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Satellite tracking of breeding black storks *Ciconia nigra*: new incomes for spatial conservation issues

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Abstract

Satellite tracking of black storks was used to estimate home range sizes and to study habitat selection during the breeding season. Breeding and non-breeding adults foraged over very large areas (ca. 54 000 ha for 12 territories), preferentially in woodlands with high number of river sources, mirroring the species needs for high quality water resource. Rearing and post-fledging ranges of breeding partners largely overlapped. Home ranges of non-breeding adults largely overlapped ranges of breeding birds, so that assessing home range size of breeding pairs from observed densities is not reliable. Protection and management of breeding and feeding habitats appear to be the most important conservation measures to be considered. This study allowed to evaluate how large these protected areas should be, and which habitat types they should encompass. Conservation measures for the species in western Europe should include protection of very large forest areas and also focus on managing river networks to ensure a high water quality as far as 20 km away from nests.

Keywords: Satellite tracking; Black stork; Home range size; Habitat selection; Conservation measures

1. Introduction

Conservation measures commonly focus on emblematic and patrimonial species, that are predicted to be good indicators of the habitat quality. As a group of high political concern, birds are subject to conservation plans for those species facing an unfavourable conservation status at an European scale (Tucker and Heath, 1994), while a special attention should be paid by nations to design Special Protected Areas (SPAs) for those species listed in Appendix 1 of the Directive of the Council of the European Community on the Conservation of Wild Birds (Directive 79/409/CE). Large species are certainly more concerned by habitat fragmentation and degradation because of their large home ranges and spatial needs. As almost all large bird species, storks are declining worldwide: 15 of 19 species are considered as regionally threatened (Del Hoyo et al., 1992). The exact causes for the regression differ by species, but they comprise habitat loss, excessive use of pesticides and direct exploitation by man (Tucker and Heath, 1994). In many cases, too little is known on species-specific ecological requirements to help with defining efficient conservation measures.

Deforestation or intensive forest exploitation – though less obvious in temperate zones – threaten specialist species depending on trees or forests to breed (Tucker and Evans, 1997). Many large bird species use tall trees to build their nests (especially raptors, herons), but few of them use also forests as foraging habitats. The latter species depend directly on the forest management and habitat quality for their fate. The black stork *Ciconia nigra* is one of them, as it nests and forage in old open deciduous forests, feeding on small vertebrates found along river streams or in small pools. Following Del Hoyo et al. (1992), the black stork should be considered as globally threatened and highly needs conservation policy, but its specific habitat needs in space and time have not yet been investigated.

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Though satellite tracking was first used on wild birds to study foraging ranges of breeding seabirds (Jouventin and Weimerskirch, 1990), the technique is currently predominantly used to study migratory strategies and identify wintering grounds of migratory species (see e.g. James et al., 2000; and review in Guan and Higuchi, 2000). Satellite tracking has already been used as a new conservation concept for migrating storks, providing opportunities for bird protection and scientific work (Kaatz and Kaatz, 1995). Though this technique is widely used to identify assembly points, resting areas and risk factors along migration routes of white *C. ciconia* and black storks (Berthold et al., 2001; Jadoul et al., 2001), it had never been used to identify ecological needs of breeding pairs. If white storks breed and forage in open habitats allowing the study of breeding pairs by distant observational surveys of colour-ringed birds, this is not the case for the shy black stork which forages mainly in remote forests. In this study, we used satellite-tracking of adult black storks during the breeding season to determine home range size, habitat use and habitat selection of the species. Our main aim was to determine minimal areas to be designated as SPAs and suitable breeding habitat to be included within these protected areas, in order to ensure efficient conservation of this threatened secretive species.

2. Materials and methods

2.1. Trapping and satellite tracking

During the breeding season, black storks generally feed alone or in loose non-territorial groups along rivers, brooks and pools. Birds were captured using special traps disposed on frequented water streams, then ringed and fitted with a satellite transmitter (PTT platform with harness, 70 g), before being released. Their geographical locations were recorded automatically until the transmitter battery died, during migration or in the winter quarters. Four adult breeding birds (both partners of two pairs, with nests 19 km distant from each other) were thus captured and fitted with satellite-transmitter in June–July 2000, during the chick rearing period. No capture of breeding adults was attempted earlier in the season because of conservation concerns as risks of breeding failure. One of the breeding female had already been fitted with a satellite-transmitter in summer 1998 to record its autumn migration route, and its transmitter was still emitting in early 1999, from January to 27th March (while it arrived on the breeding grounds on 13th March). During the 2000 breeding season, three non-breeding adults were also fitted with satellite-transmitters and followed in June, July and August, before they started to migrate.

To summarize, we obtained location data during the breeding season for: (1) one female during the pre-breeding season (during two weeks just after its arrival on the breeding grounds); (2) both adult partners of two breeding pairs during the chick rearing (chicks still at nest) and after the chicks' fledging (until their departure in migration); (3) three non-breeding adults during the summer (until their departure in migration).

Locations were obtained for each bird every five days during 15 consecutive hours. Confidence indices reported in this study are thus provided by the Argos system (from higher to lower quality codes of location estimates: Location Class (LC) 3-2-1-0-A-B). We mapped the individual locations using a Geographical Information System (ArcGIS 8; ESRI, 1999).

2.2. Home range modelling

Territories were modelled using the RangesV package (Kenward and Hodder, 1996), using the fixed kernel estimator (Worton, 1989). Home ranges determined by 95% of the bird locations were considered to represent the global range. Core ranges were determined using the first sharp step in the graph plotting the fixes contribution against the range size (Kenward and Hodder, 1996). For each breeding adult, home ranges were modelled using locations: (1) from date of capture until the chicks' fledging (last day of chick presence on the nest) for the rearing period; (2) from the first day of contact after the chicks' fledging to the departure in migration for the post-fledging period. Home ranges of non-breeding birds were modelled using locations from date of capture to the departure in migration (see Table 1 for details on tracking dates).

For the purpose of home range modelling, we used data with LC 3, 2, 1 and 0 pooled together. Adding locations of lowest confidence indices (A, B) could greatly increase home range sizes by considering some largely outlying locations (see Hays et al., 2001). We included data with LC 0 though their precision are over 1 km according to the official information given by Argos. As this might bias further estimations of home range sizes by increasing the effective ranges, we based our final analyses on core ranges, not global ranges, thus aiming to minor the effects of potentially low-precision locations. All Argos locations were also reported on maps to verify their eventual relevance and their occurrence on sites known to be potentially visited by storks (e.g. close to rivers and streams). The four breeding storks were also radio-tagged, and surveys at their nests were organized on some days in June–July, when the satellite transmitters were operating. This allowed to verify that Argos locations on that days were effectively close to the nest when the birds were at nest or in its vicinity (e.g. when the signal of the radio-transmitter was recorded from the nest). Overall, a small minority of locations with index 0 were erroneous and have not been considered when modelling home ranges. We finally performed an Analysis of Variance to test

Table 1
Home range parameters and sizes of black storks during the breeding season (using the fixed kernel estimator)

Group	Individual	Breeding status	First and last location dates	Number of locations	Global range (ha)	Core range (%) (ha)
Pair 1	1 (male)	R	31/05 – 11/07	66	82 952	39 730 (75%)
		PF	16/07 – 22/09	30	70 520	38 170 (75%)
	2 (female)	PB	13–27/03/1999	8	51 398	42 476 (85%)
		R	07/06 – 07/07	44	55 094	33 809 (85%)
		PF	12/07 – 07/09	38	44 044	28 829 (85%)
Pair 2	3 (male)	R	22/07 – 17/08	26	149 393	84 002 (90%)
		PF	22/08 – 01/09	10	16 182	16 182 (95%)
	4 (female)	R	16/07 – 16/08	37	172 020	40 685 (70%)
		PF	17/08 – 17/09	30	112 360	112 360 (95%)
Unpaired adults	5	NB	01/07 – 06/08	14	144 650	65 949 (80%)
	6	NB	16/07 – 06/09	41	121 930	61 900 (75%)
	7	NB	17/06 – 18/07	59	183 810	82 111 (80%)

All data from year 2000 if not stated otherwise. Global range is the 95% range, while the percentage of points contributing to the core range is given in brackets. For the breeding status, PB = pre-breeding, R = rearing, PF = post-fledging period, NB = non-breeding.

whether the inclusion of data with confidence index 0 had an effect on home range estimates. Estimates of core ranges using LC 0 to 3 did not differ significantly from estimates of global ranges when using LC 1 to 3 ($F_{1,21} = 0.002$, $P > 0.95$), while there was also no effect of the number of locations used to model ($F_{1,21} = 0.59$, $P = 0.45$). These arguments all put together, we are confident with our estimations of home ranges by considering all locations with confidence indices 3 to 0.

For breeding birds rearing chicks (still at nest), we measured the maximum foraging distance from the nest using the GIS package. Home ranges of breeding partners or of individual breeding adults considered were compared by pairs. For this purpose, all locations of the considered bird(s) (i.e. both partners during the same period, or one partner during both rearing and post-fledging periods) were mixed, and randomly divided into two sets of similar size, which were used to model fictive home ranges. This operation was repeated 10 times for each data group. Overlap values between pairs of modelled or fictive ranges were obtained using the RangesV package (two values: proportion of range 1 overlapping range 2, and proportion of range 2 overlapping range 1). The observed overlap values (minimal and maximal) were thereafter compared to the mean and standard deviation of the corresponding overlap values of the 10 fictive range pairs. If falling in between mean ± s.d., the two modelled ranges were considered not to differ significantly.

2.3. Habitat use and selection

Global and core ranges were further superimposed to a digitalized representation of the habitat over the region (CORINE Land Cover database, with 44 different habitat categories), using the GIS, and habitat polygons within the ranges were selected and stored to study habitat use. Respective areas covered by each of the 44 categories were similar in global and core home ranges when pooling all birds together ($r > 0.97$). Hence, only habitat use in core ranges is presented here.

We used a geo-referenced map of European rivers – included in the Arcview package – to obtain three more habitat parameters within the core ranges: total length of river streams, number of different river streams and number of river heads. To obtain a control set of same habitat parameters on random units, 20 random points located in forest habitats were generated within the region where the tracked storks had been localised. These points were used as centres to draw circles covering 54 000 ha each (the mean size of modelled core ranges) to be considered as control ranges, where the three river-related variables were measured. The variables obtained within storks' core ranges were further standardized to correspond to a reference area of 54 000 ha (standardized value = measured value/core range size × 54 000). Variables 'number of river streams' and 'number of river heads' were further log-transformed before conducting statistical analyses comparing control and observed core ranges. No analysis was perform to study the habitat selection in relation to forest covers, as the species is well known to exploit preferentially this habitat. We controlled that random ranges included at least 30% of forest habitats.

All statistical analyses were performed using the S-PLUS package (MathSoft, 1999). Results were considered significant for $p < 0.05$.

3. Results

3.1. Home range sizes and overlaps

Results on home range modelling are presented in Table 1, and core ranges of breeding adults, nest locations and river network are shown in Fig. 1. Mean core

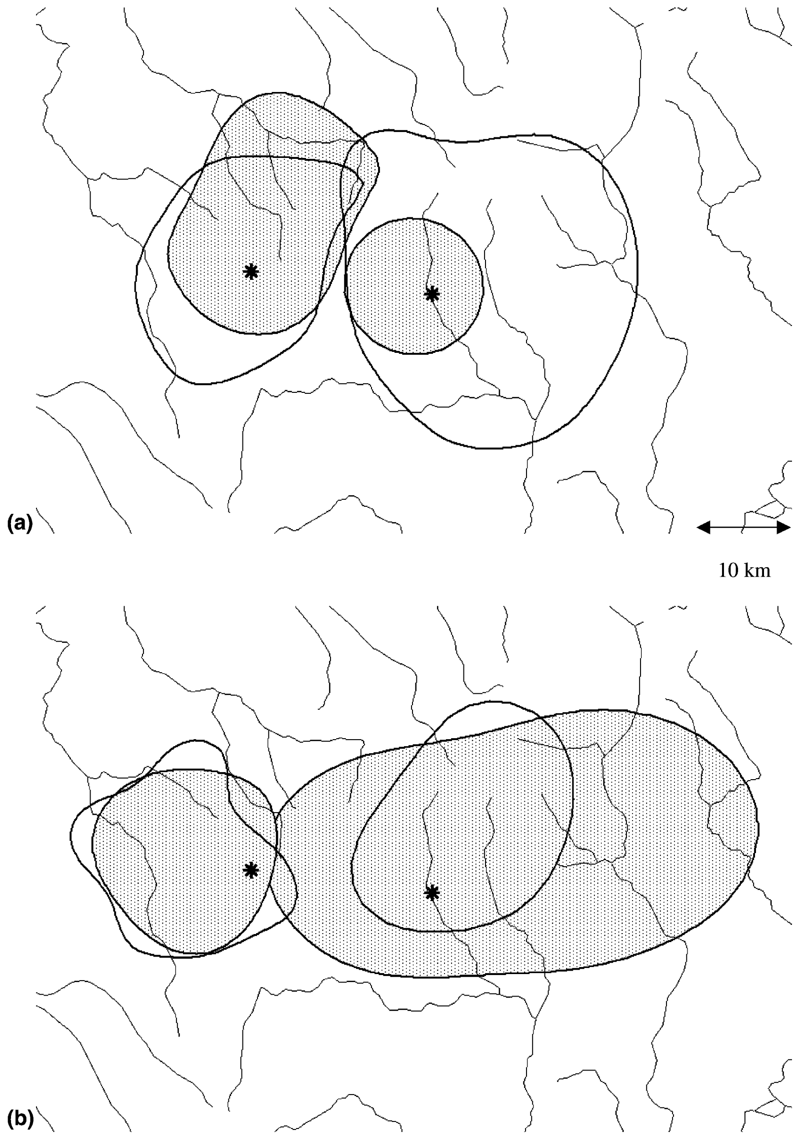

Fig. 1. Core ranges of both partners of two black stork breeding pairs during the rearing (open areas) and post-fledging (dotted areas) periods; (a) males and (b) females. The nest location (crosses) and the local river network are also shown.

ranges were: 49 556 ± 23 164 ha for adults with chicks at nest ($n = 4$); 48 885 ± 43 265 ha for adults with fledged chicks ($n = 4$); 69 987 ± 10 693 ha for non-breeding adults ($n = 3$), while the pre-breeding female used ca. 42 500 ha. We found no correlation between core range sizes and the number of locations ($r = 0.09$, $n = 12$) or the duration of the tracking period considered ($r = 0.003$, $n = 12$). Mean pre- and post-fledging core ranges of breeding adults were very similar, though with high individual variation. Whatever the sex and status of the bird and the period considered, mean core range size was: 53 850 ± 27 858 ha ($n = 12$). For birds rearing chicks at nest, the maximum foraging distance away from the nest was 19.7 ± 3.5 km (range 14.9–22.6 km, $n = 4$). Total foraging areas of breeding pairs covered 51 125 and 87 433 ha for pair 1 and 2 respectively during the rearing period, and 53 023 and 112 360 ha, respectively during the post-fledging period.

Overlaps between observed home ranges are presented in Table 2. Range overlaps between breeding pairs existed but were small, while they were more consistent between non-breeding and breeding adults. Mean and standard deviation of fictive home ranges overlaps are presented in Table 3. In pair 2, both partners exploited similar areas during the study period, so that we found no differences between ranges used by male and female (during the rearing or the post-fledging period), and no difference between the ranges used during the rearing and the post-fledging period (by the male or the female). In pair 1, only the female used similar ranges during the two periods, and the partners used different foraging areas during each of the study

Table 2
Overlap matrix of 10 ranges modelled for breeding and non-breeding black storks during summer 2000

Group	Individual	Status	Pair 1				Pair 2				Adults	
			1 (male)		2 (female)		3 (male)		4 (female)		5	6
			R	PF	R	PF	R	PF	R	PF	NB	NB
Pair 1	1 (male)	R	100	**69.5**	**56.4**	**54.1**	1.8	0	0	23.4	38.5	**50.0**
		PF	**72.3**	100	38.0	36.6	6.3	0	0	29.3	24.3	**76.0**
	2 (female)	R	**66.3**	42.9	100	**78.8**	0	0	0	4.3	28.2	20.7
		PF	**74.6**	48.5	**92.5**	100	0	0	0	1.6	23.5	26.1
Pair 2	3 (male)	R	0.9	2.9	0	0	100	19.2	44.3	**82.5**	28.4	30.1
		PF	0	0	0	0	**99.5**	100	**81.8**	**100**	49.2	38.5
	4 (female)	R	0	0	0	0	**91.6**	32.5	100	**93.6**	**50.7**	**51.5**
		PF	8.3	9.9	1.3	0.4	**61.7**	14.4	33.9	100	26.4	30.5
Unpaired adults	5	NB	23.2	14.1	14.5	10.3	36.2	12.1	31.3	45.0	100	47.4
	6	NB	32.1	12.1	11.3	12.2	40.9	10.1	33.9	**55.4**	**50.5**	100

Ranges of individuals in row overlap with ranges of individuals in columns. For the breeding status, R = rearing, PF = post-fledging period, NB = non-breeding. Values in bold are those >50%.

Table 3
Minimum and maximum overlap values for pairs of fictive home ranges and pairs of observed black stork ranges (a) for breeding partners during the same period (R = rearing, PF = post-fledging), (b) for individual breeding adults during both rearing and post-fledging periods)

	Group	Fictive overlap (mean ± s.d.)		Observed overlap	
		Minimum %	Maximum %	Minimum %	Maximum %
(a)	Pair 1, R	56.2 ± 19.0	97.9 ± 4.3	**56.4**	66.3
	Pair 1, PF	71.6 ± 10.6	88.9 ± 7.2	36.6	48.5
	Pair 2, R	67.3 ± 14.1	94.7 ± 4.1	44.3	**91.6**
	Pair 2, PF	64.4 ± 23.8	95.4 ± 5.7	14.4	**100**
(b)	Male pair 1	73.2 ± 11.9	95.8 ± 5.5	**69.5**	72.3
	Female pair 1	74.3 ± 6.3	93.4 ± 6.9	**78.8**	**92.5**
	Male pair 2	56.9 ± 12.0	99.3 ± 1.5	19.2	**99.5**
	Female pair 2	61.5 ± 11.9	94.0 ± 5.7	33.9	**93.6**

Observed values in bold are those within mean ± s.d. of corresponding fictive ranges.

Table 4
Habitat use of adult black storks during the breeding season, as main woodland and farmland habitats, and variables linked to the river network included in core ranges (modelled using the fixed kernel estimator)

Group	Individual	Breeding status	% deciduous forest	% mixed forest	% coniferous forest	% grassland	Total river length (m)	Number of river units	Number of river sources
Pair 1	1 (male)	R	34.9	5.5	4.6	6.8	43 286	5	4
		PF	37.6	5.3	4.5	6.9	52 084	6	5
	2 (female)	PB	50.1	5.1	4.7	6.2	70 673	8	3
		R	32.4	4.4	3.0	6.9	30 204	3	2
		PF	33.7	4.4	2.3	7.3	31 905	3	1
Pair 2	3 (male)	R	32.3	3.6	5.2	10.5	120 980	9	7
		PF	51.2	6.0	1.4	8.8	14 039	1	0
	4 (female)	R	43.3	3.8	4.2	14.3	44 650	6	6
		PF	31.3	3.4	4.4	14.6	137 018	12	9
Unpaired adults	5	NB	41.2	5.7	3.0	8.2	53 350	6	5
	6	NB	41.0	4.8	3.7	9.8	74 154	10	9
	7	NB	9.7	0.1	0.2	29.2	112 249	10	6

For the breeding status, PB = pre-breeding, R = rearing, PF = post-fledging period, NB = non-breeding.

periods. Non-breeding bird 7 was captured and subsequently foraged in a different zone, so that its range did not overlap others.

3.2. Habitat use and selection

Results on habitat use within core ranges are presented in Table 4. Core ranges were predominantly composed by deciduous forest (35.7 ± 5.2%), but also coniferous (4.2 ± 0.9%) and mixed forests (4.3 ± 0.8%). Other main habitats included in ranges were intensive agricultural areas (37.1 ± 9.2%), which is the commonest habitat in the region and in France, and grasslands (9.6 ± 3.5%). Globally, about half the ranges was covered by woodland, predominantly deciduous forests, except for one non-breeding adult with a very large home range and a large grassland cover. Total forest areas included in core ranges of all birds were meanly 22 257 ± 11 300 ha (range 8191–43 979 ha, $n = 12$), whatever the sex and status of the bird and the period considered.

We found no difference in total river lengths and number of river units included in random and observed storks' ranges ($F_{1,30} = 1.82$, $p = 0.19$ and $F_{1,30} = 3.54$, $p = 0.07$, respectively), but the latter included more river heads ($F_{1,30} = 8.58$, $p = 0.006$) than random ranges.

4. Discussion

4.1. Home range sizes and spatial needs

Though one should have expected such a species to forage over large areas when breeding, the observed range sizes were surprisingly large, and almost similar between breeding and non-breeding adults and for breeding birds during three stages of the breeding cycle. Owing to the methods used to model ranges from locations, these are minimal home ranges, and areas really used for breeding certainly exceeded values presented here. The small sample size available (seven birds) did not allow to compare birds of different sex or status, but individual variations in range size were eventually noted, and larger home ranges used by one of the breeding pairs could be linked to its later start in breeding. There are no available data on range sizes of breeding black storks in the literature, though information on breeding pair densities can provide cues to approach spatial needs during the breeding season. A recent study conducted on a Croatian flood plain with important forested area found high breeding density of one pair per 75 km^2 (for a total of ca. 60 pairs) thus representing potential mean breeding ranges of 7500 ha, if low territory overlaps were to be encountered. Similarly, maximum breeding densities are one pair per 1250 ha in Poland (Keller and Profus, 1992), per 500 and 2000 ha in two Latvian populations (Strazds et al., 2001), per 7400 ha in central Spain (Fernandez et al., 2001). Dornbusch (1992) suggested that black stork pairs need 5000–15 000 ha of suitable habitats to breed in Germany, and that adults feed within 6–15 km of the nest. Following a recent review by Lakeberg (1995), home ranges of breeding white stork pairs in western Europe vary from 100 to 3500 ha. In southern Germany, the same author found high inter-annual variations in breeding range size of the same pairs, from 200 to 1000 ha, while foraging areas of breeding pairs represented 950–4100 ha in Schleswig-Holstein (Thomsen, 1995) and 4400 to 6300 ha in The Netherlands (Jonkers, 1995). These range sizes are quite similar to those previously suspected for the black stork, but do not mirror the results found here for the latter species.

The large breeding ranges observed in the French black stork population could result from the method we used to model territories (satellite tracking, kernel estimator), but analysis of data were highly precautious in considering only good quality locations (see Hays et al., 2001) and core not global ranges. An explanation to these large territory sizes could be the exploitation of suitable but non-optimal breeding habitats by these storks, leading to large areas to be prospected for finding sufficient food resource to cover breeding needs. This population was only recently settled in the 1990s (Villarubias et al., 2001), and the number of known breeding pairs have been almost stable for many years. Though this stability was believed to be hardly comprehensible after the rapid colonisation (Villarubias et al., 2001), the marginal position of this population within the species range and the needs to forage over very large areas could explain the stagnation of the breeding pair number and density. Large overlaps between territories used by breeding pairs and non-breeding adults illustrate the difficulty to determine breeding home range sizes by simply measuring local densities in breeding populations. The larger individual variations in range sizes during the post-fledging period highlights the need to study the foraging habits of parents in relation to the chick dispersion during this period.

4.2. Habitat selection and conservation measures

The black stork shuns contact with humans and breeds preferentially in undisturbed open woodland (Del Hoyo et al., 1992). Alluvial forests remain the main foraging habitat of the species in eastern Europe (Schneider-Jacoby, 1999), but this optimal habitat is hardly available in western Europe. In this study, habitats used by the storks during the breeding season consisted of a mixture of woodlands and open areas, the former mainly deciduous forests, the latter comprising grasslands. The high proportion of ranges covered by intensive agricultural systems just mirrored the abundance of this habitat type in the region. As only the number of river heads included in used territories was significantly higher than that in random ranges, one important habitat parameter for breeding storks seemed to be linked with water quality of these rivers, as this quality could be expected to be higher closer to the sources and as the quantity of the river resource did not explain the habitat selection. These results confirm those found by Mahieu (2001) in Luxemburg during the post-fledging period on a breeding pair fishing in unpolluted streams with high biotic indices. Therefore, conservation measures for the black stork in western European low density populations should cover very large territories (from 50 000 to 100 000 ha per breeding pair) of predominantly deciduous woodland, and should especially focus on managing the river quality as far as 20 km away from the nests. The large observed overlaps and similar sizes between territories used by breeding partners during the chick rearing and the post-fledging periods should ensure the efficiency of such conservation measures. However, more studies are needed to investigate the potential temporal variations in habitat needs during the whole breeding cycle, though home ranges are probably smaller during incubation than during the chicks' rearing.

Protection and management of breeding and feeding habitats, such as slow-flowing rivers and streams within wooded areas, appears to be one of the most important conservation measures to be undertaken, and this study raised the opportunity to evaluate how large these protected or managed areas should be to efficiently ensure the breeding of the species in low density populations. The establishment of shallow artificial pools in grasslands or along rivers to improve food resources for storks (Tucker and Heath, 1994) would certainly help with increasing the breeding success and density in such populations. Considering the large observed breeding ranges in France, we should not expect local breeding densities to increase in the future if the river network is not managed, but if the breeding range expansion of the species should go on in the future, having studied ecological needs of the species allows to identify potential suitable breeding habitats elsewhere in the country where the species could be looked for. Potential variations in ecological needs for breeding black storks should also be investigated in the future by comparing home range sizes, habitat use and selection in populations with contrasting breeding densities and in different geographical areas over the species range.

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