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Source: Journal of Wildlife Management, 75(6):1324-1329. 2011.

Published By: The Wildlife Society-2

URL: http://www.bioone.org/doi/full/10.1002/jwmg.173

The Journal of Wildlife Management 75(6):1324–1329; 2011; DOI: 10.1002/jwmg.173

Research Article

Potential Use of Weather Radar to Study Movements of Wintering Waterfowl

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ABSTRACT To protect and restore wintering waterfowl habitat, managers require knowledge of routine wintering waterfowl movements and habitat use. During preliminary screening of Doppler weather radar data we observed biological movements consistent with routine foraging flights of wintering waterfowl known to occur near Lacassine National Wildlife Refuge (NWR), Louisiana. During the winters of 2004–2005 and 2005–2006, we conducted field surveys to identify the source of the radar echoes emanating from Lacassine NWR. We compared field data to weather radar reflectivity data. Spatial and temporal patterns consistent with foraging flight movements appeared in weather radar data on all dates of field surveys. Dabbling ducks were the dominant taxa flying within the radar beam during the foraging flight period. Using linear regression, we found a positive log-linear relationship between average radar reflectivity (Z) and number of birds detected over the study area ($P < 0.001$, $r^2 = 0.62$, $n = 40$). Ground observations and the statistically significant relationship between radar data and field data confirm that Doppler weather radar recorded the foraging flights of dabbling ducks. Weather radars may be effective tools for wintering waterfowl management because they provide broad-scale views of both diurnal and nocturnal movements. In addition, an extensive data archive enables the study of wintering waterfowl response to habitat loss, agricultural practices, wetland restoration, and other research questions that require multiple years of data.

KEY WORDS foraging flight, ground-truth, Louisiana, NEXRAD, waterfowl, weather radar, winter.

Understanding wintering waterfowl habitat use and movements is necessary to effectively manage and conserve the landscape that supports them (North American Waterfowl Management Plan 2004). The coastal wetlands of Louisiana are a primary wintering area for waterfowl in the Mississippi Flyway (Johnsgard 2010). High wetland loss rates of 88 km^2 per year threaten this critical habitat (Barras et al. 2004). Winter habitat conditions affect waterfowl survival and reproductive success (Heitmeyer and Fredrickson 1981, Haramis et al. 1986, Heitmeyer 1988, Raveling and Heitmeyer 1989); thus, waterfowl managers strive to protect and restore winter foraging habitat and ensure that excessive disturbance does not prevent waterfowl from accessing foraging sites (Esslinger and Wilson 2003). Many waterfowl species make daily flights from diurnal roosting areas to nocturnal foraging sites, but data on these nocturnal movements are limited (Tamisier 1976, Baldassarre and Bolen 1984, Miller 1985, Cox and Afton 1996, Link 2007). The WSR-88D (Weather Surveillance Radar, 1988 design year, Doppler capable) may be an effective tool for waterfowl management because it provides a broad-scale view of both diurnal and nocturnal bird movements, and its extensive data archive would allow the study of seasonal movements and changes in habitat use across years.

During the 1990s, the United States network of weather radars was upgraded to the current WSR-88D system (Crum and Alberty 1993). This technological advance was important to ornithological research because the WSR-88Ds have an enhanced ability to detect weak echoes from biological targets, are Doppler capable allowing for measurements of target speed and direction, and collect and archive data in a digital format (Diehl and Larkin 2005). Since its deployment, the WSR-88D has been used to study landbird migration patterns from landscape to continental scales (Diehl et al. 2003; Gauthreaux et al. 2003, 2006; Buler 2006; Felix et al. 2008), identify landbird roost sites (Russell et al. 1998, Larkin 2006), and, most recently, study movements of migrating waterfowl (O'Neal et al. 2010). There are no published studies that evaluate WSR-88D as a tool for studying the movements of wintering waterfowl.

Lacassine National Wildlife Refuge (NWR) in southwest Louisiana is regularly used by thousands of wintering waterfowl. The refuge lies at the interface between freshwater marsh and agricultural fields. Species such as northern pintail

Received: 24 May 2010; Accepted: 25 January 2011;
Published: 13 July 2011

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(*Anas acuta*), mallard (*Anas platyrhynchos*), and green-winged teal (*Anas crecca*) spend the day roosting on the refuge (Tamisier 1976), then depart just after sunset presumably to forage in rice fields north of the refuge (Cox and Afton 1996). Using radiotelemetry, Cox and Afton (1996) found that northern pintails departed on evening flights (hereafter foraging flights) an average of 22 min after sunset. Most birds remained in agricultural fields overnight (Cox and Afton 1997) and returned to roosting areas before sunrise (Tamisier 1976). Preliminary screening of WSR-88D data revealed daily northward and southward movements near Lacassine NWR at times that coincided with the findings of Cox and Afton (1996) and Tamisier (1976), suggesting that waterfowl may be the source of radar echoes.

Our objective was to evaluate the use of WSR-88D as a tool for studying wintering waterfowl movements by 1) identifying the source of radar echoes emanating from Lacassine NWR and 2) testing for significant statistical relationships between field observations and radar data. This field confirmation is necessary before WSR-88D data can be used to address management questions about wintering waterfowl.

STUDY AREA

During the winters of 2004–2005 and 2005–2006, we conducted field surveys of duck foraging flight activity from Lacassine NWR, Louisiana (30.0094° N, 92.9315° W; Fig. 1). The refuge was mainly freshwater marsh with wooded wetlands, coastal prairie, and agricultural fields comprising <10% of the habitat. Rice and other agricultural fields dominated the landscape immediately north of the refuge. A prominent feature of the refuge was a 6,475-ha freshwater marsh impoundment that was used by large concentrations of wintering waterfowl.

METHODS

Weather Surveillance Radar Data

The WSR-88D samples the airspace by rotating 360° through a series of 5–14 elevation angles over a period of 5–10 min. Each 5- to 10-min volume scan generates a data file that is archived at the National Climatic Data Center (NCDC; http://has.ncdc.noaa.gov). To quantify waterfowl movements, we acquired archived base reflectivity (Level II) data for the Lake Charles, Louisiana radar station (KLCH). Reflectivity is a measure of the radio energy returned by targets (e.g., rain, insects, birds) in a pulse volume and has been used in ornithology as a relative measure of bird density (Black and Donaldson 1999, Gauthreaux and Belser 1999). The spatial resolution of reflectivity data was a 1° × 1-km pulse volume. We analyzed data collected at the lowest elevation angle (i.e., 0.5°) for the time periods that coincided with the routine evening departure and morning return flights near Lacassine NWR. We used the NOAA Weather and Climate Toolkit (Version 2.5.3, www.ncdc.noaa.gov/oa/wct/, accessed 14 Apr 2011) to export reflectivity data to a shapefile format for analysis. We spatially aligned radar data to a fixed polar grid by resampling at a finer spatial resolution (0.25° × 1 km) according to the recommendations of Buler and Diehl (2009). The NCDC archives reflectivity data in logarithmic units known as decibels of reflectivity (dBZ). We converted dBZ to linear reflectivity (*Z*) for analysis (Black and Donaldson 1999). Using ArcGIS version 9.3 (Environmental Systems Research Institute, Redlands, CA) we extracted the reflectivity data for the pulse volumes that overlapped the survey area. The radar pulse volumes that overlapped the survey area were 30–32 km from the radar at azimuths of 114.75–117.25° relative to the radar and covered a 3-km^2 area. We then averaged reflectivity over the selected pulse volumes for each 5- to 10-min time interval during the survey period.

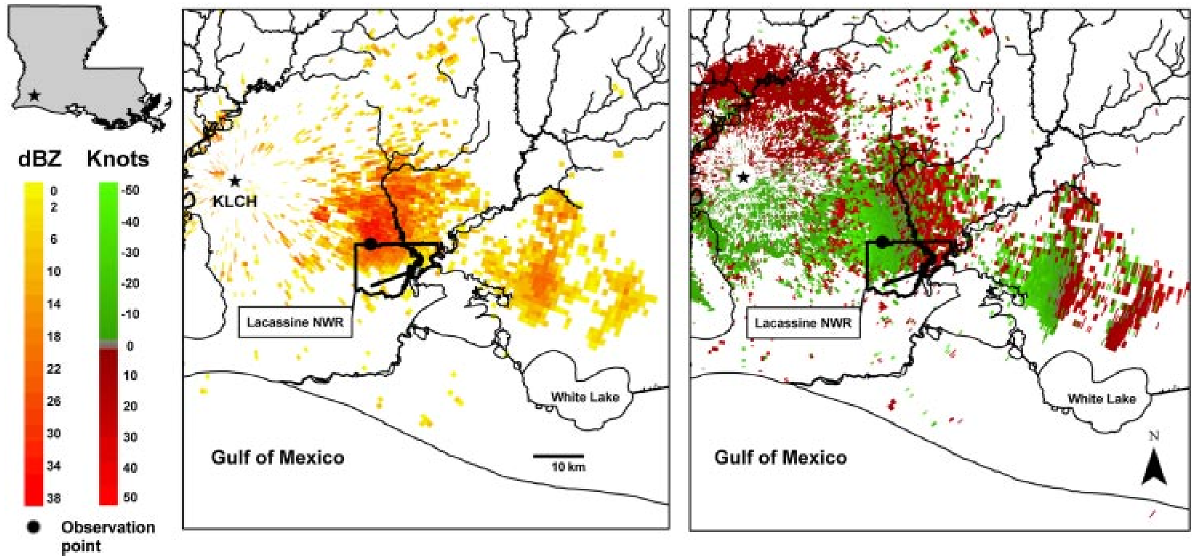

Figure 1. Waterfowl evening foraging flight as recorded by the Lake Charles, Louisiana radar (KLCH) on 22 December 2005 at 1733 hours. Reflectivity data (left) indicates large concentrations of birds in flight near Lacassine National Wildlife Refuge (NWR) and north of White Lake. Radial velocity data (right) confirms that birds were flying toward agricultural areas north of the refuge (targets moving toward the radar in green, targets moving away from the radar in red). We removed reflectivities <0 decibels of reflectivity (dBZ) for image clarity.

We estimated the flight direction of waterfowl at our study area using reflectivity data collected at the time of field surveys. Using ArcGIS version 9.3, we animated sequential volume scans of reflectivity data, then measured the flight direction through the center of the moving cluster of targets.

Field Surveys

To identify the source of radar echoes, we conducted field surveys between 1600 hours and 1830 hours on 3 evenings in winter 2004–2005 (10 Dec, 8 Jan, and 14 Jan) and on 4 nights in winter 2005–2006 (22 Dec, 5 Jan, 18 Jan, and 9 Feb). In winter 2004–2005, we also surveyed 2 morning return flights between 0600 hours and 0800 hours (9 Jan and 20 Jan). We selected the dates of data collection based on precipitation-free conditions during the survey period. We positioned the field survey point on the northern levee of the impoundment to maximize observations of birds flying between diurnal roost sites on the refuge and nocturnal foraging sites north of the refuge. The observation point was 30 km from KLCH. Assuming standard atmospheric refraction, the estimated height of the lower boundary of the radar beam was 73 m above ground level (Rinehart 2004), allowing us to easily detect birds within the beam. For all birds that passed over the survey point, we recorded data on date, time, location, species, number of individuals, flight direction, and height above ground. In 2004–2005, we estimated bird location and height by using the location and height of nearby landscape features (e.g., levees, tree lines, man-made structures). We confirmed within-beam detections post-survey by modeling observed beam propagation paths according to the methods of Buler and Diehl (2009). In 2005–2006, we refined bird location and height measurements. Using ArcGIS version 9.3, we determined where the boundaries of radar range gates (intervals of range in which returning radar signals are measured) intersected the refuge levee. We marked the boundary points in the field and then assigned bird detections to the appropriate range gate. We estimated bird height by applying the principles of a right triangle. Prior to the first survey of the season, we used a Global Positioning System (GPS) to record the location of a series of reference points in the survey area. We used ArcGIS version 9.3 to measure the distance from the observation point to the reference points. During each survey, the observer used a protractor to determine the angle between the bird detections and the horizon. We recorded birds as in or below the estimated height of the radar beam (min. ht = 73 m) based on the measured angle and distance to known reference points.

To compare field observations to radar reflectivity data, we summed bird detections over 5- to 10-min time intervals that coincided with radar data collection. Using the starting azimuth, time, and duration of the 0.5° elevation scan, we determined the time (to the nearest minute) the radar beam passed over the survey area. We focused the analysis on the foraging flight and restricted data to observations gathered between 1656–1809 hours and 0630–0700 hours. We omitted birds detected below the radar beam. We used linear regression (SAS Version 9.1, SAS Institute, Cary, NC) to test the relationship between the average radar reflectivity (Z) and the total number of birds detected over the study area. We treated each time interval of data as an independent observation because we considered 5 min sufficient time for birds to fly out of the sampled area. The maximum north-south distance of the sampled area was 1.7 km and the maximum east-west distance was 2.4 km. Day to day variation in atmospheric conditions could affect beam propagation and thus influence the relationship between radar and field data. We used the forward model selection approach (PROC GLMSELECT, SAS Institute) to determine if day had an effect on the relationship between average radar reflectivity (Z) and the total number of birds, and we selected the best model using the Bayesian Information Criterion (Burnham and Anderson 2002). We assessed the fit of the final model and log-transformed variables to meet the assumptions of normality and homoscedasticity (PROC GLM, SAS Institute). We report significant relationships at $P \leq 0.05$.

RESULTS

Large, unidirectional movements consistent with evening waterfowl foraging flights appeared in WSR-88D data on all dates of field surveys (Fig. 1). A well-defined increase in radar echoes appeared over the survey area 4–14 min after sunset and overlapped the timing of field-observed departures for all flights surveyed. One post-sunset peak in movement characterized the evening foraging flights surveyed on 8 January and 14 January 2005, 22 December 2005, and 18 January 2006. On 5 January and 9 February 2006, ducks began flying out of the refuge 30–60 min prior to sunset with a surge in activity near sunset (6 min before sunset on 5 Jan 2006; 9 min after sunset on 9 Feb 2006). The WSR-88D recorded a less-defined peak prior to sunset with a well-defined increase in echoes over the survey area 4 min and 12 min after sunset, respectively.

The direction of evening departure flights was consistently northward. Field observations in 2004–2005 and 2005–2006 found that 96% and 99%, respectively, of ducks flew towards a direction between 315° and 45°. The direction of the morning return flight on 9 January 2005 was southward with 92% of the ducks flying towards 180°–225°. Likewise, the radar reflectivity data consistently recorded northward movement in the evening with the direction of travel ranging from 12° to 20°. The morning return flight was southward towards 197°.

During the first survey on 10 December 2004, hundreds of ducks flew northward over the survey point while thousands of geese circled overhead and observers found it difficult to place discreet values on the number of detections. Rather than use very coarse estimates of the number of birds detected, we removed the survey from the regression analysis. We also excluded data collected on 20 January 2005 because fog created poor visibility conditions. We estimated 49% of the 6,482 birds observed during the remaining 3 foraging flight surveys in 2004–2005 as flying at heights within the radar beam (range: 76–305 m). Over all surveys in 2004–2005, 90% of the birds detected within the beam were

Table 1. Ground-based observations of duck foraging flight activity at Lacassine National Wildlife Refuge, Louisiana in winters 2004–2005 and 2005–2006. Counts include birds detected in the radar beam between 1656 hours and 1809 hours.[a]

	Total observations				% observations		
	Ducks	**Geese**	**Other**	**Total**	**Ducks**	**Geese**	**Other**
2004–2005							
8 Jan 2005	1,473	267	0	1,740	85	15	0
9 Jan 2005	145	7	2	154	94	5	1
14 Jan 2005	1,205	17	40	1,262	96	1	3
Total	2,823	291	42	3,156	90	9	1
2005–2006							
22 Dec 2005	4,599	441	0	5,040	91	9	0
5 Jan 2006	1,642	80	3	1,725	95	5	0
18 Jan 2006	7,631	92	80	7,803	98	1	1
9 Feb 2006	3,377	0	61	3,438	98	0	2
Total	17,249	613	144	18,006	96	3	1

[a] On 9 January 2005, we monitored a morning return flight from 0630 hours to 0700 hours.

dabbling ducks (Table 1). Foraging flights included 3 species of ducks with mallard and northern pintail making up most identifiable observations (Table 2). The remaining 10% of detections within the beam were geese and wading birds.

In 2005–2006, we estimated 18,006 of the 19,223 birds detected during foraging flights as flying within the radar beam. Dabbling ducks comprised 96% of the birds detected within the beam. Seven species of ducks were included in the evening flights. Most observations were mallard, northern pintail, and green-winged teal (Table 2). Geese, wading birds, shorebirds, and landbirds comprised the remaining 4% of detections within the beam. We found a positive log-linear relationship between average radar reflectivity and total number of birds ($P < 0.001$, $r^2 = 0.62$, $n = 40$). The intercept of the relationship between reflectivity and number of birds was similar among days, but the slope varied among days (Fig. 2).

DISCUSSION

Temporal patterns of radar echoes we observed over Lacassine NWR were consistent with field survey data and published observations of duck foraging flights in the region (Tamisier 1976, Cox and Afton 1996, Link 2007). Cox and Afton (1996) surveyed radiomarked northern pintail 0.5 hr prior to sunset until 1 hr after sunset. Northern pintails departed Lacassine NWR during this entire period with an average departure of 22 min after sunset. Tamisier (1976) found that northern pintail and green-winged teal

Table 2. Number of observations for each species detected within the radar beam during one morning (0630–0700 hours) and 6 evening (1656–1809 hours) foraging flights at Lacassine National Wildlife Refuge, Louisiana in winters 2004–2005 and 2005–2006.

	No. of observations	
Species	**2004–2005**	**2005–2006**
Ducks		
Gadwall (*Anas strepera*)	0	42
American wigeon (*Anas americana*)	0	154
Mallard	1,242	11,607
Mottled duck (*Anas fulvigula*)	0	11
Northern shoveler (*Anas clypeata*)	38	37
Northern pintail	299	3,982
Green-winged teal	0	678
Teal spp.	0	40
Duck spp.	1,244	698
Total ducks	2,823	17,249
Geese		
Greater white-fronted goose (*Anser albifrons*)	111	587
Snow goose (*Chen caerulescens*)	71	15
Geese spp.	109	11
Total geese	291	613
Other species		
Great blue heron (*Ardea herodias*)	2	0
White ibis (*Eudocimus albus*)	40	3
Plegadis spp.	0	4
Northern harrier (*Circus cyaneus*)	0	2
Killdeer (*Charadrius vociferus*)	0	2
Long-billed dowitcher (*Limnodromus scolopaceus*)	0	20
Larus sp.	0	3
Blackbird spp.	0	110
Total other species	42	144

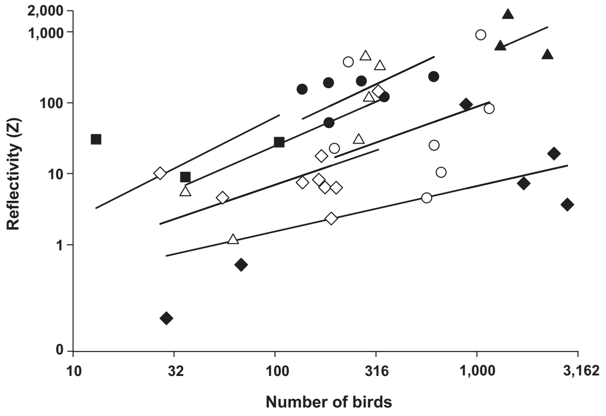

Figure 2. Relationship between reflectivity (*Z*) and number of birds detected during 7 surveys conducted at Lacassine National Wildlife Refuge, Louisiana in winters 2004–2005 and 2005–2006. Each group of symbols represents a separate survey day. We log transformed reflectivity and number of birds for linear regression.

departed for foraging areas about 25 min after sunset and returned to the roosting area 10–40 min before sunrise. On 5 January and 9 February 2006, the radar detected targets moving northward prior to sunset. The earlier movements may have been related to wind conditions. Tamisier (1976) observed that ducks departed from Lacassine NWR earlier on windy days. Cox and Afton (1996) found that northern pintails adjusted the timing of their departure from roost sites according to the weather conditions of the day, and winds >8 kilometers per hour (kph) prompted earlier departures. On 5 January 2006, ducks would have encountered headwinds of 28 kph. On 9 February 2006, birds would have flown into a cross breeze with winds out of the east at 15 kph.

Directional patterns of radar echoes over Lacassine NWR agreed with field surveys and published research results (Tamisier 1976). Using visual observations, Tamisier (1976) found that green-winged teal flew towards the northeast and northwest during their routine evening departures from Lacassine NWR. Radiotelemetry research indicates that northern pintails (Cox and Afton 1997) and mallard (Link 2007) were also active at night in the agricultural fields north of Lacassine NWR.

Our field observations and the positive relationship between reflectivity data and number of birds confirm that WSR-88D records the routine evening departure and morning return flights of dabbling ducks. The slope of the relationship between radar and field data varied among days, and we suspect that the height of the lower edge of the beam may account for some of the variation. In 2005–2006, we identified birds as being within the beam based on an estimated beam height of 73 m. Because of beam elevation angle settings and atmospheric conditions, the actual height of the lower boundary of the radar beam was 74 m to 99 m. Thus, some birds that we identified as being within the beam were actually below beam.

The synchronized foraging flights of wintering waterfowl produce consistent temporal and spatial patterns in WSR-88D data suggesting that radar reflectivity can be used as a relative index of wintering waterfowl activity. By calculating changes in reflectivity strength and distribution within the landscape, waterfowl biologists could use WSR-88D data to study the response of wintering waterfowl to disturbance, changes in land use, habitat management, and other questions of interest. For most radar stations, radar data are archived from 1995 to present. Thus, studies would not be restricted to one winter season, and managers could study questions that require multiple years of data.

MANAGEMENT IMPLICATIONS

Our results suggest that WSR-88D data can be used to study wintering waterfowl movements. Radars within the WSR-88D network are similar in design, thus data from multiple radars can be used to characterize wintering waterfowl movements from a local (one radar) to regional (multiple radars) scale. The WSR-88Ds are operated continuously, and the data has been archived since the mid 1990s for most radars. Thus, waterfowl biologists can access an extensive dataset that can be applied to questions about the movement and distribution of wintering waterfowl. Weather radar data are not without limitations. Precipitation, anomalous propagation, echoes from multiple types of biological targets (e.g., birds, bats, and insects), range bias, and lack of taxonomic resolution are some of the factors that restrict data use (Diehl and Larkin 2005). Despite these challenges, weather radar data would be particularly valuable for identifying locations of diurnal roost sites, nocturnal foraging habitats, and assessing wintering waterfowl response to habitat loss, agricultural practices, and habitat restoration.

ACKNOWLEDGMENTS

We thank J. Buler for helpful discussions about the analyses and manuscript, D. Johnson for statistical assistance, and D. Haukos for comments on an initial draft of the manuscript. We also thank the staff of Lacassine NWR for providing access to the refuge. Our research was funded by the United States Fish and Wildlife Service, Gulf Coast Joint Venture. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the United States Government.

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Associate Editor: Graham Hall.