

## SHORT COMMUNICATIONS

### Autumnal Bird Migration Over the Windward Caribbean Islands

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For more than two decades radar has been used to observe autumnal bird migration over the western North Atlantic Ocean and the Caribbean Sea (see Richardson 1980). Richardson (1976) used search radars to observe from the island of Puerto Rico from mid-August to early or mid-November, 1970 and 1971. Williams et al. (1977) made simultaneous short-term observations with a network of radars on the windward islands of Antigua, Tobago, and Barbados during each October from 1970 to 1973. Radar observations obtained over Antigua from 20 August to 30 September 1978 provided coverage of the fall migratory season comparable to that obtained at Puerto Rico. All data from the windward islands have been rescored and reanalyzed. The results presented here revealed an error in our previously published results and allow the development of a more unified theory of autumnal migratory behavior of birds in the Caribbean area.

The FPQ-6, a long-range tracking radar (5-cm wavelength, 3-MW peak power, 0.4° beam width at 3 db points), was used on Antigua in 1970 and 1971, and the RC-32-B, a meteorological radar (10-cm wavelength, 500-kW peak power, 1.9° beam width), was used on Antigua in 1972, 1973, and 1978 and Tobago and Barbados in 1973. Additional information on the radars may be found in Williams et al. (1977).

Data were recorded from the radar Plan Position Indicator (PPI) screens on Polaroid type 107 film. In time exposures of 3–10 min slowly moving targets, such as birds, produced streaks on the film that were used to determine the direction, speed of movement, and density of migrants as described in Gauthreaux (1970) or Williams and Williams (1972). During the last minute of exposure the camera shutter was closed for 30 s and then reopened, producing a dot at the leading end of each complete track. Altitude was computed from range, angle of elevation, and correction factors for curvature of the earth and index of refraction of the atmosphere. Density of migration was determined from the maximum density observed in any PPI photograph during a 1-h period. Light, moderate, and heavy migrations were arbitrarily defined as fewer than 10 echoes in 4 min, 10–20 echoes, and more than 20 echoes. Winds aloft were measured by radiosondes launched within 5 km of the radar sites, except at Tobago where the radio-sonde site is located 40 km to the southwest. In almost all cases these wind data were measured within 4 h of our radar observations.

Radars in the Caribbean usually operate from 0800 to 1600 local time (1200–2000 GMT). In 1978, our fi-

nal observation at Antigua was at 2200 GMT daily. At all sites observations occasionally were interrupted by equipment failures or other projects with higher priority. These interruptions are shown in Fig. 1. Within the limitations of the work schedules at the radars, we obtained three observation periods/day with two or more photographs at different angles of elevation/observation period.

The methods of analysis used here differ in several important respects from those used by Hilditch et al. (1973) and Williams et al. (1977). To insure uniform treatment for different years, I rescored all the original PPI photographs and rejected all tracks that could not be scored accurately for speed and altitude even if direction was unambiguous. This criterion may bias the data against small birds and those flying singly. The resulting data set of more than 2,000 tracks was used for all analyses unless otherwise indicated in the text. All statistical tests and correlations were calculated with individual tracks, not daily means. Track and ground speed refer to the velocity of a bird relative to the ground. Heading and airspeed refer to the velocity of the bird relative to the air mass and are calculated from track and ground speed by vector addition of the negative velocity of the wind measured at the altitude of the bird.

Radar data show that autumnal migration over the island occurred as early as late August, with peaks in early September and again in October (Fig. 1). The heaviest migrations occurred in mid-October. Averaging tracks/observation over several years obscured the peak numbers observed during individual years. Heavy migrations in October commonly produced photographs with more than 40 complete tracks and at least 20 incomplete tracks. No photograph taken before October exceeded 14 complete tracks. Mean track by day varied from 127° to 207° with mean heading by day showing much less variation (128°–166°). Neither tracks nor headings were significantly ( $P > 0.05$ ) correlated with date.

I divided migrants into two groups, those observed before 15 September (early) and those observed after 20 September (late). There were no moderate or heavy migrations between those dates. Observations of the departure of migrants from North America (Drury and Nisbet 1964; Nisbet 1970; Williams et al. 1977; Richardson 1979, 1980) and ground observations in the Caribbean (McCandless 1961, Richardson 1976, Holland and Williams 1978) suggest this division corresponds to the peak migrations of shorebirds (early) and wood warblers (late).

Histograms of the distributions of observed tracks

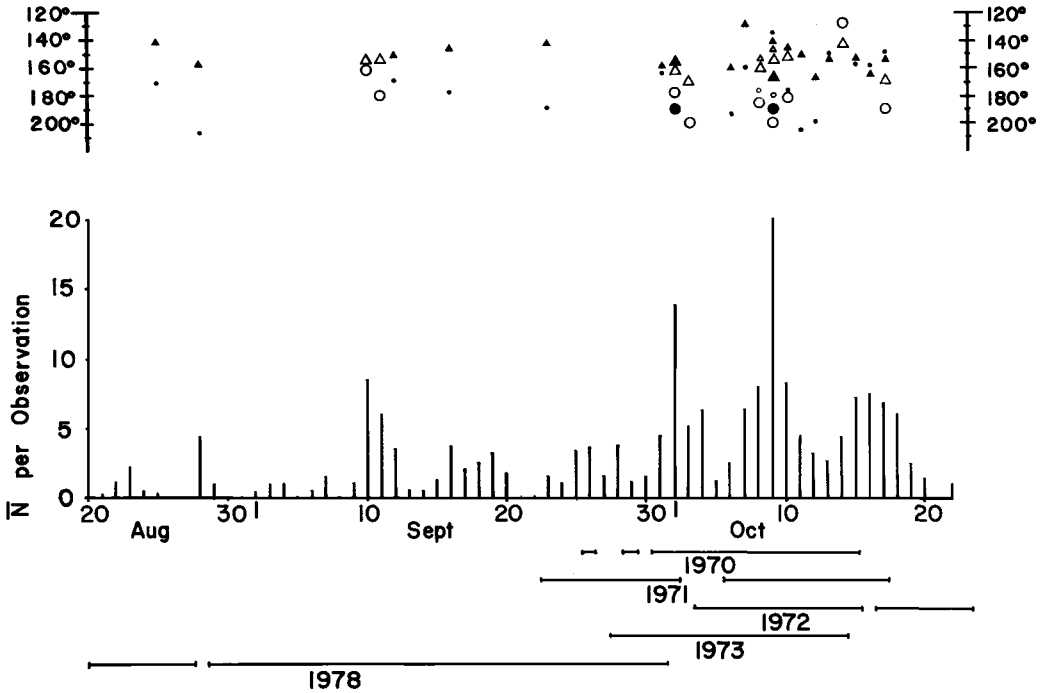


Fig. 1. Average number of migrant birds over Antigua per PPI photograph (4 min) with time of observations and mean heading and track for all moderate and heavy migrations. Heading indicated by triangles, track by circles, moderate migration by small symbols, and heavy by large symbols. Open and solid symbols serve to distinguish migration on the same dates.

and calculated headings show very strong peaks to the south and a much smaller number of birds moving north (Fig. 2). The birds moving north may be either reverse migrants similar to those often reported from continental radar studies or they may be birds moving toward the island of Barbuda 45 km north of Antigua. Barbuda is sparsely inhabited and has excellent habitat for shorebirds and waterfowl.

The mean track for all migrants was  $175^\circ$  [ $r = 0.73$  ( $r$  is inversely related to angular dispersion; see Batschelet 1965, 1981)]. The mean heading for all migrants was  $153^\circ$  ( $r = 0.89$ ). As discussed by Williams and Williams (1978) and Richardson (1980), the southward displacement of tracks from headings and the greater variability of tracks are most simply explained by wind drift by northeast tradewinds on relatively constant headings.

There was no significant difference ( $P > 0.05$ ) between the early and late groups of migrants for either heading or track by the Watson-Williams 2-sample test (Batschelet 1965). Early migrants' mean heading was  $153^\circ$  ( $r = 0.89$ ), and late migrants' mean heading,  $152^\circ$  ( $r = 0.86$ ). Early migrants' mean track was  $171^\circ$  ( $r = 0.83$ ), late migrants' mean track  $175^\circ$  ( $r = 0.73$ ).

Altitude of migrants was distributed as shown in Fig. 3. A Student's  $t$ -test showed no significant dif-

ference between early (mean = 2,100 m) and late (mean = 3,090 m) migrants ( $P > 0.05$ ).

There were significant differences in both the air-speed and the ground speed of early and late migrants (Student's  $t$ -test,  $P < 0.001$ ), and thus, these groups are plotted separately (Fig. 4). The mean air-speed of 72 km/h (20 m/s) for the early groups would be expected for shorebirds; the mean for the late group, 47 km/h (13 m/s), suggests passerines primarily (see Richardson 1976, Williams et al. 1977). The ratios for ground speed/airspeed of 0.88 for the early and 0.93 for the late groups are consistent with previous evidence that birds migrating over the Caribbean do not, in general, fly in favorable winds. One-way analyses of variance were performed for all days of moderate and heavy migration in the late migratory group. Significant differences between days ( $P < 0.01$ ) were found for track, heading, and altitude but not for airspeed ( $P > 0.05$ ).

There was no significant difference (Watson-Williams two-sample tests,  $P > 0.05$ ) in heading of migrants over Antigua and those detected over Barbados or Tobago. A large and significant (Student's  $t$ -test,  $P < 0.01$ ) difference occurred in altitude as has been reported (Williams et al. 1977). There were also small but significant ( $P < 0.05$ ) differences in track, air-

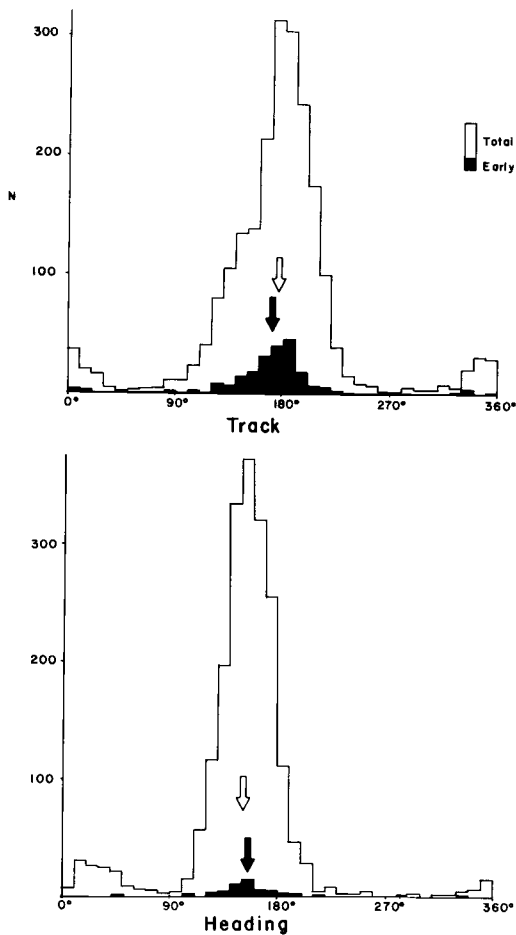


Fig. 2. Distribution of headings and tracks of birds over Antigua. Early refers to birds detected before 15 September.

speed, and ground speed, but these should be interpreted cautiously as the radars on the three islands differed in their sensitivity to birds at low angles of elevation.

High-altitude flight over the Caribbean benefits migrants by allowing them to fly in more favorable wind conditions. This was shown for wind conditions averaged over 1 month and for 9 specific days by Richardson (1976), averaged over 10 days of high-altitude migration (Williams et al. 1977), and for 1 selected day (Alerstam 1981). The present analysis revealed that if birds do select altitude for advantageous winds, they are far from perfect. On all 3 days on which the mean head-wind component was greater than 15 km/h, the majority of birds flew in the 1.5-km altitude range with the worst head winds and could have improved flight conditions by flying either higher or lower.

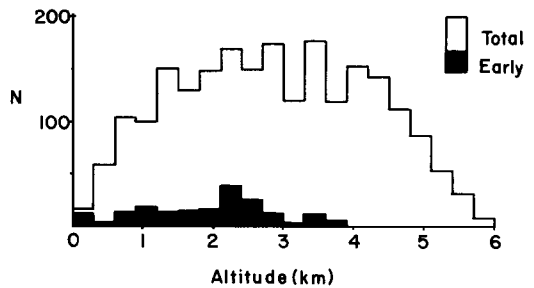


Fig. 3. Distribution of altitude for birds over Antigua. Early refers to birds detected before 15 September, late to those detected after 20 September.

As a result of a complete reanalysis of previous data (Williams et al. 1977), I conclude that the division of migrants observed over Antigua into two groups was invalid. This division of birds approaching from either the Atlantic or from the Greater Antilles was based on visual estimates of modal direction(s) in PPI photographs. The bimodal distribution (Williams et al. 1977: Fig. 3) was due to many days that were themselves judged to be bimodal. I tested the distribution of measured tracks for all moderate and heavy migrations at Antigua using the Chi-square test for goodness of fit (Batschelet 1965, 1981). Only two days showed significant deviations from a circular normal distribution: 2 October 1970 ( $P < 0.05$ ) and 7 October 1971 ( $P < 0.05$ ). A similar analysis revealed that the heading distributions conformed to circular normal even on the two days when tracks did not. The apparent bimodality of tracks on these and other days was due to discontinuities in wind velocity with altitude. The distribution of both tracks and headings presented here are strongly unimodal (excluding birds flying north), and none of the daily mean headings was sufficiently far east for the birds to have originated their flights in the Greater Antilles (see Stoddard et al. 1983). This analysis does not pertain to the division of migrants into two groups by Richardson (1976), as the group of migrants that he reported moving along the Antilles was not seen during the daytime and all of our observations were diurnal.

Although early (primarily shorebird) and late (primarily passerine) migrants are distinguished by air-speed and time of arrival, they do not differ in altitude, heading, or track as they pass over Antigua. The migrants we observed over the windward islands may be considered a single group [Atlantic migrants in Richardson's (1976, 1980) terminology]. They have headings normally distributed around a mean of  $153^\circ$ , and their tracks are drifted from these headings by local wind conditions to a degree dependent upon the winds they encounter.

Radar data taken on autumnal migrants at other sites on the Atlantic route strengthen my conclusion.

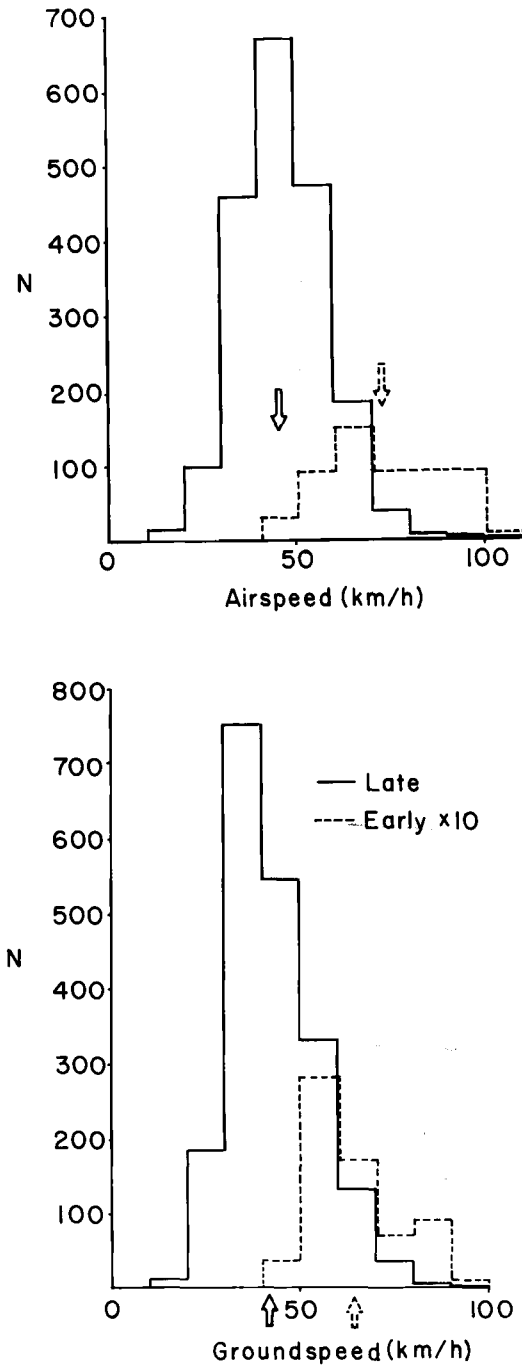


Fig. 4. Distribution of ground speeds and airspeeds for early and late fall migrants over Antigua.

Distribution of headings was unimodal at Bermuda and Miami (mean values of 157° and 152°, respectively; see Williams and Williams 1978). The Watson-Williams two-sample test showed no significant difference ( $P > 0.05$ ) between mean heading recorded at Miami, Barbados, and Tobago and that recorded at Antigua. Bermuda was significantly different at  $P < 0.05$ . Richardson (1975, 1976) reports that tracks and estimated headings of migrants over Puerto Rico were normally distributed with no difference for early and late autumn. The mean heading was between 166° and 174° depending on how wind conditions were estimated (Richardson 1980).

The significant difference between the mean heading observed on different days at Antigua and the more southerly heading at Puerto Rico is to be expected from a constant heading migration strategy with departures at varying points along the North American coast. Stoddard et al. (1983: Fig. 1) illustrated that a group of birds with normally distributed headings would disperse as they moved south, and only a small portion of the original group would pass over Antigua. Birds moving over Puerto Rico would tend to have more southerly headings, and birds with headings more to the east would pass east of the Antilles. Because migrants departing from different sites along the North American coast would need different headings to reach the same Caribbean island, the daily mean heading observed from any one island should vary depending on departure site of the migrants and wind conditions en route.

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### Investigator Perturbation and Reproduction of the Cliff Swallow

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Measurement techniques of any type influence the value of the variable measured. This deviation must be understood so that an investigator can choose appropriate methods to reduce the experimentally induced error. Human perturbation has adversely affected reproduction in numerous avian species. Colony-nesters, especially nonpasserine waterbirds, appear particularly heavily affected. Recently, investigators of such phenomena have attempted to quantify their own impact upon procellariids (Ollason and Dunnet 1980), phalacrocoracids (Ellison and Cleary 1978), ardeids (Goering and Cherry 1971, Werschkul and McMahon 1976, Tremblay and Ellison 1979, Parsons and Burger 1982), larids (Kadlec and Drury 1968, Hunt 1972, Gillett et al. 1975, Robert and Ralph 1975), rynchopids (Safina and Burger 1983), and alcids (Cairns 1980). We are aware of no comparable data that relate directly to investigator-induced effects on colonial passerines. Although researchers of such species may be cautioned by data on nonpasserine species, these must be supplemented by data obtained for passerines.

During a study of the basic reproductive ecology

of the Cliff Swallow (*Hirundo pyrrhonota*) in southern Texas, we observed colonies of sufficient size to permit determination of the effects of alternate data-collection methods on several reproductive parameters. Here we provide the results of that experiment as well as basic nesting data.

Four multiple-sectioned highway culverts in Goliad and Bee counties, Texas were chosen as study sites in March 1983; these were separated by a maximum straight-line distance of 72.5 km. Cliff Swallows built their enclosed mud nests high on concrete culvert walls near or at their juncture with passage-way ceilings. A total of 1,239 nests and their contents was examined 3 times/week on alternate days from 19 April to 8 June 1983, the period of the first wave of reproductive activity of the study population. A flexible-head flashlight and inspection mirror allowed visual observation of nest contents. Nest condition, number of eggs, number of young, and subjective estimates of nestling age, condition, and parasite load were recorded.

Three treatments were used to assess the effects of nest perturbation on various nesting parameters. The