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The Luangwa Valley, Zambia: flyway and stopover site for White Storks *Ciconia ciconia*

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Analyses of satellite telemetry data of White Storks *Ciconia ciconia* from the eastern populations at their stopover sites and staging areas document the importance of the Luangwa Valley, eastern Zambia, as a migration corridor bridging eastern and southern Africa. Twice each year from November to April, up to 100 000 White Storks may transit and rest in the area. Radio-tracked storks took from one to four days in either direction to traverse the entire Luangwa Valley. The preferred habitats for stopover sites and short-term staging, obtained using GIS, are deciduous woodlands and scrublands with sparse trees; croplands are preferred for longer staging periods.

Introduction

White Storks *Ciconia ciconia* migrate yearly from their breeding areas in Europe to Africa, where they spend their non-breeding season. Populations follow two different migration routes into their African staging areas: those fledged in Western European countries migrate in a western route via the Straits of Gibraltar into western Africa, while those from Eastern Europe (and partly Asia) follow a route to eastern or southern countries of Africa (Schüz 1971, Schulz 1988, Berthold *et al.* 1992).

The majority of White Storks migrating into Africa via the eastern flyway spend their winters in north-eastern and eastern Africa from Sudan or Chad to Kenya and Tanzania. One part of the population heads further south following the Rift Valley to stage in Zambia, Zimbabwe, Botswana, the Republic of South Africa or, more rarely, in Namibia. The storks pass several narrow corridors before reaching their African staging sites. As typical soaring birds, they avoid open water and exploit thermal convections generated by mountain ranges. The most important corridors identified so far for the eastern populations are the Bosporus, the Gulf of Iskenderun, the Jordan valley and the Gulf of Suez at El Tor (Van den Bossche *et al.* 2002, Kaatz 2004). They are located in the northern parts of their migration routes, leading into (and out of) the African continent. Little attention has yet been paid whether comparable corridors also exist along the migration route within Africa. Schulz (1988, pp 385 and 392) concluded from ringing analysis that in Zambia, besides a variety of regions, 'the Luangwa Valley may prove to be an important staging area for White Storks'. Besides a few ring recoveries, inaccessibility of the region prevented direct observations, particularly during the rainy season, lasting from the end of November until March or April, which is the time when storks pass through that area. Using satellite telemetry data we wanted to find out if the Luangwa Valley acts as such a migration corridor, how many White Storks may be expected in that area each year and when, as well as which habitats they use for resting and staging.

Satellite telemetry provides a means to characterise migration patterns for birds passing over impassable regions where traditional techniques of ground-based radio tracking or direct observations are not as feasible. Since migration routes of White Storks have been tracked by satellite telemetry from 1991 onward (Berthold *et al.* 1992, Van den Bossche *et al.* 1999), important details of their migratory behaviour such as spatial orientation and choice of stopover sites have been identified (Berthold *et al*. 2001, 2002, 2004). Duration, location and habitat requirements of staging areas can thus be analysed, as well as the exact flyways used for transit to and from these areas (Kaatz 2004, Gerkmann and Riede 2005). Knowledge of these details is essential for conservation efforts because storks face several threats along their migration routes especially from fences and wires, but also directly and indirectly from pesticides used on farmlands (Dallinga and Schoenemakers 1989, Oatley and Rammesmeyer 1998, Hockey *et al.* 2005).

Study area

The Luangwa Valley forms the south-western extension of the Great Rift Valley, stretching some 600–700 km with an average width of about 100 km. In the west, the valley borders on the steep slopes of the Muchinga Escarpment. In the east it smoothly climbs into the mountain ranges of western Malawi. The Luangwa River rising at the Malawi–Zambia–Tanzania border is one of the main tributaries of the Zambezi River. The valley floor drops from 1800–1500 m at the source to about 500 m at its deepest point, and is on average 1000 m lower than the surrounding plateaus. The valley floor from the upper middle is flat and sandy, so the Luangwa River is wide, slow flowing and muddy. The Luangwa River floods in the rainy season, around February, and falls considerably during the dry season, sometimes completely drying out in its upper reaches.

Materials and methods

For the identification of stork occurrences we used telemetry data collected during a tracking project carried out by the Max Planck Institute for Ornithology from 1991 onwards. For this publication, data collected between 1991 and 2003 (and until 2005 for the individual 'Princess') were used (Van den Bossche *et al.* 2002, Kaatz 2004). To obtain high-accuracy data with a considerably low error, we applied a method developed by Kaatz (1999, 2004) to assess the accuracy of localisation. ARGOS provides accuracy information for each signal as a localisation class, but Kaatz (2004) and Hays *et al.* (2001) could verify divergence in data by comparing ARGOS positions with associated GPS positions.

Kaatz (1999) developed a new method to evaluate position accuracy, using correlation analyses of several parameters that come with every position, e.g. signal strength or stability of frequency. For every ARGOS localisation class and parameter, the mean deviation is calculated and comparable deviation groups are ordered by quality (from 1 = least coordinate deviation to 3 = largest deviation) (see Kaatz 1999). In this study, we used data with a deviation of less than 5 km.

To ensure that the storks we analysed did not just cross the region but stayed for feeding or resting, we used telemetry data from early morning hours before storks start or evening data when storks have already landed according to Kaatz (2004). Data presented here include already published information (Kaatz 2004) with some additional telemetry data from the migration years 2003/04 and 2004/05 (Table 1). Satellite data were visualised using ArcView 8 and ArcGIS 9. Mapping allowed the overlay of resting places to ecoregions, conservation areas and anthropogenic influence (Gerkmann and Riede 2005). To obtain information about habitat preferences two GIS-based data systems were used: the World Wildlife Fund (WWF) Terrestrial Ecoregions of the World (Olson *et al.* 2001) and the Global Landcover 2000 (GLC) map with a resolution of 1 km² (Hansen *et al.* 2000, Mayaux *et al.* 2004). More detailed vegetation maps of Zambia only cover smaller areas, e.g. the South Luangwa National Park (Astle 1989) and therefore could not be applied to the whole area under study.

GIS-based data were ground-truthed during the White Stork migration period in several regions of Botswana and the Republic of South Africa. They offered exact agreement for only 60% of the data (Gerkmann 2007). Giri *et al.* (2005) compared the GLC map with other satellite information and found an overestimation of croplands. Because most parts of the Luangwa Valley are inaccessible during the rainy season between December and May, ground-truthing during the migration period was impracticable. Thus, although not perfect, we had to rely on telemetry data mapped onto the vegetation as provided by the GLC map as so far the best available classified data set.

Results and discussion

Time and duration of rests

Without exception, all tagged White Storks that continued

Table 1: Basic data for White Stork occurrences in Zambia

Stork ring number	Name	Date or period of rest	Migratory route	Wintering area
KA 0749	Princess	20 December 1998	Autumn migration	Republic of South Africa
		6 March 1999	Spring migration	
		15–16 December 2001	Autumn migration	
		1–2 March 2002	Spring migration	
		17 March 2003	Spring migration	
		23–25 December 2003	Autumn migration	
		12–14 March 2004	Spring migration	
		5–8 December 2004	Autumn migration	
		8–10 March 2005	Spring migration	
V 6497		28–31 December 1996	Autumn migration	Botswana
		9–10 October 1997	Spring migration	
L 4298		19 November 1996	Autumn migration	Republic of South Africa
E 848		17–18 January 2000	Autumn migration	Botswana
		10–12 March 2000	Spring migration	
		20 December 2000	Autumn migration	
E 819		19–22 February 1999	Autumn migration	Zimbabwe/Mozambique
		31 March–2 April 1999	Spring migration	
E 817		30 January–14 February 1999	Autumn migration	Zambia and Zimbabwe
		10 April 1999	Spring migration	
E 846	Penelope	10 December 1998	Autumn migration	Botswana
		25–26 February 1999	Spring migration	
		30 December 1999–5 January 2000	Autumn migration	

their migration out of East Africa to staging areas in the south between 1996 and 2005 passed through the Luangwa valley and rested there for at least 1 d per trip. Ten adult individuals (out of a total of 26 tagged storks with complete information on their migration routes) passed over the area within a period from November to April (Table 1). Fourteen flights to and 11 flights from their terminal staging areas led these birds through Zambia (Figure 1). The remaining 16 storks staged in areas further north. Five storks wintered exclusively in regions of the Sahel (Chad and Sudan), and another two in eastern Africa, i.e. Kenya or Tanzania. Six storks wintered exclusively in north-eastern Africa. Ringed stork E 848 stayed in the Sahel in 1998/99, and the following two years it passed the Luangwa valley and wintered in southern Africa. Finally, two storks followed an 'erroneous' eastward route into the Yemen, which is described in detail in Berthold *et al.* (1997).

Datasets for the 10 storks heading for southern Africa included 118 occurrences that could be traced consistently either until arrival at staging grounds or even until arrival at their breeding areas in Europe, some also in subsequent years (Table 1). Flyway patterns of southward and northward migration seem to differ slightly: on their way south, storks stayed more often within the Luangwa Valley, whereas for homeward migration a more westerly route along the escarpment and mountain plateaus was taken (Figure 1). A similar pattern of variation in flyways of spring and autumn migration has been described by Schüz (1971), Schulz (1988) and Leshem and Yom-Tov (1998) for storks passing through the Jordan valley.

Storks stayed mainly within a corridor of about 150 km, and more to the western shores of the Luangwa River up to the lower altitudes of the Muchinga mountain range. From the few satellite data available for storks resting at the transit area at the Tanzania–Malawi border to Zambia, no specific corridor into Zambia could be identified. Storks seem to cross the Tanganyika–Malawi Rift Valley between 31° and 34° E. Individuals E 846 and E 817 rested around Tunduma (9°10′ S; 32°46′01″ E), while other storks took a more westerly passage, but data are too sparse to allow any further analysis.

The earliest arrival date in the Luangwa region during southward migration was 19 November (individual L 4298 in 1996) and the latest found so far was 19 February (E 819 in 1999). On its way back to Europe the earliest stork rested on 25 February (E 846 in 1999) and the latest on 10 April (E 817 in 1999). Although from the migration phenology two waves, one towards and the other from staging areas, may be expected, movements to and from staging areas are obviously not as sharply separated as observed in the more northern corridors. In 1999, individual E 819 left the Luangwa Valley on 22 February for southward migration and E 846 'Penelope' arrived from its staging area in Botswana on 25 February. Southward and homeward migrating individuals could thus even meet within the same area, although no such overlap was observed for these tracked individuals.

The radio-tracked storks took between 1 and 4 d in either direction to traverse the entire Luangwa Valley (about 600 km). Two individuals, E 846 and E 817, rested for a longer period within the area (Table 1). Stork E 817 chose

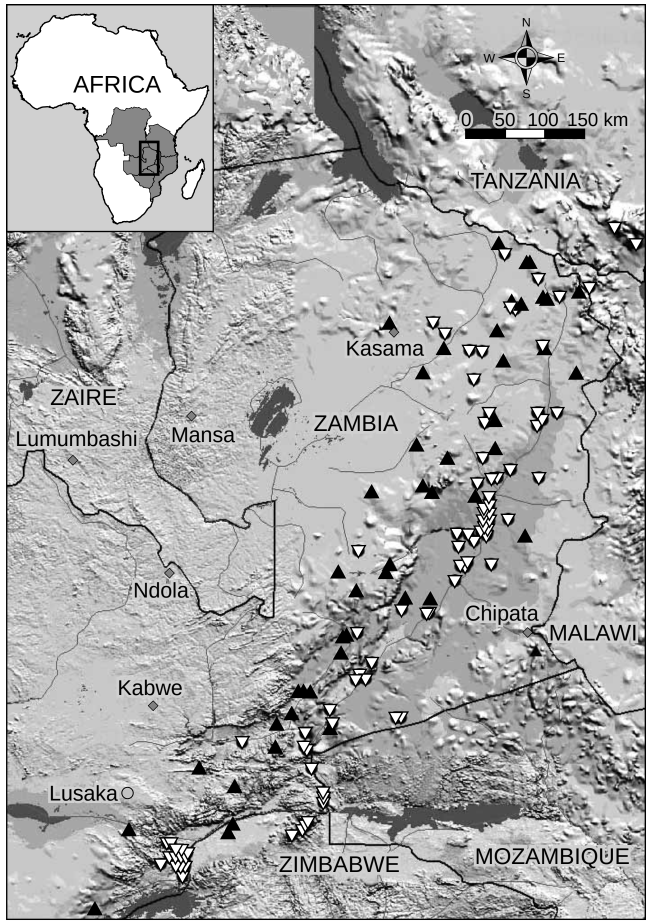

Figure 1: Stopover sites of White Storks in Zambia mapped on the Global Shaded Relief (GTOPO30). White triangles = southward migration, black triangles = northward migration

Zambia and the Zambian–Zimbabwe border region, respectively, as staging areas during the year 1999. The average time spent by all 10 White Storks during austral passage is 3.6 d if all storks are considered (mean = 3.6 ± 3.97, n = 14) and 2.7 d (mean = 2.7 ± 1.84, n = 13) if the extreme staging time of individual E 817 is excluded. Mean migration speed for crossing the region in boreal passage is 2.3 d only (mean = 2.272 ± 1.009, n = 11). A Mann–Whitney U-test revealed only marginally significant differences in duration between southward and homeward migration in the corrected dataset (p = 0.049).

Habitat choice

Ground data of White Storks arriving between November and February show a concentration along the banks and tributaries of the Luangwa River. During southward and northward migration White Storks rested in different ecoregions, whereas no preference for either ecoregion as staging area was observed. Only three stopovers were taken in other habitats: in water, flooded grassland and *Acacia* habitats (Table 2). The significant seasonal differences in habitat use during migration (Table 2) may be due to the fact that flyway patterns of austral and boreal migration differ: on their way south all storks used a smaller corridor and stayed almost only within the Luangwa Valley where mopane prevails, whereas their homeward migration route takes them into the miombo-dominated escarpment.

Since the distinction between the two WWF ecoregions gave only a rough picture of habitats found in the Luangwa area because they were actually composed of a mosaic of subhabitats and transition zones (Astle 1989, Yang and Prince 2000), we tried a more detailed ecological evaluation of staging areas by use of the Global Landcover 2000 classification map. Throughout Zambia six habitats were identified as important stork resting habitats (Table 3): deciduous scrubland with sparse trees and deciduous woodland are, according to this classification, the preferred stopover sites (for the night), and croplands the main staging habitats (Figure 2). These results match a more comprehensive study based on all routes for all the 38 tracked individuals throughout Africa. An overlay with the GLC 2000 map showed a significant preference for croplands, open scrubland and open grassland during resting and staging; preference was tested against randomly selected points in the same area (Gerkmann 2007).

To evaluate the habitat status of White Stork staging areas, we split resting incidences depending on whether they were taken within National Parks or outside. National Parks and other protected areas were deemed to represent

Table 2: Stopover and wintering sites of tagged White Storks by World Wildlife Fund (WWF) ecoregions (Olson *et al.* 2001)

WWF ecoregion index	WWF ecoregion	Number of storks	Number of records for spring migration ($d\ stork^{-1}$)	Number of records for autumn migration ($d\ stork^{-1}$)	Total number of stopover days	Number of staging records ($d\ stork^{-1}$)
AT0725	Zambezian and Mopane Woodland	10	11	31	42	16
AT0704	Central Zambezian Miombo Woodland	7	27	16	43	12
AT0709	Kalahari Acacia–Baikiaea Woodland	1	1	0	1	1
	Water	1	1	0	1	1
AT0907	Zambezian Flooded Grassland	1	1	0	1	1

Table 3: Stopover and staging sites of tagged White Storks by habitat following Global Landcover 2000 (Hansen *et al.* 2000, Mayaux *et al.* 2004)

GLC label	Description	Number of storks	Number of records ($d\ stork^{-1}$)	Total number of records (d)
9	Closed deciduous forest	3	1, 1, 2	4
10	Deciduous woodland	7	11, 1, 1, 4, 3, 3, 1	24
11	Deciduous shrubland with sparse trees	8	16, 5, 1, 5, 2, 7, 5, 6	47
12	Open deciduous shrubland	4	2, 1, 1, 1	5
13	Closed grassland	2	1, 3	4
18	Cropland	8	1, 9, 2, 1, 28, 1, 3	45

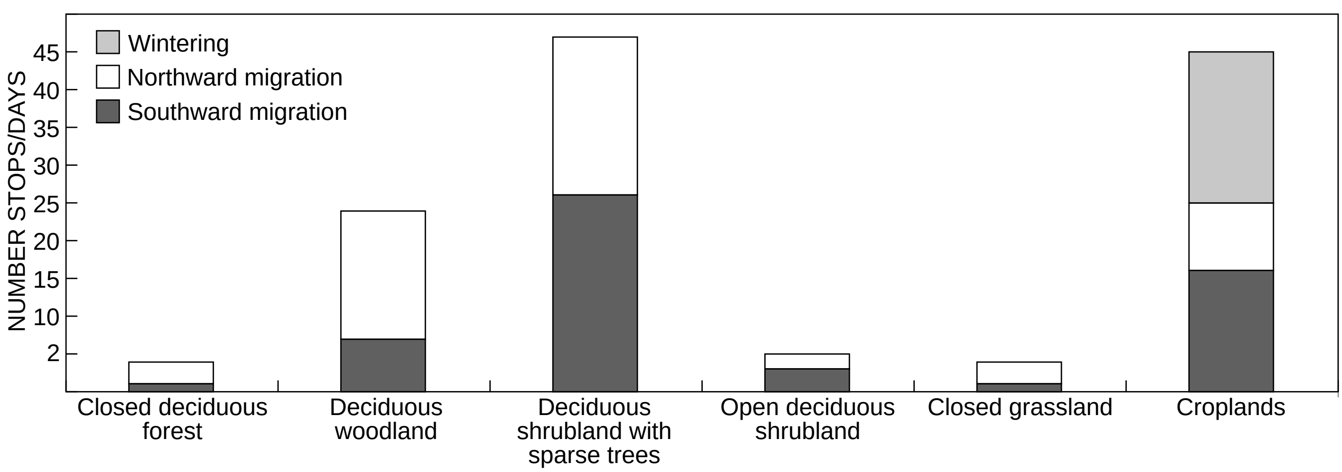

Figure 2: Number of White Stork occurrences (staging days) by habitat following Global Landcover 2000

relatively undisturbed, pristine areas, whereas areas outside were more disturbed, with more human impact. Out of the total of 118 occurrences of the storks, 30 (c. 25%) were in protected areas. This high proportion of incidence is probably due to the fact that also a high proportion of the Luangwa Valley is covered by conservation areas. A previous study testing all staging localities of White Storks in eastern to southern Africa found only 9% situated within protected areas (Gerkmann 2007).

Threats along the flyway

The 2004/05 White Stork census estimated the world population at 230 000 breeding pairs (NABU 2006). The East European population comprises about 300 000 individuals. If we assume that our sample of storks equipped with satellite transmitters is representative for the Eastern population, and that all south-migrating individuals transit the Luangwa Valley as indicated by the tagged target group (10 out of 26 individuals), more than one-third of the eastern White Stork population (about 100 000 White Storks) may be expected regularly within that area each year between November and April.

White storks are attracted to the Luangwa Valley as a migration corridor because of its geographical conditions, providing thermals and wind flow and thus good flying conditions for soaring bird species. The occurrence of three national parks situated along the Luangwa River (North Luangwa National Park, Luambe National Park and South Luangwa National Park) safeguard protection of an important part of the migration corridor of White Storks mainly during southward migration. However, the northward flyway directs storks towards the escarpment and thus towards more populated areas.

According to habitat choice White Storks prefer croplands both in their European breeding grounds as well as in European and African migration areas. In eastern Zambia more than 75% of the tagged White Storks rested outside protected areas and thus possibly outside of pristine habitats. Croplands therefore play an important role as feeding habitat. Along the migration flyway from Europe to South Africa tagged storks were 'lost' in many different prestaging and staging areas (Van den Bossche *et al.* 2002). Causes of death have been analysed in detail for the Bet She'an Valley in Israel, where Van den Bossche *et al.* (2002) specified electric wires as the most common cause of death. No White Storks were poisoned within the region during the study period, but fields were sprayed with pesticides. Nevertheless, contamination loads with chemicals like mercury, PCB, DDT and other biocides in the blood and liver of White Storks in their breeding grounds in Germany and in the regions of passage through Israel and Egypt were (with one exception) relatively low and considered as non-critical (Van den Bossche *et al.* 2002).

Negative influences of large-scale application of pesticides by aerial spraying on feeding storks were observed in South Africa (Gerkmann 2007). The author noticed a sudden avoidance of peanut fields by White Storks after these had been sprayed. Most probably, individual 'Princess' not only left her feeding grounds in February 2004 immediately after spraying but also started her early homeward migration due to this. In the Luangwa Valley fences and high-voltage lines are still uncommon so may not pose a serious threat presently. Even in the denser-populated southern reaches of the river and at the escarpment, power transmission lines are still few, although this could change in the near future. Concerning negative impacts due to usage of pesticides no information is available for eastern Zambia until now, but spraying of crop fields with pesticides/biocides from airplanes is not as prevalent as it is in South Africa.

The Luangwa Valley and its adjacent regions are clearly vital as a stork highway, holding sizeable concentrations of White Storks during their migration from East to South Africa and back. More information on the whereabouts of White Storks during their staging period from November to April needs to be collected in order to answer important questions such as potential foods and farmland preferences or relationships and interference with humans. These data are relevant for conservation efforts, as conditions of resting and feeding during migration and in the non-breeding stopover and staging sites are known to strongly influence breeding success (Schulz 1988, Dallinga and Schoenemakers 1989, Van den Bossche *et al.* 2002). As a human commensal, the fate of White Storks is tightly connected with cropland cultivation and agricultural land use in Africa.

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