RADAR AND VISUAL OBSERVATIONS OF AUTUMNAL (SOUTHWARD) SHOREBIRD MIGRATION ON GUAM

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ABSTRACT.—Several species of shorebirds migrate between eastern Asia and the southern Pacific islands, Australia, and New Zealand. Observations made from Guam (13°25'N, 144°45'E) during autumn 1983 indicate that a significant number of birds take a direct route over the western Pacific Ocean. Radar observations and ground counts of migrants on Guam showed two periods of autumnal migratory activity. The first, largely adult birds, was in August and September. The second, largely juveniles, was in late September and October. Radar indicated that large numbers of birds passed over the island to the south with no evidence of compensation for drift by the easterly winds. Comparison of radar and ground observations on Guam showed that only a small subset of migrants stop on the island, suggesting that some species may make nonstop flights between eastern Asia and the South Pacific. *Received 3 August 1987, accepted 22 February 1988.*

ORNITHOLOGISTS in Europe and North America can draw on more than a century of migration studies using bird banding and on 40 years of radar observations. The study of migration patterns from Asia to Australia and the South Pacific is comparatively recent. McClure (1974) reviewed autumn banding records of several species of shorebirds (Charadriiformes) from southeast Asia, the Philippines, eastern China, and Japan. The movement was primarily southwest along the mainland coast to southeast Asia and the Philippines, with a few recoveries as far south as Australia. Weishu and Purchase (1983) reviewed the preliminary results of the Australian Bird Banding Scheme and reported several recoveries of northbound shorebird migrants to China from Australia but no recoveries of southbound birds returning to Australia. These data suggest a southward movement over open water rather than along a coastal route. Reviews of the distribution of shorebirds indicate that several species migrate between eastern Asia and Micronesia (Baker 1951; Owen 1977; Pyle and Engbring 1985, 1987), Australia (Lane 1987), and New Zealand (Davies 1986, Sagar 1986).

In the western Pacific islands the primary migrant shorebirds are Lesser Golden-Plovers (*Pluvialis dominica fulva*) and Ruddy Turnstones (*Arenaria interpres*) (Bell 1948; Johnson 1973, 1979; Smart 1973; Thompson 1973; Jenkins 1981; Schipper 1985; Pyle and Engbring 1985; Williams and Grout 1985; Hayes 1986). Nonshorebird migrants to Micronesia are rare, with the exception of the Cattle Egret (*Bubulcus ibis*) (Pyle and Engbring 1985, 1987; Williams and Grout 1985).

We conclude from these studies that significant numbers of Lesser Golden-Plovers and Ruddy Turnstones, as well as smaller numbers of other shorebirds, including both tattler species (*Heteroscelus incanus* and *H. brevipes*), migrate annually from northern breeding grounds to small islands and atolls in the western and southern Pacific. Bar-tailed Godwits (*Limosa lapponica*) and Red Knots (*Calidris canutus*) also make regular migrations in large numbers from breeding grounds in northern and eastern Asia to New Zealand. These species and the Great Knot (*C. tenuirostris*), Rufous-necked Stint (*C. ruficollis*), Sharp-tailed Sandpiper (*C. acuminata*), and Curlew Sandpiper (*C. ferruginea*) make regular annual migrations to Australia. There is insufficient evidence at present to determine whether their flights are primarily over southeast Asia or whether they take a more direct route over the western Pacific. Migrants not regularly seen in Micronesia may make a long, nonstop flight passing over the islands, as suggested for the Hudsonian Godwit (*Limosa haemastica*) in the Atlantic (Hager 1966). The Great Knot is large enough to fly nonstop between the north coast of Australia and Shanghai, a distance of 5,500 km (Barter 1986).

Southward migratory activity of shorebirds in Micronesia commences in early to mid-August and continues through October, with two peak periods of arrivals. This migratory pattern is similar to that on Hawaii, where most adult Lesser Golden-Plovers arrive in late August and either remain as residents during the nonbreeding ("winter") season or resume migration to more southerly islands throughout the Pacific. Juveniles arrive in Hawaii in late September and October (Johnson et al. 1981, Johnson and Johnson 1983). A similar 4–6 week time lapse occurs between adult and juvenile Ruddy Turnstones passing through the Pribilof Islands on their southward migration (Thompson 1973).

Southward movements over the western Pacific are comparable to southward migrations over the western North Atlantic Ocean (Williams et al. 1977, Richardson 1980, Williams 1985). This nonstop overwater flight significantly shortens the route from eastern North America to South America and makes use of prevailing wind patterns to assist the flight. If the patterns of migration in the western Atlantic are determined primarily by geography and wind patterns, we would predict similar migration routes for the western Pacific where a direct overwater crossing offers similar advantages. Guam, located in the Mariana Islands 13° north of the equator and about 3,000 km from the Asian mainland, offered a location well suited to test this prediction.

Comparisons of radar observations with counts of birds on the ground at continental sites often report poor agreement on the density of migration (Eastwood 1967, Williams et al. 1981). The poor correlation might be due either to groups of birds flying over large areas of a continent without landing or to the observers' inability to survey systematically a significant part of a continental area. Such comparisons gave good agreement at Maui, Hawaii, where a significant proportion of the island habitat could be surveyed and the island was a terminus of migration (Kloeckner et al. 1982). Observations on Guam offered an opportunity to test whether the correlations on Maui were due to the better survey conditions on isolated islands or to the fact that most migrants in the area landed on the island.

Materials and Methods

Visual observations were made daily from 16 August through 22 October 1983 at Dungcas Beach on Guam, Mariana Islands (13°25′N, 144°45′E) as close as possible to 23 cm above mean low water on a rising tide (Fig. 1). Two observers counted shorebirds on the

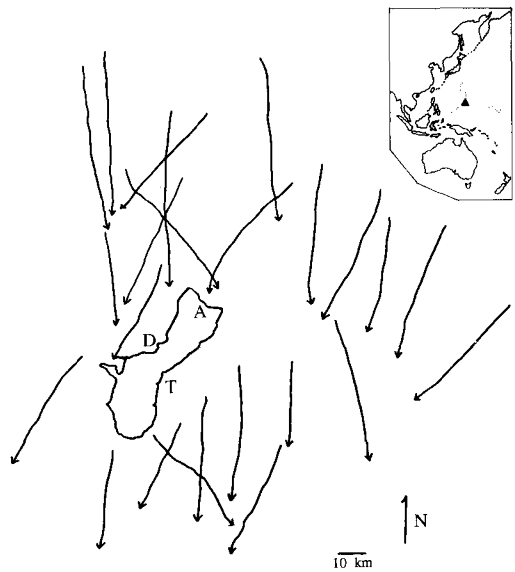

Fig. 1. Observation sites on Guam and long tracks of radar echoes from birds. A = Andersen Air Force Base runways, D = Dungcas Beach, T = Togcha Beach. The figure contains the 10 longest tracks and other selected long tracks showing the range of track directions and movement toward and away from the island. Solid triangle in inset map of western Pacific Ocean shows location of Guam.

mud flats and beach with a 20× spotting scope and 10× binoculars. Additional daily counts were made at Andersen Air Force Base from 16 August through 26 October. Correlations of the numbers of birds at these two sites were either positive or insignificant (a negative correlation would have implied a single population moving between the two sites), and we summed the data from the two sites. We did not include counts from habitats not observed on a daily basis, including those made along Togcha Beach (reported by Williams and Grout 1985).

Radar observations were made from 19 August through 26 October 1983 at the Federal Aviation Administration Guam Combined Center/RAPCON at Andersen Air Force Base, Guam. From 19 August to 26 October observations were made with the ASR 5 approach control radar (frequency 2,840 MHz, 400 kW peak power, beam width at 3 db: 1.5°, beam height at 3 db: 5°, angle of tilt 1.95°, 15 RPM, conventional PPI display). A total of 10 bird echoes was recorded with this instrument. From 26 August to 26 October 756 bird tracks were recorded with the FPS 93 alpha long-range surveillance radar (frequency 1,330 MHz, peak power 2.46 MW, angle of tilt 3°, 5 RPM, raster scan bright field display; other parameters not available). Both radars were operated with the MTI receiver, linear polarization, and minimal attenuation whenever possible, although aircraft controllers made un-

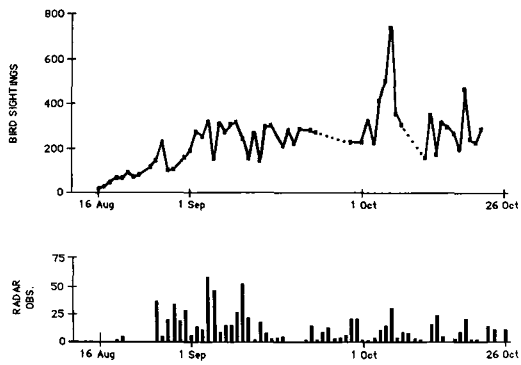

Fig. 2. Numbers of birds seen (top) and numbers of echoes detected by radar (bottom) on Guam. Top graph gives total numbers of shorebirds seen on Dungcas Beach and Andersen Air Force Base, Guam, for each day of observation. Dotted lines indicate periods when tides or weather prevented observations. Bottom graph gives the numbers of radar echoes detected in about 4 h/day of observation. Each echo probably represents a flock of shorebirds. Radar observations before 26 August were unreliable (see text).

recorded changes in these parameters during poor weather conditions. Neither radar gave accurate information on the altitude of birds.

We used two time-exposure systems and one time-lapse system for recording data from the radar PPI displays (Williams 1988). Direction of movement was measured relative to map coordinates incorporated in the radar display. Speed was determined from the endpoints of each track and the elapsed time. The time-lapse system was activated automatically every 4-6 h for 55 min. The time-exposure systems were operated manually once or twice daily between 2200 and 0700 GMT (0900-1800 local time). The three sets of data were summed to minimize the bias of any one system. (Duplication of tracks was avoided by using nonoverlapping observation times.) Fishing boats and seabirds produced curving tracks with calculated "airspeeds" (see below) of less than 25 km/h (7 m/s), and light aircraft and helicopters produced tracks with calculated airspeeds in excess of 150 km/h (42 m/s); these tracks were excluded from the analysis.

Wind velocity aloft was obtained from radiosondes launched from Guam twice daily; 89% of all winds used for analysis were easterly, and 55% were between 15 and 25 km/h (4-7 m/s). Wind shears and major changes in direction and speed over a period of 12 h or over an altitude range of 2,000-3,000 m were rare. The relative constancy of winds aloft allowed us to interpolate between radiosondes and over the altitude range covered by the radar beam width (estimated from Gauthreaux 1980).

Track and ground speed refer to the velocity of a bird relative to the ground. Heading and airspeed refer to the velocity of a bird relative to the air mass in which it flies and are calculated by vector addition of the negative velocity of wind and the vector for track and ground speed. All track and heading values were within 180°, and it was not necessary to use circular statistics (see Batschelet 1981). Mean vector values were calculated for comparison with other studies. The mean vector consists of a direction and a length, r, which is a measure of dispersion and varies from 0 (no central tendency) to 1 (no dispersion) (Batschelet 1981).

For comparisons of visual and radar data we defined day as the 24-h period before sunset. Thus, nocturnal radar observations were compared with the following day's ground counts.

RESULTS

There were two major influxes of migrants observed on Guam (Fig. 2). The first started in mid-August and ran through the beginning of September, followed by a period of relatively stable bird numbers. A second, larger influx occurred during the first week of October and peaked on 6 October. The total numbers of migrant shorebirds seen at Dungcas Beach and Andersen Air Force Base are shown in Fig. 2. Lesser Golden-Plovers and Ruddy Turnstones constituted 85% of the daily average number of birds seen. The small numbers of other migrant species that we saw are reported by Williams and Grout (1985).

The two periods of migrant activity seemed to be related to the arrivals of adult and juvenile birds. Adult Lesser Golden-Plovers first appeared at Dungcas on 19 August; a week later on 26 August we observed 2 plovers at Andersen, by which time there were 113 at Dungcas. We conclude that the plovers, upon their arrival on the island, first fed on the mudflats and later went to Andersen Air Force Base to establish their wintering territories on the grassy lawns there, as in Hawaii (Johnson et al. 1981). From 4 to 6 October, during the second period of activity when we saw 300 plovers at Dungcas, the ratio of juveniles to adults was about 10 to 1.

The timing of arrivals for Ruddy Turnstones was similar to the plovers; the first turnstone arrived at Dungcas on 16 August and at Andersen on 27 August. Most Ruddy Turnstones were seen at Andersen, where flocks of up to 211 fed together in the grass. At Dungcas we never saw more than 30 turnstones at one time. As with the plovers, the turnstone numbers peaked on 6 October with a total of 235.

Radar observations also indicated two periods of migratory activity (Fig. 2). During the first major migration we recorded weekly totals of 180, 170, and 132 echoes for the 3 weeks starting 26 August. In the fourth week (16 September) we recorded only 25 echoes. Numbers peaked again in late September; weekly totals of echoes detected were 57, 65, 64, 34, and 36 for the fifth through eighth weeks of the study. The low radar counts before 26 August probably reflect our use of only the less sensitive radar system.

Comparison of radar and direct visual observations on a weekly basis showed similar periods of migratory activity (Fig. 2). The largest influx of migrants coincided with the largest daily total of radar echoes (32) detected during the second period of activity. Day-by-day comparisons, however, revealed no significant correlations (all $P > 0.05$) between the numbers of echoes detected by radar and either the daily change in numbers or total number of birds seen. Comparisons were made for all combinations of the two major species and the observation sites. Counts of birds on the ground were not correlated significantly with daily average range, duration, track, heading, ground speed, or percentage of birds moving toward or away from the island or passing the island. Only airspeed showed a significant correlation ($r = -0.27$, $P < 0.05$) with change in numbers of Lesser Golden-Plovers at Dungcas (and thus also with change in total birds at Dungcas and change in total number of birds seen). This single significant correlation may be the result of multiple comparisons (with more than 20 comparisons of radar and visual data, we would expect at least one value of $P < 0.05$ by chance alone).

Bird tracks detected by radar often deviated slightly from a straight path (see Fig. 1) but did not show major changes in course or speed. These tracks were similar to tracks of shorebirds moving over eastern Canada (Richardson 1979). Richardson assumed the echoes were from flocks of birds rather than individuals, and we came to the same conclusion for Guam on the basis of the range of detection (up to 100 km) and the duration of tracks recorded with the time-lapse camera system (up to 2,988 s, $\bar{x} = 1,255$ s, SD = 550 s). The birds we detected at Guam almost certainly could have seen the island, its lights, and the clouds towering above the island.

We scored all tracks to determine whether an extension of the track would intersect or pass the island or could have departed from the island. Analysis of variance showed no significant difference in this variable between days, or between tracks at night or in the daylight. The percentage of birds that moved toward, away from, or passed the island was not correlated with average daily track, heading, airspeed, or ground speed. We conclude that the migrants we observed did not orient with respect to the island.

Migration density at Guam was low compared with radar observations of migration at continental sites. The heaviest migration we detected corresponded to a traffic rate of less than 1 echo·km of front^{-1}·h^{-1}. Using these traffic rates, or the fact that we detected 766 flocks of birds sampling only 4 h/day, we estimate that about 5,000 flocks must have passed within 100 km of Guam during the observation period. Even at only 10 birds/flock, on the order of 10^5 to 10^6 birds may have passed within 1,000 km of Guam during the 10 weeks of our study.

The density of migration at Guam did not appear to be associated with local weather systems. Local synoptic weather was scored in one of seven categories depending on the location of the nearest low- and high-pressure areas. Migration density on a 3-point scale was not significantly associated with these synoptic factors ($\chi^2 = 8.7$, df = 10, $P > 0.25$). This lack of association persisted when we compared only days when a low-pressure storm was located between Guam and the mainland with days when no storms were near the islands ($\chi^2 = 0.36$, df = 2, $P > 0.1$).

The mean observed track was to the south 185° (SD = 23°, $r = 0.92$ [r is a measure of dispersion around the mean]; Fig. 3). The mean heading, 169°, was east of the mean track, and the values showed less dispersion (SD = 21°, $r = 0.94$). The means were different at $P < 0.01$ ($t = 45$; see Methods for use of linear statistics). The Watson-Williams test for the concentration parameter (Batschelet 1981: 121) indicated the two values of r were significantly different ($P < 0.05$, $F = 1.32$). These relationships are consistent with drift by winds from a constantly maintained compass heading. The effect at Guam was small because of the relative constancy of the trade winds. Mean ground speed (60.7 km/h [17 m/s], SD = 14 km/h [4 m/s]) was not significantly different ($P > 0.05$) from the mean airspeed of 59.7 km/h ([16 m/s], SD = 13 km/h [3.6 m/s]). This indicates an insignificant tail-

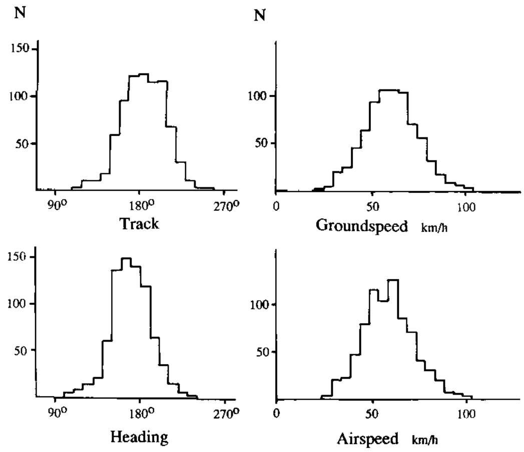

Fig. 3. Distributions of tracks, ground speed, calculated heading, and airspeeds of bird echoes over Guam. N = number of radar echoes.

wind component of the trade winds. Mean wind direction was toward 261° (SD = 45°); mean wind speed was 18 km/h ([5 m/s], SD = 7.7 km/h [2 m/s]). The relatively high calculated airspeeds are consistent with shorebird migrations reported from the Atlantic (Richardson 1979, Williams 1985).

Birds tracked by radar did not appear to compensate for wind drift. Tests for wind drift usually rely on birds migrating under a broad range of wind conditions (Able 1980, Alerstam 1981). The nearly constant wind direction over Guam (see Methods) prevented such tests, but the regression of track on the speed of the winds blowing toward the west (210–310°) was significant and positive: track = 1.16 (wind speed) + 164° ($r = 0.40, P < 0.001$). A similar regression for heading was not significant ($r = 0.08$, slope = 0.23, $P > 0.05$). Thus, in stronger easterly winds, track was shifted to the west and heading showed no compensatory shift.

For most variables there were significant differences between days but no general trend throughout the season. Analyses of variance by day of the year for duration, range, number of birds detected, track, heading, ground speed, and airspeed were significant at $P < 0.01$. There were no significant trends for daily mean ground speed, track, heading, airspeed, and duration of track against day of the year (all $P > 0.05$). The range at which birds were detected showed a highly significant upward trend against day of the year ($r = 0.42, P < 0.01$). This could imply increasing echoing area (size) of the migrant birds or flocks but also may be due only to increased sensitivity of the radar system to small echoes as the result of minor adjustments made by radar personnel interested in our project.

Discussion

We conclude that the western Pacific constitutes a significant migration route for shorebirds passing from eastern Asia to the southern Pacific and probably Australia. Perhaps half a million migrant shorebirds fly within 1,000 km of Guam from August through October. Lesser Golden-Plovers and Ruddy Turnstones are the primary migrant species of birds that land on Guam, although other species contribute significant numbers.

The density of migrants aloft as detected by radar was not reliably reflected in the changing density of migrants on the island of Guam. Birds that land on Guam represent a small and probably nonrandom sample of the migratory population aloft. The large numbers of birds detected by radar over Guam on days when the numbers on the island remained stable suggest that many migrants do not land on the island. Such observations lend support to the hypothesis that some species (e.g. the Great Knot) make nonstop flights over the western Pacific, or rarely stop enroute. The major increases in ground counts on days when we did not detect significantly increased bird numbers on radar seem paradoxical. One hundred to 200 birds, however, could be contained in only 2 or 3 flocks, and each flock would produce only a single radar echo. Because the radars were filmed only 4–6 h/day, we could not reliably detect these flocks, thus preventing a significant correlation. The arrival of more than 150 juvenile Lesser Golden-Plovers simultaneously on 6 October suggests they migrate in large flocks. The lack of correlation between other radar observations, such as speed and direction, and the change in species counts on the island also suggest that distinct populations (perhaps whole species) passed over the island without landing.

We conclude that the lack of good agreement between radar and ground observations is a general phenomenon except at locations, such as Hawaii, that are termini for migration (Kloeckner et al. 1982). At other locations neither the numbers of birds seen on the ground nor their species composition are necessarily a good indicator of migrations aloft.

The behavior of birds detected over Guam corresponded closely to the behavior of transatlantic autumnal migrants detected in the Caribbean (Williams et al. 1977, Richardson 1980, Williams 1985). Birds appeared to maintain heading and speed without deviating toward or away from islands. Local weather conditions did not affect migratory behavior. Daily variation in migratory behavior was significant, but there were no overall trends during the autumn migration season (with the exception of passerine vs. shorebird migrants discussed below). Track was more variable than heading and was shifted clockwise. Birds appeared to drift from their southerly headings with no evidence of compensatory adjustments for strong crosswinds. These migrants probably do not make short flights between neighboring islands, but engage in long flights over open ocean. The observations on Guam were consistent with constant compass orientation for guidance of flights over the western Pacific in a manner similar to that observed for migrants over the western North Atlantic (Williams and Williams 1978).

In the Caribbean different behaviors that correspond to shorebird and passerine migration were detected in early (shorebird) and late (passerine) phases of the migration. Migratory behavior in Guam appeared uniform throughout the season and corresponded to the behavior of shorebirds in the Caribbean (Williams 1985). There is no evidence of significant passerine migration over the western Pacific.

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The **Hawk Mountain Sanctuary Association** is accepting applications for its **twelfth annual award for raptor research.** To apply for the $750 award, a student applicant should submit a brief description of his or her research program (five pages maximum), a *curriculum vitae,* and two letters of recommendation to: **Dr. Jim Bednarz, Hawk Mountain Sanctuary Association, Rte. 2, Kempton, PA 19529 USA.** The application deadline is **15 October 1988.** The Association's board of directors will make a final decision early in 1989. Undergraduate and graduate students in degree-granting institutions are eligible to apply. The award will be granted on the basis of a project's potential to improve understanding of raptor biology and its relevance to the conservation of North American raptor populations.

In connection with a **Check-list of the birds of Java and Bali,** to be published as one of the British Ornithologists' Union's Check-list series, all those who have new or interesting observations from those islands are invited to send their information to the compiler, **J. H. Becking, 7 Ericalaan, 6703 EM Wageningen, The Netherlands.**

Any information on the birds is welcome, especially recent observations from little-known areas. All records will be fully acknowledged.

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Further guidelines and application materials are available from **Theodore W. Gutzke, Research Committee Chairman, P.O. Box 121, Kenmare, North Dakota 58746 USA.** Completed applications must be received by **1 December 1988**; decisions will be announced by 15 January 1989.