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Home Range, Habitat Selection, and Foraging Rhythm in Mauritanian Spoonbills (*Platalea leucorodia balsaci*): A Satellite Tracking Study

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Abstract.—Mauritanian Spoonbills (*Platalea leucorodia balsaci*) only breed at Banc d'Arguin, Mauritania, West Africa. Their populations have declined; however, nothing is known about possible ecological factors involved, including their primary food and foraging habits. Home range sizes, habitat selection, and foraging rhythm in six adult Mauritanian Spoonbills were documented by attaching backpack harnesses with solar-powered satellite GPS-transmitters. Based on 18 bird-months of data (5,844 selected ground positions) collected between 2008 and 2010, these individuals never left the study area centered on the island of Tidra. The fixed kernel home range size was 23–101 km² (\bar{x} = 62 km²) and the core area 2–14 km² (\bar{x} = 7 km²). Home range sizes did not differ between breeding and non-breeding seasons. Mauritanian Spoonbills fed only in intertidal areas where they preferred the seagrass-covered (*Zostera noltii*) areas and they fed primarily during the ebbing tide. Furthermore, the GPS-positions away from the high tide roosts were strongly associated with creeks dissecting the seagrass beds. During the non-breeding season, foraging occurred throughout the 24-hr period, but during the breeding season they foraged exclusively by night. Received 30 July 2012, accepted 2 January 2013.

Key words.—habitat selection, home range, intertidal mudflats, Mauritanian Spoonbills, *Platalea leucorodia balsaci*, population decline, seagrass, Threshkiornithidae, tidal rhythm, *Zostera noltii*.

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In 1974, the Eurasian Spoonbills (*Platalea leucorodia*) that breed in the Parc National du Banc d'Arguin (PNBA), Mauritania, West Africa, received recognition as a separate subspecies, the Mauritanian Spoonbill (*P. l. balsaci*). This recognition was based on morphological differences from the nominate subspecies breeding in Europe (*P. l. leucorodia*) (de Naurois and Roux 1974); recently, genetic data validated this subspecies assignment (Piersma *et al.* 2012). Unlike the European-breeding relatives (*P. l. leucorodia*) that show a wide range of migration strategies (Cramp and Simmons 1977; Lok *et al.* 2011), Mauritanian Spoonbills appear sedentary, rarely being reported outside Banc d'Arguin. The Mauritanian subspecies remains one of West Africa's lesser known waterbirds.

Mauritanian Spoonbills are currently declining (Veen *et al.* 2012). Breeding num-

bers decreased from 1,943 breeding pairs in 2000 (Overdijk *et al.* 2001) to 750 breeding pairs in 2007 (Triplet *et al.* 2008). The Mauritanian Spoonbill population exhibits low levels of recruitment that appear linked to the frequent occurrences of the colony-wide desertion of nests (Veen *et al.* 2012). However, other contributing factors such as problematic feeding conditions and spatial aspects of foraging ecology have not been assessed.

This study focuses on habitat use and foraging ecology of Mauritanian Spoonbills throughout the annual cycle. Until recently, most studies of habitat selection have involved marked individuals that have been followed on the ground or via VHF telemetry to compare what types of habitats animals are using in comparison with those available (Johnson 1980; Edge *et al.* 1987; Clark *et al.* 1993). Recent advances in satellite and GPS (Global Positioning System) tracking

technology, coupled with finer resolution satellite imagery, have greatly enhanced our ability to assess use of habitats (Dickson and Beier 2002; Jiguet and Villarubias 2004; Willems *et al.* 2009), especially in difficult to access regions. Data obtained through remote sensing have the added benefit of reducing disturbance to animals (at least after recovery from capture stress), which is likely important for Mauritanian Spoonbills given their propensity for nest desertion (Veen *et al.* 2012). Here we present results obtained from GPS transmitters used to track the annual-cycle movements of six adult Mauritanian Spoonbills over a 3-year period. We specifically report on total and seasonal home range size, habitat selection at a range of scales from general habitat types to microhabitats (creek courses), and daily foraging rhythms relative to roosting sites and diurnal tides.

METHODS

Study Area

The study was conducted in the Parc National du Banc d'Arguin, Mauritania (see Wolff *et al.* 1993; Campredon 2000). The area consists of about 491 km² of intertidal flats, including 93 km² covered by dense beds of seagrass (*Zostera noltii*) and 219 km² of mudflats partially or less densely covered by seagrass (based on 1984 data; Wolff and Smit 1990). The older seagrass-covered intertidal flats are characterized by the presence of circular pools (van der Laan and Wolff 2006) and small creeks. Larger channels separate the different mudflat areas.

Satellite Tracking

During the breeding seasons of 2008 and 2009, we captured six adult Mauritanian Spoonbills on their nests using a “trap robe” and fitted them with solar-powered satellite GPS-transmitters (Model 30GPS, North Star Science and Technology) (Table 1). Birds were molecularly sexed using blood samples (T. Lok, unpubl. data).

Each transmitter was attached to the individual’s back using a harness made of Teflon ribbons (see Ueta *et al.* 2000). The transmitter was programmed to record and store data at 6-hr intervals, including data on position, position accuracy, speed, date, and time. Stored data were communicated via the ARGOS system (ARGOS 2011), which provides accuracy to < 100 m. However, the GPS transmitters could provide more accurate positions (± 15 m) (van der Winden *et al.* 2010; Chevallier *et al.* 2011). Locations were filtered in two steps based on the position accuracy and the speed. First, the most accurate locations were selected (< 26 m). Secondly, and to avoid flying birds in the analyses, only the slow fixes were included (speed < 4 m/s). A total of 5,844 GPS positions were then used for habitat selection and foraging rhythm analyses.

We partitioned GPS data into breeding and non-breeding phases of the annual cycle. We considered an individual to be breeding if it returned to its exact position more than two times per 24 hr on a known breeding site. These location data also allowed us to locate previously unknown or suspect breeding colonies (O. Overdijk, unpubl. data). To analyze movements of the birds, we used ArcGIS (Environmental Systems Research Institute 2009) in combination with Program R (R Development Core Team 2010).

Home Range Estimation

We estimated individual home ranges using a robust non-parametric method, the fixed kernel estimator (KDE) (Worton 1989; Seaman *et al.* 1999), with the reference method (h_{ref}) for estimating smoothing parameter h (Seaman and Powell 1996). We defined the 95% kernel home range (95% KDE) as the global individual home range and the 50% kernel home range (50% KDE) as the core areas. To compare home range sizes during breeding and non-breeding seasons, we selected an equal number of random GPS locations for each season and then tested for differences using Wilcoxon’s rank t-test.

Habitat and Creek Selection

We developed our land-cover map from Landsat imagery (from 18 December 2001) based on the Normalized Difference Vegetation index (NDVI) (Tucker 1979; Barille *et al.* 2010). From this we classified four habitat types: 1) land (dunes); 2) seagrass beds; 3) sand-flats; and 4) sea, including the permanent channels (Fig. 1).

Table 1. Details of the six adult Mauritanian Spoonbills (*Platalea leucorodia balsaci*) equipped with GPS transmitters in 2008 and 2009. Sex was determined from molecular assessment using Ellegren primers (Fridolfsson and Ellegren 1999). Observations ended on 12 February 2010.

Identification	Sex	Capture Site	Capture Date	No. of Fixes	Breeding Period (2009)
Hacen	male	Zira	2 July 2008	5,980	15 Mar-10 July
Abou	male	Nair	12 July 2008	5,822	13 Apr-7 Sept
Camara	male	Nair	12 July 2008	6,621	21 Apr-23 Aug
Abdoul	female	Nair	12 July 2008	5,593	13 May-16 July
Salem	unknown	Zira	4 May 2009	3,313	5 May-21 Aug
Sidi	female	Zira	4 May 2009	3,148	4 May-5 July

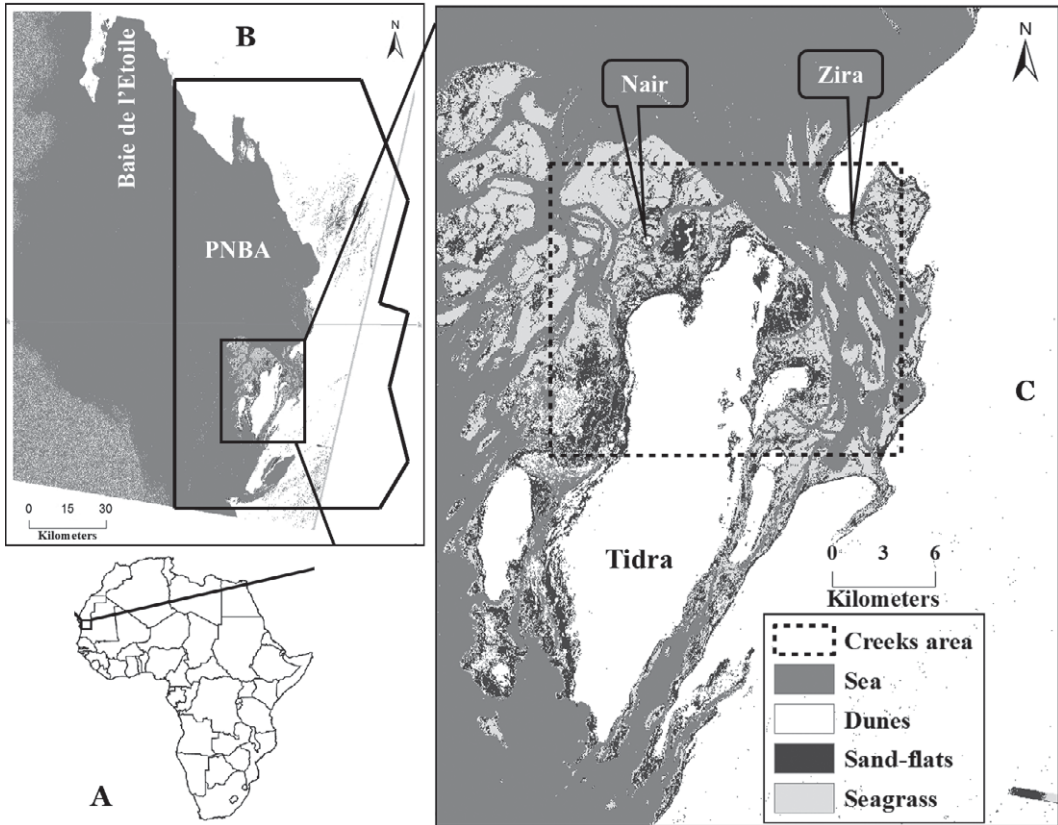


Figure 1. Habitat types in the study area based on the Normalized Difference Vegetation index (NDVI) of the Landsat Image of 2001; the dashed square outlines the area analysed for creek effects (inset C).

Dune habitat is known to be used only for roosting and was excluded from the analyses of feeding habitat selection. In order to investigate the preference of creeks as a feeding ground by Mauritanian Spoonbills, a Google Earth picture of approximately 20 by 20 km (creek zone) was selected based on its high quality and the intensive use by spoonbills. The creeks in this area were digitized in Google Earth, and then exported to ArcGIS for further analyses. In ArcGIS, we buffered the creek courses with a fixed width of 25 m using the Euclidean distance analysis tools. Then the GPS positions were overlaid onto the habitat types and the creek maps in ArcGIS (Minton *et al.* 2003; Galanti *et al.* 2006). The proportions of the different habitats and the numbers of GPS positions in each habitat/buffer were computed using the compositional analyses of the *Adehabitat* packages (Calenge 2006; R Development Core Team 2010). Pseudoreplication was not a concern since in compositional analysis the individual is the sample unit and not the telemetry locations (Aebischer *et al.* 1993).

To find evidence for habitat selection, we used the third order of compositional analysis (Aebischer *et al.* 1993) in which habitat selection is measured within the 95% KDE for each individual separately. For a possible preference to forage near and in creeks, we performed the second order (selection is measured at the popula-

tion level) of compositional analyses (Aebischer *et al.* 1993), using 3,472 GPS positions that fell within the creek zone (Fig. 1).

Foraging Rhythms

To determine if Mauritanian Spoonbills were roosting or foraging, we established a map of known or suspected high-water roost sites (after Overdijk *et al.* 2000) and used a birds' distance from the roost site as an indication of its activity. For example, a distance close to zero would indicate the bird was at the roost while increasing distance from the roost indicated the bird was likely en route to or at a foraging site. The distances to the nearest roosting site were tested for departure from normality using graphical inspection with QQ plots (Crawley 2007).

To assess foraging relative to the stage of the tide, we divided each 12-hr tidal cycle into hourly intervals and assigned GPS-location data to an hour class. We performed analyses of variance (ANOVA) to test the null hypothesis that all the distances to the nearest roost were equal for all the tidal time classes, and a Tukey HSD procedure was employed to report the statistical differences between the different tidal time classes. The local sunrise/sunset was shifting around 7:00 and 19:00 respectively. All foraging events that

took place between 7:00 and 19:00 were considered to be in the daytime foraging class; all other times were considered to be in the night-time foraging class.

RESULTS

Home range sizes based on both 95% KDE and 50% KDE varied greatly among the six adults throughout their annual cycle, ranging from 23-101 km² (\bar{x} = 62 km²) and 2-14 km² (\bar{x} = 7 km²), respectively (Fig. 2). There was no significant difference in 95% KDE home range size between the breeding and non-breeding seasons (Wilcoxon ranked t-test, P = 0.47; breeding season \bar{x} = 21.6 km², range 9-45.8 km²; non-breeding season \bar{x} = 31 km², range 6-55 km²).

Habitat selection, calculated separately for each of the six birds (third order computation of 95% KDE), was not random (Wilks' λ = 0.08, P = 0.002), with birds preferring seagrass areas followed by sand-flats. Not surprisingly, sea (including permanent channels) was least preferred (Table 2). Within the preferred habitats, combining all individuals (second order computation of habitat selection), birds preferentially selected (Wilks' λ = 0.03, P < 0.001) areas within 25 m of creeks followed by areas 25-50 m from the creeks (Table 3).

For each bird separately, the distances to the nearest roosting site were plotted per hour class relative to low tide (Fig. 3). Most individuals showed a significant increase in the distance to the roosting site about 3 hr before the low tide (Table 4). One spoonbill

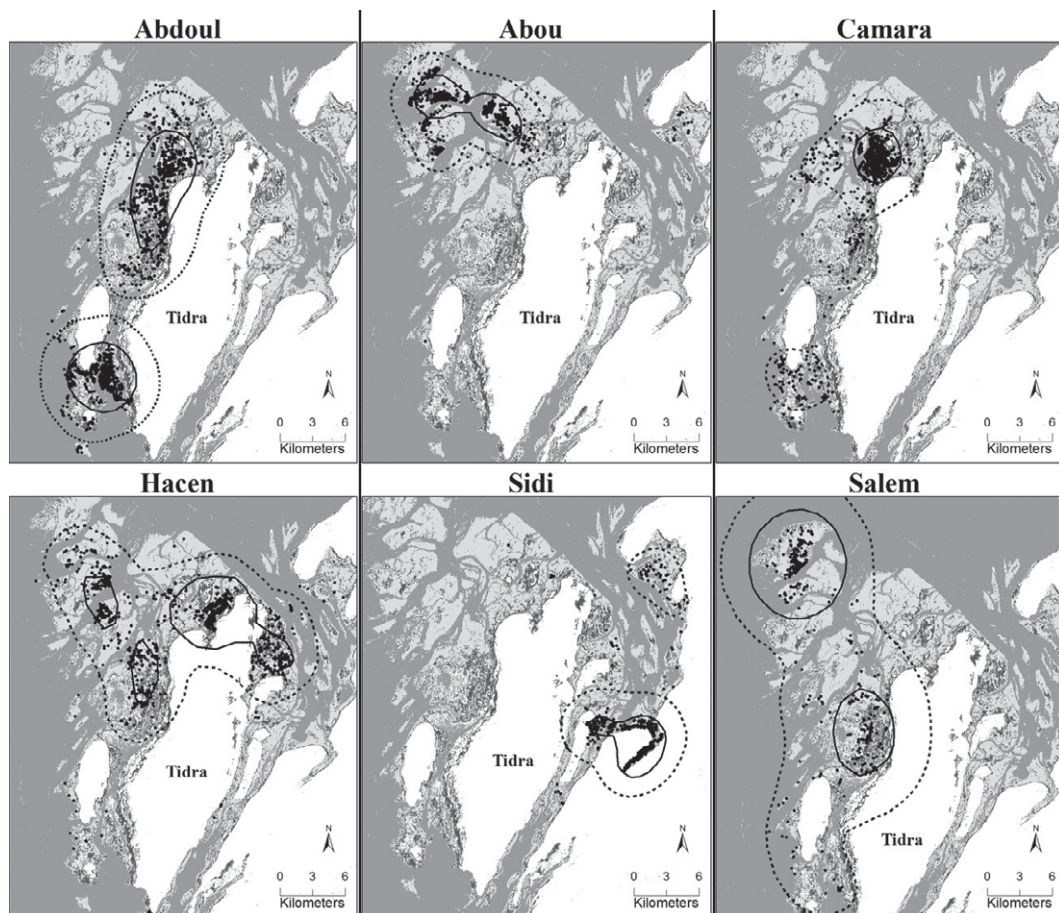


Figure 2. The core 50% KDE (solid line) and 95% KDE (dashed line) for each of six Mautrianian Spoonbills (*Platalea leucorodia balsaci*) tracked during the study.

Table 2. Ranking matrices of habitat selection by GPS-tagged Mauritanian Spoonbills (*Platalea leucorodia balsaci*). Symbols at the intersection of a row and column indicate if the habitat in the row is preferred (+) or not preferred (-) over the habitat in the column. A significant difference is indicated by a triple sign.

Habitats	Seagrass	Sand-flats	Sea	Rank
Seagrass	0	+++	+++	1
Sand-flats	---	0	+++	2
Sea	---	---	0	3

(identified as Sidi) showed a similar pattern, but in his case the increase was not statistically significant (Table 4); this spoonbill was feeding and roosting in a small area and used different sand banks as roosting places. When breeding, the Mauritanian Spoonbills remained in their nests during the day (Fig. 4), while they foraged both diurnally and nocturnally during the non-breeding season (Table 4).

DISCUSSION

Our satellite tracking over 3 years showed no movement of the six adult Mauritanian Spoonbills beyond the confines of PNBA. Nevertheless, we are aware of two instances of birds having ventured outside the Banc d’Arguin. In one case a juvenile, banded within PNBA in 2002, was observed 6 months later in the delta of the Senegal River (O. Overdijk, unpubl. data); in another case, an adult was reported in Baie de l’Etoile in northwestern Mauritania (Y. Diawara, unpubl. data). It is possible that the attached instruments and processes could have affected the individual birds’ behaviors. However, multiple observations of these individuals nesting successfully (O.

Overdijk and E. El-Hacen, unpubl. data) would argue against this.

We found the home ranges of these six birds to be restricted to relatively small parts of PNBA, with most birds using mainly the intertidal areas in the west and northwest portions of the island of Tidra (Fig. 2). Home ranges varied enormously between individuals, with two of the birds limiting their movements to small areas around their breeding sites, while the other four birds used a wider range of the available intertidal areas. Surprisingly, there was no difference in 95% KDE between the breeding and non-breeding seasons. Obviously, a sample size of six could not show the entire known feeding range of Mauritanian Spoonbills. For example, Mauritanian Spoonbills have been seen in places other than the intertidal areas around Tidra; including in Baie de Saint Jean in the south of PNBA as well as in the Baie d’Arguin in the north (E. El-Hacen *et al.* pers. obs.).

Our tracked Mauritanian Spoonbills selected seagrass beds over the other habitat types (Table 2). The selection probably reflects the distribution (Piersma 2012) and the mobility (Curio 1976) of their prey. Shrimps and prawns are known to be important prey for Mauritanian Spoonbills on Banc d’Arguin based on dropping analyses (Veen *et al.* 2012). These prey items are much more abundant on seagrass-covered substrates than on bare sandy intertidal substrates. Here, the three most abundant shrimp species were only captured in pools or in seagrass beds (Schaffmeister *et al.* 2006), and several fish and shrimp species occurred principally in seagrass areas (Mairet and Ly 1986; Jager 1993; Food and Agri-

Table 3. Ranking matrices of the creek selection by GPS-tagged Mauritanian Spoonbills (*Platalea leucorodia balsaci*). Symbols at the intersection of a row and column indicate if the creek buffer in the row is preferred (+) or not preferred (-) over the creek buffer in the column. A significant difference is indicated by a triple sign.

Buffers	25 m	50 m	75 m	100 m	125 m	> 125 m	Rank
5 m	0	+++	+++	+++	+++	+++	1
50 m	---	0	+++	+++	+++	+++	2
75 m	---	---	0	+	+	+++	3
100 m	---	---	-	0	+	+++	4
125 m	---	---	-	-	0	+++	5
> 125 m	---	---	---	---	---	0	6

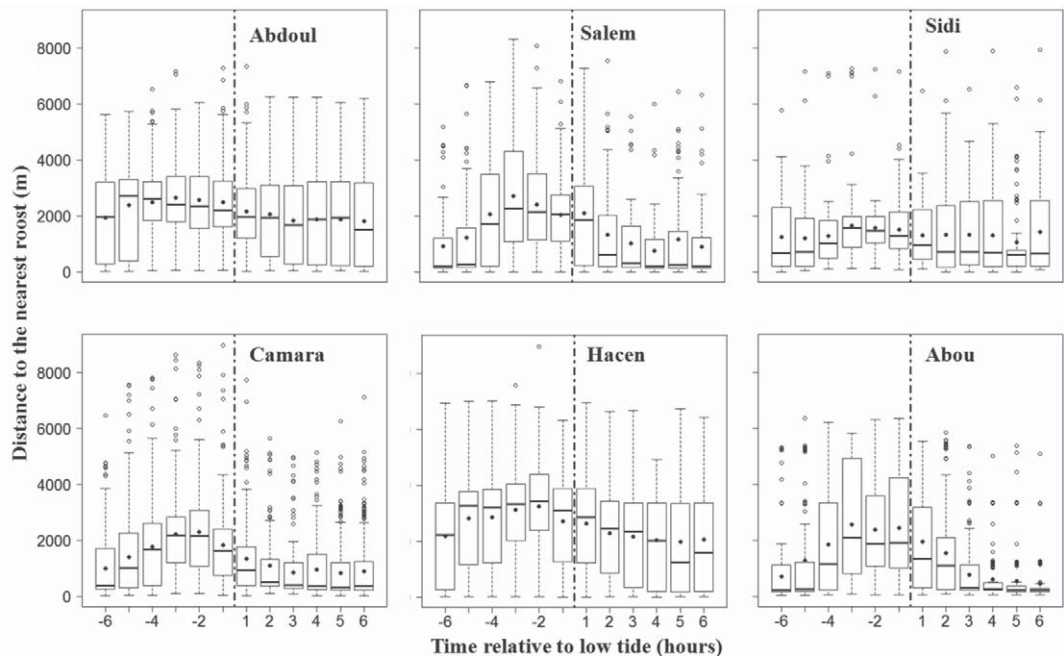


Figure 3. Distance (m) of each of six tagged Mauritanian Spoonbills (*Platalea leucorodia balsaci*) to their nearest roost shown at hourly increments before (-) or after (+) low tide (dashed line). Dots in the boxes represent the mean.

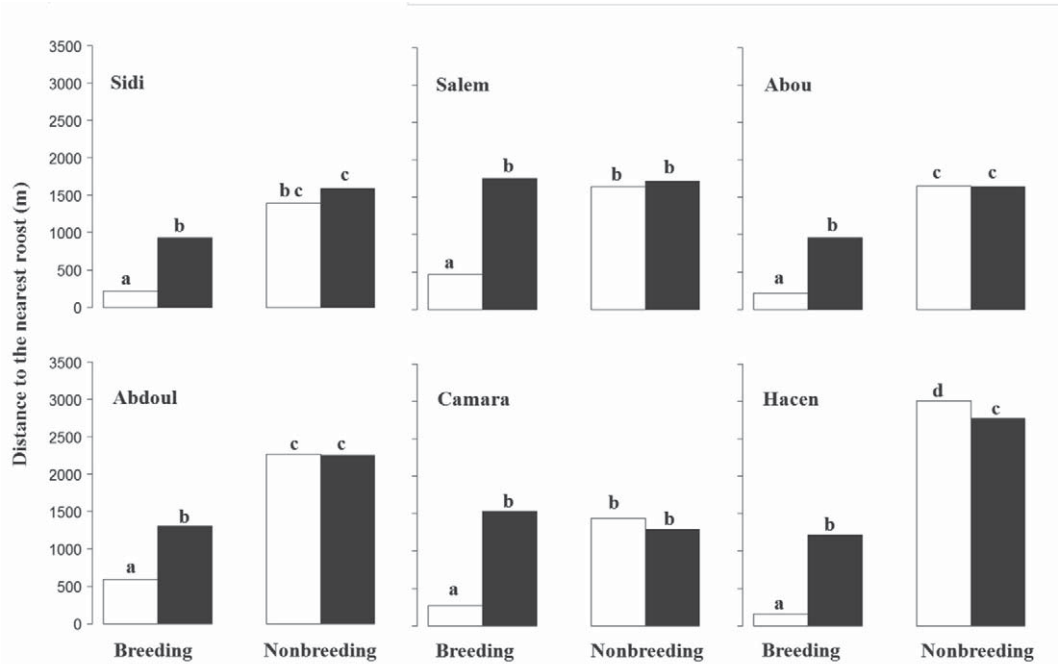


Figure 4. A comparison in distance (m) to the nearest roost among tagged Mauritanian Spoonbills (*Platalea leucorodia balsaci*) during daytime (open) and nighttime (filled) in both the breeding and non-breeding seasons. The letters above the bars denote a statistical comparisons; bars with different letters are significantly different.

Table 4. Results of ANOVA analyses on the foraging activities of the six tracked Mauritanian Spoonbills (*Platalea leucorodia balsaci*). "Distance" represents the distance to the nearest roost analysis, and "Day-night Foraging" represents activities during the non-breeding season.

Identification	Distance			Day-night foraging				
	df	Residuals	F	P	df	Residuals	F	P
Hacen	11	2,545	14.11	< 0.001	1	2,553	63.6	< 0.001
Abou	11	2,479	58.5	< 0.001	1	2,487	22.1	< 0.001
Camara	11	2,687	33.7	< 0.001	1	3,695	58.9	< 0.001
Abdoul	11	2,654	9.6	< 0.001	1	2,662	9.4	0.002
Salem	11	1,023	14.3	< 0.001	1	1,031	21.8	< 0.001
Sidi	11	1,065	1.3	0.19	1	1,073	5.7	0.01

culture Organization of the United Nations 1998). During high tide, schools of fish and shrimp will move to the shallow tidal flats to feed, but during the ebb tide these animals will retreat toward the deep water and concentrate in the creeks. This may explain why, at a finer scale, Mauritanian Spoonbills selected the creeks for feeding (Table 3).

Mauritanian Spoonbills were not active during high tide (Fig. 3), even though on the highest flats the water depth would enable them to forage there. The tendency for waterbirds in tidal habitats to forage during the ebb tide has been shown before (Becker *et al.* 1993; Anderson *et al.* 2004; Thompson *et al.* 2005; Beauchamp 2009; Rey *et al.* 2010). Apart from the prey concentration effect discussed earlier, birds foraging with the ebb may benefit from tidal eddies. Such eddies will concentrate zooplankton and the fish species that feed on the zooplankton (Hamner and Hauri 1977; Alldredge and Hamner 1980; Gagnon and Lacroix 1983; Vermeer *et al.* 1987; Brown and Gaskin 1988; Wolanski and Hamner 1988).

As previously reported for spoonbill species around the world (Piersma 1980; del Hoyo *et al.* 1992; Yu and Swennen 2004), during the non-breeding season our marked birds foraged during both the day and night. Their foraging trips were shaped by tidal cycles rather than day-night cycles. However, during the breeding season the birds foraged almost exclusively at night and stayed around the nest site during the day (Fig. 4). McNeil *et al.* (1995) found that swimming prey are more abundant at night than during the day and concluded that tactile feeders would profit more by feeding at night. In Eurasian Spoonbills, males tend the eggs during the day and females at night, with the non-attending bird presumably going off to forage (Aguilera 1990). The Mauritanian Spoonbill individuals studied here fed almost exclusively at night during breeding, including the two females. The tendency for both sexes to remain at breeding colonies during the daytime may be driven by the need to guard against predatory gulls and terns that breed on the same islets (E. El-Hacen and O. Overdijk, pers. obs.). Dual-parent

attendance at breeding colonies may also be used to manage individual heat stress in hot environments, thus allowing one adult to periodically seek relief while the other tends the nest or chicks (Amat and Masero 2004; Tieleman *et al.* 2008; AlRashidi *et al.* 2010).

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