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LARGE-SCALE MAPPING OF PURPLE MARTIN PRE-MIGRATORY ROOSTS USING WSR-88D WEATHER SURVEILLANCE RADAR

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Abstract.—Recent advances in remote sensing technologies allow researchers to inventory and study bird populations at large spatial scales. We used National Weather Service WSR-88D weather surveillance radar images, acquired from the Internet, to detect and map the locations of Purple Martin (*Progne subis*) pre-migratory roosts across the eastern United States. Purple Martins form a distinctive ring or annulus on radar during pre-dawn departures from roosts, allowing mapping of roost sites based on this signature. Overall, we identified 33 roost sites from 13 states. Although most roosts were confined to the southeastern United States, sites as far north as Missouri and Kentucky, and as far west as central Texas and Oklahoma were detected. Seventy-three percent (24/33) of roosts were clearly associated with large bodies of water such as lakes and rivers. We found that using Internet-acquired radar images for bird studies had limitations when compared with direct acquisition of images from WSR-88D radar stations or through contracts with WSR-88D product providers. However, the increased expertise and financial investment associated with these methods make Internet-acquired radar data an attractive alternative for rapid assessment of roost locations and dynamics over large geographical areas.

MAPAS A LARGA ESCALA DE LOS DORMIDEROS PRE-MIGRATORIOS DE *PROGNE SUBIS* UTILIZANDO RADARES WSR-88D PARA EL MONITOREO DEL CLIMA

Sinopsis.—Los avances rectentes en la tecnologia de monitoreo a distancia permite que los investigadores hagan inventarios y estudien poblaciones de aves en escalas espaciales grandes. Utilizamos las imágenes de radar de monitoreo del clima con sistema WRS-88D producidas por el Servicio Nacional de Meterorologia y adquiridas por el Internet para detectar y localizar en mapas los dormideros premigratorios de Progne subis a través del este de los Estados Unidos de Norteamérica. Esta especie produce un anillo cistintivo en el radar durante las salidas pre-amanecer desde los dormideros, permitiendo poner en mapas los dormideros basándose en esta señal. En total, identificamos 33 áreas de dormidero en 13 estados. Aunque la mayoría de los dormideros se hallaban en el sereste de la nación, se detectaron localidades tán al norte como Missouri y Kentucky, y tán al oeste como Oklahoma y el centro de Texas. Setenta y tres porciento (24/33) de los dormideros fueron claramente asociados con largos cuerpos de agua tales como rios y lagos. Notamos que utilizar las imágenes de radar adquiridas del Internet para estudios omitológicos tenía limitaciones al compararlas con imagenes directamente adquiridas de estaciones de radar WSR-88D o via contratos con los proveedores de productos WSR-88D. Sin embargo, la experiencia necesaria y las inversiones financieras asociadas con estos métodos hacen que los datos de radar adquiridos via internet sean una alternative atractiva para la identificación rápida de las localidades de dormideros y de sus dinámicas a través de áreas geográficamente grandes.

The ability to inventory and study animal populations at various spatial and temporal scales is essential for effective conservation and management strategies. Methods of population monitoring are expanding to address concerns about biodiversity and landscape patterns of habitat fragmentation (Dunning et al. 1992, Maurer 1994, May 1994). This shift in

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focus from smaller to larger scales is concurrent with advances in remote sensing, Geographical Information Systems (GIS), and methods for quantifying spatial and temporal attributes of landscapes (Jennings 1995, Roseberry and Hao 1996, Sample 1994, Turner 1990). However, many researchers still have limited access to these tools because of restrictive requirements for specialized and expensive computer hardware, software, and expertise (Roseberry and Hao 1996).

Difficulties in locating and studying communal roosts often arise from the inability to observe these assemblages at appropriate spatial and temporal scales (Caccamise et al. 1983, Caccamise and Morrison 1986, Eastwood 1967). Roost locations may be inconspicuous (Caccamise et al. 1983), or researcher access to roosting habitats problematical. Consequently, locating these sites often entails labor-intensive ground searches for flight lines (e.g., Caccamise and Fischl 1985). Even when roost locations are known, visual surveys provide only limited data on the spatial extent of roosting flights (Eastwood 1967), and the timing of flights (e.g., pre-dawn departures) may preclude use of visual techniques altogether. However, since the discovery in the 1940s that bird movements were visible on radar (Lack and Varley 1945), several studies have used this remote sensing technique for locating roosting assemblages and characterizing their spatial and temporal dynamics (Eastwood et al. 1962, Harper 1959, Richardson and Haight 1970, Russell and Gauthreaux 1998, Summers and Feare 1995: 293).

The National Weather Service's new doppler radar, the WSR-88D or NEXRAD, is a state-of-the-art weather surveillance radar (Crum and Alberty 1993). It provides an improved technology for detecting bird targets in the atmosphere and studying bird movements from local to continental scales (Gauthreaux 1995, Russell and Gauthreaux 1998). Recently, a WSR-88D radar was used to locate and study two Purple Martin (*Progne subis*) pre-migratory roosts in South Carolina and Georgia (Russell and Gauthreaux 1998). In this paper, we report on the use of radar data from 45 WSR-88D stations, acquired from the Internet, to map the geographic distribution of Purple Martin roosts across the eastern United States. Our objectives were (1) to evaluate an easy-to-use and inexpensive methodology for rapid assessment of roost locations, and (2) map the locations of these sites for future investigations.

METHODS

Purple Martins.—Purple Martins are neotropical migratory swallows that breed across North America (American Ornithologists' Union 1983, Price et al. 1995). In eastern North America, Purple Martins are conspicuous colonial nesters and have depended almost exclusively on man-made nesting houses for at least a century (Allen and Nice 1952, Morton 1988). As a result, martin breeding biology and behavior have been the focus of considerable study (see Morton et al. 1990, Stutchbury 1991). In eastern North America, Purple Martins often congregate in distinctive nocturnal roosts after the fledging period. These assemblages may reach enormous concentrations as a prelude to fall migration (Allen and Nice 1952, Russell 1996). Many of these roost locations appear to be persistent between years (Allen and Nice 1952). For example, a large concentration (≥700,000) of martins has been roosting at Lake Murray, South Carolina since at least the early 1980s (Russell 1996). Martins typically begin aggregating in roosts in late June, with peak densities occurring in late July or early August (Allen and Nice 1952, Caccamise and Fischl 1985:175, Russell 1996). After this time populations decrease as individuals begin to migrate south, and martins usually vacate roosts by the end of August or early September (Allen and Nice 1952, Russell 1996). Roosts usually consist of adults and juveniles of both sexes (Brown 1984, Morton and Patterson 1983).

Roosting Purple Martins engage in two daily mass movements: a near-dawn exodus for aerial foraging and an evening return (Allen and Nice 1952, Russell 1996). Peak departures occur approximately 10 min before sunrise, while peak movement into the roost occurs at sunset (Russell 1996). On WSR-88D radar the simultaneous omnidirectional departure of martins creates a distinctive annulus (360°) signature, extending as far as 100 km from the roost (Russell and Gauthreaux 1998). Occasionally, only a partial annulus is visible on radar. This pattern may result from flight altitudes of the birds, weather conditions, or distance from the roost to the radar station (Russell 1996). Because evening movements to the roost are characterized by small, sporadic flocks flying at tree-top height (i.e., below the radar beam), these movements fail to produce recognizable signatures on radar (Russell and Gauthreaux 1998).

Data collection and analysis.—We collected WSR-88D base reflectivity radar images for the lowest elevation angle (0.5°) on six days between 3 Jul. and 7 Aug. 1996. For additional information on the specifications and operation of WSR-88D radar see Crum and Alberty (1993) and Russell and Gauthreaux (1998). We obtained WSR-88D images from the following web address: www.intellicast.com. Weather Services, Inc. (WSI) is the NEXRAD Information Dissemination Service (NIDS) provider to this site. Images supplied on the Internet by WSI are generally updated once per hour, but sometimes less frequently. Our search for martin roosts focused on 45 sites, in 19 states, in the eastern United States. We focused on this region because it supports the largest breeding populations of Purple Martins (Price et al. 1995). Further, large pre-migratory roosts are not associated with martin populations in the southwestern United States (*P. subis hesperia*; Brown 1984, Cater 1944, Phillips et al. 1964). Images were collected between 0600–0900 h EST to coincide with morning departures of martins from roost sites. Images were not available for all sites, during all hours sampled, or on all days sampled. When necessary, repeated attempts to collect data from each station for each hour were made. Because evening martin flights cannot be characterized with radar, we restricted surveys to searches of the distinctive annulus formed during morning departures. Images were saved to floppy disk for analysis. Approximate roost site locations were mapped by relating the center of each

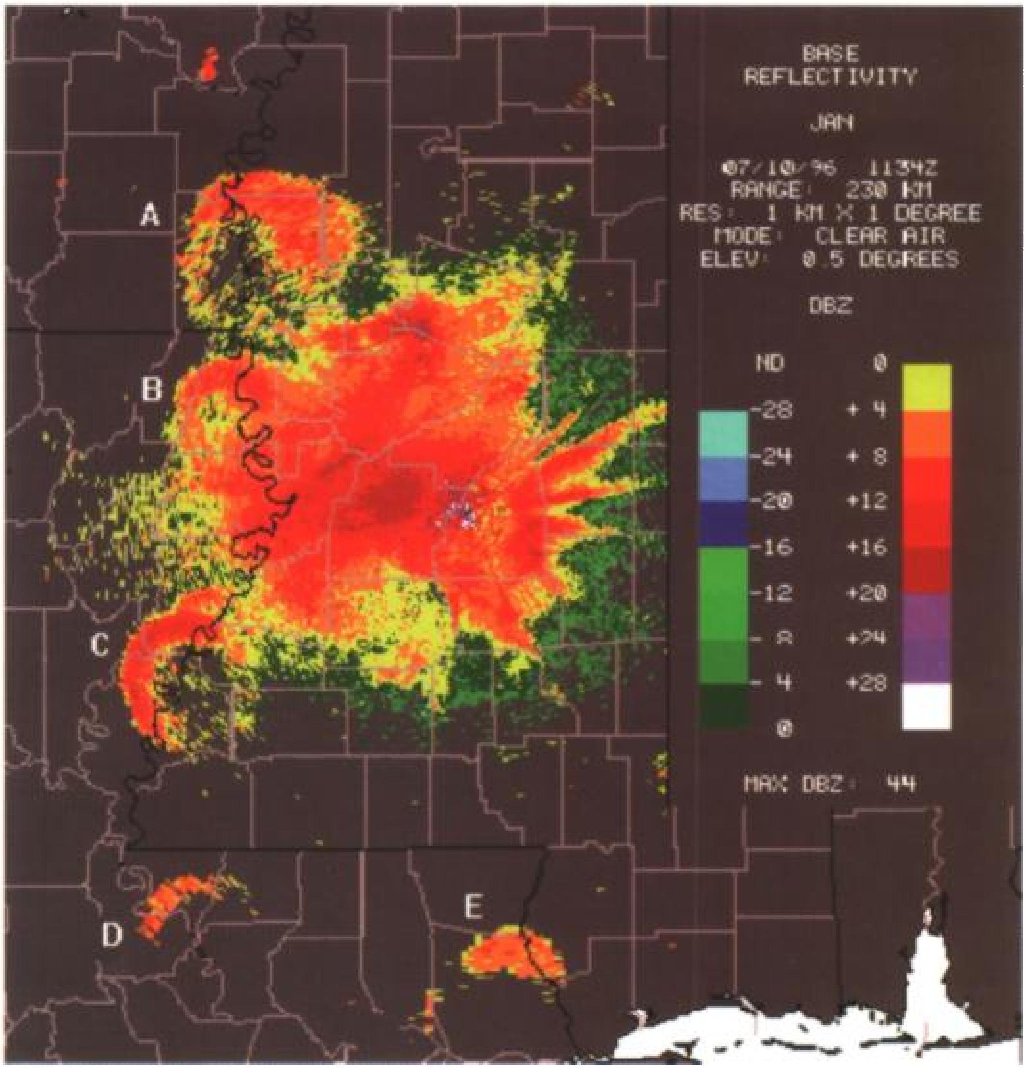

FIGURE 1. WSR-88D radar base reflectivity image (0.5°) acquired from the Internet, depicting five roost exoduses (A–E) near Jackson, Mississippi, 10 July 1996: (A) Lake Chicot State Park, Mississippi River, Arkansas–Mississippi border. (B) Lake Providence and Mississippi River, Louisiana–Mississippi border. (C) Mississippi River, Louisiana–Mississippi border. (D) Mississippi River, Louisiana. (E) Lake Pontrarchtrain, Louisiana.

annulus to conspicuous landmarks (e.g., state and county boundaries, state parks, wildlife refuges, lakes, rivers) on standard road atlases.

RESULTS

Individual WSR-88D stations were effective in mapping the geographical positions of roost sites out to a range of nearly 240 km (Fig. 1). Overall, we identified 33 roost sites from 13 states (Table 1). Most roosts were restricted to the southeastern United States, but sites as far north as southern Missouri and Kentucky (35°N), and as far west as central Texas and Oklahoma (110°W) were identified (Fig. 2). Twenty-four of the 33 (73%) sites were clearly associated with large lakes or rivers (Table 1). Although the remaining eight roost sites could not be linked with conspicuous bodies of water, the scale of our map analysis precluded us from identifying many local features.

TABLE 1. States, counties, and sites where Purple Martins roosts were detected by the WSR-88D, July–August, 1996. Also included is number of times each site was detected.

State	County	Site	Times detected
1. Alabama/ Georgia	Barbour/Quitman	Walter S. George Res.	1
2. Alabama	Calhoun/Clebourne		1
3. Alabama	Lee		3
4. Alabama	Montgomery	Talapoosa R.	1
5. Alabama	Tuscaloosa	Tuscaloosa R.	1
6. Arkansas	Crawford/Sebastian	Arkansas R.	1
7. Arkansas/ Mississippi	Chicot/Washington	L. Chicot SP/Mississippi R.	4
8. Georgia	Hart/Elbert	L. Hartwell/Lk. Russell	2
9. Georgia	Forsyth/Hall	L. Lanier	3
10. Georgia	Green/Putnam	L. Oconee	2
11. Georgia	Mitchell		1
12. Kentucky	Clark/Bourbon/Fayette		1
13. Kentucky	Monroe/Cumberland/ Clinton	Dale Hollow L.	1
14. Louisiana	Bossier/Webster	L. Bistineau	2
15. Louisiana	Calcasieu	Calcasieu R./L. Calcasieu	2
16. Louisiana	Madison	Tensas R. NWR	1
17. Louisiana	St. Tammany	L. Pontchartrain	4
18. Louisiana	West Feliciana/Pointe Coupee	Mississippi R.	1
19. Missouri	New Madrid/Lake	Mississippi R.	2
20. Mississippi/ Louisiana	Adams/Concordia	Mississippi R.	2
21. Mississippi/ Louisiana	Issaquena/East Carroll	Mississippi R./L. Providence	3
22. North Carolina	Scotland/Hoke/Robeson		1
23. Oklahoma	Carter/Murray	Chickasaw Nat'l Rec. Area	1
24. Oklahoma	Johnston	Tishomingo NWR	1
25. Oklahoma	Rogers	Oolagah L.	1
26. South Carolina	Lexington	L. Murray	6
27. Texas	Bandera/Medina		1
28. Texas	Brazos		3
29. Texas	Burnett	L. Buchanan	2
30. Texas	Fort Bend	Don George L.	1
31. Texas	Limestone	L. Mexia	1
32. Texas	McClennan	N. Fork Bosque R.	3
33. Texas	San Jacinto	L. Livingston, Reelfoot L., L. Isom NWR	1

DISCUSSION

The WSR-88D network is a powerful new remote sensing tool for identifying and monitoring bird assemblages from small to large spatial scales (Gauthreaux 1995, Russell and Gauthreaux 1998). With a minimum investment of time, equipment, and money we were able to rapidly assess the locations of Purple Martin roosts over a large portion of the eastern United States. Documenting major roost sites over relatively small areas

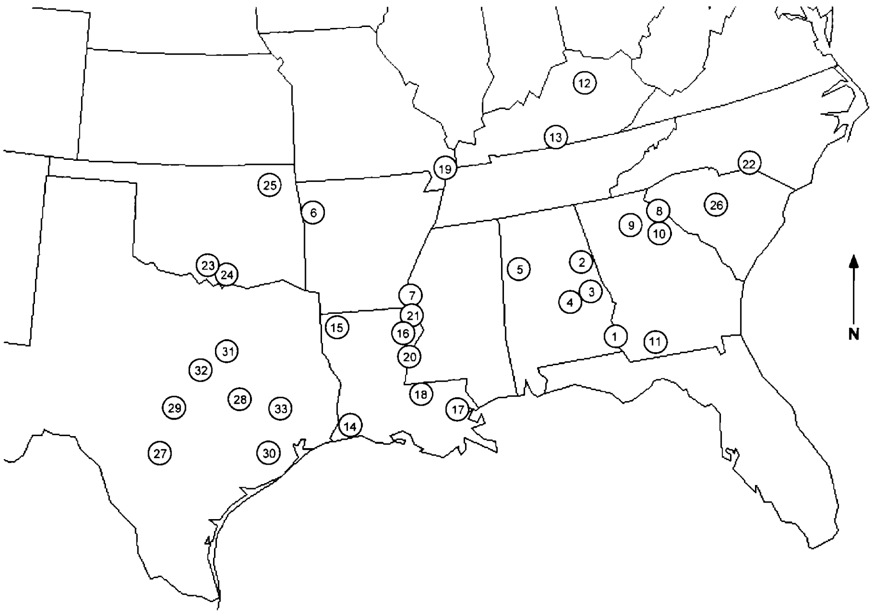

FIGURE 2. Map of roost sites (designated by circles) detected with Internet-acquired WSR-88D radar images, July and August 1996. Numbers within the circles refer to roost site descriptions in Table 1. Roost sites are not drawn to scale.

(e.g., 1000 km^2) with traditional techniques requires rigorous, extended surveys for flight lines (Caccamise et al. 1983, Caccamise and Fischl 1985). Additionally, time, logistical, and economic considerations often prevent ground-truthing or limit its efficiency. Using only an atlas we were able to associate most roost sites with aquatic habitats. However, efficient application of radar mapping for bird studies will require more advanced methods of analysis, such as the integration of WSR-88D images with GPS and GIS data. This will allow sophisticated large-scale comparisons of roost site distributions with important habitat features and land-use patterns (Russell and Gauthreaux 1998).

Although we did not confirm that Purple Martins were responsible for each of the roost sites documented in this study, several lines of evidence suggest that martins were primarily, if not solely responsible for the annular signatures we observed. In earlier work, WSR-88D radar was used to describe the spatial and temporal dynamics of martin roosts at Lake Murray, South Carolina and Lake Russell, Georgia (Russell and Gauthreaux 1998) and to confirm the presence of martins roosting at Lake Pontchartrain, Louisiana (Gauthreaux, unpubl. data). The three sites were evident during this study (Fig. 2), and all newly identified roosts exhibited identical annular patterns and temporal (e.g., daily and seasonal) dynamics. It is possible that bird species other than Purple Martins were responsible for the observed radar patterns, or that roosts consisted of mixed-species flocks with *P. subis* (e.g., Caccamise and Fischl 1985). Red-winged Blackbirds (*Agelaius phoeniceus*) and European Starlings (*Sturnus vulgaris*) also form annular patterns on radar during roost departures (Eastwood et al. 1962, Ligda 1958, Richardson and Haight 1970). Further, Purple Martins are known to associate in mixed-species roosting flocks with blackbirds, starlings, and Common Grackles (*Quiscalus quiscula*) during July and August (Caccamise and Fischl 1985). However, starlings do not depart from roosts in a constant stream, but as a series of exoduses which begin at intervals of 3 min (Eastwood et al. 1962, Feare 1995). These departures create a series of concentric rings on radar (Eastwood et al. 1962, Richardson and Haight 1970), in contrast with the single annulus formed by exoduses of Purple Martins (Russell and Gauthreaux 1998). Finally, peak roosting populations of blackbirds, starlings, and grackles occur from late summer through winter (Caccamise et al. 1983, Caccamise and Fischl 1985, Meanley 1965, Summers and Feare 1995), after most, if not all martins have departed for South America (Allen and Nice 1952, Russell 1996).

We want to emphasize that ground-truthing is always necessary for confirming the species composition of roosts identified with radar. In order to minimize costs associated with visual surveys over large geographical areas, the assistance of amateur birding clubs or other volunteer organizations in the area of each suspected roost could be employed. For example, volunteers of the Purple Martin Conservation Association are being used to verify many of the roost sites mapped during this study (J. R. Hill, pers. comm.). However, once the species composition of roost sites has been confirmed, WSR-88D radar provides researchers with simultaneous remote monitoring of spatial and temporal changes in roost dynamics on a continental scale (Russell and Gauthreaux 1998). The roosts of Purple Martins and other species represent a critically important phase of the annual cycle because tremendous numbers of birds are concentrated into a relatively small area. Because WSR-88D radar depicts roost locations as the birds depart it can indicate patterns of habitat use, supplying conservation biologists and resource managers with important data for habitat management and protection. Recently, the Lake Murray site was designated as the first martin roosting sanctuary in North America (Russell 1996), but protection of other critical roosting areas will depend on identification of their locations and associated habitats. Additionally, because WSR-88D radar provides remote data on the relative magnitude of birds aloft (Gauthreaux and Belser 1998, Russell and Gauthreaux 1998), the NEXRAD network could be used to monitor annual changes within and among roost populations, yielding important information on potential declines (e.g., Peterjohn and Sauer 1995).

Although using the Internet has obvious benefits, we found that it presented limitations when compared with direct acquisition from radar sites (Gauthreaux 1995, Russell and Gauthreaux 1998) or contracts with NIDS providers (Gauthreaux and Belser 1998). Radar images provided by WSI on the Internet are updated at a maximum rate of one per hour. On some mornings individual stations were unavailable or images were not updated at 1 h intervals. Detailed radar studies of roosting behavior require image acquisition at intervals of 10 min or less (Russell and Gauthreaux 1998). Images can be obtained reliably from radar sites and NIDS providers at intervals of 5–10 min, and direct acquisition also provides an increased range of WSR-88D products (Crum and Alberty 1993). For example, radial velocity images, which depict the speeds and directions of birds aloft (Gauthreaux 1995, Russell and Gauthreaux 1998), are not available currently from the Internet. However, direct acquisition of products requires access either to radar sites (and associated expertise) or costly contracts with NIDS providers. Direct access to NIDS data through a provider requires a monthly investment of at least $900.00 (e.g., access fees, long-distance phone charges) in excess of computer hardware and software costs (Gauthreaux, unpubl. data). The increased expertise and financial investment associated with direct acquisition of WSR-88D products make Internet-acquired radar data an attractive alternative for rapid assessment of bird movements over large geographical areas.

Even when radar images are taken from the Internet at the appropriate time, on some mornings the radar failed to detect the presence of known roosts. On these mornings the radar beam likely was not bent downward by the refractive index of the atmosphere (Buurma 1995, Eastwood 1967, Rinehart 1991), and consequently it missed birds flying at lower altitudes (e.g., birds departing from a roost). However, only ground truthing can determine whether atmospheric conditions or abandonment of the roost is responsible for the disappearance of roost signatures on radar (Russell and Gauthreaux 1998). In addition, on several mornings we noted that rain prevented the detection of roost departures (e.g., Eastwood 1967, Russell and Gauthreaux 1998). Recognizing these effects requires some empirical knowledge of radar characteristics, weather patterns, and general knowledge of the behavior of target species (Buurma 1995, Eastwood 1967, Gauthreaux 1970).

Despite the limitations characteristic of any remote sensing technology (Sample 1994), WSR-88D radar offers unmatched opportunities for simultaneous detection and monitoring of bird movements over large spatial scales. We emphasize that our survey of martin roost sites is not meant to be comprehensive, but rather a demonstration of the cost-effectiveness and usefulness of WSR-88D products acquired from the Internet. We encourage other researchers to apply and expand use of this radar network for ornithological research, including the mapping of additional roost sites of martins and of other species across North America.

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LITERATURE CITED

ALLEN, R. W., AND M. M. NICE. 1952. A study of the breeding biology of the Purple Martin (*Progne subis*). Am. Mid. Nat. 47:606–665.

AMERICAN ORNITHOLOGISTS' UNION. 1983. Check-list of North American birds. 6th ed. American Ornithologists' Union, Washington, D.C.

BROWN, C. R. 1984. Light-breasted Purple Martins dominate dark-breasted birds in a roost: implications for female mimicry. Auk. 101:162–164.

BUURMA, L. S. 1995. Long-range surveillance radars as indicators of bird numbers aloft. Israel J. Zool. 41:221–236.

CACCAMISE, D. F., AND J. FISCHL. 1985. Patterns of association of secondary species in roosts of European Starlings and Common Grackles. Wilson Bull. 97:173–182.

———, AND D. W. MORRISON. 1986. Avian communal roosting: implications of diurnal activity centers. Am. Nat. 128:191–198.

———, L. A. LYON, AND J. FISCHL. 1983. Seasonal patterns in roosting flocks of Starlings and Common Grackles. Condor 85:474–481.

CATER, M. B. 1944. Roosting habits of Martins at Tucson, Arizona. Condor 46:15–18.

CRUM, T. D., AND R. L. ALBERTY. 1993. The WSR-88D and the WSR-88D operational support facility. Bull. Am. Meteorol. Soc. 74:1669–1687.

DUNNING, J. B., B. J. DANIELSON, AND H. R. PULLIAM. 1992. Ecological processes that affect populations in complex landscapes. Oikos 65:169–175.

EASTWOOD, E. 1967. Radar ornithology. Methuen, London. 278 pp.

———, G. A. ISTED, AND G. C. RIDER. 1962. Radar ring angels and the roosting movements of Starlings. Philos. Trans. Royal Soc. London B Biol. Sci. 156:242–267.

GAUTHREAUX, S. A., JR. 1970. Weather radar quantification of bird migration. Bioscience 20: 17–20.

———. 1995. Radar ornithology: tracking bird migrations by radar. WildBird 9:38–39.

———, AND C. A. BELSER. 1998. Displays of bird movements on the WSR-88D: patterns and quantification. Weather and Forecasting, *in press.*

HARPER, W. G. 1959. Roosting movements of birds and migration departures as seen by radar. Ibis 101:201–208.

JENNINGS, M. D. 1995. Gap analysis today: a confluence of biology, ecology, and geography for management of biological resources. Wildl. Soc. Bull. 23:658–662.

LACK, D., AND G. C. VARLEY. 1945. Detection of birds by radar. Nature 156:446.

LIGDA, M. G. 1958. Radar observations of Redwing Blackbird Flights. Texas J. Sci. 10:255.

MAURER, B. A. 1994. Geographical population analysis: tools for the analysis of biodiversity. Blackwell Scientific Publications, London. 130 pp.

MAY, R. M. 1994. The effects of spatial scale on ecological questions and answers. Pp. 1–18, *in* P. J. Edwards, R. M. May, and N. R. Webb, eds. Large-scale ecology and conservation biology. Blackwell Scientific Publications, London.

MEANLEY, B. 1965. The roosting behavior of the Red-winged Blackbird in the southeastern United States. Wilson Bull. 77:217–228.

MORTON, E. S. 1988. Dawnsong of the Purple Martin. Att. Nat. 38:38–48.

———, AND R. M. PATTERSON. 1983. Kin-association, spacing, and composition of a post-breeding roost of Purple Martins. J. Field Ornithol. 54:36–41.

———, E. S., L. FORMAN, AND M. BRAUN. 1990. Extrapair fertilizations and the evolution of colonial breeding in Purple Martins. Auk 107:275–283.

PETERJOHN, B. G., AND J. R. SAUER. 1995. Purple Martin population trends from the North American Breeding Bird Survey, 1966–1994. Purple Martin Update 6:2–8.

PHILLIPS, A. R., J. MARSHALL, AND G. MONSON. 1964. The birds of Arizona. University of Arizona Press, Tucson, Arizona. 212 pp.

PRICE, J., S. DROEGE, AND A. PRICE. 1995. The summer atlas of North American Birds. Academic Press, New York. 364 pp.

RICHARDSON, W. J. 1978. Timing and amount of bird migration in relation to weather: a review. Oikos 30:224–272.

———, W. J., AND M. E. HAIGHT. 1970. Migration departures from Starling roosts. Can. J. Zool. 48:31–39.

RINEHART, R. E. 1991. Radar for meteorologists, 5th ed. Knight Printing Company, Fargo, North Dakota. 334 pp.

ROSEBERRY, J. L., AND Q. HAO. 1996. Interactive computer program for landscape-level habitat analysis. Wildl. Soc. Bull. 24:340–341.

RUSSELL, K. R. 1996. Spatial and temporal patterns of a Purple Martin (*Progne subis*) roost: a radar and direct visual study. M. S. thesis, Clemson Univ., Clemson, South Carolina.

———, AND S. A. GAUTHREAUX, JR. 1997. Use of weather radar for characterizing movements of roosting Purple Martins in South Carolina. Wildl. Soc. Bull. In press.

SAMPLE, V. A. 1994. Remote sensing and GIS in ecosystem management. Island Press, Washington, D.C. 400 pp.

STUTCHBURY, B. J. 1991. Coloniality and breeding biology of Purple Martins (*Progne subis hesperia*) in saguaro cacti. Condor 93:666–675.

SUMMERS, R. W., AND C. J. FEARE. 1995. Roost departure by European Starlings *Sturnus vulgaris:* effects of competition and choice of feeding site. J. Avian Biol. 26:193–202.

TURNER, M. G. 1990. Spatial and temporal analysis of landscape patterns. Landscape Ecol. 4:21–30.

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