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FLIGHT BEHAVIOR OF RAPTORS DURING SPRING MIGRATION IN SOUTH TEXAS STUDIED WITH RADAR AND VISUAL OBSERVATIONS

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Hawk migration has been most commonly studied by counting migrants as they pass along ridges or coastlines (Heintzelman 1975). Migration counts of hawks are now routinely conducted at dozens of sites across North America. The reliability of the count method has been questioned, however, by Murray (1964) who suggested that high altitude migration biased counts to low flying birds. Kerlinger and Gauthreaux (1984) and Kerlinger (1984) employed radar and visual observations to show that the altitude and visibility of Sharp-shinned Hawks (*Accipiter striatus*) migrating at Cape May Point, New Jersey were directly related to weather conditions and that counts were, at times, unreliable. These studies also pointed out the need for more detailed studies of flight behavior. Here we present quantitative data from radar and visual observations on flocking behavior, flight direction, migration altitude, and abundance of migrating hawks during spring migration in south Texas.

STUDY SITE AND METHODS

Observations were conducted in the parking lot of the Santa Ana National Wildlife Refuge, Hidalgo Co., Texas (26°07'N, 98°18'W) during the period 28 March–16 April 1982. The refuge (elev. ~ 20 m) consists of 2000 ha of woodlands situated on the north bank of the Rio Grande River. The area surrounding the refuge for many km is flat and the only topographic features of prominence are the Rio Grande River which extends to the northwest and the Gulf of Mexico some 80 km to the east. The land is thus devoid of topographic leading lines oriented appropriately for migration of most species considered here. Landuse, for the most part, is restricted to cultivation.

Direct visual observations began at 0700 at which time 7 and 10× binoculars were used to scan for migrants. A marine surveillance radar (Decca 150, 3 cm, 10 kW), powered by a gas generator, was used from approximately 0800–1030 to scan for flocks of hawks. From approximately 1030–1500 a fixed-beam radar (Marconi Seafarer, 3 cm, 10 kW) with a vertically aligned parabolic antenna was used. Both radars were mounted on the roof of the Avian Migration Mobile Research Laboratory, a 7 m motor-home modified for research purposes. The radars were operated by one person who watched the radar screen for echoes. When a radar echo was detected, the radar operator informed an observer as to the range and, or direction of the echo so that a visual identification could be made. Radar operations were halted for equipment maintenance at frequent intervals (ca. ½ to 1 h), although direct visual observations by at least one observer were continuous. The time of day and duration of radar operations were dependent upon the intensity and altitude of migration. After 1600 only direct visual observations were conducted. Daily operations were halted at 1800, although casual observations were made until sunset.

We recorded flock size (and identification of species within the flock), flight altitude (above ground level), and direction of flight when possible. Notes pertaining to flight behavior and visibility of migrants were recorded when time allowed or behavior seemed abnormal. At times there were so many migrants in view that we resorted to estimating (counting by 5s or 10s) the numbers of some species. Flight direction was determined by reading directions from the surveillance radar screen or by taking a disappearing azimuth with a sighting compass (for birds that were within approximately 25° of the zenith). The latter method was frequently used simultaneously with the vertical fixed-beam radar. Altitudes were determined either directly using the vertical fixed-beam radar or indirectly (especially for flocks) using the surveillance radar and an inclinometer. The flight behavior of Broad-winged Hawks (*Buteo platypterus*) will be described elsewhere. Directional statistics were computed according to Zar (1974).

Surface wind direction and speed were measured with a hand-held compass and anemometer. Upper air wind conditions (WBAN Constant Pressure) taken at Brownsville, Texas were obtained from the U.S. Climatic Center at Asheville, North Carolina.

RESULTS

Of 12 species observed during the study, the Broad-winged Hawk was the most numerous migrant (Table 1) accounting for 94% of all migrants. Swainson's Hawks (*B. swainsoni*) and Turkey Vultures (*Cathartes aura*) accounted for about 5% of the total, while other species accounted for less than 1% of hawks counted. The number of Swainson's Hawks was a result of one very large flight, mostly in 3 flocks, that passed in 2 h on 8 April. Other individuals of this species were spread throughout our observation period. The Sharp-shinned Hawk increased in numbers after 6 April, while the American Kestrel (*Falco sparverius*) seemed to decrease in numbers after 4–5 April. The Mississippi Kite (*Ictinia mississippiensis*) did not become common until 11 April, although a few individuals were seen in the previous week. Other species were fairly evenly distributed throughout the 20-day observation period.

Flocking.—Flocking was noted in all species except for one Red-shouldered Hawk (*B. lineatus*) and 2 Peregrine Falcons (*F. peregrinus*). Flocking occurred during both circle-climbing flight in thermals and in gliding flight between thermals. Mixed-species flocks were often as cohesive as mono-specific flocks and often maintained integrity while soaring in thermals and during subsequent glides. The degree of flocking and the type of flocking varied dramatically from species to species (Table 2). The first 4 species listed in Table 2 tended to flock far more often and form larger flocks than the remaining 4 species. In mixed-species flocks the

TABLE 1. Daily hawk counts for spring 1982 migration at Santa Ana National Wildlife Refuge, Texas.

Date	Sharp-shinned Hawk	American Kestrel	Mississippi Kite	Turkey Vulture	Swainson's Hawk	Broad-winged Hawk	Totals[a]
28 March	0	2	0	4	0	0	8
29	1	17	0	34	24	8703	8785
30	3	10	0	21	6	4362	4406
31	2	4	0	14	2	822	846
1 April	1	3	0	5	1	11,021	11,033
2	2	3	1	8	0	4793	4812
3	1	1	1	3	0	1695	1703
4	3	1	1	62	14	7536	7620
5	2	12	1	263	3	20,044	20,326
6	0	0	1	20	56	399	478
7	22	3	4	18	6	2185	2241
8	9	5	1	6	3477	146	3645
9	2	0	2	1	56	5	67
10	1	0	0	3	20	3	29
11	9	2	6	45	45	919	1030
12	17	2	36	22	9	5507	5595
13	8	1	30	10	4	363	419
14	21	3	24	47	5	2189	2295
15	27	4	15	32	19	169	267
16	3	0	0	0	4	1034	1041
Totals (%)	134 (0.2)	73 (0.1)	123 (0.1)	618 (0.7)	3751 (4.2)	84,595 (94.5)[b]	89,346[a]

[a] Total includes 4 Northern Harriers (*Circus cyaneus*), 3 Black Vultures (*Coragyps atratus*), 2 Peregrine Falcons (*Falco peregrinus*), 1 Red-shouldered Hawk (*Buteo lineatus*), 23 Cooper's Hawks (*Accipiter cooperii*), and 19 Ospreys (*Pandion haliaetus*).

[b] Total includes 12,700 hawks seen on 25 March by Santa Ana National Wildlife personnel.

TABLE 2. Flocking tendencies of raptors during spring migration in south Texas.

Species	Mono-specific flocks (%)[a]	Mixed-species flocks (%)[a]	Largest flock size[b]	Frequency with Broad-winged Hawks[c]
Swainson's Hawk	95.3	2.3	1500	24/36
Turkey Vulture	19.9	77.6	200	41/46
Mississippi Kite	80.5	3.3	30	3/4
Osprey	10.5	26.3	2	2/4
Sharp-shinned Hawk	9.7	20.9	3	23/24
Cooper's Hawk	0.0	26.3	—	6/6
American Kestrel	16.4	13.7	2	6/10

[a] Percentage of totals given Table 1.
[b] Largest number of conspecifics seen together at one time.
[c] Number of times a species was seen with Broad-winged Hawks/total number of times the species was seen in mixed-species flocks.

most common "host" species was the Broad-winged Hawk. Occasionally, non-raptorial species were associated with raptor flocks, including Anhinga (*Anhinga anhinga*), Purple Martin (*Progne subis*), and Franklin's Gull (*Larus pipixcan*). These three species were seen with hawks soaring in thermals, but not during inter-thermal glides.

Altitude and visibility.—Before 0900 birds usually flew too low to detect with the vertical fixed-beam radar. These migrants gained altitude using flapping flight, weak thermals, or wind deflected upwards off trees. Thermals developed quickly after 0900–1000 and it was rare to see migrants flying at altitudes less than approximately 100 m. Migrating raptors usually remained at altitudes >300 m until 1700.

During the mid-day period (0900–1500), the measured altitudes of hawks ranged from 257–1287 m and the mean altitudes for all species ranged from 531–745 m (Table 3). Less than 3% of all hawks flew below 300 m and 1% flew higher than 1000 m. Nearly 89% were seen between 300 and 800 m, while 76% were between 300 and 600 m. We found no obvious differences in altitudinal ranges among species (Table 3).

TABLE 3. Summary of mean altitudes (above ground level) of migrating raptors at Santa Ana National Wildlife Refuge, Texas.

Species	Mean altitude ± SD (meters)	Number of radar measurements	Number of raptors
Sharp-shinned Hawk	745 ± 205	14	18
Cooper's Hawk	726 ± 403	4	5
Swainson's Hawk	531 ± 161	15	154
American Kestrel	551 ± 232	11	13
Turkey Vulture	552 ± 245	12	26
	585 ± 227	56	216

TABLE 4. Summary of flight directions during spring migration at Santa Ana National Wildlife Refuge, Texas.

Species	Mean track direction ± angular deviation	Length of mean vector	Sample size
Mississippi Kite	005° ± 31°	0.865**	10
Turkey Vulture	004° ± 19°	0.948**	12
Swainson's Hawk	360° ± 20°	0.942**	31
American Kestrel	349° ± 16°	0.960**	25
Sharp-shinned Hawk	349° ± 24°	0.917**	33
Climbs in thermals (all species)	323° ± 15°	0.967**	27

** Indicates significant at the $P < 0.01$.

Although most birds were readily visible to an observer using 7 or 10× binoculars, many birds flying directly overhead were difficult or impossible to see with the unaided eye. Smaller raptors such as Sharp-shinned Hawks and American Kestrels became difficult to see against a cloudless sky at altitudes of 500 m and were not visible without binoculars at altitudes of 700–800 m on at least three occasions. Larger raptors and flocks of hawks were sometimes difficult to see at altitudes above 600 m without binoculars, and at times they were not visible to the naked eye at altitudes over 900 m. Many Sharp-shinned Hawks were noticed only when associated with flocks of Broad-winged Hawks. Only 11 radar echoes at altitudes >480 m were not visible to the observer even with the aid of binoculars. Some of these echoes could have been swifts, swallows, insects, or possibly small hawks. Undoubtedly, many migrating hawks would have been missed were it not for cueing by the radar.

Wind and flight direction.—Surface winds at Santa Ana National Wildlife Refuge during our study were from the SE–SSE ($\bar{x} = 309° \pm 62°$, length of mean vector (r) = 0.55, $P < 0.01$, $n = 19$ days; Zar 1974). On 7 of 19 days, winds at noon were from the NE or NW and unfavorable for migration. Winds aloft (900 mb = 1000 m) were similar ($\bar{x} = 333° \pm 50°$, length of mean vector (r) = 0.68, $P < 0.01$, $n = 20$ days). Thus, wind direction was predictable and favorable for migration during the study period.

Direction of flight during thermalling flight for all species was nearly downwind (Table 4). The dispersion around the mean is small, although it is not uniformly distributed around the downwind direction as expected. Instead, the distribution is skewed in a slightly clockwise direction from downwind in the same direction as the wind shift from the surface up to the 1000 m level. The mean directions of glides of all 5 species were similar, ranging from 349° to 5° (Table 4) and were well oriented (length of mean vector (r) > 0.86).

DISCUSSION

Previous studies of hawk migration have primarily focused on counts of raptors at such topographic features as ridges (Broun 1935), coastlines (Alerstam 1978, Allen and Peterson 1936, Haugh 1972, Mueller and Berger 1961) and other concentration points (Evans and Lathbury 1973, Smith 1980). Few studies (Kerlinger 1982, Kerlinger and Gauthreaux 1984, 1985, Kerlinger et al. 1985) have examined the flight behavior of migrating raptors away from distinct topographic features. The flight behavior of migrants in south Texas was quite different from that reported from ridges and coastlines. The major differences were: (1) all raptors relied almost solely on thermal convection for lift as opposed to wind generated lift used along ridges and hills, (2) raptors were spread over a broad front as opposed to being channeled by a leading line, and (3) migration regularly proceeded at high altitudes and was frequently difficult to detect.

Flocking of soaring migrants has been hypothesized to function (1) in navigation or orientation (Hamilton 1962, Thake 1980) and (2) in location of thermals (Kerlinger and Gauthreaux 1985, Kerlinger et al. 1985, Pennycuick 1972). We prefer the latter hypothesis because it is unlikely that the preferred directions of the different individuals and species are the same. Pennycuick (1972) hyothesized that spacing out of migrants during cross-country glides increased the chance of encountering thermals. His argument can be applied to both Swainson's Hawks and Turkey Vultures, because these species form extended cluster formations (Heppner 1974) during inter-thermal glides similar to Broad-winged Hawks (Kerlinger and Gauthreaux 1985). Other species (especially Sharp-shinned Hawks) that flew with large flocks of Broad-winged Hawks could be considered commensals. The advantage of migrating in flocks would be a more efficient means of locating thermals thereby achieving more rapid and energetically less costly migration.

While it is easy to understand how a mono-specific flock maintains integrity during flight, factors which should promote disintegration of mixed-species assemblages include (1) disparate aerodynamic performance (glide ratios or air speeds), (2) differences in preferred direction of migration, and (3) agonistic behavior (Hamilton 1962). Although the mixed-flocks we observed seemed to maintain integrity, it would be of interest to know how long flock integrity was maintained.

The altitudes reported in this paper (average nearly 600 m) agree with altitudes of soaring migrants measured by radar in Texas (Kerlinger and Gauthreaux 1985), New York (Kerlinger et al. 1985), New Jersey (Kerlinger and Gauthreaux 1984), and southern Sweden (Pennycuick et al. 1980). Smith (1980), however, reports altitudes of 3000–4000 m for Swainson's Hawks and Turkey Vultures migrating through Panama in autumn. If migration occurs at altitudes >3000 m, we believe that they go undetected by ground-based observers. Our finding that raptors frequently fly at altitudes beyond the limit of human vision has implications for previous studies that have employed visual counts of migrating raptors. Stone (1937), Evans and Lathbury (1973), and Heintzelman (1975) have also suggested that raptors sometimes fly at altitudes that are too high to be detected with the naked eye. Reports of peak abundances of accipiters and buteos in mid-morning, before convective elements are fully developed (Mueller and Berger 1973, Heintzelman 1975) may be a function of reduced visibility of birds flying at high altitudes. It is probable that hawk migration counts have been biased toward raptors flying at low altitudes.

Use of portable marine radars.—Both of the marine radars were excellent tools for studying hawk migration, although each had its limitations. Use of the surveillance radar was limited mainly to raptors travelling in flocks or single birds the size of kestrels within 1.8 km. Large flocks (several hundred to 1000s) were detectable to 7 km when the radar was set at the 11.1 km range and were sometimes tracked for up to 8 km. Because the cross-sectional area of a bird fluctuates as it circles or turns, echoes from birds often disappeared and reappeared on the radar screen. A second limitation with the surveillance radar is the wedge-shaped beam that only detects birds within 20° of the horizon. Birds flying over the 20° wedge were not detectable, and consequently the radar was most useful early in the day when migration was at low altitudes. As the altitude of migration increased, targets had to be detected at greater distances to be within the 20° beam. At distances greater than 2.5 km only stronger targets could be detected.

The vertical, fixed-beam radar also had its limitations. The narrow width of the radar beam (4°) accounts for its accuracy when determining altitude, but limits observations to a narrow cone of airspace. For this reason, sample sizes were small. A wider beam width could be achieved by employing a smaller parabolic antenna on the radar, but reduced radar sensitivity would also result.

Although each radar had its limitations, they complemented each other when used in sequence (surveillance early in the day and vertical fixed-beam from mid-morning on). The fact that marine radars are relatively inexpensive and portable makes them ideal for studying raptor migration. Finally, we emphasize that when marine radars are employed to study raptor migration, simultaneous visual observations are a necessity.

SUMMARY

The flight behavior of raptors migrating through south Texas in spring was studied with marine surveillance radar and vertical fixed-beam radar combined with simultaneous visual observations. Broad-winged Hawks accounted for a majority (94%) of the total hawks, while Swainson's Hawks and Turkey Vultures accounted for about 5% of the total. Flocking was noted in almost all species and was most prevalent among longer distance migrants (Swainson's Hawks, Turkey Vultures, and Mississippi Kites). Wind direction was highly predictable and favorable for migra-

tion, although easterly winds could potentially drift migrants off course. Migrants averaged nearly 600 m in altitude and employed thermal convection for lift. We suggest that hawk counts by ground-based observers may be biased toward sampling low altitude migrants because raptors in this study often flew at altitudes beyond the range of human vision. Marine radars, combined with simultaneous visual observations, proved an excellent means of collecting quantitative information on several aspects of raptor migration including orientation and altitude.

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