The influence of wind conditions and topography on soaring migrants on the western side of the southern gulf of Suez, Egypt

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The flight behaviour of soaring birds during northward migration was studied in the desert migration bottleneck of the Zait bay area, Egypt. This area is situated close to the narrowest straits of the southern gulf of Suez (25 km in width) and is used by birds migrating towards the Sinai region. Eleven soaring species were studied. Observations were performed at 26 observation sites, situated 5 km apart along two *c*NW–SE directed rows (parallel to the coast). A systematic working schedule ensured that at all hours between sunrise and sunset different sites were covered by one or other team of observers, changing observation sites every 60 minutes. A wide range of flight directions was recorded. On average, migrants flew in northerly directions. As the gulf of Suez extends from NW–SE, by maintaining their mean direction they would reach the coast. Black Kite *Milvus migrans* and Steppe Buzzard *Buteo vulpinus* were the species with median directions deviating furthest to the east and Lesser Spotted Eagle *Aquila pomarinus* furthest to the west. Whereas eight of the studied species compensated for wind drift, European Honey Buzzard *Pernis apivorus*, Black Kite and Steppe Buzzard were shown to tolerate drift in certain circumstances. Steppe Buzzards maintained their usual flight direction if crosswinds came perpendicularly from the right of the median direction and allowed themselves to be drifted if the wind was from the left. In European Honey Buzzards it was the other way round. Steppe Buzzards tolerated drift all along the N–S extent of the study area. In the central section, they were oriented furthest to the east *ie* towards the coastal mountain range of Gebel El Zait. From our results we deduced two migration strategies. Migrants either compensate for drift and cross the coast for Sinai wherever they reach it or they tolerate drift and gain height at the mountain ridge of Gebel El Zait, fly along the ridge to the north and depart to Sinai.

INTRODUCTION

Soaring birds depend on thermals to perform their annual migration. Regular concentrations of thermals as well as their lack have a strong influence on migration routes. Accordingly, there are areas where the birds concentrate in narrow corridors and others where their routes are spread more widely (Bildstein 2006). Because of the lack of thermals over the sea, soaring birds are very reluctant to cross water bodies. If they do not avoid a sea crossing completely, they generally choose the narrowest point to cross (Meyburg *et al* 2003). At these bottlenecks they often wait for circumstances good enough for crossing (Bildstein *et al* 2009).

We studied the orientation of soaring migrants in the desert plain near Zait bay (Figure 1), Egypt, situated close to the southern part of the gulf of Suez, where migrants arrive in spring before they cross the gulf of Suez (Grieve 1996, Baha El Din 1999, Tammens 2008, Hilgerloh 2008, Hilgerloh *et al* 2009). The study is based on the first systematic observations during spring migration in the area (Hilgerloh 2009).

We investigated the influence of wind conditions and topography on directions of the movements. There are differences in flight strategies between the various species *ie* broad-winged birds depend more on updraft than small winged and some species avoid sea crossings more than others or are more prepared to fly in adverse winds than others (*eg* Bernis 1980, Alerstam 1990, Finlayson 1992, Pennycuick *et al* 1994, Agostini & Duchi 1994, Shirihai 1996, Spaar *et al* 1998, Meyer *et al* 2000, Agostini *et al* 2005, Bildstein *et al* 2009). However, there may also be traits in spring that differ from autumn.

Soaring birds are known to respond in various ways to crosswinds depending on the age of the bird and on the situation it finds itself in (Alerstam 1979, Thorup *et al* 2003, Klaassen *et al* 2011). Because of the prevailing strong NNW wind, birds crossing the straits

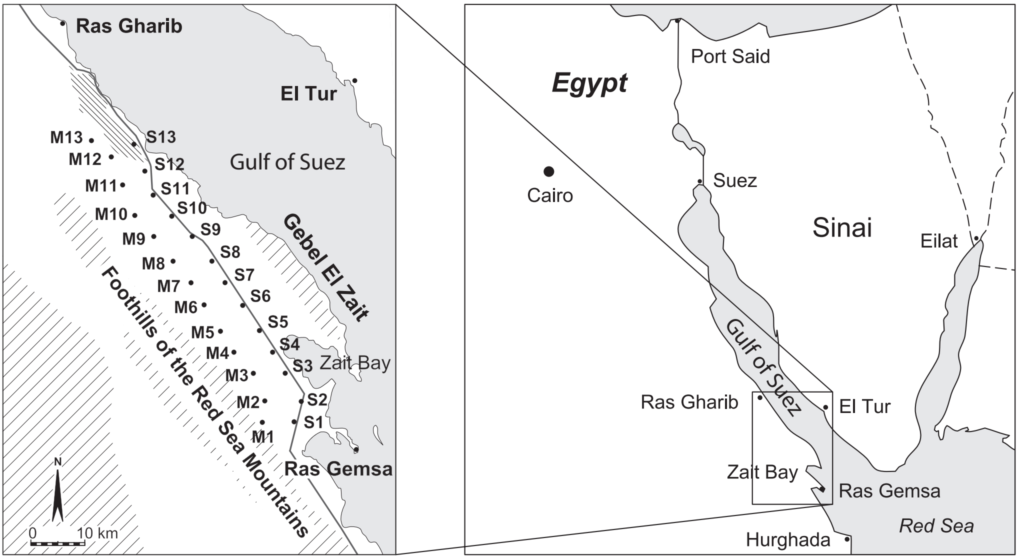

Figure 1. Location of the Zait bay study area in Egypt and details of the study area including position of the two rows of observation sites (M1–M13, S1–S13).

face the risk of being drifted out into the open sea. These wind conditions are known and predictable. And so, in anticipation of the drift, birds might compensate or even overcompensate for it before they start the crossing of the gulf. There might be differences between species.

Updrafts created by mountains are often used by soaring birds to gain height (Bildstein 2006). Thus migration routes tend to be funnelled along mountain ridges. Should it be that the coastal mountains were used to gain height, this would emerge in the regional pattern of flight directions.

Although the migration route through the Zait bay area leads to Sinai there are always migrants that either wait out a night near the coast before continuing or even return to inland sites to join those migrating towards Suez and thus circumvent the gulf of Suez. It is not known to what extent wind conditions influence these decisions.

METHODS

Study area

The data were collected to assess the risks to migratory soaring birds from proposed wind turbines, a circumstance that afforded a unique opportunity to study many species simultaneously. The study area (Figure 1) is bordered in the west by the foothills of the Red sea mountains and in the east by plains stretching to the foothills of the Gebel El Zait range (up to 460 m asl) and to the sea. Except for a salt depression in the north, the study area consists of a dry desert plain.

Ornithological observations

Two parallel rows of observation points were established 5 km apart (27.70° N, 33.44° E to 28.16° N, 33.23° E). Each row contained 13 sites at 5 km intervals (Figure 1). Two alternating teams of experienced field ornithologists made observations from sunrise to sunset. The first team worked from sunrise to noon and the second from noon to sunset thus avoiding any count duplication between teams. They used 10 x 40 binoculars and a 20–60x magnification telescope for identification. Horizontal distances over 1 km from the observer were determined by reference to known distances to topographical features previously measured by means of GPS. During the first weeks the composition of the teams was changed regularly in order to achieve standardized procedures and minimise differences between individual observers and between teams (for details see Hilgerloh 2009).

The following parameters were determined and documented: the site, time and date of observation, observation period, species observed, number of birds and flight direction and distance from observer. A rotation schedule was set up, in order to visit all sites of the entire study area at different times of the day. Observation periods usually lasted 60 minutes during which time all birds sighted were logged. Observations were made 20 February–6 May 2007 for a total duration of 604.4 h. Flight directions were grouped into 16 compass point sectors (*eg* N, NNE, NE, ENE, E). The N sector, for example, contained flight directions between 348.75° and 11.25° with a midpoint of 360°. Only directions noted within a circle of radius 2.5 km were considered, as estimation of flight direction will be more accurate at shorter distances than at longer ones and detection of birds is easier. Principle compass directions were marked on the ground for comparison. On days with sand storms (three days) we had to stop observations in order to avoid damage to optical devices.

Weather measurements

The wind was measured continuously at 50 m over the ground in the central part of the study area. Mean wind direction and strength were calculated automatically every ten minutes. On the basis of these 10-minute values the average wind strength and direction were calculated for the time interval 09.00–15.00 h each day (the most important period of the day for soaring birds). No wind data were collected 20, 21, 23 and 24 February and 29 April 2007.

Data analysis

Only species with numbers exceeding 100 individuals per season were included. Analyses were performed using (independent) observations/records including single flying birds or groups of birds. Group frequencies of the records, per species, are shown in Table 1. The mean direction μ was calculated by vector addition. The vector magnitude r is a measure of the spread of directions and varies between 0 (random) and 1 (all birds in the same direction). The Rayleigh test (Batschelet 1981) was used to detect whether the mean direction was used significantly. By use of the Watson Williams F-test one can test whether the mean directions of two samples differ significantly, if r exceeds the value of 0.7 and

Table 1. Number of (independent) records, n, by species. Birds were classified as flying singly or in groups of 2–10, 11–20, 21–100, 101–200 and 201–1000 birds or in groups of more than 1000 birds.

	Black Stork	White Stork	White Pelican	European Honey Buzzard	Black Kite	Levant Sparrow-hawk	Steppe Buzzard	Lesser Spotted Eagle	Steppe Eagle	Booted Eagle	Common Crane
group size	n	n	n	n	n	n	n	n	n	n	n
1	9	4	1	24	133	9	462	61	176	63	0
2–10	15	8	1	42	121	6	599	31	159	18	7
11–20	9	4	2	11	25	2	92	1	16		1
21–100	14	11	4	18	7	2	185		12		18
101–200	2	15	3	1		1	20				9
201–1000		22	3			5	5				9
>1000		8				2					

if the value of r is similar in each of the two samples (Batschelet 1981). These conditions were only fulfilled in two species, White Pelican *Pelecanus onocrotalus* and Common Crane *Grus grus*, and their mean flight directions did not differ significantly. In order to compare the frequency distributions of the directions the Mardia Watson Wheeler test and Watson's U^2 test were performed.

Mean direction and vector length were calculated and Rayleigh test, Mardia Watson Wheeler test and Watson's U^2 test were performed using the software package Oriana (Kovach Computing Services 2003). If the difference between two distributions is significant, the Mardia Watson Wheeler test does not distinguish whether the difference is in the mean angle, the angular variance or both. The Watson's U^2 test does not distinguish whether the difference is in the distribution, the mean direction or in some other parameter.

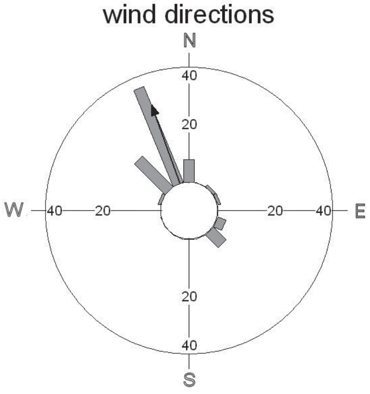

Figure 2. Average daily wind directions in the study period (n = 71, μ = 340°, r = 0.72). Mean direction and vector length are shown by an arrow. The mean direction was significant (Rayleigh test P<0.001).

The crosswind vector was expressed as the sinus of the wind direction perpendicular to the median flight direction multiplied by the wind strength (m/s). The E wind vector was positive and W wind vector negative. Correlations between the crosswind vector and deviation of the median flight direction (Thorup *et al* 2003) were analysed by means of the non-parametric Spearman rank correlation test (Statistica 2010).

In order to approximate the coastal arrival area of each movement, observed flight directions were projected onto a map from the centre of the corresponding observation circle. Discrepancies between the numbers of records in and between different tables are due to the fact that on some days no wind data were collected.

RESULTS

At Zait bay north winds prevailed during the study period (n = 71, μ = 340°, r = 0.72, Rayleigh test P<0.001, median = 335°, Figure 2). Southerly winds were experienced from 20 March onwards every 5.3 days for one or two days (in total 9 days). Northerly winds mostly came from NNW (n = 62, μ = 335°, r = 0.95, Rayleigh test P<0.001, median = 333°). On days with southerly winds they came from SE (n = 9, μ = 125°, r = 0.99, Rayleigh test P<0.001, median = 127°). Sandstorms were experienced on days with northerly winds of more than 16 m/s (3 days) and once locally for an hour in a south wind of 14 m/s.

The following eleven species were studied (numbers per species exceeded 100 individuals per season): Black Stork *Ciconia nigra*, White Stork *Ciconia ciconia*, White Pelican, European Honey Buzzard *Pernis apivorus*, Black Kite *Milvus migrans*, Levant Sparrowhawk *Accipiter brevipes*, Steppe Buzzard *Buteo vulpinus*, Lesser Spotted Eagle *Aquila pomarinus*, Steppe Eagle *Aquila nipalensis*, Booted Eagle *Aquila pennata* and Common Crane.

The studied species differed in their propensity to group with other conspecifics during flight. There were species like Booted Eagle and Lesser Spotted Eagle that flew mostly alone or in the company of very few other birds and other species that preferred to migrate in flocks of hundreds or even thousands such as White Stork, Levant Sparrowhawk or Common Crane (Table 1).

Flight directions of the migrants were spread over a wide range (Figure 3, Table 2). On average they flew over the study area in northerly directions. Mean directions of the different species scattered in a sector of 40° between NNW and NNE (Table 2). In eight of

Table 2. Number of (independent) records (n, single birds or groups of birds), mean direction (μ), vector length (r), circular Standard Deviation (SD) and median flight direction of the different species. The vector length r is a measure of the spread of directions and varies between 0 (random) and 1 (all birds in the same direction). According to the Rayleigh test (Batschelet 1981) the mean directions (μ) of all species were significant (P<0.001). Mean values of the Mardia Watson Wheeler test statistic (M) and Watson's U² test (W), comparing the difference of distributions of flight directions between species, were tested for significance (P<0.01 = **, P<0.001 = ***, left blank if not significant). According to the Bonferoni correction differences were only considered significant if P< 0.01.

	n	μ	r	SD	median		BS	WS	WP	HB	BK	LS	SB	LE	SE	BE
Black Stork (BS)	49	3°	0.56	62.03	360°	M	X									
						W	X									
White Stork (WS)	72	6°	0.57	61.02	360°	M		X								
						W		X								
White Pelican (WP)	14	1°	0.76	42.72	360°	M			X							
						W			X							
European Honey Buzzard (HB)	96	358°	0.58	59.69	360°	M				X						
						W				X						
Black Kite (BK)	286	18°	0.64	54.36	22.5°	M		**			X					
						W					X					
Levant Sparrowhawk (LS)	27	348°	0.42	75.66	360°	M						X				
						W					**	X				
Steppe Buzzard (SB)	1363	27°	0.52	66.00	45°	M		**			**		X			
						W					**		X			
Lesser Spotted Eagle (LE)	93	349°	0.57	60.58	337.5°	M					**		***	X		
						W					***		***	X		
Steppe Eagle (SE)	363	357°	0.56	62.03	360°	M					***		***		X	
						W					***		***		X	
Booted Eagle (BE)	81	348°	0.63	55.27	360°	M					**		***			X
						W				**	***		***			X
Common Crane	44	3°	0.71	47.34	360°	M					**		***			
						W							**	**		

the eleven species the median value was 360°. The median deviated furthest to the west (337.5°) in the Lesser Spotted Eagle, and Black Kite and Steppe Buzzard were the species with median directions deviating furthest to the east (22.5° and 45° respectively) (Table 2). In both the Mardia Watson Wheeler and the Watson's U² tests, the frequency distributions of the directions of the Black Kite and Steppe Buzzard differed significantly from those of Lesser Spotted Eagle, Steppe Eagle and Booted Eagle, while directions of Steppe Buzzards also differed significantly from those of the Common Crane. Frequency distributions of Black Kite and Steppe Buzzard differed significantly from each other (Table 2).

We investigated whether birds tolerated wind drift. Three of the eleven studied species showed a significant correlation of their flight directions to the crosswind vector: European Honey Buzzard, Black Kite and Steppe Buzzard (Table 3, Figure 4). The steepest regression coefficient between deviations from the median flight direction and the crosswind vector was for European Honey Buzzard. However, this species did not migrate in strong crosswinds unlike the other two species. If Steppe Buzzards maintained their flight direction, the stronger the crosswind vector from the left the further to the south they would arrive at the coast (Spearman rank correlation P<0.001).

The mean flight direction in crosswinds from the left of the median direction amounted to 27° in the European Honey Buzzard and Black Kite and 39° in the Steppe

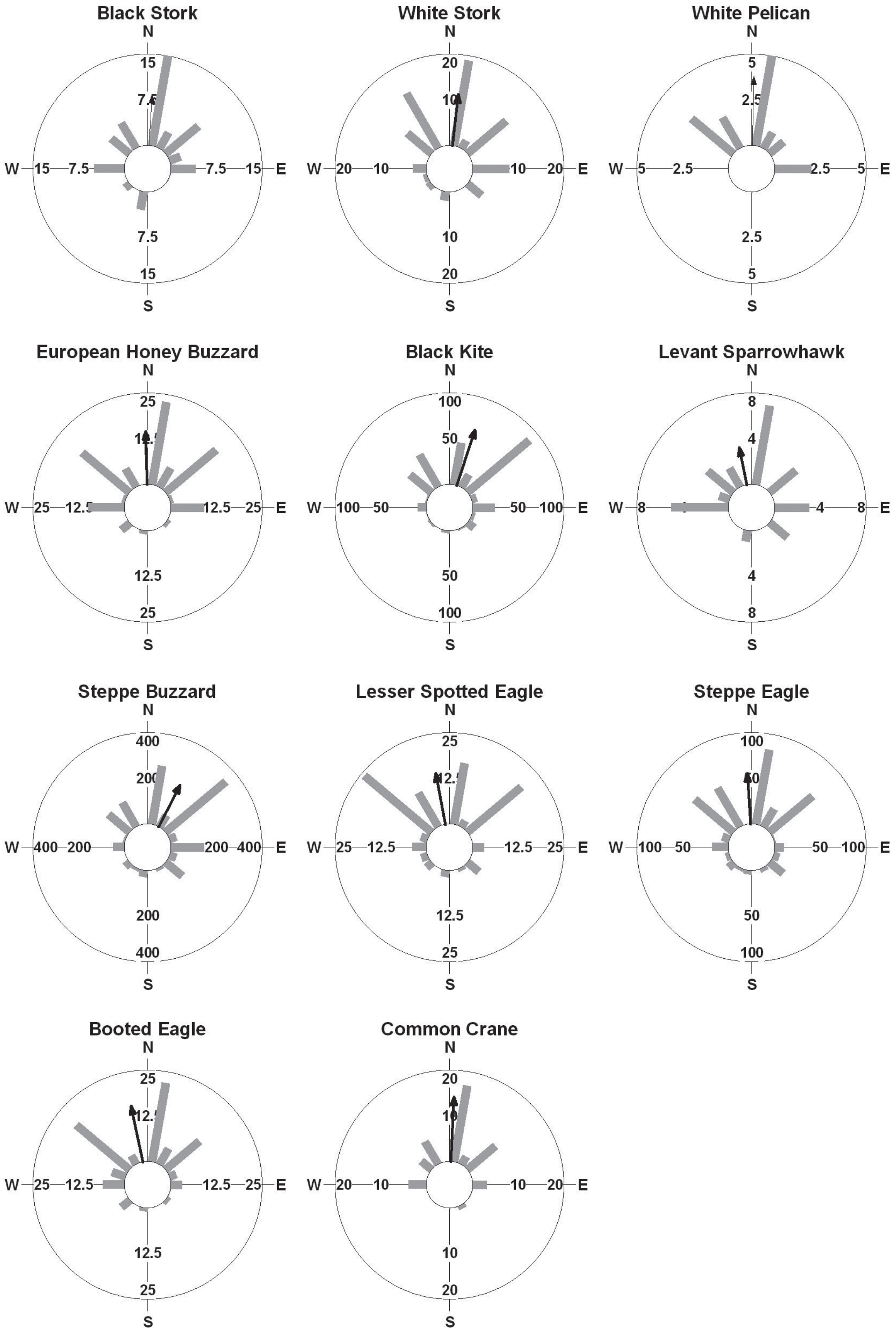

Figure 3. Frequency distributions of flight directions of eleven soaring species in the study area. Mean direction and vector length are shown by an arrow. For further details see Table 2.

Buzzard. In crosswinds from the right of the median direction, the mean directions were 329°, 360° and 354° in the European Honey Buzzard, Black Kite and Steppe Buzzard respectively. In each of the three species the frequency distributions in both wind conditions differed significantly from each other (Mardia Watson Wheeler and Watson's U tests $P<0.001$). European Honey Buzzards and Steppe Buzzards accepted drift only from one side, while in winds from the other side they maintained their flight direction. The European Honey Buzzard tolerated drift from the right (Spearman rank correlation $r = -0.44$, $t = -3.22$, $P<0.002$, $n = 45$) and the Steppe Buzzard from the left ($r = -0.17$, $t = -5.88$, $P<0.001$, $n = 1114$).

In the event that the coastal mountains in general were used to gain height, this would emerge in the regional flight directions in the study area. We verified whether migrants crossing the southern and central part of the study area were heading towards the coastal mountain range or not. At sites 1 and 2 they were expected to fly in northerly directions and at sites 3–8 in more easterly directions. At sites 9–13 we would expect northerly directions towards the coast, as the coastal mountains are situated in the southeast. This analysis was performed for species with high numbers of records in these groups of sites: Black Kite, Steppe Buzzard and Steppe Eagle. The Steppe Buzzard was the only species where the frequency distributions of directions in all three sections differed significantly (Mardia Watson Wheeler and Watson's U^2 tests $P<0.001$). In all three sections Steppe Buzzards tolerated drift (Table 4).

Not all migrants that arrived in the study area appeared to continue towards the coast. In nine out of

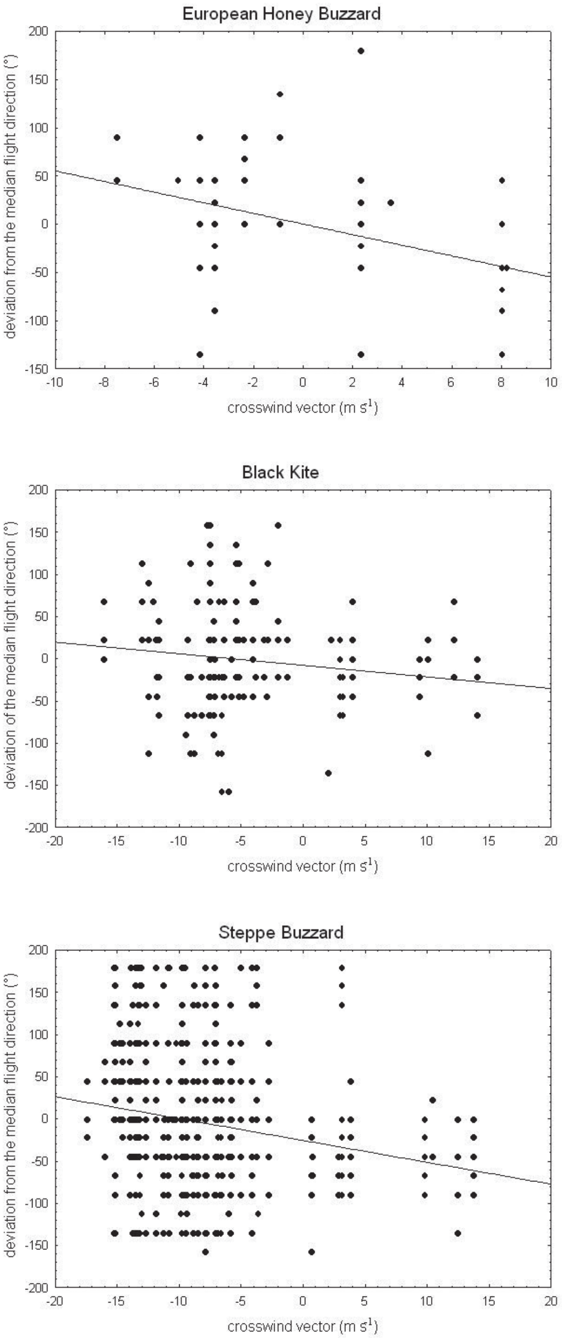

Figure 4. The effect of crosswind on flight directions of European Honey Buzzards *Pernis apivorus* (n = 95), Black Kites *Milvus migrans* (n = 278) and Steppe Buzzards *Buteo vulpinus* (n = 1322). Each flight direction is expressed as the positive (to the right) and negative deviation (to the left) of the median direction. The cross wind component is calculated in relation to the median migration direction of each species. European Honey Buzzard: $y = -5.51x + 0.221$, Black Kite: $y = -1.37x – 7.66$, Steppe Buzzard: $y = -2.59x – 25.49$.

Table 3. The effect of crosswind on flight directions of eleven species of soaring birds. For further details see methods. Correlations between the crosswind vector and the flight directions were analysed by means of the non-parametric Spearman rank correlation test (r, t, P).

	n	r	t	P
Black Stork	46	-0.09	-0.58	0.565
White Stork	69	-0.22	-1.82	0.073
White Pelican	14	0.14	0.47	0.645
European Honey Buzzard	95	-0.48	-5.31	<0.001
Black Kite	278	-0.16	-2.61	0.009
Levant Sparrowhawk	27	0.28	1.47	0.153
Steppe Buzzard	1322	-0.31	-11.66	<0.001
Lesser Spotted Eagle	89	-0.05	-0.49	0.623
Steppe Eagle	341	-0.11	-2.05	0.041
Booted Eagle	80	0.25	2.27	0.025
Common Crane	43	-0.12	-0.75	0.456

eleven species more than 60% of the movements were coast directed (Table 5). The highest percentage was observed in the Common Crane with 82%. The figure was over 70% in White Pelican, Black Kite and Steppe Buzzard. In Lesser Spotted Eagle and Booted Eagle the percentage was between 50 and 60%.

Situations with coast-directed and not coast-directed flights did not display significant differences in the strength of the crosswind vector (Mardia Watson Wheeler test, Watson's U^2 test). In eight out of eleven species the average crosswind vector was stronger from the left when the birds were heading towards the coast than when oriented inland (Table 5). The extremes were Steppe Buzzard and European Honey Buzzard. Average crosswind vector from the left was 8 m/s when Steppe Buzzards were oriented towards the coast and the average crosswind vector from the right was 3.6 m/s when European Honey Buzzards were inland oriented.

Considering only birds that were heading towards the coast, drift was proved for the same species as for the full set of directions: European Honey Buzzard, Black Kite and Steppe Buzzard. Within the group of coast-directed movements more than 50% were heading towards the coast north of the Gebel El Zait range (Table 5).

DISCUSSION

On average, the different species were heading on a broad front in northerly directions and as the coast follows a SSE–NNW line, mean directions mostly led to the coast of the gulf of Suez. Lesser Spotted Eagles, though, were heading to the NNW. We suppose that

Table 4. Regional mean flight direction (μ), vector length (r) and standard deviation (SD) of Steppe Buzzard *Buteo vulpinus* and test for correlation between the deviations perpendicular to the median direction and the crosswind vector. Analyses are based on independent records (corresponding to single birds or groups of birds). Data of different sites are grouped while western and eastern rows are not separated. All mean directions (μ) were significant (Rayleigh test P<0.001). The Spearman rank correlation (r, t) resulted in a significant correlation of the deviations of the median flight direction and the perpendicular wind vector (significant correlation in all three groups of sites, P<0.001). The regression analysis produced a regression coefficient (slope) for each section; the steeper the slope the stronger the drift element. Differences in sample sizes are due to lack of wind data for some days (see methods).

Sites	n	μ	r	SD	median	n	Spearman r	Spearman t	regression slope
1–2	192	3°	0.62	55.76°	360°	192	-0.25	-8.50	-2.04
3–8	817	41°	0.55	63.17°	45°	815	-0.29	-3.62	-2.46
9–13	354	7°	0.49	68.90°	360°	315	-0.30	-5.60	-3.04

Table 5. Percentage of all movements directed towards the coast. Within the group of coast-directed flyers, the percentage of movements towards the coast north of Gebel El Zait is given. Mean crosswind vector and SD are given for coast-directed and non coast-directed birds.

	coast directed		coast-directed movements			not coast-directed movements		
	% of all movements	% to N of Gebel El Zait	n	mean crosswind vector	SD	n	mean crosswind vector	SD
Black Stork	67.35	76	31	1.2	6.9	15	-1.62	6.28
White Stork	68.06	73	49	-2.39	4.27	20	1.18	6.34
White Pelican	71.43	60	10	-2.29	3.64	4	-1.55	8.00
European Honey Buzzard	65.63	68	62	-1.35	4.1	33	3.63	4.86
Black Kite	72.38	76	203	-4.74	6.88	33	-2.41	7.41
Levant Sparrowhawk	62.96	82	17	-2.07	3.13	10	2.97	2.26
Steppe Buzzard	76.30	59	1016	-7.99	7.00	306	-4.97	8.14
Lesser Spotted Eagle	55.91	74	49	-0.40	2.66	40	0.66	2.88
Steppe Eagle	62.81	75	209	-2.24	5.91	132	-2.94	5.04
Booted Eagle	58.75	72	46	1.80	5.82	32	-2.80	4.13
Common Crane	81.82	94	35	-1.66	4.55	8	-0.29	5.26

they continue their migration towards Suez, which is consistent with the fact that Lesser Spotted Eagles avoid water crossings (Meyburg *et al* 2002, Shirihai *et al* 2000, Grieve 1996).

The eastern border of the study area and the coastline are several kilometres apart. Thus we could not observe from the study area where the birds started their sea crossings. During our travels along the road parallel to the coast and our visits to the ridge of Gebel El Zait, we observed that raptors often started the crossing from the northern end of Gebel El Zait after gaining height and following the mountain ridge to the north, while Common Cranes started the sea crossing immediately after arriving at the southern end of Gebel El Zait. Common Cranes started the sea crossing either at high altitude or only a few metres or so above the water. This is consistent with the fact that this species does not depend so much on updrafts, being able to revert to active flight for long periods (Pennycuick *et al* 1979).

Soaring birds in general are known to be drifted partially, but there are differences according to the situation *ie* whether they have to cross a barrier, whether they are flying close to a coast or whether they are experienced migrants or not (Alerstam 1979, Thorup *et al* 2003, Klaassen *et al* 2011). In our study, all birds must have migrated at least once, between breeding areas and wintering sites. Thus they should be able to navigate by sight, using memory of ground features, and be aware of drift effects. Migrants are known to compensate or overcompensate for drift when they face the risk of being blown into hazardous situations (Klaassen *et al* 2011). If at Zait bay, birds start crossing the water too far south they might get drifted over the Red sea proper because of the prevailing NNW winds. We would expect anticipatory compensation or overcompensation of drift before they start the sea crossing. We discovered two different strategies in our study. While most species compensated for drift as expected, European Honey Buzzard, Black Kite and Steppe Buzzard accepted drift partially (Table 3, Figure 4). The Black Kite and European Honey Buzzard are known to migrate in conditions unsuitable for other soaring birds (Finlayson 1992, Agostini & Duchi 1994). In Gibraltar, Black Kites are observed to accept drift and to compensate for it later (Bernis 1980). European Honey Buzzards, however, are observed to be very wind selective at the crossing from Tunisia to Italy, where they prefer to migrate with following and weak lateral winds (Agostini *et al* 2005).

The regional pattern of flight directions of Steppe Buzzards and the fact that they tolerate partial drift support the idea that migrants of this species use the opportunity to gain height and fly along the mountain ridge in order to anticipate the drift to be expected during the sea crossing.

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