2012

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**Abstract:** Managing European starlings with DRC-1339 near urban and suburban areas can lead to adverse publicity resulting from encounters by the public with dead and dying birds. Collectors could retrieve the birds, if the likely sites of mass mortalities were known. In December 2009, we radio tagged 50 starlings at 3 sites in central New Jersey and studied their movements and behavior. Two of the sites were ensconced in a mosaic of suburban and urban habitats, whereas the other was in a rural setting. The sites were selected from a list of agricultural producers that had requested assistance from the Wildlife Services program in New Jersey. Starlings using the rural study site showed strong site fidelity ($\bar{x}$ = 78% of days tracked), stayed closer during daytime wanderings ($\bar{x}$ = 2 km), and roosted onsite. In contrast, starlings in the urban-suburban mosaic showed less fidelity ($\bar{x}$'s = 10% and 36%), wandered farther ($\bar{x}$'s = 6 km and 4 km), and seldom roosted onsite. No study sites were visited by members from the other radio-tagged cohorts. Major roosts in the urban-suburban mosaic averaged 10 km (*n* = 4, SE = 1.4) from the study sites. We predict that most starlings will remain within 6 km of the site during daytime. Poisoned starlings may become lethargic and seek refuge in dense vegetation (e.g., evergreens) near the baited site. Birds >6 km from a bait site are probably on a direct bearing between the bait site and roosting site.

**Key Words:** New Jersey, DRC-1339, European starling, movements, radio telemetry, roosts, site use, *Sturnus vulgaris*

**Proc. 25th Vertebr. Pest Conf.** (R. M. Timm, Ed.)
**Published at Univ. of Calif., Davis. 2012**. Pp. 230-234.

## INTRODUCTION

The European starling (*Sturnus vulgaris*) is an Old World passerine species introduced in the eastern U.S. in the late 1800s. European starlings (henceforth, starlings) are peridomestic and often use human-altered habitats for food and shelter. Starlings are agricultural pests throughout North America (Feare 1984, Pimentel et al. 2005, Linz et al. 2007). Additionally, they form large winter roosts in urban and suburban areas causing conflicts with society. In New Jersey, starlings are probably the second most abundant bird behind only the American robin (*Turdus migratorius*) (Sauer et al. 2011).

When nonlethal techniques fail to manage infestations of starlings, USDA APHIS Wildlife Services may use the avicide, DRC-1339 (3-chloro-4-methylaniline hydrochloride). It is very toxic to starlings, but it is a slow-acting compound. Thus, mass starling mortalities may occur several kilometers from a DRC-1339-treated site. Because public relations can rapidly deteriorate if suburban and urban residents unexpectedly encounter the consequences of a successful DRC-1339 baiting, its use near populated areas can be problematic. For example, during the 2008-2009 winter thousands of dead and dying starlings were found by New Jersey suburbanites who resided near a treated site. Unaware that a DRC-1339 treatment had occurred, concerned citizens alerted media and governmental agencies. Extensive negative publicity ensued. Several other states have had similar incidences, highlighting a liability of using DRC-1339 to manage starlings.

During the winter of 2009-2010, we used radio telemetry to investigate site use and movements of starlings in central New Jersey. Our goal was to understand the behavior of wintering starlings in landscapes consisting of mosaics of agricultural, suburban, and urban habitats.

## STUDY AREA

The study was conducted in the Piedmont and Coastal Plain physiographic regions of New Jersey. We visited 14 sites in 10 counties using a list of agricultural producers that had requested assistance in managing starling damage. We found consistent numbers of starlings at 3 sites, one in each of the following counties: Mercer, Middlesex, and Ocean. One site was a game bird farm (Site A); 2 were livestock facilities (Sites B and C). The center of the study area (40.25N, -74.64W) was 10 km northeast of Trenton. The average distance between the 3 study sites was 35 km (SE = 4.8), whereas the average distance from the study area center to the 3 sites was 20 km (SE = 3.0). We did not count starlings, but we estimated that the smallest population was 1,000 to 2,000 birds and the largest was 5,000 to 10,000 birds. Between 1 December 2009 and 31 January 2010, the average temperature and precipitation were 1°C and 22 cm, respectively; whereas 30-year averages were 0°C and 20 cm.

## METHODS

### Radio Telemetry

We captured starlings from 17-29 December 2009. The birds were caught using mist-nets and decoy traps. Sex was determined by external characteristics (Kessel 1951, Smith et al. 2005). We allowed natural variation to determine the sex ratio of the radio-tagged birds. Birds selected for radio tagging were fitted with Model A2440 radio transmitters (Advanced Telemetry Systems, Inc., Isanti, MN). The radios had a mass of 2 g and a battery life of 100 days at 40 pulses per minute. The transmitter was mounted on the anterior dorsal surface of the bird's fused pelvic region using a leg harness that consisted of 0.8-mm elastic beading cord (Rappole and Tipton 1991, Homan et al. 2010). The radio was attached to the harness with epoxy. Total mass of the radio transmitter with harness was 2.2 g. All candidates for radio tagging had a mass of ≥73 g to maintain an auxiliary banding criterion that the transmitting unit be ≤3% of body mass.

Pertinent capture and tagging information were gathered, including radio frequency, capture date, capture site, mass, leg-band number, and sex. Before attaching the radio transmitter, it was checked for functionality. We released the radio-tagged birds at the capture site immediately after banding them on the left leg with a No. 2 USGS aluminum band. We allowed a 2-day acclimation period before collecting data. We used 50 radios. Twenty radios were allocated to Site A, because this site had a very large number of starlings (≥5,000). Additionally, it had been baited with DRC-1339 the previous winter and had caused public relations problems. We allocated 15 radios each to Sites B and C. The study ended on 30 January 2010.

**Tracking**

We used a fixed receiving system at each study site to constantly monitor for the presence of radio-tagged birds. The system consisted of an elevated, 6-element yagi antenna and a battery-powered, programmable, data-logging receiver secured in a weatherproof container (R4500s Digital Signal Processor; Advanced Telemetry Systems, Inc.). The working range for Model A2440 radios is ≤1 km using this type of receiving system (Homan et al. 2010). We placed the receiving system in a panoramic location away from buildings and other objects that could dampen or block radio signals. The data logger scanned through all 50 radio frequencies staying on each frequency for 6 seconds. If a frequency was detected, it was monitored for 90 seconds, after which the strongest signal was stored along with date, time, and number of radio pulses. We downloaded the data twice weekly to a laptop PC. All receivers were time- and date-synchronized prior to deployment.

A mobile receiving system was used to search the study area and approximate a random sampling of radio-tagged birds within a 50-km radius of the study area center. The mobile system was a 4-w-d pickup truck with roof-mounted, rotatable, dual 6-element yagi antennas. Each antenna was cabled to a null-peak box, which in turn, was linked by coaxial cable to a R4500s DSP receiver and GPS unit. Receiving range for the mobile receiving system was about 2 km. An onboard PC-laptop with a GIS system was used both to store the mobile unit's directional track and to access information on prior detections. The mobile unit was operated 5-7 days per week with search times from 6 to10 hours per day.

**Data Analysis**

The raw data were culled of false-positive detections using Visual Basic® for Applications (Microsoft®, Redmond, WA). We used the metric, track day, for analysis of daily fidelity to the study sites. A track day was tallied whenever a unique frequency was detected during daytime (0700-1700 h) by the fixed receiving system. Only one track day per frequency could be assigned each day per site. Site fidelity was the proportion of track days occurring over the bird's radio lifespan. We defined lifespan to be the number of days from the end of the bird's acclimation period until its last date of detection within the study area. Site fidelity was reported as a percentage. Percentage use of the study sites for roosting was derived similarly.

Detections by the mobile receiving system ≤1 km from a study site were not counted, provided that the frequency had been logged by the fixed receiving system. All mobile detections ≤1 km from a study site were counted as the bird being present at the study site. If the mobile system made repeated offsite (i.e., >1 km) detections on a bird during daytime within a day, the detections had to be separated by ≥1 hour starting from the minute the frequency was first detected. There were 15 instances of multiple, within-day detections; 14 of these consisted of 2 within-day detections and 1 consisted of 3 within-day detections. Nighttime detections were constrained to one per bird per night using only the strongest signal.

The decimal-degree coordinates of daytime and nighttime detections by the mobile receiving system were imported into a GIS. The GIS basemap consisted of high-resolution (1-m), digital orthophoto quadrangles, along with vector data of county boundaries, city boundaries, and roadways. Distances of offsite detections were measured using the haversine-distance formula (Sinnott 1984).

We used one-way ANOVA to test for differences (P ≤0.05) among sites in site fidelity, onsite roosting, and offsite distances. We used the Tukey-Kramer multiple comparisons method to separate means. Percentages were converted to proportions and then arcsine transformed before analyses. Sample sizes were too small to test for sex differences in behavior among sites.

**RESULTS**

We obtained sufficient data to analyze movements and site use of 41 birds (13 females, 28 males). The average radio lifespan was 30 days (SE = 1.5, range: 12-42 days). The transmitters were active for 1,248 days; birds were detected by either the fixed or mobile receiving systems on 646 (52%) of those days. During the last week of the study, we detected 27 birds. One bird was found dead at Site B on 19 January.

The fixed receiving systems recorded 529 track days. Fidelity differed among study sites ($F_{2,38}$ = 28.5, P <0.001). Stronger site fidelity was shown by birds from Site C ($\bar{x}$ = 78%, $n$ = 14, SE = 5.8) than Sites A ($\bar{x}$ = 10%, $n$ = 15, SE = 4.3) and B ($\bar{x}$ = 36%, $n$ = 12, SE = 10.2). All means were statistically separate. No visits by birds that were radio tagged at the other study sites were recorded.

The number of daytime detections offsite was 115 (Site A = 66, B = 36, and C = 13) (Figure 1). Average offsite distance differed among study sites ($F_{2,28}$ = 7.9, P = 0.002), with Site A ($\bar{x}$ = 6 km, $n$ = 13, SE = 2.7) greater than Sites B ($\bar{x}$ = 4 km, $n$ = 11, SE = 1.4) and C ($\bar{x}$ = 2 km, $n$ = 7, SE = 0.4). Means were not statistically different between Sites B and C.

The number of nighttime detections offsite was 63 (Site A = 39, B = 23, C = 1). Average offsite distance differed among study sites ($F_{1,22}$ = 4.6, P = 0.04), with Site A ($\bar{x}$ = 12 km, $n$ = 14, SE = 6.8) greater than Site B ($\bar{x}$ = 7 km, $n$ = 10, SE = 3.1). No statistical comparisons could be made with Site C. We found 4 major offsite roosts (Figure

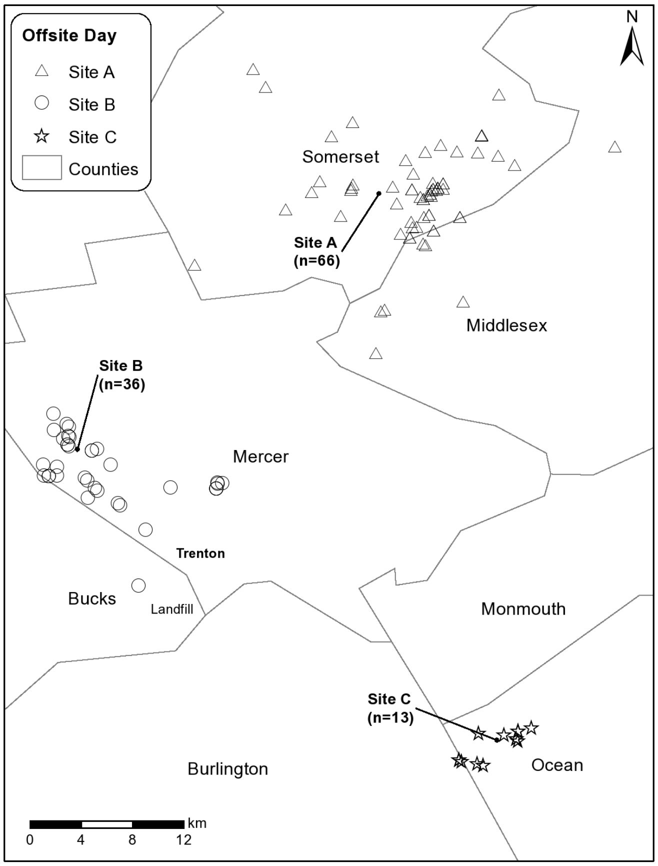


**Figure 1. Offsite (>1 km) detections during daytime of starlings captured and radio tagged at 3 study sites in central New Jersey during late December 2009 and tracked until 30 January 2010. Numbers in parentheses are the number of detections of birds from each site.**

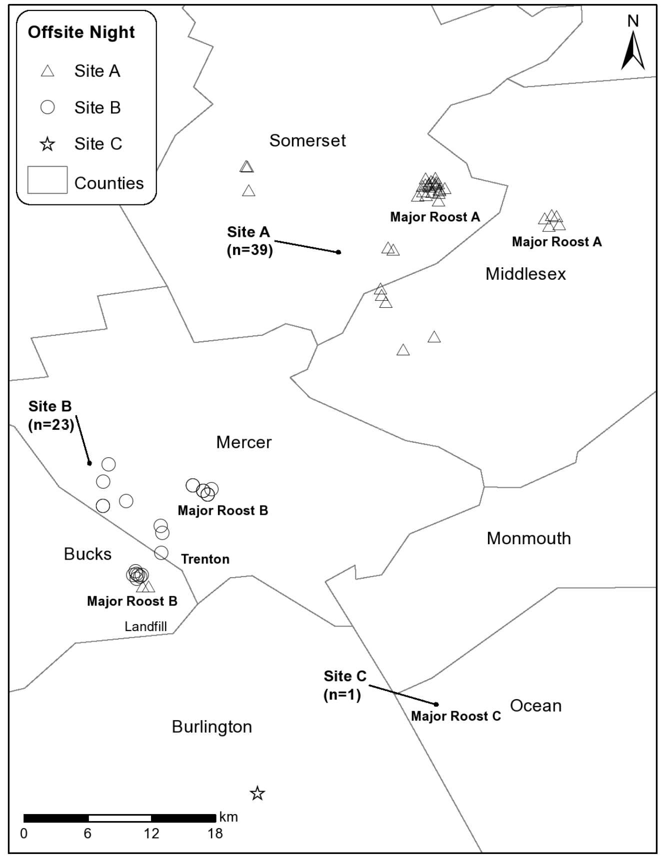


**Figure 2. Offsite (>1 km) detections during nighttime of starlings captured and radio tagged at 3 study sites in central New Jersey during late December 2009 and tracked until 30 January 2010. Numbers in parentheses are the number of detections of birds from each site.**

2). They averaged 10 km (SE = 1.4) from the study sites. Major roosts were located in relatively secluded areas not heavily used by the public. Except for the landfill roost site, none of the major roosts were shared by members of the other radio-tagged cohorts. To our knowledge, the landfill roost was used by only one bird from Site A.

Onsite roosting was detected only at Sites B (3 birds, 4 nights) and C (10 birds, 219 nights). Percentage of nights differed between the two sites ($F_{1,24}$ = 15.5, P <0.001), with Site C ($\bar{x}$ = 47% km, *n* = 14, SE = 10.5) greater than Site B ($\bar{x}$ = 2%, *n* = 12, SE = 1.0). The birds at Site C were using livestock barns for roosting. Ten birds were detected roosting at Site C, with 7 of the 10 very consistent in their use ($\bar{x}$ = 83% of nights, SE = 1.8); 4 birds never used Site C as a roost, instead using it only for daily activities. We found 1 of the 4 birds roosting either within or near McGuire Air Force Base, 15 kilometers to the southwest of Site C; however, we could not get permission to enter the airbase to ascertain its exact location. It is unknown if the other radio-tagged birds from Site C were using McGuire Airbase as a roost.

## DISCUSSION

The fixed receiving systems at Sites A and B indicated low site fidelity; however, offsite detections by the mobile system indicated that the birds stayed clustered nearby. This type of starling behavior, wherein a small-sized activity area is maintained and used consistently over time, has been observed previously in several different landscapes (Morrison and Caccamise 1990, Caccamise 1993, Homan et al. 2006, 2010). Daily use of small-sized activity areas may confer a survival advantage through increased foraging efficiency and reduced predation (Tinbergen 1981, Caccamise and Morrison 1986). Remarkably, the birds at Site A (i.e., the game bird farm) showed fidelity to the area surrounding the site despite a switch to a less-preferred food in late December, when the producer switched from a high-protein meal to whole kernel corn. The starlings immediately curtailed their use of the study site after the switch.

The average distance of offsite detections for Site A was greater than Site B. Thus, the loss of Site A as a food resource may have affected foraging quality in the area, but not enough to cause the birds to abandon the area. Site A was probably a supplemental foraging site and not the focal point of daily activities. The 2009-2010 winter was mild with only a few days of snow cover; we often found birds from Site A congregated about 3 km east of the study site. They appeared to be foraging in lawns. During harsher winter periods, we speculate that the birds would probably have abandoned their use of lawns and perhaps their activity areas, in addition to abandoning their roosts

(Morrison and Caccamise 1985, 1990).

By contrast, birds from Site C were nearly obligate users of their site during daytime. We could not detect a significant difference between Sites B and C in offsite distance during daytime; however, only 7 birds from Site C were found offsite, whereas 11 were found offsite at Site B. Site C was in an agricultural landscape, and it may have lacked the diversity of habitats that would have caused starlings to have larger activity areas. Starlings show strong site fidelity in rural landscapes because of the lack of usable alternative habitats (LeJeune et al. 2008, Homan et al. 2010, Gaukler et al. 2012). Both Site B and Site C were categorized as livestock facilities, but the former site (a prison farm) had just a few animals, whereas Site C was an actual working farm with numerous animals.

The distance that starlings traveled to reach their roost sites was in agreement with estimates of 3-12 km from earlier radio telemetry studies conducted in the same area of New Jersey (Morrison and Caccamise 1990). The study sites in the urban-suburban habitats each had 2 major roosts associated with them. Three of the major roosts were in stands of mixed evergreens and deciduous trees. The landfill roost, southwest of Trenton and used mostly by birds from Site B, was a large lake that was fringed with emergent vegetation (*Phragmites australis*). There were several minor roosts, which were often just small stands of evergreens either in yards or along streets and roads. Trenton proper was also used as a minor roost.

Compared to agriculturally dominated landscapes, where quality roost sites are rare or unique and draw large numbers of starlings from distances of 30 km or more (Homan et al. 2010, Gaukler et al. 2012), the starlings from Sites A and B traveled shorter distances to their roosts, were less concentrated, and were dispersed throughout the landscape. Even the major roosts probably consisted of no more than a few thousand birds, as we rarely saw flightlines leading to the roosting sites. The landfill roost did have a small flightline associated with it, and it was the largest roost.

## MANAGEMENT IMPLICATIONS

The average distance from the study area center to the 3 study sites was 20 km, and there were no interactions from members of the other radio-tagged groups at any study site. Indeed, this lack of intermingling at the study sites affirms the mobile receiving system's sampling efficacy in the study area. Our data support the hypothesis that wintering starlings have small winter ranges when using urban-suburban habitats. We predict that the majority of overwintering starlings in central New Jersey will rarely be ≥10 km from heavily used diurnal sites. Birds >6 km from a bait site are probably on a direct bearing between the bait site and roosting site.

The majority of birds at Site C, in addition to having a more limited range when offsite, also roosted onsite. Using DRC-1339 to manage starlings at Site C would have the least amount of risk for causing negative public reaction. Because several roosting sites were used and the birds were more widely scattered around the sites, conducting DRC-1339 interventions at Sites A and B would be fraught with challenges. Trapping with live decoys may be the best alternative (Conover and Dolbeer 2007).

## ACKNOWLEDGMENTS

We thank the following Wildlife Services personnel in New Jersey for their support and assistance with our project: K. Gurlavich, J. Mastantuono, A. Randall, and L. Spinelli. We also thank all the cooperators who allowed us access to their properties. The research was conducted under Study Protocol QA-1695 approved by the National Wildlife Research Center, Fort Collins, CO. Animal care and use procedures were followed in accordance with USDA APHIS Wildlife Services' National Wildlife Research Center IACUC guidelines. The Study Director was H. J. Homan. Use of commercial products by the U.S. Government does not constitute an endorsement of these products.

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