DETERMINATION OF NEARSHORE SEABIRD DENSITY ON THE UPPER TEXAS COAST

Submitted By

Robert W. McFarlane
McFarlane & Associates
Houston, Texas

and

L. James Lester
Houston Advanced Research Center
The Woodlands, Texas

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Use of Radar and Human Observation to Assess the Risk of Bird Mortalities at Potential Wind Turbine Installations on the Upper Texas Coast
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EXECUTIVE SUMMARY

Marine radar is a useful tool for the study of birds. It is more effective over water than over land, where ground clutter can interfere with bird detection. It is particularly useful for night observations when visual observations cannot be undertaken. Marine radar is of limited use in directly quantifying bird abundance because it fails to detect all birds present. It does provide a simple method to determine accurate distance to the radar targets, providing information that can be used with the computer program DISTANCE to estimate bird densities. Estimates of bird densities are good indications of bird abundance but, by themselves, contribute little to the estimation of bird mortality from collisions with wind turbines. A new dual-sampling technique combining point transects, used to estimate bird density, with simultaneous plane transects, used to indicate bird behavior, is proposed. A comparison that demonstrates the absence of a relationship between bird density and bird exposure to wind turbines is provided. Bird densities along the upper Texas coast were rather uniform, in both gulf and bay waters, throughout four seasons, ranging from 3.2 to 17.4 birds per square kilometer (approximately 25 acres).

INTRODUCTION

There is increasing interest in the upper Texas coast as a potential site for electricity-generating wind turbines. The area is also a crossroads for trans-Gulf and circum-Gulf migrating birds. Wind turbines do constitute a risk to birds (NWCC 1999, 2001, 2004). Concern for the potential of bird collisions with turbines has led to this attempt to quantify and predict the risk of avian mortality due to construction and operation of wind turbines in this area.

The avifauna of the study area and its seasonal fluctuation are well known. Birds are diverse and abundant. The annual Audubon Christmas bird counts from the Freeport area in Brazoria County typically rank among the highest in the nation for the total number of species observed. Spring migration of trans-Gulf migrants at High Island in Chambers County is world renown. But quantifying the actual number of birds, rather than the kinds of birds, is more challenging. Visual observations are restricted to daylight hours but birds are known to move at night, particularly during migration. Wind turbines operate throughout the diel cycle of light. The potential for avian mortality may be greatest during the hours of darkness when turbines, operating where birds least expect them, are less visible.

In recent years marine radars have been used to study bird movements, especially at wind farms (Harmata et al., 1999). Radar observers detected as many as twelve times the number of birds as visual observers but did not detect all birds in the vicinity. In paired comparisons, 48% of observations first detected by radar were subsequently detected by the visual observer, while 67% of observations first detected visually were subsequently detected by the radar.

The **purposes** of this study were to:
□ determine the efficacy of marine radar for observing coastal birds
□ quantify the density of coastal birds along the upper Texas coast, and
□ predict the potential for avian mortality due to the presence of wind turbines.

METHODS

Radar System and Operation

The marine radar selected for this study (Furuno Model 7112) was a 12,000 watt X-band radar with a maximum range of 72 nautical miles (nm). The transceiver operated at a frequency of 9410 MHz. The scanner was 120 cm (4 ft) in length, with a horizontal beamwidth of 1.2° and vertical beamwidth of 22°, rotating at 24 rpm (2.5 sec/rotation). The unit was powered by two 12-volt deep-cycle marine batteries

and mounted on a steel frame attached to the body of a small extended cab pick-up truck. The display was a 12-inch rectangular monochrome CRT mounted on a wooden platform strapped to the existing jump-seat in the cab. Control cables were fed into the cab through the sliding rear window. The revolving scanner was 2 meters above ground level when operational. The steel roof of the cab eliminated 98% of radiation emanating from the transceiver. A plywood shield covered with sheet metal was placed over the rear window to prevent radiation from passing through the glass. When desired, the CRT screen was photographed with a digital camera. The head-up bearing of the radar was positioned to coincide with the front of the truck but the actual position appeared to be 10-12° off-center.

The radar can be operated at 0.25, 0.5, 0.75, 1.5, 3, 6, and more nautical miles. Inasmuch as the horizon at sea level is less than 4 nm distant, the radar was typically operated at 0.5 to 1.5 nm. The pulse length can be either short or long; a longer pulse is more likely to detect a target but the distance to the target is measured less accurately. Short pulses were used throughout this study. A useful feature of the radar is the ability to retain echoes on the display screen for selected periods of time. This may permit a “track” of the target to be displayed on the screen. Echoes are displayed in eight tones of green according to strength of the echo. Distances to the detected objects can be determined automatically with a trackball cursor. Figure 1 shows a photograph of the screen during observations and illustrates the ease with which distance can be determined.

Figure 1. Photo of the CRT screen during observations at the Texas City Dike. The scan is set at 0.5 nm. Image shows the effect of whitecaps in the water on the radar reflection. The lower half of the image is birds plus whitecaps. The upper half is birds only. The cross-hair is positioned on a navigational marker 147 meters distant.

Study Locations

The study area extended from the mouth of the Brazos River northward to include Follets Island, Galveston Island, the Bolivar Peninsula, and High Island to the western boundary of the McFadden National Wildlife Refuge, a reach of approximately 80 miles of coastline. Over-land observations were conducted at the Brazoria National Wildlife Refuge, the Anahuac National Wildlife Refuge, the Candy Abshier Wildlife Management Area, and the vicinity of Smith Point in Chambers County.

The Gulf of Mexico shoreline was accessed primarily through public beach access points. The vehicle was parked as close as possible to the waterline, perpendicular to the beach. At various times, the gulf was sampled from 50 locations; 16 between the Brazos river and San Luis Pass, 17 between San Luis Pass and Bolivar Roads, and 17 from Bolivar Roads northward (see Figure 2). The bay shorelines, which lack Texas Open Beaches access, were more difficult to reach with the vehicle and yield a clear view for the radar. A total of 38 sites were sampled; 6 from Follets Island, 9 from the Bolivar Peninsula, 10 from Galveston Island, and 13 from the Texas City dike and vicinity.

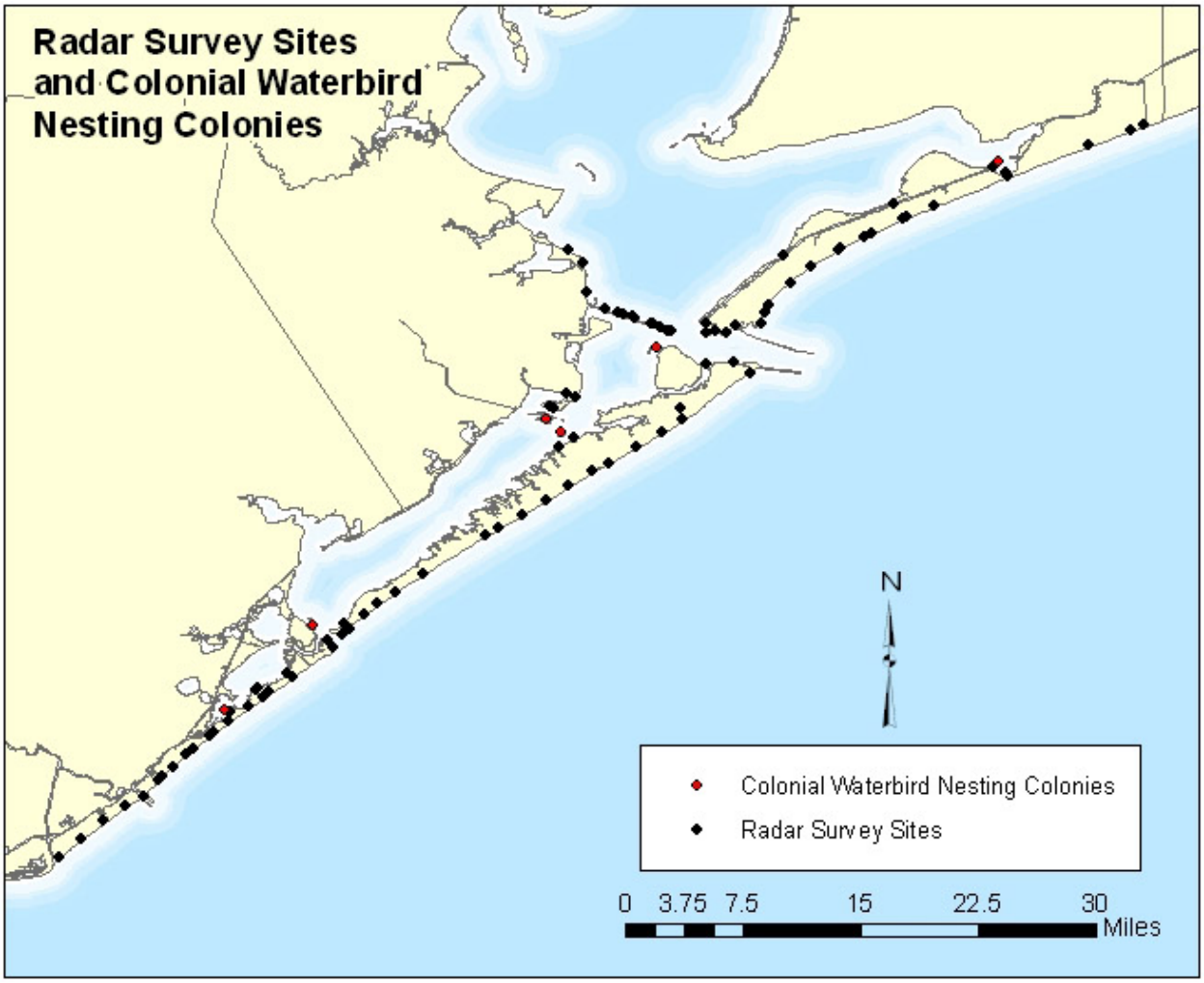


Figure 2. This map of the Southeast Texas coast around Galveston Bay shows the locations of all of the radar observations made for this study and the locations of colonial waterbird nesting colonies that were observed remotely.

Bird Density Estimation

The computer program DISTANCE was used to calculate bird densities (Buckland et al., 1993; Buckland et al., 2001, Buckland et al., 2004, Thomas et al., 2004). DISTANCE has been developed and refined over the past 25 years and has a sound theoretical basis. It is based on the common observation that the probability of detecting the presence of a bird or other object of interest declines with increasing distance between the observer and the object. There are three critical assumptions inherent to the method: (1) objects at the observation point are detected with certainty; (2) objects are detected at their initial location; and (3) measurements are exact. This survey utilized a semi-circular point transect technique, with the circle primarily of 0.5 nm radius.

Densities are expressed as the number of birds per square kilometer of space. A major advantage of DISTANCE is that it does not require that all birds be detected, for it calculates the number of birds that have been missed by the observer.

The first assumption, certain detection at the observation point, is the weakest point of this survey. The 22° angle of the radar beam ensures that the observation zone increases in height with distance from the radar, being zero height at the transceiver. The radar is blind to any object above the beam close to the radar. In addition, a certain amount of "ground clutter" surrounds the radar, obscuring any object within this zone, which may vary from 50 to 100 meters. To detect a bird which passes overhead, the bird must be detected first as it approaches or recedes from the radar.

The second assumption, detection at the initial location, becomes an issue as birds become more numerous. If several birds appear on the display screen nearly simultaneously, some birds will have moved before the distance to them can be determined. An echo remains on the screen for 2.5 seconds before being replaced or wiped out. If the echo trail feature is enabled, the screen may become cluttered and obscured with retained images.

The third assumption regarding exact measurement, is the least problematic. Range resolution is considered to be 20 m or less.

Ideally, one would prefer an instantaneous count of the birds in a given area, to minimize the chance that birds enter or depart from the count area during the count. With DISTANCE, 60 to 80 observations are needed to produce reliable estimates. In practice, an observer can reasonably keep track of 20 to 25 radar echoes without double counting. In this study, distances to 20 to 25 birds could be determined within 3 to 4 minutes of observation for a point transect. Most observations were conducted at the 0.5 nm radar setting with concentric range circles of 0.125, 0.25, 0.325 and 0.5 nm displayed on the screen. The distance to the outermost ring was 922 meters, and the greatest distance visible on the screen was 1050 meters. The area within a semi-circle of 0.922 km radius is 1.34 km^2. This setting maximized the opportunity to detect individual birds and minimized measurement error in determining the distance to the bird.

Marine birds spend considerable time flying in circles or irregular flight patterns in search of prey organisms. To assist in estimation of the number of times a bird may cross a line or an array of wind turbines, plane transects were also established at the same time as point transects. The radar was positioned so that the head-up bearing of the radar screen was perpendicular to the coast. Each time that a radar target crossed or touched the reference line, 922 m in length, during a 15-minute observation period, the target was tallied. The result was an estimate of targets per kilometer per hour that crossed the reference plane.

RESULTS

Efficacy Of Marine Radar

Radars exhibit a certain amount of background "noise" that can usually be removed by adjusting the receiver sensitivity (gain). Unfortunately, too much adjustment also removes the ability to detect birds. At longer distances, the noise is readily discerned as an overall pattern on the display screen. At shorter distances, the 0.5 to 1.5 nm ranges that best display birds, the noise is still present but scattered and intermittent, leading the operator to mistake the faint echoes for small birds. These false indications can be eliminated by noting that such echoes do not leave a track during echo-trail operation.

Large, highly-reflective objects, such as ships, towboats and barges, can present a distorted image, with the angle subtended on the display screen being much greater than the visual angle. As an example, two towboats with barges approaching one another from opposing directions in the same narrow channel may appear to be passing each other on the radar when visual observation indicates that several hundred meters still separate the two vessels. Large ocean-going vessels may present multiple images, several in a row, one behind the other on the screen. Other large "mystery" images appear with some regularity. Apparent "shadows" of islands, peninsulas and bridges may rapidly appear or disappear without obvious causation. Such images, although intriguing, are not confused with birds.

The radar may not present a consistent image of a stationary object, varying from one revolution of the antenna to the next. For example, a white plastic PVC pipe, commonly used to mark channels through the oyster reefs, identified both on the radar and visually, with the distance verified by the radar and a laser rangefinder, may present a single echo, a double echo, or no echo at all on successive revolutions. Permanent objects typically exhibit a varying, but repeating, pattern with each revolution. Recognition that such variability can emanate from a static object explains some of the variation exhibited by birds. Detecting and tracking a bird has been described as "tracking a bag of salt water."

The radar does detect birds very well. It can produce an echo trail but more commonly will yield a single echo or just two or three echoes and then disappear from the screen. If a trail is produced, the echoes may change in size or brightness, or "empty" spots will appear in the trail where a rotation failed to detect the bird as illustrated in Figure 3. This variation appears to be related to the bird's activity. These are birds actively foraging over water, searching for prey, wheeling and turning, and plunging to the surface when suitable prey are detected. Thus the bird may present a lateral view, with or without a down-stroke wing, or a frontal or rear view with wings in edge profile. The silhouette of the bird presented to the radar beam is constantly changing. If the bird plunges to the surface of the water it may remain there momentarily, or for a prolonged period. Birds swimming in the water are visible to the radar, perhaps intermittently as they rise or fall with swells. Diving birds, such as cormorants, loons and certain ducks, appear and disappear from the screen as they dive and resurface.

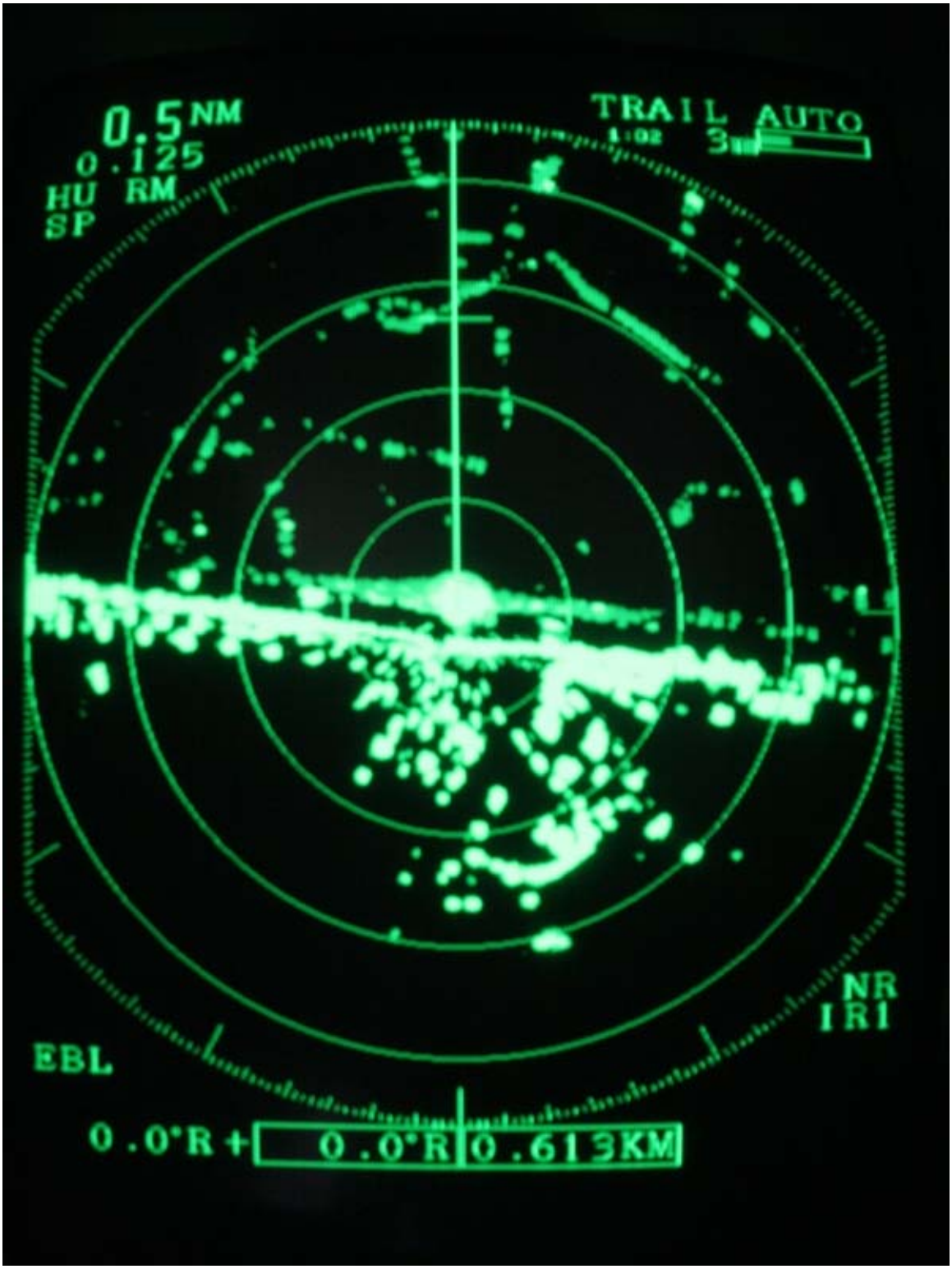


Figure 3. Photo of CRT during observations at Pointe San Luis on west Galveston Island at 0.5 nm with a 1 minute echo trail. Bright areas in the lower half of the image are beach vegetation and stationary objects. The small surf line is the horizontal blur at the center. Note the curved echo trails of birds, gaps where an echo was not received, and changing echo size in the trails..

Birds can be detected at considerable distances, routinely beyond one kilometer and occasionally as distant as 3 km (nearly two miles). Birds cannot be accurately counted with the radar, even at relatively short distances. A visual count revealed about a dozen Forster's terns foraging but no more than 6 or 7 were detected by the radar at one time. A visual count of larger royal terns was estimated as two dozen but no more than 9 or 10 appeared on the radar. Accurate counts of large flocks of birds following shrimp boats, ferries, towboats or ocean-going vessels are hopeless. When bird flocks exceed 100 or more individuals only a small fraction of the birds appear as radar echoes. This apparently results from the summation of returned radar signals. Two or more birds flying close together may appear as one echo. A flock of ten large brown pelicans flying single file in a straight line produced a single straight echo trail across the screen; a single bird would have produced a trail of intermittent individual echoes. Even large birds can be missed by the radar; a line of seven brown pelicans flying up a beach were visually observed approaching the radar, flew directly overhead, and continued up the beach until out of sight without ever being detected by the radar. A flock of birds flying close together will produce a single irregular echo glob that changes shape as the flock maneuvers, including gaps where the entire flock was missed by the radar.

Other objects produce echoes that resemble birds. A pod of bottle-nosed porpoises, exposing their backs and dorsal fins while breaking the surface to breathe, closely resembles birds. A jumping mullet caught in the radar beam may do the same thing. Waves are particularly troublesome. Breaking surf along the beach produces strong echoes that effectively screen out birds flying over the surf zone. With strong winds, the surf echoes can be used to accurately locate and count the hidden sandbars along the shoreline. Whitecaps are especially troublesome. Whitecaps reflect the radar beam and persist for two or three revolutions. They can be identified under close examination as they always approach the beach. If the echo moves laterally or away from the beach, it is likely to be a bird. On two occasions false echoes appear to have been produced by electromagnetic components of low-elevation sunlight bouncing off of the surface of the water.

The radar cannot identify the birds that are detected. Seabirds commonly observed along the coast included brown pelicans, neotropic and double-crested cormorants, laughing and ring-billed gulls, and royal, Forster's and least terns. While a brown pelican (wingspan up to 79 inches) is unlikely to turn up as a weak echo (except perhaps at a great distance) and a least tern (wingspan up to 20 inches) is unlikely to produce a bold echo at any distance, there is considerable overlap otherwise. Rapid versus slow straight flight, or meandering paths, may provide some clues as to species identity, but certainty is absent. Over land, small songbirds are difficult to detect. For example, a flock of 75 to 100 tree swallows foraging low over an open field seldom returned more than 6 to 8 echoes at any given moment.

Birds of similar size vary in their ability to reflect a radar beam. Seabirds, with dense, waterproofing plumage, appear to be more visible to radar than land birds, such as hawks, with fluffy, less dense plumage. In one study of raptors, 42% of birds first detected with the radar were also detected by visual observers, while only 18% of birds first detected by visual observers were also detected by the radar (Harmata et al. 1999). In the present study, the radar placed at the edge of Galveston Bay at the Smith Point Hawk Watch station appeared to be more successful detecting seabirds than hawks.

Radar observations over land areas are problematic. Vegetation reflects the radar beams and ground clutter obscures the display screen, rendering birds difficult to detect. At an extreme, radar reflections from marsh vegetation along Bastrop Bayou totally obscured everything except open water areas. Birds flying above the marsh could not be detected except when they passed above open water. Tall vegetation, such as trees, may obscure the weak radar signals being reflected by birds beyond the trees. The radar display, being two-dimensional, may become cluttered with reflections of vegetation and the operator is unable to detect a high-flying bird in clear view above the vegetation.

Determination Of Bird Densities

The DISTANCE sampling program fits a probability of detection function to the data and estimates the number of birds, or radar targets in this instance, that have been missed due to increasing distance from the observer. This study has investigated the amount of variation associated with scale, geography, season and time of day.

Spatial and Temporal Variation

A comparison of the estimated density of birds using three different radar settings (0.5 nm, 0.75 nm, and 1.5 nm) is shown in Table 1 below. All data were collected sequentially at each of five sampling locations on Follets Island on the same day. Upper and lower 95% confidence limits are provided for the density estimates. As the density estimates are based on sample observations, another observer sampling the same locations, would most likely provide a slightly different number. One can be certain that another estimate should have a 95% probability of falling between the upper and lower limit. The percent coefficient of variation is a measure of the variability of the measurement; lower values permit greater confidence in the estimate and are affected by the size of the sample.

Table 1. Target densities determined with different radar settings.

RANGE	NO. OF SAMPLES	# OBSERV.	WIDTH (M)	EFF. DETECT. RADIUS (M)	**BIRDS/ SQ KM**	LOWER 95%CL	UPPER 95%CL	% COEF. VARIATION
0.5 nm	5	146	1088	755	**8.1**	2.3	28.9	71.2
0.75 nm	5	126	1725	761	**6.9**	3.7	13.1	32.8
1.5 nm	5	145	3079	848	**6.4**	5.5	7.6	8.3

Birds were detected at the limit of each range but the effective detection radius was extended less than 100 meters although the range was tripled. Densities declined slightly (but not statistically significantly) as the range was extended, suggesting that perhaps densities are highest closer to shore, or simply that birds are more difficult to detect farther offshore.

The spatial and seasonal variation associated with birds of the gulf and bay ecosystems is shown in Table 2. Overall, the densities are remarkably similar, with little more than a five-fold difference among them.

Table 2. Spatial and temporal variation in seabird densities along the upper Texas coast.

Ecosystem	Season	Location	Number Of Samples	Number Of Observations	Birds/Sq Km	Lower 95% Cl	Upper 95% Cl	% Coef. Of Variation
Gulf	Spring	Bolivar	8	225	**6.4**	2.1	19.3	60.4
		Galveston	11	147	**4.5**	1.8	11.3	49
		Follets	6	88	**3.6**	2.4	5.5	20.3
	Summer	Bolivar	7	177	**9.4**	7.5	11.7	11.3
		Follets	4	89	**5.5**	4	7.6	16.2
	Autumn	Bolivar	3	101	**16.4**	1.3	206	201.9
		Galveston	3	89	**9.1**	1.5	54.4	111.5
		Follets	3	103	**7.3**	0.4	132.2	272.7
	Winter	Galveston	3	74	**6.2**	4.1	9.4	20.2
		Follets	3	82	**17.4**	12.8	23.8	15.8
Bay	Spring	Bolivar	5	92	**13.1**	8.4	20.6	23
		Galveston	3	73	**8**	3.4	18.6	30.6
		Follets	3	37	**3.2**	1.8	5.7	27.8
		Texas City	8	201	**11**	8.2	14.8	14.4
	Summer	Follets	3	47	**3.6**	1.7	7.8	32.14
	Autumn	Bolivar	2	60	**10.9**	1.6	74.7	123.6
		Galveston	2	51	**10.6**	7.1	16	19.1
		Follets	2	50	**5.7**	3.5	9.2	23.8
		Texas City	3	92	**10.8**	2.9	39.3	72.9
	Winter	Texas City	3	63	**6.1**	4	9.2	20.9

A major advantage of radar as an observational tool is its ability to function in total darkness. The results of overnight observations are shown in Table 3.

Table 3. Day-night differences in bird densities.

Ecosystem	Season	Location	Number of Samples	Number of Observations	Birds/sq km	Lower 95% CL	Upper 95% CL	% Coef. Of Variation
Gulf	Folletts	dusk	5	147	**16.5**	4.6	58.4	71.25
		night	5	104	**8.3**	3.7	18.4	42.13
		morning	4	89	**5.5**	4	7.6	16.2
	Surfside	night	3	61	**7.5**	1	53.3	127.47
		morning	4	93	**5.5**	3.7	8.1	19.2
Bay	Folletts	night	3	71	**9.2**	2.3	37	79.4
		morning	3	47	**3.6**	1.7	7.8	32.1

The waning hours of daylight are usually a period of active feeding. These birds are visual feeders, depending upon their eyesight to locate and capture fishes and other prey organisms. On this particular night (May 31st/June 1st) a sliver of a quarter-moon did not arise until 3:22 am, thus the birds had been actively feeding in total darkness. There are two surprising features about these observations. First, that the birds were feeding at all in total darkness, and second, the bird densities were higher during the night than in the following morning, when bird feeding activity is presumed to be the greatest.

Observation of Avian Concentration Areas

A goal of this study was to study areas of bird concentrations, which were well known locally, and determine if principal flight paths existed between roosting, loafing and feeding areas. The limited range of bird detection with the radar proved to be inadequate for this task.

Birds were concentrated at Bolivar Flats at the base of the North Jetty protecting the entrance to Galveston Bay, at East Beach at the base of the South Jetty, the Galveston Harbor, and the broad sand flats at San Luis Pass at the west end of Galveston Island. Both seabirds and shorebirds congregate at these areas. Shorebirds on the flats were difficult to detect on the radar although quite conspicuous visually. The birds were visible when flocks took flight but they were irregular blobs on the screen. The detection of the arrival and departure of migrating shorebirds will require prolonged radar surveillance beyond the limits of this study.

Colonial waterbird nesting colonies were examined at six localities. These locations are of particular interest because annually between 200,000 and 450,000 adult coastal birds of types detectable by the radar nest at locations around Galveston Bay. Seabirds, such as the gulls and terns, could be discerned around the colonies and feeding areas identified. Wading birds, such as herons, egrets and spoonbills, were less conspicuous and less prone to fly in groups. No flight lines to feeding areas were discerned. At Rollover Pass near Gilchrist, seabirds fed in the shallow waters of Rollover Pass and the Gulf Intracoastal Waterway, rather than in East Bay. Little Pelican Island was viewed from the Texas City dike but it was at the limits of the radar range at 1500 meters. Visually, birds were plentiful but few were picked up by the radar above the island vegetation. Feeding areas were not detected. North Deer Island was partially viewed from several sites on Tiki Island but a broad view of the entire island was not possible. Feeding activity appeared to be along the adjacent Gulf Intracoastal Waterway. South Deer Island was viewed from a jetty at Eight Mile Road and feeding activity appeared to be limited to West Bay adjacent to the island. West Bay Bird Island was beyond the range of the radar when viewed from the San Luis Pass County Park in Brazoria County, 2.2 km from the island. Feeding activity was concentrated in San Luis Pass. The Drum Bay colony provided the closest access. Feeding activity was concentrated in the adjacent shallow waters south of the island, rather than in Drum Bay to the north. On several occasions the radar was positioned between the Drum Bay colony and the gulf beaches but very little movement between the colony and the gulf was detected. Overall, colonial seabirds appeared to feed very close to their nesting islands. This suggests that the area around nesting colonies in which rates of bird collisions with turbines would be elevated is relatively small.

Prediction Of Avian Mortality Due To Wind Turbines

There have been a number of studies to estimate avian fatalities from existing wind turbines but predicting mortality before turbine construction has remained elusive, although several approaches have been explored.

U.S. Fish & Wildlife Service Methodology

The USFWS has issued guidelines to avoid and minimize the impact of wind turbines on wildlife through (1) proper evaluation of potential wind resource areas, (2) proper location and design of turbines and associated structures within wind resource areas selected for development, and (3) pre- and post-construction research and monitoring to identify and/or assess impacts to wildlife. (USFWS 2003).

The guidelines feature a Potential Impact Index (PII) that estimates use of a specific site by selected wildlife species as an indicator of potential impact. This procedure is useful for comparing specific sites to rank their potential impact. It does not address the conversion of estimates of avian density into estimates of avian mortality.

National Wind Coordinating Committee Methodology

The NWCC has prepared industry guidelines for wind power development (NWCC 1999). The guidelines offer no methodology that can be used to predict avian mortality resulting from bird-rotor collisions prior to the erection and operation of turbines. The guidelines do offer the proposed wind development area at Buffalo Ridge, Minnesota, as a case study utilizing a BACI (before-after, control-impact) design (Johnson et al., 2000). The results of this four-year study reveal some of the flaws in methodology utilized.

The study at Buffalo Ridge cited use of the variable circular plot method, modified by adjustments to correct for visibility bias using DISTANCE, but the distances from observer to bird were estimated rather than measured, thus limiting the accuracy of the density estimations. At Buffalo Ridge a relative risk to turbine abundance was calculated for all bird species using the mean abundance for each species adjusted for visibility bias, the proportion of all observations of each species where activity was recorded as flying, and the proportion of all flight height observations of each species that are within the rotor-swept zone of the turbines.

There are significant errors associated with each of the three factors involved in calculating the exposure to turbines. There are errors in the mean abundance estimate due to estimation, rather than measurement, of the distances involved in the calculation. The proportion of each species' activity spent flying is grossly overestimated by use of these observations. Flying birds are more conspicuous than non-flying birds and many, perhaps most, birds are detected while flying. It is incorrect to assume that most birds spend most of their time flying, as such observations imply. There are two errors associated with the third factor because two estimates are made in determining whether a given observed bird is (1) above, or (2) below the rotor-swept zone. There is no accurate, rapid method of measuring the height of a bird above ground at varying distances. Therefore, in many instances the estimation of bird height is merely a guess.

Finally, even if one is willing to assume that the calculated exposure index is reasonably accurate, it merely provides a comparison between species, indicating that some species are more likely than others to encounter turbine rotors. It does not provide an estimate of mortality. Bird behavior and bird avoidance of the turbines are not factors involved in the determination. Although the Buffalo Ridge study also determined actual bird mortality, no correlations between predicted mortality and actual mortality were provided.

Only one study has attempted to correlate a predictive index of mortality with actual mortality (Smallwood and Thelander. 2004). It found that overall bird mortality correlated with the number of birds observed per hour during point counts, but it did not correlate significantly with the number of megawatts generated by the turbines. Curiously, raptor mortality correlated significantly with the overall number of birds observed, but not with the number of raptors observed, nor with the number of megawatts generated.

Plane Transect Methodology

We are proposing a new dual-sampling method that may improve estimation of avian mortality although it will not completely solve the problem. The method would combine a point survey using DISTANCE methods, with distances determined with a radar rangefinder, in tandem with a plane transect aligned perpendicular to the coastline. Each point survey will be of 3 to 5 minute duration to minimize opportunities for birds to leave or enter the site during a survey, or double-counting of birds detected. Surveys will be equally distributed over the daylight hours. Measured distances will be entered into the DISTANCE computer program to produce estimates of birds per square kilometer with 95 percent confidence intervals.

Upon completion of each point transect, a plane transect will be established at the same location. All radar targets crossing or touching the reference line, 922 m in length, during a measured time period will be tallied and their distance from the radar determined. Fifteen minutes has proven to be an adequate time period during trials with this method. Plane transects will be summed to provide an estimate of birds per km per hr traversing the plane.

The dimensions of the proposed turbine strings will be estimated and the area (length of string x top of rotor-sweep height) of the plane determined. The area of the rotor-swept zone will be determined. Factors that enter into the calculation of potential mortality are:

a = area (m^2) of the vertical turbine plane = length x height
b = frontal area (m^2) of the turbine blade
c = probability of collision = rotor frontal area (m^2)/km x birds/km
d = measured distance (km) from observer to termination of plane transect
e = exposure rate = R x p
h = height (m) of vertical plane
M = predicted mortality = birds/km/yr x probability of collision (c)
N = number of birds observed to pass through rotor-swept height band
p = rotor-swept proportion of turbine plane = Z ÷ a
r = radius (m) of rotor sweep
R = passage rate (birds/km/hr) = N / d / t
t = observation time (hr)
z = rotor-swept zone (m^2) = π x r^2

Sample calculation:

An observer tallies 5 birds passing through an observational plane transect of 200 m length at 120 meters or less above the ground during a 30-minute period.

Passage rate R = N / d / t = 5 birds/ 0.2 km/ 0.5 hr = 50 birds/km/hr

Assume a string of turbines placed 400 meters apart. The turbines have a 40 m rotor radius extending from 40 m to 120 m above ground level. Thus

r = 40, rotor-swept area (z) = πr^2 = 5027 m^2, placement = 2.5 turbines/km, yielding 12,568 m^2 of rotor-swept area per km.

Assume that the frontal dimensions of the rotor blade (b) are 0.25 m in width and 40 m in length, yielding 10 m^2 of frontal surface per blade, x 3 blades per turbine, times 2.5 turbines per km. Birds approaching the plane of the turbine string are exposed to 75 m^2 of turbine blade per km. The probability of a bird colliding with a turbine blade is 75/120,000 [120m ht x 1000m length] or 0.000625. This assumes that the

altitude of the birds is randomly distributed, which is not the case. Our observations indicate that the altitude of most bird flights observed in this study were less than 40 m.

In the absence of knowledge regarding nocturnal bird passage, assume 12 daylight hr/da, or 4380 hr/yr.

0.5 birds/km/hr = 2190 birds/km/yr	x collision probability 0.000625	= 1.37	bird collisions/km/yr
1.0 birds/km/hr = 4380 birds/km/yr	"	= 2.74	"
5.0 birds/km/hr = 21,900 birds/km/yr	"	= 13.69	"
10.0 birds/km/hr = 43,800 birds/km/yr	"	= 27.38	"
50.0 birds/km/hr = 219,000 birds/km/yr	"	= 136.88	"
100.0 birds/km/hr = 438,000 birds/km/yr	"	= 273.75	"

Conversion of the above to birds/turbine/yr (dividing by 2.5 turbines/km) produces estimates of 0.5 to 110 bird collisions per turbine per year.

The bird densities estimated by plane transect in this study range from 28.4 to 172.8 birds/km/hr (Table 4), but the estimates are for the entire plane from ground level to the top of the radar beam. At the lower level of 28.4, the maximum potential mortality rate would be 77.75 birds/km/yr if the density only obtains during daylight hours or 155.5 if the density applies to the entire 24 hour period. Using the 24 hour assumption about density, the maximum potential mortality would be 62 birds/turbine/yr. Although no measurements of bird elevation above the water were made during this study, it is our impression that the vast majority of seabirds observed flew below the lower limit of the rotor-swept zone of a wind turbine (assumed to be 40 meters or 131 feet). We believe that a plane transect method employing a vertically oriented radar from which height information could be obtained would greatly reduce the estimated maximum potential mortality rate.

The probability of a bird-rotor collision is affected by many factors not included here, including the speed of the rotor, the speed of a bird traversing the rotor plane, and most importantly, the evasive actions taken by birds upon detection of the turbines. We have no quantitative information on the amount by which avoidance behavior lowers mortality below the maximum potential value. Avoidance coefficients are likely to be dependent on location, species and weather. This method should provide estimates of maximal potential mortality for comparison to the range of bird-wind turbine collision mortality currently experienced in the United States (NWCC 2001). The dual nature of the sampling will permit direct comparison between avian density and avian mortality due to wind power installations.

Avian behavior complicates the estimation of avian mortality. An estimate of bird density (the numbers of birds estimated to occupy some unit of area) provides little insight into how many times a given bird may be expected to pass through the plane of wind turbines during a given time period.

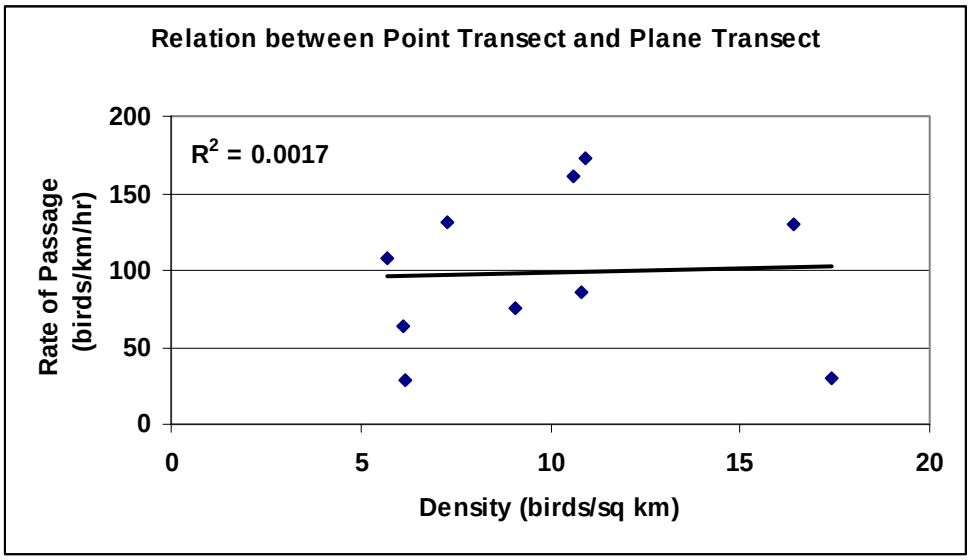
A comparison of a point transect with a simultaneous plane transect is shown in Table 4 below. Data collected for the point transect were collected within a 3 to 4 minute period to provide an instantaneous estimate, immediately followed by collection of data for a plane transect. The estimate of bird density is from Table 2. The estimate of birds/km/hr is likely to include cases in which the same bird crossed the plane multiple times.

Table 4. Comparison of plane transect estimates with simultaneous point transect estimates.

LOCATION	ECOSYSTEM	MONTH	OBSERVA-TIONS	LENGTH (KM)	TIME (HR)	BIRDS /KM	BIRDS /KM/HR	BIRDS /SQ KM
Bolivar	gulf	October	269	2.77	0.75	97.1	129.5	16.4
	bay	October	159	1.84	0.5	86.4	172.8	10.9
Galveston	gulf	October	157	2.77	0.75	56.7	75.6	9.1
	gulf	December	59	2.77	0.75	21.3	28.4	6.2
	bay	October	148	1.84	0.5	80.4	160.9	10.6
Follets	gulf	September	244	2.77	0.67	88.1	131.5	7.3
	gulf	December	61	2.77	0.75	22	29.4	17.4
	bay	September	99	1.84	0.5	53.8	107.6	5.7
Texas City	bay	September	177	2.77	0.75	63.9	85.2	10.8
	bay	December	117	2.77	0.67	42.2	63	6.1

The absence of a relationship between the two transect methods is demonstrated in Figure 4 below.

Figure 4. The relationship between point transect estimates and plane transect estimates.



This suggests that point transects provide a useful estimate of the number of birds found in a given vicinity but they are unlikely, by themselves, to provide an estimate of avian mortality due to collision with wind turbines. Plane transects, on the other hand, provide a measure of bird flight behavior and ultimate exposure to the turbines. Yet unmeasured is that reaction of birds to the presence of turbines and the avoidance behavior they may utilize.

RELATIONSHIP OF FINAL REPORT TO CONTRACT DELIVERABLES

The contract specified that the final report would include an estimation of bird mortality associated with the construction of wind turbines in the study area and the relationships among bird types, seasonal usage, daily activity pattern and flight altitude.

The study produced an improved methodology for the estimation of maximum potential bird mortality. The estimates produced by this study are incomplete because they need associated coefficients that will reduce the estimate according to flight altitude and avoidance behavior. Nevertheless, the methodology provides a powerful approach to comparison among potential sites for relative risk of bird-turbine collisions.

Regarding the relationship among bird types and mortality potential, the study found that the methodology was unable to detect very small birds, such as migratory warblers, and that wading birds, such as herons, were infrequently observed in the shoreline study sites. The most frequently observed types of birds at the shoreline locations were gulls, terns, pelicans and cormorants. Despite differences in size, the radar signal is not a satisfactory instrument for differentiating between the largest, brown pelican, and the smallest, least tern. In addition, the study determined that seabirds with dense plumage are more likely to produce a radar echo than terrestrial birds with less dense plumage.

Seasonal bird densities are shown in Table 2. There is no striking difference among the seasons in bird usage of coastal sites. The confidence intervals are large for all density estimates and no statistically significant differences between seasons were observed. It was thought that migration or summer nesting activities might produce spikes in the observations of birds in shoreline areas, but this was not the case. No concentrations of migratory songbirds were observed during the radar observation episodes, but migratory shorebirds were present during some observation times. The lack of differentiation among seasons suggests that it may not be possible to significantly reduce the mortality probability for shoreline wind farms by shutting down turbine operation for a brief seasonal period.

Perhaps the most interesting and significant finding of the study was the density of seabirds flying at the sites during the hours of darkness. These predatory birds are assumed to locate prey using their vision. It is not clear how this method of fishing could be as efficient at night as during daylight hours. However, radar observations made during darkness produce density estimates that are not significantly different from those based on daylight observations.

Flight altitude is not a parameter that could be adequately studied. The original study plan called for two radars, one mounted horizontally and one mounted vertically. The revised study had significantly less funding and only one radar could be purchased. There was no way to safely mount a radar so that it could be altered from horizontal to vertical in the field. Visual observations were made of typical altitudes of seabird flight in the shoreline locations. The subjective estimations of Dr. McFarlane, an expert observer, of the altitudes of gulls, terns, cormorants and pelicans seldom exceeded 40 meters, the lowest position of a rotating blade. However, no instrumentation was available to provide a quantitative, independent measurement of the altitude.

The results of this study have created a framework for a methodology to compare sites in terms of potential bird-turbine collisions. The radar observations are imperfect because not all birds are observed, but they are readily quantifiable and defensible. The plane transect method offers a direct corollary to the interaction of birds in flight and turbine blades. It could be significantly improved by restricting the plane of observations to the zone actually occupied by the rotating blades and incorporating information on avoidance behavior.

SUGGESTED FURTHER STUDIES

There are several actions that can be undertaken to further explore the usefulness of marine radar for avian studies.

1. Evaluate the potential for a larger antenna to improve radar performance. The radar unit used in this study can also be fitted with a 6 foot antenna, increasing the length 50 percent. This may increase the useful range of the radar.
2. Evaluate the usefulness of a "radar fence" to eliminate ground clutter. This would involve construction of a circular barrier around the radar, occluding the lower portion of the transceiver signal. In this way return signals from surrounding vegetation would be eliminated, the radar display screen would be cleared of ground clutter, and birds at higher elevations would become distinguishable. Birds at very low elevations would not be detected. This would expand the usefulness of radar over land areas.
3. Evaluate the ability of the radar to be rotated 90 degrees to transmit a vertical, rather than horizontal, beam. In this manner the altitude of birds above the ground, as well as their distance, can be measured. Results would be limited to a single transmission plane. Over water, it will be necessary to devise a reference point to designate the horizon.
4. Evaluate the potential of a S-band radar, which transmits a different wavelength of energy, to detect birds. One study indicated that birds could be detected as distant as 4 nautical miles.
5. Perform studies at existing wind turbine sites to permit estimation of avoidance factors that could be used as coefficients for the predicted mortality rates to correct them to some extent for bird avoidance behavior.

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