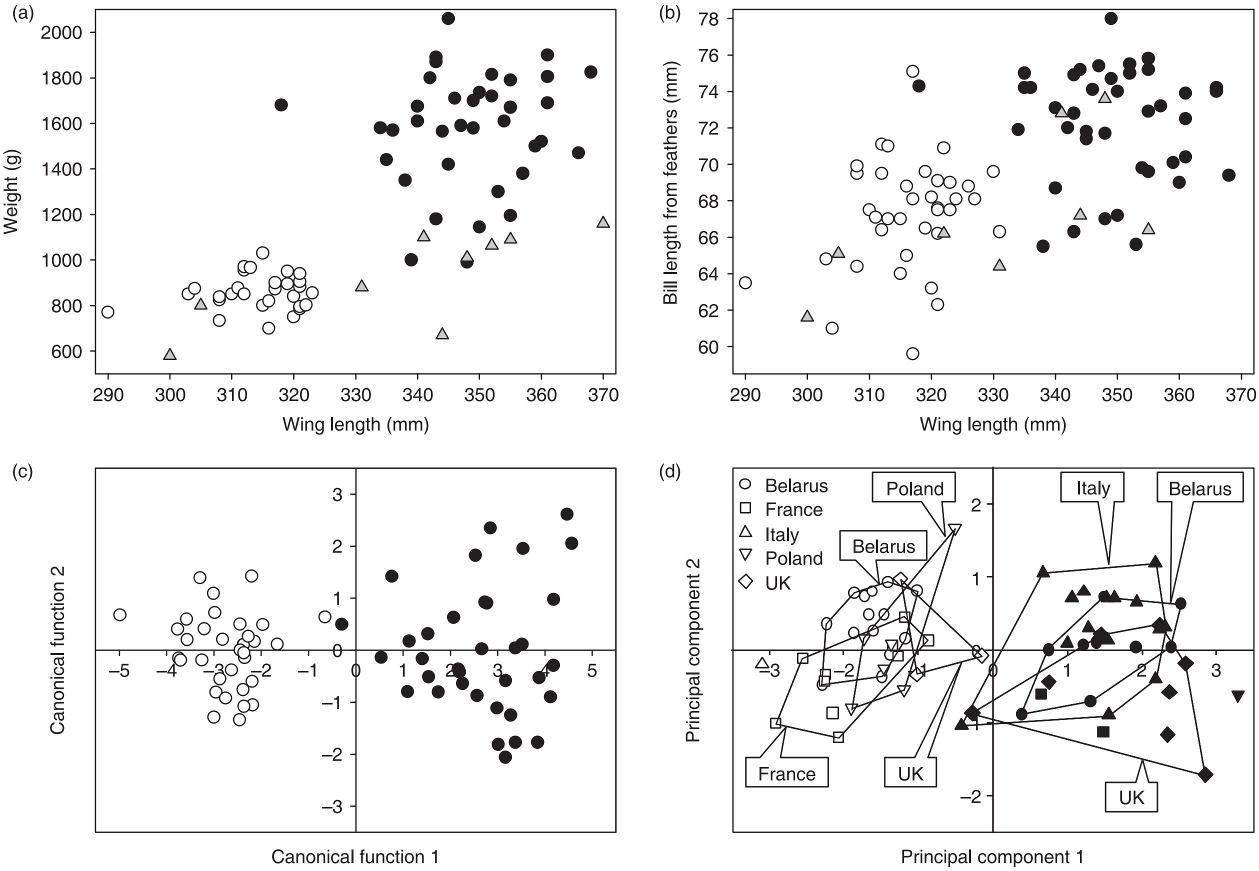

Figure 2. (a) Relationship between wing length and body weight: black dots, males; white dots, females; grey triangles, sex unknown. (b) Relationship between wing length and bill length; same symbols as in (a). (c) Results of a discriminant analysis using the four biometric parameters and performed on 69 Great Bitterns of known sex (see Methods for sexing procedure, and statistical details): black dots, males; white dots, females. (d) Results of a principal component analysis performed on the same 69 individuals: black dots, males; white dots, females.

variable between seasons with nearly 50% increase between non-breeding and breeding periods (1103 ± 281.3 g, $n = 10$ vs. 1619 ± 198.7 g, $n = 38$; $F_{47,1} = 44.6$, $P < 0.0001$). This was the reverse for females, which lost weight, though not significantly (855 ± 80.2 g, $n = 33$ vs. 913 ± 198.1 g, $n = 6$; $F_{38,1} = 1.57$, $P = 0.22$).

Moult, bare parts and ageing

The colour of the cap and the moustache varied due to wear, from black (new feathers) to pale brown. Its length varied considerably between individuals, irrespective of sex (M.D., L.P. and L.D. pers. obs.). Crown feathers were brown, worn and faded in 21 of 35 birds caught in spring, and black in only six (intermediate in eight cases), independently of sex ($\chi^2 = 1.36$, $df = 2$, $P = 0.51$).

No bird was caught in active moult. Feathers of different generations appeared randomly distributed in 48 individuals that had primaries of more than one generation. We were able to compare the same wing before and after a postnuptial moult in five birds within the same season ($n = 50$ primaries): 32% were moulted in two consecutive years, 62% in a single year and 6% never. For the ten external secondaries, these scores were, respectively, 26, 60 and 14% ($n = 50$). Thus, flight-feathers were renewed on average every second year, but some were moulted annually, while others were retained for two consecutive moults. Moreover, in nine cases we were able to compare both wings of the same bird; moult was not synchronized because for each bird, 1–3 corresponding feathers were of a different generation. Furthermore, primary coverts were of the same age as corresponding primaries in 68% of cases ($n = 28$ from 18 individuals), whereas the greater secondary coverts never were.

During the reproductive period (March–June), lore colour as well as orbital ring were either greyish-olive (more or less brownish tinged) or entirely greyish, or dull to pale blue. All birds of the first group were females (*n* = 31), while all birds of the second were males (*n* = 34). In the non-breeding season, all birds (*n* = 7) belonged to the first group, irrespective of sex. Iris colour did not differ between sexes and was distributed as follows: type 1 (seven), type 2 (18), type 3 (23), type 4 (14), with two individuals intermediate between types 1 and 2, and two between types 2 and 3. The iris colour of recaptured birds (eight recoveries for seven birds) became either darker with age (three cases) or unchanged, and never lightened. All but one bird with a single wing-feather generation had iris type lower than 2 (mean = 1.3, *n* = 10), while all birds with three wing-feather generations had an iris type higher than 2.5 (mean = 3.25, *n* = 14).

DISCUSSION

Geographical variation in Great Bitterns across Europe

Although distributed over much of the European continent, and despite birds being measured from Italy to Belarus, we failed to detect any clear pattern of geographical variation in body size (PC1) or shape (PC2). There was a large overlap among the different countries in both sexes. We did, however, detect significant geographical variation in overall body size, and some biometric parameters (tarsus and body weight for females, bill length for males). It is unlikely that different methods of measurement between countries account for this variation, although we cannot totally dismiss this possibility.

Sexing Great Bitterns

Male Great Bitterns are larger than females for all measurements (see also Cramp & Simmons 1977, Voisin 1991, Baker 1993). However, body weight varies greatly in males (50% increase from winter to summer), and also in birds from migratory populations that increase their fat reserves before leaving the breeding grounds (M.D. & L.D. pers. obs.). Furthermore, Bitterns are reported to lose weight during adverse environmental conditions (Cramp & Simmons 1977). All biometric parameters are remarkably variable in this species. Although coefficients of variation ranged from 3 to 15% according to parameter and sex (data extracted from Table 2), the range of values found in this study is particularly large for body weight (700–2060 g), and even for wing length (290–368 mm; see Table 2). We therefore recommend the use of discriminant functions involving wing and bill lengths, or possibly the four biometric parameters, as they provide more than 95% correct sex identification in adult Bitterns. These discriminant functions are presumably valid for all European populations, as data were collected across the continent (except Scandinavia).

Sexing during the reproductive period (mid-March to June) is also possible by coloration, as male lores are bluish (see also Hancock & Kushlan 1984), a character apparent even at some distance. However, as in other Ardeids, this disappears in winter (del Hoyo *et al.* 1992). Conversely, colour and the size of the cap and the moustaches, which have been suggested to be sexually dimorphic (e.g. Alessandria *et al.* 2003), as in the American Bittern (Gibbs *et al.* 1992), appear to be of no use for the Great Bittern.

Ageing Great Bitterns

All previously suggested plumage criteria for ageing Great Bitterns proved unreliable. However, our study shows that a combination of parameters may allow age evaluation. Iris colour varied between individuals, but darkened with age in recaptured birds. We also examined over 300 chicks and juveniles in the nest before fledging, and all had olive-yellow irides, i.e. type 1 following our classification. In several raptors, changes of the iris colour are known to be related to age (Newton 1986, Leroux & Bretagnolle 1996, Forsman 1999), and this is apparently also the case in the Great Bittern. However, the precise course of change is not known currently, so that this is not a reliable character (see below). Although rarely mentioned in the literature, iris colour appears to have been described erroneously for the Great Bittern: yellow to red (Bauer & Glutz von Blotzheim 1966, Géroudet 1978), yellow (Cramp & Simmons 1977, Hancock & Kushlan 1984), orange-red (Yeates 1940) and white in juvenile (Naumann 1838; Voisin 1991). Wood (1986) even concluded that 'the normal iris colour of all species of *Botaurus*, regardless of sex and age, is yellow' and changes to orange-red during courtship.

Moult pattern is the best criterion for ageing many birds, especially when a contrast between juvenile and post-juvenile feathers is discernible (see, for example, Jenni & Winkler 1994). The moult of the flight-feathers in Ardeidae is known to be irregular (Cramp & Simmons 1977, del Hoyo *et al.* 1992, Baker 1993); they moult from several centres, in either ascending or descending direction, and a variable quantity are retained from one year to the next. For the Great Bittern, Baker (1993) suggests that between post-juvenile moult and the following spring, old flight-feathers and juvenile wing-coverts discriminate between immatures and adults. However, according to Cramp and Simmons (1977), during their first winter some individuals may moult some flight-feathers and wing-coverts, suggesting that a contrast is not sufficient to age birds in spring. From our experience, there is no systematic contrast of pattern and wear between juvenile and post-juveniles, because this varies greatly between individuals and possibly habitats.

However, if used jointly, iris colour and flight-feather moult allow Bitterns to be aged reliably. In autumn, after the post-juvenile and post-breeding moults, first-year birds have all flight-feathers of the same generation and an olive-yellow iris. Conversely, adults have been found with several generations of flight-feathers (one single exception) and a yellow-orange to reddish-brown iris. As in winter, some immatures can moult some flight-feathers (Cramp & Simmons 1977), and as a few adults may moult all the flight-feathers in summer, in spring we consider it unsafe to regard birds with only one generation of flight-feathers as immatures and those with two generations as adults. Only birds with three generations of primaries or secondaries are definitively adults. The immatures (second year) can be recognized as such only if the iris is still of juvenile type (types 1–2, based on birds with a single generation feather). Similarly, adult status is assured if iris is orange-brown with a small yellow ring around the pupil, or uniformly brown or dark reddish-brown (types 3–4).

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