Assessment of Bird Response to the NRCS Migratory Bird Habitat Initiative using Weather Surveillance Radar: Final Report

Prepared by

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May 2013

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EXECUTIVE SUMMARY

In response to the Deepwater Horizon oil spill in summer 2010, the Natural Resources Conservation Service implemented the Migratory Bird Habitat Initiative (MBHI) beginning in the fall of 2010 to provide temporary wetland habitat via managed flooding of agricultural lands for migrating and wintering waterfowl, shorebirds, and other birds along the northern Gulf of Mexico. We used weather surveillance radar observations to conduct broad regional assessments of bird response to MBHI activities on more than 16,000 hectares within the Mississippi Alluvial Valley and the West Gulf Coastal Plain during the initial fall, winter, and spring management periods. Across regions, birds responded positively to MBHI management by exhibiting greater relative diurnal bird density (i.e., higher seasonal mean radar reflectivity at the onset of evening feeding and migratory flights) within sites relative to prior years when no management was implemented and also concurrently relative to non-flooded agricultural lands. Bird density at MBHI sites was generally greatest during winter for both regions. Unusually high natural flooding in the years prior to implementation of the MBHI confounded detection of overall changes in remotely-sensed soil wetness across sites. Despite this, an average of 40% of all hectares assessed showed an increase in mean soil wetness (i.e., a proxy of intensity of water management). The magnitude of bird response at sites compared to prior years and concurrently with non-flooded agricultural lands was generally related to the surrounding landscape context such as proximity to areas of high bird density and composition such as the amount of forested wetlands, emergent marsh, non-flooded agriculture or permanent open water. However, these relationships varied in strength and direction between regions and seasons which we attribute to differences in seasonal bird composition and broad regional differences in landscape configuration and composition. Notably, we detected greater increases in relative bird use at sites in closer proximity to areas of high bird density during winter in both regions. This indicated that

flooding agricultural fields near established concentrations of birds exist generally attracted more birds. Additionally, bird density was greater during winter at sites with more emergent marsh in the surrounding landscape. Thus, maximizing bird use for similar programs in the future should focus on enrolling lands located near known bird concentration areas and within a mosaic of existing wetlands. Weather radar observations provide strong evidence that MBHI sites provided wetland habitat used by a variety of birds inland from coastal wetlands impacted by the oil spill.

INTRODUCTION

The northern Gulf Coast is home to an extensive series of wetlands stretched along 75,000 km of shoreline that serves as habitat for a wide variety of resident and migratory waterbirds (Helmers 1992, Mikuska et al. 1998, Musumeche et al. 2002). These wetlands have been significantly degraded by human-induced landscape alterations (Britsch and Dunbar 1993, Ellis and Dean 2012, Nestlerode et al. 2009), sea level rise associated with climate change (Hoozemans et al. 1993), powerful storms (Barras 2006, Lopez 2009) and, recently, by the largest oil spill in history off of the Gulf Coast (Copeland 2010).

In response to the oil spill associated with the Deepwater Horizon event in April 2010, the National Resources Conservation Service (NRCS) implemented the Migratory Bird Habitat Initiative (MBHI) in order to provide migrating and wintering waterfowl, shorebirds, and other birds with alternative habitats to compensate for coastal wetlands impacted by the oil spill. Wetland habitat was created through the MBHI program by paying private landowners to flood existing farmed wetlands, previously converted croplands, and other lands which had not been actively flooded during the winter months for the previous three years. Numerous bird species use flooded agricultural lands and adjacent areas for daytime roosting and foraging along the Gulf Coast (Floyd 2000, Huner 1995, Musumeche et al. 2002, Remsen et al. 1991). The Mississippi Alluvial Valley (MAV) and West Gulf Coastal Plain (WGCP) ecoregions were identified as program priority areas because of their adjacency to oil spill impacted wetlands. In the fall of 2010, MBHI activities commenced on private agricultural or other lands already enrolled in existing Farm Bill Programs; Wetlands Reserve Program (WRP), Environmental Quality Incentives Program (EQIP), and Wildlife Habitat Incentive Program (WHIP). Program activities continued through the winter for all MAV sites and through the spring of 2011 (or longer for some sites in Louisiana with multiyear contracts) for sites within the WGCP. Approximately 188,375 hectares were enrolled into MBHI within the MAV and WGCP across five states (TX, LA, AR, MO, and MS; USDA NRCS 2012).

Water levels at MBHI sites were managed for shallow water, mudflat, and sandflat habitats to create or enhance habitat for shorebirds and waterfowl. According to the NRCS Practice Standard for shallow water development and management (code 646; USDA NRCS 2010), flooding between 0 and 4 inches from July to October provides habitat for shorebirds, and water depth ranging from 6 to 10 inches from October to March benefits waterfowl. Although water management among sites within each state was intended to be identical, variability in actual water management, site characteristics and location, and features of the surrounding landscape could result in differential bird use among sites. For example, in the Central Valley of California, wintering waterfowl use of managed wetlands is greater at sites with greater soil wetness (i.e., extent of managed flooding), with fewer wetlands in the surrounding landscape, and in closer proximity to flooded rice fields where waterfowl typically foraged at night (Buler et al. 2012a). The amount and type of agricultural fields in the surrounding landscape may attract some species while deterring others that are more sensitive to human disturbance and development (Czech and Parsons 2002, Niemuth et al. 2006). The amount of open water in the surrounding landscape (Fairbairn and Dinsmore 2001, Manley et al. 2005) may also play a role in how birds use wetlands for roosting and feeding. Waterfowl may react to avian and terrestrial predators by moving to open water and grouping together in refugia (Tamisier 1976). Cox and Afton (1997) found that female *Anas acuta,* northern pintail, regularly use pools of open water on hunting refuges during the fall hunting season in southwestern Louisiana. MBHI sites located in close proximity to refuges with high bird concentrations may be used more heavily than sites far from refuges based on refuging theory (Cox and Afton 1996, Link et al. 2011).

Due to rapid implementation of the MBHI program, data of bird use prior to management at sites is lacking and limits assessment of the efficacy of the program through traditional field survey methods. Additionally, a comprehensive assessment of the response of birds among the numerous and widespread sites in both regions through traditional field surveys is not financially and logistically feasible. Instead, remotely-sensed weather surveillance radar observations of bird activity can provide a more comprehensive assessment of bird use at numerous sites and, because they are archived, provide observations of bird use prior to enrollment in the MBHI program. The current national network of weather surveillance radars (model WSR-88D, commonly referred to as NEXRAD) is an important tool to study a variety of bird movements across the United States (Bonter et al. 2007; Diehl et al. 2003; Gauthreaux and Belser 1998, 2003; Kelly et al. 2012). NEXRAD can be used to measure bird densities and map their distributions “on the ground” as birds take flight en masse from terrestrial habitats at the onset of highly-synchronized broad-scale movements like nocturnal feeding flights of wintering waterfowl and migratory flights of landbirds (Buler and Diehl 2009, Buler and Moore 2011, Buler et al. 2012a). Specifically, along the Gulf Coast during the winter, waterfowl and other associated species regularly undertake flights in large groups between roosting sites, usually wetlands and bodies of water, and feeding habitat such as agricultural fields (Buler et al. 2012a, Paulus 1988, Randall et al. 2011). These highly-synchronized movements tend to occur at sunrise and sunset and are closely related to sun elevation (Baldassarre and Bolen 1984, Cox and Afton 1996, Ely 1992, Raveling et al. 1972). Similarly, many birds including waterfowl, shorebirds, and land birds initiate nocturnal migratory flights shortly after sunset (Akesson et al. 1996, Bonter et al. 2009, Diehl et al. 2003, Gauthreaux and Belser 2003, Hebrard 1971).

OBJECTIVES

Our objective was to assess the effectiveness of the MBHI program to provide temporary wetland habitat for birds. Specifically, we used NEXRAD data to conduct a quantitative, broad-scale assessment of relative bird use at all observed MBHI sites within the MAV and WGCP regions. We examined relative bird use at MBHI sites during active management in two ways: 1) compared with bird use within sites during the two years prior to enrollment, and 2) compared with concurrent bird use on unmanaged agricultural fields in the surrounding region. We also examined the influence of site and landscape variables in explaining differential bird use among MBHI sites to provide insight into where similar future wetland habitat enhancement or management could be implemented with maximal bird response.

STUDY AREA

MBHI sites were located within several states of the MAV (Missouri, Arkansas, Mississippi) and the WGCP (Louisiana, and Texas) (Figure 1). The predominant agricultural land uses are soybean and rice fields in the MAV, and aquaculture (rice-cultivation and crawfish farming), pastures, hayfields, and idle/fallow cropland in the WGCP region (USDA-NASS CDL 2010). Rice farming is ideal for integrating an established agricultural practice with the goals of waterbird conservation because rice farming requires water control infrastructure capable of flooding and draining fields, allowing for water management for waterbird habitat (Elphick 2000, Huner et al. 2002, Norling et al. 2012). Six NEXRAD stations are located within the study area and potentially provide surveillance of MBHI sites: Lake Charles, LA (KLCH), Houston, TX (KHGX), Little Rock, AR (KLZK), Memphis, TN (KNQA), Paducah, KY (KPAH), and Ft.

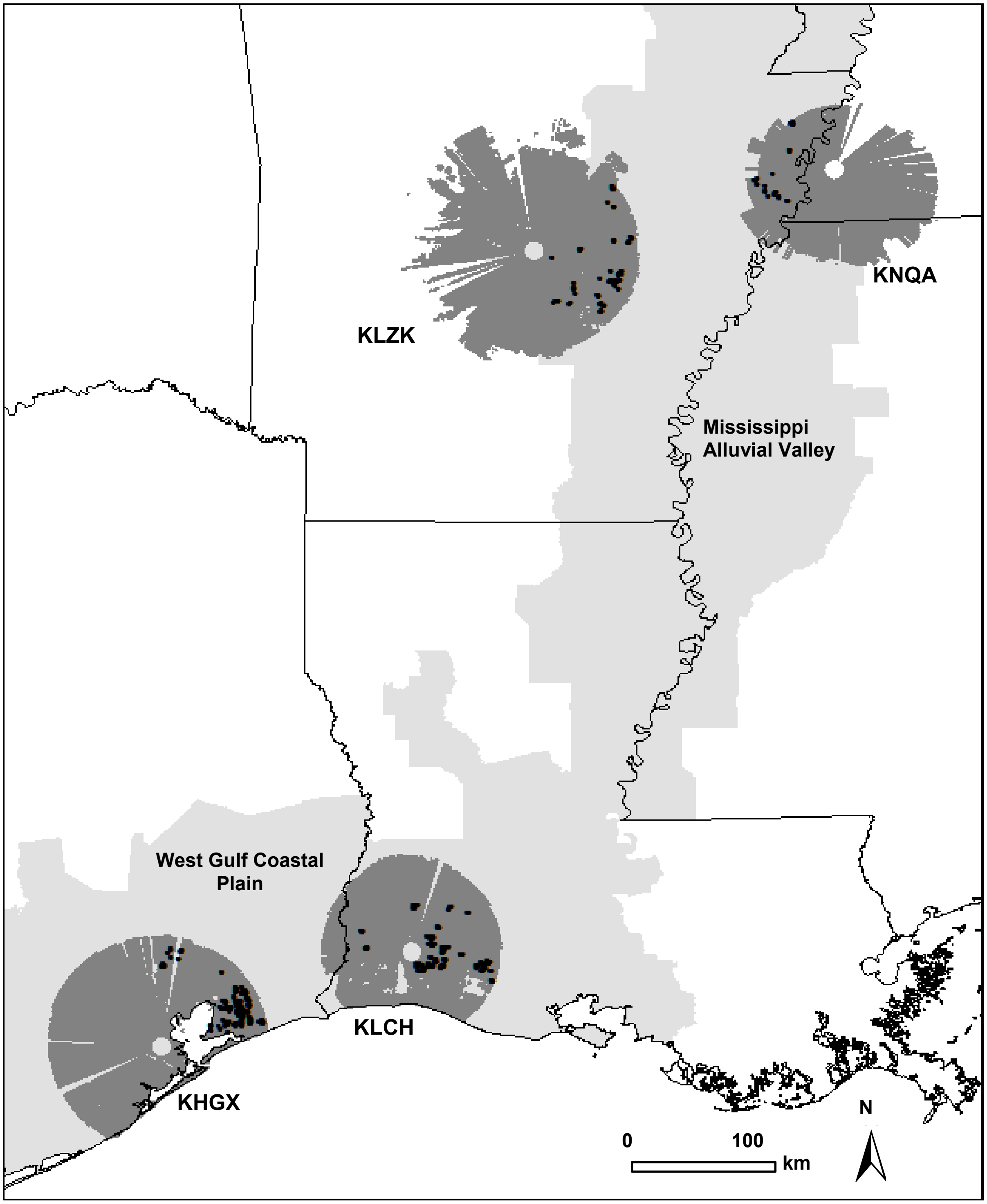

Figure 1. Locations of MBHI sites (black dots) within the effective observation areas (dark grey) of four weather surveillance radars (labeled by name) within the Mississippi Alluvial Valley and West Gulf Coastal Plain regions of the southern U.S.A. The light grey area denotes counties of states included in the MBHI program.

Polk, LA (KPOE). However, we did not consider data from KPOE because it is not archived in its native Level II format. From state NRCS offices, we obtained information about MBHI tract boundaries and management activities. We excluded from analysis individual sites that were smaller than 0.5 ha in area. Only Arkansas sites were within the effective radar detection range for radars within the MAV; so sites in Mississippi and Missouri and all data from KPAH were excluded for analysis.

MBHI sites were under some degree of active moist soil management, depending on the timing and intensity of water level manipulation according to the guidelines of each state. In Texas and Arkansas, fields were flooded to a water depth of 2 to 18 inches. The depth of flooding was intentionally varied at sites in Louisiana to benefit different groups of waterbirds. Four different practice types existed: mudflats which were disked or rolled and flooded to a maximum of 2 inches to benefit early migrating waterfowl and shorebirds; food/cover habitat where the vegetation was left standing and flooded to a depth of 6-10 inches to provide forage and sanctuary for wintering waterfowl; crawfish ponds to provide invertebrate prey for waterbirds through the winter to mid-summer; and an extension of either the mudflat or food/cover practice type. Because the management was more variable in Louisiana, we limited the fall analysis of Louisiana sites with mudflats (maximum water depth of 2 inches) or active flooding (6 to 10 inches of water) and our analyses in winter and spring to sites with active flooding (6 to 10 inches) for comparison to other states. We defined our seasons for Louisiana sites as fall (October 1 – October 31), winter (November 15-January 30) and spring (March 1-March 31). Management occurred in Texas from October 1-March 31. We therefore defined our seasons for analyses as fall (October 1-October 31), winter (November 1-February 28), and spring (March 1-March 31). In the MAV, management occurred from October1-Februray 28 (no spring management) and we defined our seasons for analyses as fall (October 1 - October 31), and winter (November 1 - February 28).

In the WGCP, we analyzed sites totaling 14,177 ha in the fall (7,732 in TX and 6,445 in LA), sites totaling 12,141 ha in the winter (6,039 in TX and 6,102 in LA) and sites totaling 6,924 ha in the spring (6,400 in TX and 524 in LA). In the MAV, we analyzed sites totaling 2,575 ha and 2,519 ha for fall and winter, respectively. Variability in the area analyzed is due to differences in the amount of area enrolled between seasons and differences in the effective detection range of the radar among sampling days. Overall we sampled approximately 10% and 15% of all area enrolled in MBHI within Arkansas (MAV) and Texas and Louisiana (WGCP), respectively.

METHODS

Weather surveillance radar data

We obtained radar data collected during time periods associated with migrating and wintering bird movements from 15 August through 31 May for the years 2008 through 2011 at KLCH, KHGX, KZLK, and KNQA from the National Climatic Data Center data archive (http://www.ncdc.noaa.gov/nexradinv/). Radars measure reflectivity (Z) in the form of returned radiation (Crum and Alberty 1993) within sample volumes having dimensions of 250 m in length by 0.5º in diameter. The density of birds on the ground is positively correlated to radar reflectivity at the onset of flight exodus (Buler and Diehl 2009, Buler et al. 2012a). We used radar data from nights with no discernible contamination from precipitation or ground returns from extreme radar beam refraction. Additionally, we excluded data from individual sample volumes subject to persistent ground clutter and beam blockage. We “flattened” radar sample volumes into their two dimensional polar boundaries (250 in depth and 0.5º wide) to produce sample polygons for overlaying onto land cover maps within a GIS. These sample polygons represent the elementary measurement resolution of radar reflectivity.

We interpolated reflectivity measures to when the sun reached an elevation angle of 5.5° below horizon following Buler et al. (2012a) to reduce temporal sampling error and bias (Buler and Diehl 2009). Buler et al. (2012a) found this is the optimal sun angle for quantifying ground densities of waterfowl, and it is close in time to the onset of nocturnal feeding flights of wintering waterfowl (Baldassarre and Bolen 1984, Cox and Afton 1996, Miller 1985, Randall et al. 2011, Tamisier 1976) and nocturnal flights of migrating birds (Akesson et al. 1996, Gauthreaux 1971, Hebrard 1971). We adjusted reflectivity measures to reduce range-dependent measurement bias caused by the systematic change in how the vertical distribution of birds in the airspace is sampled as the beam spreads with range from the radar using algorithms implemented in the software program BIRDS as described and developed in Buler et al. (2012a).

Soil wetness data

We used remotely-sensed Landsat Thematic Mapper (TM) data to quantify the extent of flooding during the MBHI management year and two previous years via a soil wetness index. The extent of actual flooding is often dependent on water supplies and land owner compliance (Randall, L., U.S. Geological Survey, National Wetlands Research Center, Lafayette, Louisiana, pers. comm., Huner et al. 2002). We did not measure water depth at MBHI sites directly. Remote sensors such as TM can detect soil moisture and the extent of the surface water (Rodgers and Smith 1997, Alsdorf et al. 2007, Baker et al. 2007). We screened and downloaded all available TM data to obtain as many cloud-free images as possible per season from the USGS (http://glovis.usgs.gov/). We calculated the mean soil wetness index via the Tasseled Cap transformation of Huang et al. (2002) for TM 7 data and Crist (1985) for TM 5 data. TM data have a spatial resolution of 30m x 30m. Increasing values indicate increasing soil wetness. We considered index values greater than -0.05 to indicate open surface water (flooded soil) condition based on visual inspection of imagery. We used this threshold to determine the extent of flooding within MBHI enrolled areas. We also determined the change in soil wetness from baseline years (2008 and 2009) to the management year (2010) in fall and winter. During the spring of 2011, all TM images in the KHGX and KLCH radar ranges were obscured by clouds and we therefore could not compare site soil wetness during spring management to the baseline years.

Landscape composition and position data

We quantified the amount of four land cover types surrounding individual radar sample polygons as measures of landscape composition. We calculated the percent of non-flooded agricultural land, emergent marsh, permanent open water, and forested wetlands in the surrounding landscape at multiple scales using the 30-m resolution 2006 National Land Cover Dataset produced by the USGS Multi-Resolution Land Characteristics Consortium (http://www.mrlc.gov/). We classified non-flooded fields as agricultural land that had a maximum seasonal wetness index value below -0.05. We determined a single characteristic scale at which birds responded most strongly to each land cover type in the landscape (sensu Holland et al. 2004) according to the strongest correlation between mean radar reflectivity of individual sample polygons within MBHI site boundaries and the proportion of land cover surrounding polygons among a nested set of 9 landscapes within 500 m to 4500 m radius from polygon

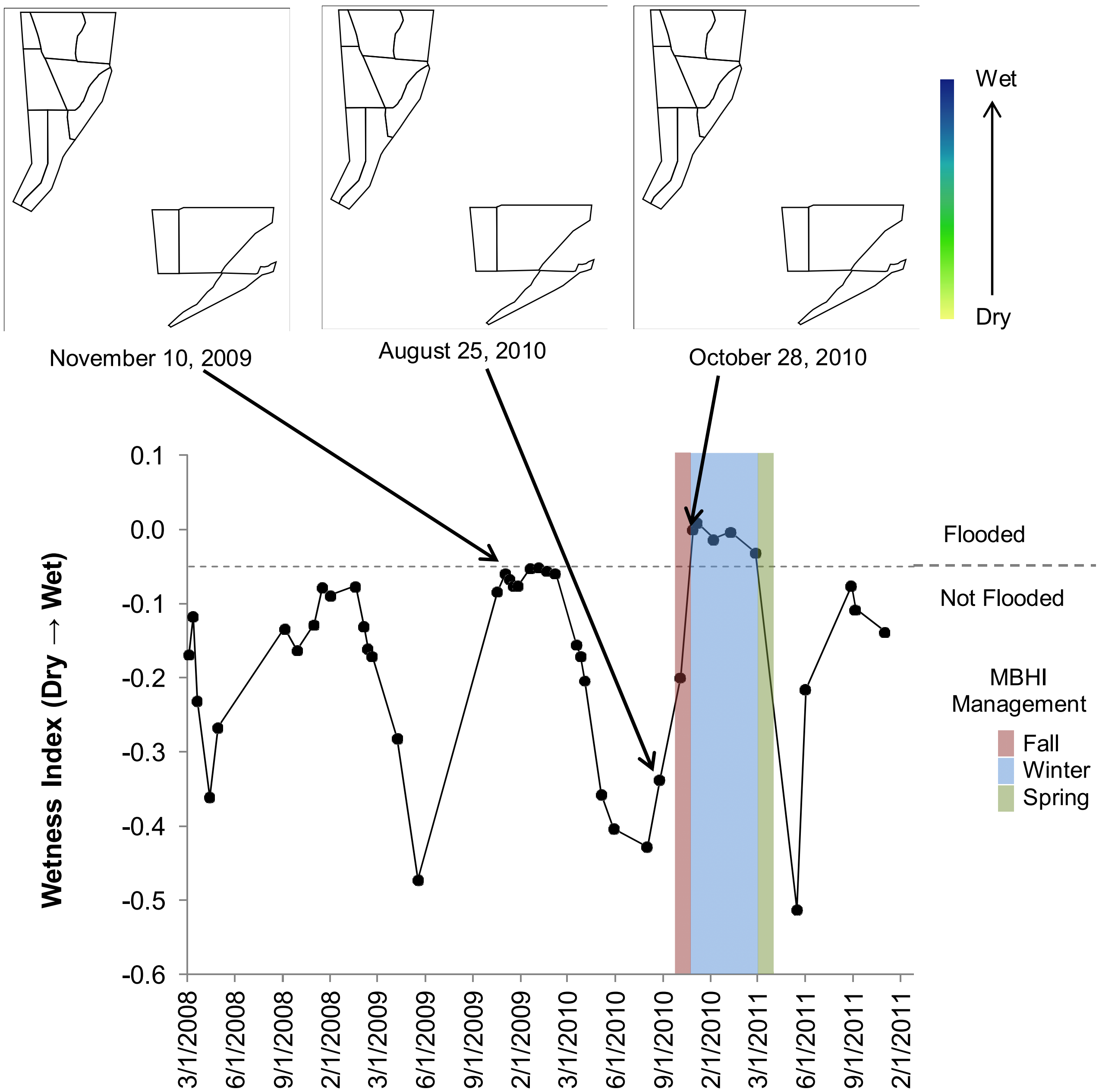

Figure 2. Mean soil wetness index data for 12 MBHI sites (black outlines) located in Texas derived from TM data. Three TM images show temporal variation in wetness data. Sites are completely flooded in the October 2010 image in accordance with MBHI management. Corresponding mean wetness index values are plotted for the entire study period illustrating the fall-winter-spring flooding regime on the 12 MBHI sites.

boundaries at intervals of 500 m. We analyzed data from each radar separately by season. We drew 25 samples of 20 polygons separated by at least 4 km for testing. We averaged Spearman rank correlation coefficients among the set of samples to assess correlations. We did not assess correlations for KNQA because of the scarcity of MBHI enrolled areas.

We calculated the mean distance of each sample polygon to the nearest polygon having a seasonal mean reflectivity during baseline years above the 90th percentile as a measure of its placement within the landscape to an area of high bird density. We used the area-weighted mean reflectivity of all sample polygons to determine the value of the 90th percentile of reflectivity by radar and season. This effectively identified areas with the highest bird density (top decile) that occurred within each radar-observed area. Some of these are areas where birds are historically known to concentrate, such as wintering waterfowl at Lacassine National Wildlife Refuge (NWR) and Cameron Prairie NWR, in Louisiana (Link et al. 2011) (Fig. 3).

Data analyses

We standardized reflectivity measures in order to control for annual fluctuations in overall bird populations that could influence absolute reflectivity measures. Because we were also interested in comparing relative bird density on flooded (i.e., managed) agricultural lands to unflooded (i.e., unmanaged) agricultural lands, we standardized reflectivity values by dividing the seasonal mean reflectivity of a given sample polygon by the area-weighted seasonal mean reflectivity of all radar sample polygons dominated (>75% of area) by non-flooded agricultural lands for each radar, season, and year combination. We excluded non-flooded agricultural areas within 1 km from flooded agriculture to minimize potential contamination from birds using nearby flooded fields at the time of sampling. Thus, a standardized reflectivity value of 1 equals

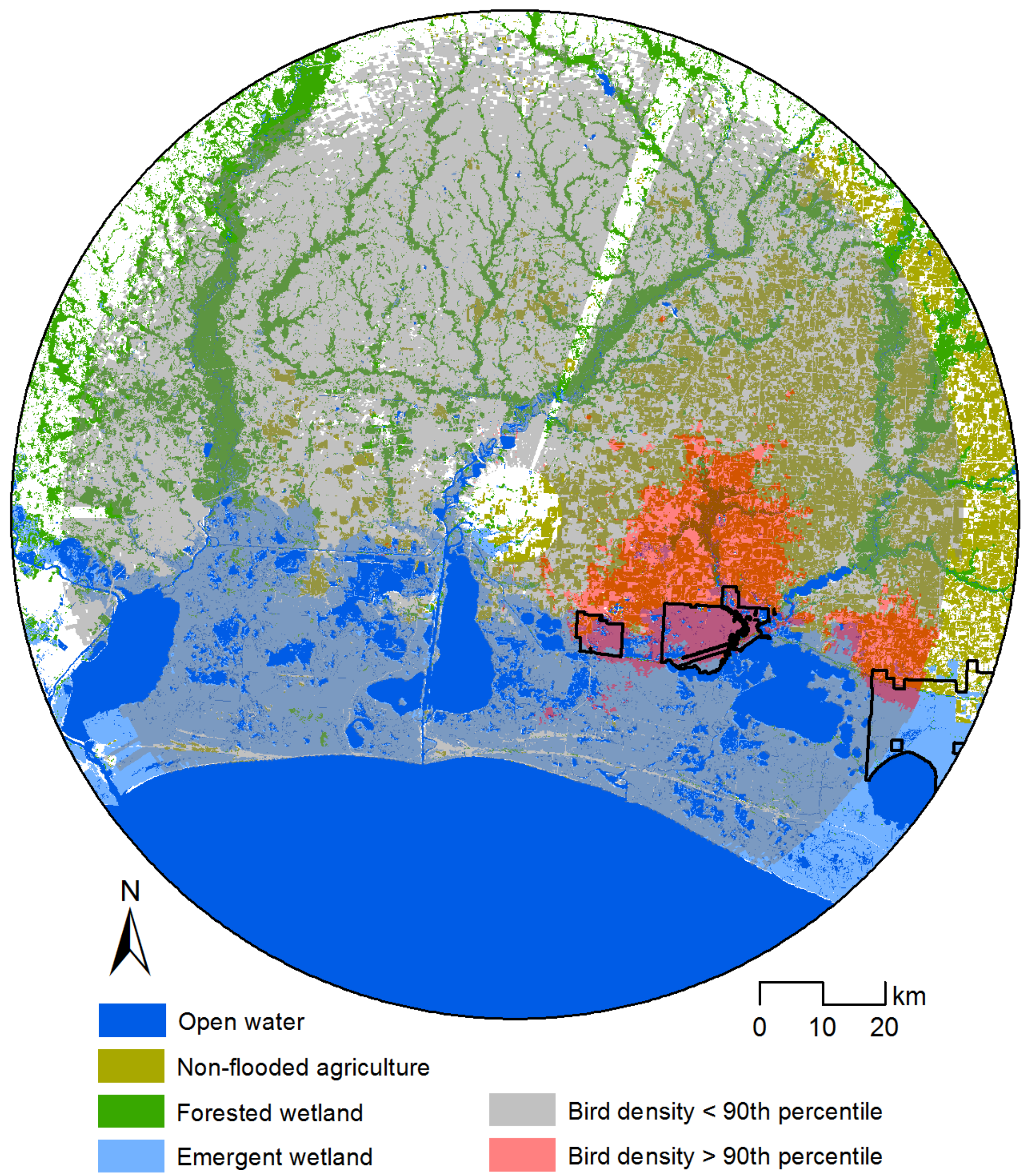

Figure 3. Map of high bird density areas and land cover types around the KLCH radar during winter. Red shaded areas denote where the mean winter reflectivity during baseline years is above the 90th percentile. Grey shaded areas denote where reflectivity is below the 90th percentile. Black outlines denote (from west to east) the boundaries of Lacassine and Cameron Prairie National Wildlife Refuges and the White Lake Wetlands Conservation Area.

the mean relative bird density of non-flooded agricultural fields for a given season, year, and region. Distinguishing non-flooded from flooded agriculture required the use of TM images to calculate soil wetness presented earlier. For the spring 2011, when images were unusable due to cloud contamination, we standardized reflectivity values by dividing the mean reflectivity within a given sample polygon by the area-weighted seasonal mean reflectivity of all radar sample polygons dominated (>75% of area) by agriculture. For MBHI managed areas, we calculated the area-weighted mean standardized reflectivity of the portion of sample polygons within site boundaries. We used this standardized reflectivity as an indicator of bird response to MBHI management and the response variable for modeling bird use of MBHI areas within the management year.

We also examined the response of birds to MBHI activities by comparing bird density in the two years prior to management (2008 & 2009) to bird density during the active management year (2010). To do this, we divided the standardized reflectivity at MBHI areas during the management year by the standardized reflectivity at areas across the prior years by season and region. We used this ratio as a second indicator of bird response to MBHI management and the response variable for modeling bird use of MBHI areas between years. A ratio value greater than 1 indicates that bird density was greater during the management year. Additionally, using this ratio helps to control for perennial contamination in the airspace from birds taking flight from the surrounding landscape (Buler et al. 2012b). To understand how management practices influenced our total assessed area, we also calculated the proportion of MBHI area that showed increases in mean wetness, mean reflectivity during the management year and mean reflectivity relative to prior years.

Modeling bird response

We used linear regression modeling with an information theoretic approach to determine the relative importance of variables in explaining variation in reflectivity among areas (Burnham and Anderson 2002). To minimize spatial autocorrelation while maintaining adequate sample sizes, we sampled 25 subsets of 20 radar sample volumes spaced at least 4km apart. We averaged results across sample runs when assessing models. However, as reported earlier, we were unable to model bird response for the KNQA radar. We also did not model bird response during spring for the WGCP because we had no suitable TM imagery to determine soil wetness. We modeled two response variables; standard reflectivity during the management year and the ratio of reflectivity relative to prior years. Explanatory variables including a single soil wetness variable (either soil wetness during the management year or the change in site wetness from prior years) and several landscape variables including: 1) proximity to high bird density area, 2) amount of forested wetlands in the surrounding landscape, 3) amount of non-flooded agricultural fields in the surrounding landscape, 4) amount of permanent open water in the surrounding landscape, and, for WCGP radars, 5) amount of emergent marsh in the surrounding landscape (Table 1). We considered all possible combinations of models with main effects; 63 for WGCP radars, and 31 for KLZK. We did not include amount of emergent marsh in the landscape as a covariate for the KLZK because there was almost no emergent marsh in the landscape (maximum value of 1%). Data were log transformed when necessary to improve normalcy in their distributions. We used Akaike's Information Criterion adjusted for small sample sizes and Akaike weights to determine support for models (Burnham and Anderson 2002). After summing the weights across all models to estimate the relative importance of the variables of interest, we calculated the mean standardized regression coefficient for all models to determine the direction and importance of effect sizes. We estimated precision using an unconditional variance estimator that incorporates model selection uncertainty (Burnham and Anderson 2002) and considered the effect of an explanatory variable effects as strong if the 90% confidence interval of the regression coefficient did not span zero.

Table 1. Summary statistics of landscape variables used for modeling bird response among Migratory Bird Habitat Initiative sites by radar and season. Sample sizes reported in Table 3.

Variable	KLCH	KHGX	KLZK
	Mean (Range)	Mean(Range)	Mean(Range)
Fall			
Percent cover within 4.5 km around polygon			
Permanent open water	0.02(0.00-0.23)	0.03(0.00-0.48)	0.05(0.01-0.16)
Forested wetland	0.06(0.00-0.47)	0.04(0.00-0.24)	0.15(0.01-0.35)
Non-flooded agriculture	0.59(0.05-0.90)	0.22(0.00-0.50)	0.65(0.29-0.94)
Emergent marsh	0.08(0.00-0.53)	0.17(0.00-0.84)	0.00(0.00-0.01)
Proximity to high bird density area (km)	2.61(0.00-26.20)	7.38(0.00-23.87)	2.42(0.00-11.78)
Winter			
Percent cover within 4.5 km around polygon			
Permanent open water	0.03(0.00-0.24)	0.03(0.00-0.48)	0.05(0.01-0.16)
Forested wetland	0.06(0.00-0.38)	0.04(0.00-0.24)	0.15(0.01-0.35)
Non-flooded agriculture	0.43(0.05-0.70)	0.21(0.00-0.47)	0.64(0.28-0.94)
Emergent marsh	0.08(0.00-0.50)	0.16(0.00-0.84)	0.00(0.00-0.01)
Proximity to high bird density area (km)	1.25(0.00-18.26)	14.67(1.17-31.63)	8.20(0.00-48.26)

RESULTS

After including only potential days during active MBHI management seasons and eliminating days with contaminated radar data, we sampled a total of 125 out of 546 (23%) days for KHGX and 97 out of 420 (23%) days for KLCH in the WGCP. For the MAV, we sampled 113 out of 453 (25%) days for KLZK and 86 out of 453 (19%) days for KNQA. We determined soil wetness index using an average of 2.8 TM images per season per radar during the management year, and an average of 6.4 TM images per season per radar during the prior two years, excluding the spring (Table 2).

Table 2. Sample size (number of days) for determining mean reflectivity from NEXRAD data and mean soil wetness index from Thematic Mapper data by year, season, and radar.

Season	Remote Sensor	Radar			
		KLCH	KHGX	KLZK	KNQA
Management year (2010-2011)					
Fall	NEXRAD	9	12	5	8
	Thematic Mapper	3	2	3	4
Winter	NEXRAD	12	27	41	16
	Thematic Mapper	1	4	2	3
Spring	NEXRAD	7	10	n/a	n/a
	Thematic Mapper	0	0	n/a	n/a
Prior years (2008-2010)					
Fall	NEXRAD	14	24	16	20
	Thematic Mapper	2	2	3	3
Winter	NEXRAD	51	41	51	41
	Thematic Mapper	8	14	11	8
Spring	NEXRAD	4	11	n/a	n/a
	Thematic Mapper	1	1	n/a	n/a

Daily mean radar reflectivity (i.e., relative bird density) varied considerably between the radars throughout the management periods with the KLZK and KLCH radars showing much higher reflectivity overall (Figure 4). For all radars, reflectivity peaked during winter management although the timing differed among radars; KHGX showed an early winter peak, KLZK and KNQA a mid-winter peak and KLCH in late winter.

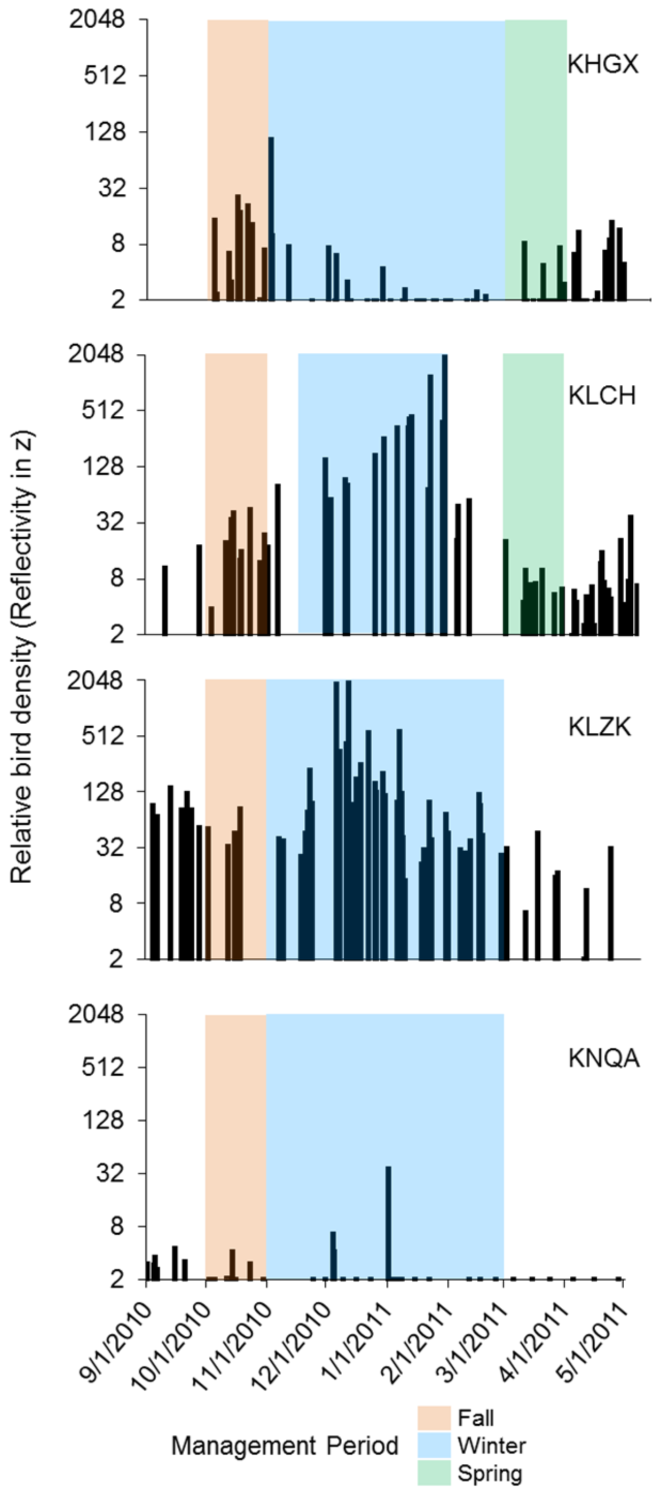

Figure 4. Daily mean relative bird density during the management year at MBHI sites for each radar. Colored bars distinguish the periods of active management.

Overall, we found increases in bird density relative to prior years and relative to non-flooded agriculture (NFA) in the management year in nearly all seasons and radars (Table 3).

Table 3. Summary statistics of soil wetness and bird response metrics among Migratory Bird Habitat Initiative sites in the West Gulf Coastal Plain and the Mississippi Alluvial Valley by radar and season. Sample size is number of sample polygons assessed.

Variable	West Gulf Coastal Plain		Mississippi Alluvial Valley	
	KLCH	KHGX	KLZK	KNQA
	Mean (Range)	Mean(Range)	Mean(Range)	Mean(Range)
Fall	*n* = 2743	*n* =1616	*n* =534	*n* =171
Soil wetness index during management year	-0.14(-0.42-0.03)	-0.13(-0.55-0.04)	-0.22(-0.41- -0.04)	-0.19(-0.29-0.01)
Change in soil wetness index from prior years	-0.02(-0.29-0.27)	-0.01(-0.33-0.22)	-0.09(-0.21-0.09)	-0.08(-0.24-0.12)
Standard reflectivity during management year	2.33(0.00-14.85)	2.60(0.00-20.32)	2.66(0.08-9.03)	0.91(0.23-2.29)
Reflectivity relative to prior years	2.74(0.02-96.24)	9.44(0.03-209.83)	7.82(0.20-75.50)	1.21(0.38-2.85)
Winter	*n* = 2921	*n* =1531	*n* =534	*n* =148
Soil wetness index during management year	-0.09(-0.33-0.06)	-0.07(-0.18-0.03)	-0.13(-0.23-0.02)	-0.05(-0.13-0.02)
Change in soil wetness index from prior years	0.00(-0.24-0.19)	0.01(-0.13-0.16)	-0.03(-0.13-0.13)	0.03(-0.03-0.10)
Standard reflectivity during management year	1703.38 (0.27-29211.01)	5.06(0.13-112.62)	29.86(0.00-415.51)	1.93(0.10-44.90)
Reflectivity relative to prior years	10.27(0.10-272.19)	5.71(0.12-91.99)	1.64(0.05-16.71)	2.80(0.18-29.10)
Spring	*n* = 206	*n* =1603		
Standard reflectivity during management year	2.45(0.01-20.29)	0.24(0.00-7.00)	n/a	n/a
Reflectivity relative to prior years	2.21(0.01-9.61)	1.97(0.01-35.51)	n/a	n/a

This is indicated by the mean standardized reflectivity and the ratio of reflectivity relative to prior years having values greater than one. The exceptions were at sites relative to NFA in the management year within the KNQA radar range in fall (0.91) and the KHGX radar range in spring (0.24). When cast in terms of area, a majority of MBHI area exhibited greater bird use relative to NFA within the management and relative to prior years for fall (mean across radars of 65% & 74%, respectively) and winter (mean across radars of 78% & 82%, respectively), but not during spring (mean across radars of 6% & 42%, respectively) (Table 4). Exceptions for a majority increase in bird use relative to NFA in the management year by radar included KNQA during the fall and KLCH and KHGX in the spring. Additionally, a majority (60%) of the area around KHGX during the spring did not increase in bird use relative to prior years.

Table 4. Proportion of MBHI area that increased in soil wetness and bird use from prior years and with greater bird use relative to non-flooded agriculture areas during the management year by season and radar.

Season		Radar			
		KLCH	KHGX	KLZK	KNQA
Fall	Total hectares assessed	7613	6445	1964	611
	Proportion with increased mean soil wetness from prior years	0.44	0.43	0.06	0.10
	Proportion with mean standardized reflectivity greater than 1 during management year	0.63	0.65	0.81	0.31
	Proportion with increased mean relative reflectivity from prior years	0.65	0.82	0.86	0.62
Winter	Total hectares assessed	5884	6102	1964	555
	Proportion with increased mean soil wetness from prior years	0.52	0.54	0.22	0.92
	Proportion with mean standardized reflectivity greater than 1 during management year	0.96	0.64	0.73	0.50
	Proportion with increased mean relative reflectivity from prior years	0.91	0.86	0.46	0.78
Spring	Total hectares assessed	512	6400	n/a	n/a
	Proportion with mean standardized reflectivity greater than 1 during management year	0.35	0.04	n/a	n/a
	Proportion with increased mean relative reflectivity from prior years	0.63	0.40	n/a	n/a

The magnitude and extent of increases varied among seasons and radars such that the greatest increases in the amount and extent of reflectivity relative to prior years occurred during winter in Louisiana (KLCH) and easternmost Arkansas (KNQA) sites and during fall in Texas (KHGX) and western Arkansas (KLZK) sites. The greatest use by birds of MBHI managed sites relative to NFA occurred during winter at all radars. The greatest responses to MBHI management both within and between years, across all radars and seasons occurred at Louisiana sites during the winter. Here, over 90% of MBHI area had increased bird use relative to previous years and NFA such that the average bird density was over 10 times that from previous years and over 1,700 times that of NFA. Because of the sensitivity of private landowner information, we do not present maps of these results with individual MBHI areas identified. Rather we provide data from an example MBHI area to illustrate the strong bird response during winter at a Louisiana location (Fig. 5). The weakest bird response to MBHI management overall occurred during the spring in Texas.

Mean soil wetness index during the management year nearly always indicated non-flooded soil conditions on average at sites during fall and winter. However, there were usually areas that were flooded within MBHI site boundaries even if the entire site was not flooded (see Fig 5). The change in mean soil wetness index from prior years in fall was always negative, indicating dryer soil in the management year. However, it was slightly positive for the KHGX and KNQA radars in winter. Soil wetness was greatest during winter, though only slightly more than half of the MBHI area was considered flooded with surface water in the WGCP. During winter in the MAV, nearly all of the MBHI area was flooded at KNQA, but less than a quarter was flooded at KLZK. The lower soil wetness during fall is consistent with the fall moist soil management for shorebirds and the higher soil wetness in winter is consistent with the open water management for wintering waterfowl.

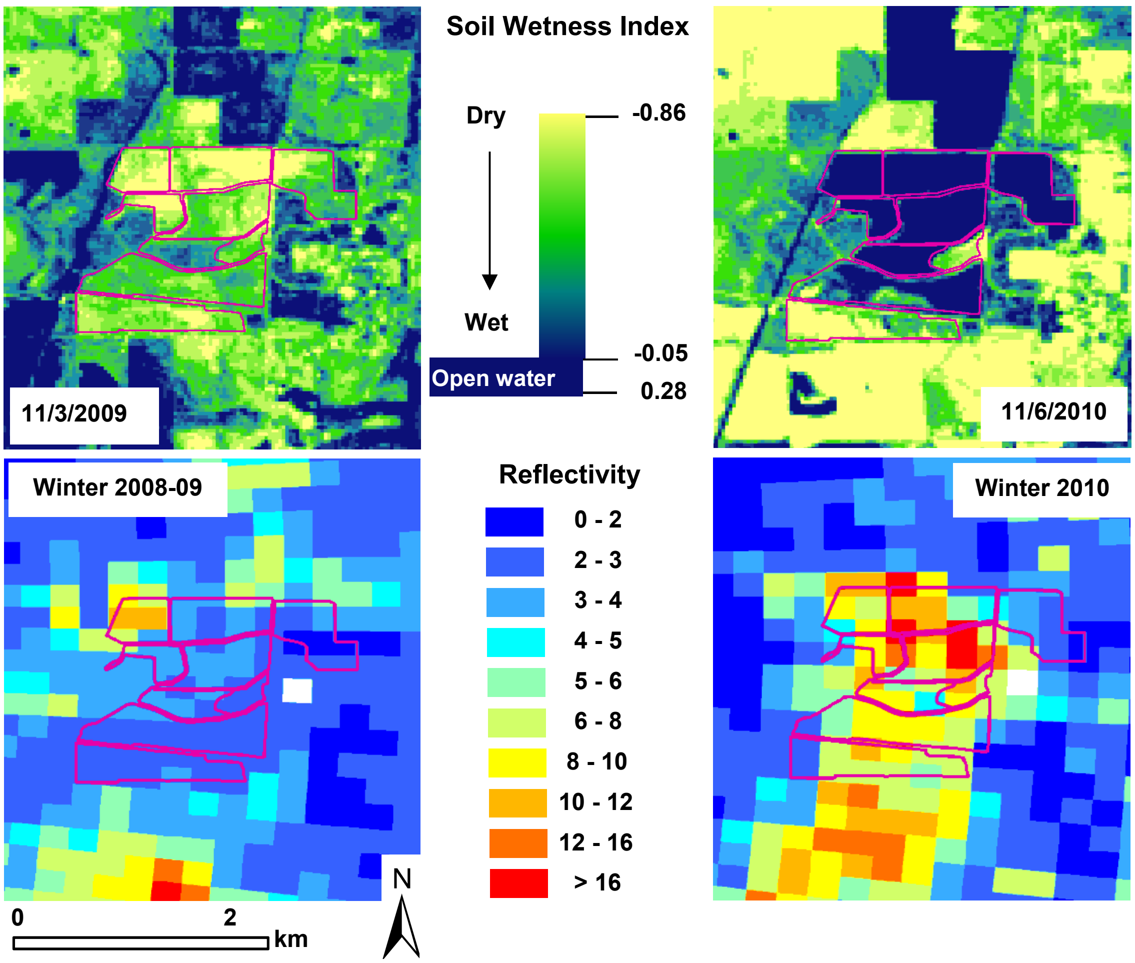

Figure 5. Images of remotely-sensed soil wetness and radar reflectivity data at 8 MBHI sites (pink outlines) within Louisiana. As depicted by imagery from single dates, MBHI sites are mostly flooded by surface water during the management year (top right panel) and relatively dry during a prior year (top left panel). Mean standardized radar reflectivity at the onset of evening flight (i.e., relative bird density) is greater within and around MBHI sites during the winter of the management year (bottom right panel) than during the previous two winters (bottom left panel).

Bird response modeling

Fall: During fall, the global models generally explained less than half of the variation in relative bird density within the management year (Table 5) and relative to prior years (Table 6). At both radars within the WGCP, the most important variable in explaining bird density within the management year was proximity to areas of high bird density, such that bird density increased in closer proximity to high bird density areas. Additionally, bird density at Texas sites increased with greater soil wetness. Within central Arkansas, however, the amount of forested wetlands in the landscape was most important in explaining bird density within the management year, such that bird density increased with increasing amount of forested wetland. The importance and direction of the relationship of variables explaining the change in bird density relative to prior years differed among all three radars. In Texas, MBHI areas with less open water and forested wetland, and greater emergent marsh in the landscape had a greater increase in density relative to prior years. In Louisiana, MBHI areas in closer proximity to high bird density areas and with more open water in the landscape had a greater increase in density relative to prior years. In central Arkansas, MBHI areas in farther from high bird density areas and with lower soil wetness relative to prior years had a greater increase in density relative to prior years.

Table 5. Mean relative variable importance, mean effect size and effect frequency of explanatory variables in explaining **fall standardized bird density within the management year** at MBHI areas based on a candidate set of linear regression models (63 models for KLCH and KHGX, 31 models for KLZK). Each model set assessed using a set of 25 samples with 20 sample polygons for each sampling set. Effect size is the mean standardized regression coefficient across all models averaged across sample sets ± unconditional SE. Effect frequency is the proportion of sample sets for which the variable exhibited a strong effect. Landscape radius for quantifying land cover in parentheses. The mean global model R^2 values were 0.48 (KLCH), 0.54 (KHGX), and 0.40 (KLZK). Results in bold indicate variable of greatest importance and other variables with importance above 0.5 and/or effect frequency above 0.33.

Explanatory Variable	KLCH			KHGX			KLZK		
	Mean Importance	Mean Effect Size ± SE	Frequency of Effect	Mean Importance	Mean Effect Size ± SE	Frequency of Effect	Mean Importance	Mean Effect Size ± SE	Frequency of Effect
Site Wetness Index	0.38	-0.12±0.11	0.28	**0.58**	**0.39±0.07**	**0.56**	0.39	-0.11±0.06	0.28
Non-flooded Agriculture (4.5/4.5/0.5 km)	0.34	-0.20±0.06	0.12	0.33	0.16±0.13	0.12	0.42	0.18±.08	0.24
Forested Wetland (2.5/2.5/4.5 km)	0.33	0.06±0.08	0.16	0.29	-0.03±0.05	0.16	**0.58**	**0.37±0.10**	**0.48**
Permanent Open Water (3.0/4.0/4.5 km)	0.46	0.35±0.03	0.24	0.40	-0.31±0.04	0.24	0.32	-0.06±0.05	0.12
Proximity to High Bird Density Area	**0.47**	**-0.33±0.14**	**0.32**	**0.61**	**-0.44±0.04**	**0.60**	0.35	-0.14±0.06	0.16
Emergent marsh (4.5/3.5/n/a km)	0.35	-0.24±0.13	0.08	0.38	0.19±0.16	0.16	n/a	n/a	n/a

Table 6. Mean relative variable importance, mean effect size and effect frequency of explanatory variables in explaining **fall ratio of bird density during the management year relative to the prior two years** at MBHI areas based on a candidate set of linear regression models (63 models for KLCH and KHGX, 31 models for KLZK). Each model set assessed using a set of 25 samples with 20 sample polygons for each sampling set. Effect size is the mean standardized regression coefficient across all models averaged across sample sets ± unconditional SE. Effect frequency is the proportion of sample sets for which the variable exhibited a strong effect. Landscape radius for quantifying land cover in parentheses. The mean global model R^2 values were 0.45 (KLCH), 0.58 (KHGX), and 0.41 (KLZK). Results in bold indicate variable of greatest importance and other variables with importance above 0.5 and/or effect frequency above 0.33.

Explanatory Variable	KLCH			KHGX			KLZK		
	Mean Importance	Mean Effect Size ± SE	Frequency of Effect	Mean Importance	Mean Effect Size ± SE	Frequency of Effect	Mean Importance	Mean Effect Size ± SE	Frequency of Effect
Change in Site Wetness Index	0.31	-0.04±0.06	0.08	0.39	0.09±0.10	0.28	**0.46**	**-0.18±0.09**	**0.36**
Non-flooded Agriculture (1.0/4.5/4.5 km)	0.34	0.12±0.07	0.12	0.43	0.47±0.16	0.32	0.34	-0.10±0.05	0.16
Forested Wetland (1.5/4.5/0.5 km)	0.32	0.14±0.06	0.16	**0.48**	**-0.38±0.06**	**0.40**	0.30	-0.08±0.04	0.08
Permanent Open Water (4.0/3.0/2.0 km)	**0.50**	**0.35±0.07**	**0.40**	**0.55**	**-0.43±0.07**	**0.48**	0.34	0.08±0.06	0.20
Proximity to High Bird Density Area	**0.52**	**-0.33±0.10**	**0.44**	0.29	0.10±0.06	0.04	**0.59**	**0.37±0.03**	**0.52**
Emergent marsh (4.5/2.0/n/a km)	0.37	-0.03±0.13	0.16	**0.49**	**0.41±0.16**	**0.36**	n/a	n/a	n/a

Winter: During winter, the global models generally explained most (>70%) of the variation in relative bird density within the management year (Table 7). At all radars, the most important variable in explaining standardized bird density within the management year was proximity to areas of high bird density, such that bird density increased in closer proximity to high bird density areas. Additionally, within the WGCP, bird density was positively related to greater amounts of emergent marsh in the surrounding area. In Louisiana, MBHI areas with greater non-flooded agriculture in the landscape and soil wetness also had greater bird density. In Arkansas, MBHI areas with greater non-flooded agriculture and open water in the landscape had greater standardized bird density in the management year. During winter, the global models did not explain as much variability in bird density relative to prior years than they did for standardized bird density within the management year, but they still explained a majority (>50%) of the variation (Table 8). The variation in bird density relative to prior years in winter was explained by greater amounts of emergent marsh in the surrounding landscape at both WGCP radars. Otherwise, the importance and direction of the relationship of variables explaining the change in bird density relative to prior years differed among all three radars. In Texas, MBHI areas with less open water in the landscape and in closer proximity to areas of high bird density also had a greater increase in density relative to prior years. In Louisiana, MBHI areas with greater non-flooded agriculture in the landscape and a greater increase in soil wetness also had a greater increase in density relative to prior years. In central Arkansas, MBHI areas with more open water and forested wetland in the landscape had a greater increase in density relative to prior years.

Table 7. Mean relative variable importance, mean effect size and effect frequency of explanatory variables in explaining **winter standardized bird density within the management year** at MBHI areas based on a candidate set of linear regression models (63 models for KLCH and KHGX, 31 models for KLZK). Each model set assessed using a set of 25 samples with 20 sample polygons for each sampling set. Effect size is the mean standardized regression coefficient across all models averaged across sample sets ± unconditional SE. Effect frequency is the proportion of sample sets for which the variable exhibited a strong effect. Landscape radius for quantifying land cover in parentheses. The mean global model R^2 values were 0.88 (KLCH), 0.71 (KHGX), and 0.86 (KLZK). Results in bold indicate variable of greatest importance and other variables with importance above 0.5 and/or effect frequency above 0.33.

Explanatory Variable	KLCH			KHGX			KLZK		
	Mean Importance	Mean Effect Size ± SE	Effect Frequency	Mean Importance	Mean Effect Size ± SE	Effect Frequency	Mean Importance	Mean Effect Size ± SE	Effect Frequency
Site Wetness Index	**0.44**	**0.16±0.02**	**0.36**	0.36	0.01±0.06	0.24	0.37	0.11±0.01	0.28
Non-flooded Agriculture (4.0/3.5/4.5 km)	**0.70**	**0.33±0.03**	**0.72**	0.33	-0.04±0.17	0.16	**0.49**	**0.27±0.02**	**0.36**
Forested Wetland (4.0/0.5/4.5 km)	0.28	0.06±0.04	0.16	0.25	0.06±0.02	0.04	0.36	0.15±0.02	0.20
Permanent Open Water (4.5/4.5/4.5 km)	0.31	0.04±0.02	0.20	0.42	-0.26±0.14	0.28	**0.70**	**0.29±0.01**	**0.76**
Proximity to High Bird Density Area	**0.91**	**-0.63±0.04**	**0.92**	**0.78**	**-0.54±0.06**	**0.80**	**1.00**	**-0.70±0.01**	**1.00**
Emergent Marsh (1.5/ 4.5/n/a km)	**0.69**	**0.32±0.03**	**0.68**	**0.78**	**0.65±0.08**	**0.80**	n/a	n/a	n/a

Table 8. Mean relative variable importance, mean effect size and effect frequency of explanatory variables in explaining **winter ratio of bird density during the management year relative to the prior two years** at MBHI areas based on a candidate set of linear regression models (63 models for KLCH and KHGX, 31 models for KLZK). Each model set assessed using a set of 25 samples with 20 sample polygons for each sampling set. Effect size is the mean standardized regression coefficient across all models averaged across sample sets ± unconditional SE. Effect frequency is the proportion of sample sets for which the variable exhibited a strong effect. Landscape radius for quantifying land cover in parentheses. The mean global model R^2 values were 0.68 (KLCH), 0.57 (KHGX), and 0.51 (KLZK). Results in bold indicate variable of greatest importance and other variables with importance above 0.5 and/or effect frequency above 0.33.

Explanatory Variable	KLCH			KHGX			KLZK		
	Mean Importance	Mean Effect Size ± SE	Effect Frequency	Mean Importance	Mean Effect Size ± SE	Effect Frequency	Mean Importance	Mean Effect Size ± SE	Effect Frequency
Change in Site Wetness Index	**0.57**	**0.34±0.03**	**0.68**	0.36	0.00±0.09	0.24	0.33	0.15±0.03	0.16
Non-flooded Agriculture (4.5/1.5/4.5 km)	**0.73**	**0.53±0.05**	**0.76**	0.39	0.07±0.14	0.24	0.40	-0.20±0.09	0.24
Forested Wetland (3.5/3.5/3.5 km)	0.40	0.11±0.11	0.32	0.41	-0.08±0.16	0.24	**0.55**	**0.34±0.10**	**0.44**
Permanent Open Water (4.0/4.5/2.0 km)	0.38	0.05±0.05	0.28	**0.47**	**-0.37±0.12**	**0.40**	**0.55**	**0.34±0.04**	**0.48**
Proximity to High Bird Density Area	0.31	-0.01±0.08	0.16	**0.44**	**-0.24±0.11**	**0.36**	0.37	0.23±0.02	0.16
Emergent Marsh (1.0/3.5/n/a km)	**0.56**	**0.33±0.03**	**0.52**	**0.63**	**0.57.±0.18**	**0.56**	n/a	n/a	n/a

DISCUSSION

We used weather surveillance radar to quantify relative bird densities at the onset of evening flights to determine the efficacy of the MBHI in providing diurnal habitat for waterbirds across a broad spatial and temporal scale. Our analysis indicated that on the majority of managed MBHI lands, bird densities increased when compared to prior non-managed years and were often higher than densities found on surrounding non-flooded agricultural land. There were marked differences in relative magnitude of bird responses across seasons and regions with the greatest bird responses to MBHI activities observed within the WGCP region during winter. For example, over 90% of radar-observed MBHI area within Louisiana increased in winter bird use an average of over 10 times relative to previous years. The density of birds was lower and their relative responses were weaker during the fall likely due to the short duration and late timing of fall management with respect to shorebird migration. The weakest response to birds of MBHI activities was during spring in the WGCP, for which we could not remotely assess moist soil management. We expected to see such differences as the numbers and composition of birds changed through time during the different management periods and differed in space due to differences in the local and regional characteristics of the landscape.

Different groups of birds migrate through the area at different times of the year with landbirds and shorebirds passing through first in spring and fall followed by waterfowl that often stay through the winter (Tamisier 1976). Fall management occurred during the month of October, when the majority of shorebirds have already passed through and only a few species, such as *Limnodromus* sp. (Dowitchers), *Calidris minutilla* (Least Sandpiper) and *Tringa* sp.(Yellowlegs), are still migrating (Ranalli and Ritchison 2012, Robbins and Easterla 1991, Twedt et al. 1998). Landbird migration, however, is at its peak along the Gulf Coast in October

(Able 1972, Gauthreaux and Belser 1999). Flights of early migrant waterfowl such as northern pintail and blue-winged teal (*Anas discors*) begin as early as September (Cox and Afton 1996, 1997, eBird 2013, Tamisier 1976), while the first big push of wintering waterfowl generally occurs in early November (Tamisier 1976). Consistent with this, the most abundant birds at MBHI sites were landbirds during the month of October based on field surveys conducted in Louisiana during 2011 (W. Barrow unpub. data). Shorebird abundance was about four times lower than landbirds, and waterfowl abundance was 10 times lower than landbirds. During this period, radars should have observed landbirds, shorebirds and early waterfowl engaging in evening migratory flights. This mix of evening flight activity from different bird groups during Octobermay in part explain why less variability in bird densities were explained by our models in both regions compared to the winter.

During fall management in the MAV, with migrating landbirds being dominant, bird densities at MBHI sites were positively associated with forested wetlands. Areas with more forested wetland in the surrounding area had higher bird densities during the management year likely indicating contamination of the airspace over areas by landbirds initiating migration from adjacent forested habitats, which are known to harbor high densities of migrating landbirds (Buler and Moore 2011, Gauthreaux and Belser 1999). Additionally, some waterfowl such as green-winged teal (*Anas carolinensis*) and northern pintail use forested wetlands in the MAV throughout the spring and fall (Heitmeyer 1985). Our data also indicate that many sites in the MAV were not actually flooded in October, and that drier sites were weakly associated with a greater increase in bird density in the management year relative to prior years. During fall management in the MAV, sites were drier than those in the Gulf and observed bird densities may reflect shorebirds using drier mudflat sites or, again, landbirds (blackbirds en route to their roosts or neotropical migrants departing the nearby forested wetlands) utilizing the landscape adjacent to the sites.

Within the WGCP during fall and winter, the only variable that exhibited a consistent relationship with bird density among the two radars was proximity to high bird density area. Established areas of high waterbird densities along with the tendency of waterbirds to form traditional large roosting flocks (Tamisier 1985) are two likely reasons we saw greater increases at sites close to high bird density areas. Large concentrations of waterfowl have historically used the marshes and adjacent wet prairie lands situated along the Gulf Coast (Bateman et al. 1988, Bellrose 1976, Tamisier 1976). An estimated four million ducks and hundreds of thousands of geese were wintering in coastal Louisiana in the late 1960s (Lynch 1975; Tamisier 1976), with a more recent estimated 4 million waterfowl in coastal Texas (U.S. Fish and Wildlife Service 1999). The MAV has also historically harbored millions of waterfowl with the number of wintering mallards alone estimated at 1.5 million (Bellrose 1976). A great portion of the extensive wetlands along the Gulf Coast that support waterbirds has since been converted for rice and other agricultural products, overlapping with historic winter ranges (Eadie et al. 2008) and altering the landscape and distributions of birds (Hobaugh et al. 1989). Likewise, much of the forested wetland area of the MAV was converted for agricultural use throughout the last century (Forsythe 1985). Despite these changes, the WGCP and the MAV regions remain as two of the most important for migrating and wintering waterbirds in North America (Bellrose 1976) evidenced by the millions of birds that congregate each year to use agricultural fields for feeding and roosting (Hobaugh et al. 1989, Remsen et al. 1991).

Communal roosting is characteristic of many shorebird and waterfowl species (Colwell 2000, Tamisier 1976). Some birds may use the same winter roost or feeding sites year after year

(Tamisier 1985). For example, Cox and Afton (1996) reported high fidelity (71%) of radio-marked female northern pintails to Lacassine National Wildlife Refuge in coastal Louisiana following nightly foraging trips to nearby agricultural land. Additionally, although changes in flooding occurred on the landscape throughout the winter, ducks maintained consistent flight directions when leaving Lacassine National Wildlife Refuge (Tamisier 1976). Within Louisiana, radar observations indicate birds are concentrated in marsh and agricultural areas within and around Lacassine and Cameron Prairie National Wildlife Refuges and the White Lake Wetlands Conservation Area (Fig. 5). These areas are well-known roosting areas for wintering waterfowl (Link et al.. 2011). These findings support the idea that birds use certain areas consistently during the winter and that these areas may be important predictors of waterbird activity.

Regional habitat differences associated with emergent marsh also influenced differential bird responses across the sites. Although much of the emergent marsh inland from the northern Gulf Coast has been converted to cropland (Hobaugh et al.1989), we found that there is still considerably more marsh in the WGCP compared to the MAV. The importance of emergent marsh in predicting bird densities was apparent in the winter with our finding that increased bird densities at sites in the WGCP region were related to higher amounts of emergent marsh in the surrounding landscape. Waterfowl use of natural wetlands is generally positively related to the amount of wetlands in the local landscape (Brown and Dinsmore 1986, Fairbairn and Dinsmore 2001, McKinstry and Anderson 2002, Stafford et al. 2007, Webb et al. 2010). These wetland habitats have traditionally supported many waterbirds and are important wintering grounds for ducks and other waterfowl (Tasimier 1976). For example, Link (2011) found that mallards roosting in marsh habitats during the day engage in evening feeding flights, but may be able to acquire most of their energetic requirements from or in close proximity (3-15 km) to marsh habitats. Emergent marshes are often part of large and diverse wetland complexes (Cowardin et al. 1979) that support a diversity of birds (Brown and Dinsmore 1986). Wetland complexes in various stages of succession have proven to be the most beneficial to waterbirds (Fredrickson and Reid 1986, Kaminski et al. 2006, Murkin and Caldwell 2000, Van der Valk 2000, Webb et al. 2010).

During winter in the MAV, reflectivity was greater at sites with more forested wetland and open water in the landscape relative to the baseline years. In the winter of 2009-2010, Arkansas Game and Fish Commission (AGFC) noted that waterfowl may have shifted to using more forested wetlands when colder than normal temperatures produced ice on much of the water associated with agricultural fields (Arkansas Game and Fish Commission 2010a, 2010b). There were high concentrations of waterfowl in northeastern Arkansas in December 2010 based on aerial surveys (Arkansas Game and Fish Commission 2011a). In January 2011, waterfowl were concentrated closer to KLZK, which corroborates the greater bird density observed by the radar for winter of 2010-2011 (Arkansas Game and Fish Commission 2011b). However, duck numbers were nearly half that observed in January 2010 likely due to dry conditions across the state (Arkansas Game and Fish Commission 2011c). Lack of water on the landscape may explain the positive relationship that open water had with bird density at a large scale within the winter. There was a 21% increase in waterfowl numbers in January 2011 compared to the previous year attributed to drier conditions from below average precipitation in the MAV (Louisiana Department of Wildlife and Fisheries 2011). Additionally, Tamisier (1976) found that green-winged teal and northern pintails gathered in concentrations on open water even when surrounding fields and marshes were flooded. This observation held true independent of water levels and hunting pressure outside of Lacassine National Wildlife Refuge.

Although we detected some increases in bird density during spring management in the WGCP region, the increases were slight. Lack of wetness data and few enrolled sites prevented us from investigating how site and landscape variables influenced bird densities. Some waterbirds may have already departed on migration during the month of March, when management occurred (see Hobaugh et al. 1989). For example, mallard and northern pintail begin leaving wintering grounds in early February (Bellrose 1976) and the majority of ducks depart coastal Texas during the month of February with few left by mid-March (Hobaugh et al. 1989). A few shorebird species, such as American Avocet (*Recurvirostra americana*), may leave Texas in early March (Oberholser 1974) but many shorebirds are present south of the WGCP during March and into April (Withers and Chapman 1993). Alternatively, food resources on local flooded fields may be too depleted by spring to support large groups of waterbirds (Cox and Afton 1996, Hamilton and Watt 1970, Hobaugh et al. 1989).

Increases in bird density occurred despite our finding of little or no increases in soil wetness at the managed sites. The remotely-sensed data that we used to calculate soil wetness index may have limited our ability to detect such changes. We had few usable images for each radar per season with which to calculate the index. Additionally, we had no information about the extent of flooding within individual properties. Thus, a landowner's contract may require flooding on only a portion of their property, and our analysis may have included the whole property boundary. Moreover, drought conditions, restricted water supplies, or other circumstances may have prevented landowners from complying fully with their contracts.

Soil wetness in the MAV region were probably also influenced by natural fluctuations in precipitation patterns. The baseline years were relatively wet years in the MAV; October 2009 in Arkansas was the wettest recorded in more than 100 years (NOAA National Climatic Data Center 2009). In contrast, much of Arkansas was under drought conditions in 2010 (NOAA

National Climatic Data Center 2010). Thus these conditions complicated quantification of changes in site wetness (i.e. flooding) during the management year.

Variability in the intensity of moist soil management can have an important effect on wintering waterfowl use (Kaminski et al. 2006, O'Neal et al. 2008). MBHI sites in the MAV and those in Texas received minimal modifications. In the MAV, contracts simply required landowners to keep surface water on their fields for a specified amount of time across a wide range of depths (2 to 18 inches) to potentially benefit a wide variety of shorebirds and wading birds. However, surface water depths are difficult to remotely measure. Regular direct water depth measurements would have allowed us to better quantify habitat for particular taxa of waterbirds.

Ranalli and Ritchison (2012) note that mudflat habitat associated with agricultural fields is unpredictable in the MAV because it is dependent on precipitation in a given year. Thus, management activities associated with the MBHI may have provided steady stopover habitat for migrating shorebirds. Landowners may have been unable to maintain winter flooding at such a depth that would benefit waterfowl, but any water on the fields likely benefited shorebirds because they are known to identify and use saturated soils within days of being inundated (Skagen and Knopf 1993, Skagen et al. 2008).

The attractiveness of MBHI wetlands to waterfowl may have varied based on the land use of sites prior to flooding. Some fields were pastures (15% in the MAV 20% in the WCGP; USDA-NASS CDL 2010) during the management year and may not have provided much forage in the form of wetland plant seed during the first year of the program. Rice seed persists longer in wetlands than other seeds associated with crop harvest waste, thereby potentially increasing available forage for waterbirds compared to other flooded crops (Nelms and Twedt 1996).

However, only 20% of MBHI sites in the MAV were rice fields compared to 40% in the WGCP (USDA-NASS CDL 2010), which may account for greater positive changes in reflectivity values in the WCGP. Although waterfowl feed on non-flooded waste grain (Bellrose 1976, Kross et al. 2008, Reinecke et al. 1989), flooding rice fields increases habitat for waterfowl and other waterbirds in California (Elphick and Oring 1998).

Buler et al. (2012b) found that waterfowl use of restored wetlands was negatively related to the amount of wetlands in the local landscape, and speculated that this may be because newly-restored wetlands were lower quality habitat than natural wetlands. Similarly, studies have found that flooded agricultural fields do not necessarily act as surrogates for natural wetlands (Bartzen et al. 2010, Czech and Parsons 2002). Ma et al. (2004) found that although natural wetlands provided better habitat, artificial wetlands attracted some waterbird species during winter. Because portions of the MAV and WGCP have, in the last 150 years or so (Hobaugh et al. 1989), been farmed for rice each year, waterbirds may be dependent on flooded agricultural fields for wintering habitat in which case the MBHI provided valuable areas that landowners may not have flooded in a drought year.

In the wake of a major environmental disaster, the MBHI program provided waterbirds with temporary wetland habitats by flooding agricultural fields within the MAV and WGCP regions. We detected increases in bird densities on the majority of MBHI sites during migration and wintering periods for waterfowl and shorebirds. The greatest relative responses by birds to MBHI sites occurred in the WGCP during the winter management period at sites closer to areas of high bird density and with more emergent marsh in the surrounding landscape. We acknowledge the need to provide immediate habitat for resident and migratory waterbirds after the Deep Water Horizon event but suggest that future programs focus on enrolling landowners in such a way as to maximize clusters of fields into a mosaic of wetlands that more closely resemble natural wetland complexes (Brown and Dinsmore 1986). We also recommend that bird surveys be conducted on the ground when possible, in conjunction with remote sensing studies (Albanese and Davis 2013, Albanese et al. 2012, Buler et al. 2012a, Randall et al. 2011). With predictions of changing climactic conditions (Intergovernmental Panel on Climate Change 2007), providing habitat for migratory birds in the MAV and WGCP will continue to be important for all stakeholders particularly with the knowledge that migration is a limiting factor for shorebirds and waterfowl (Afton et al. 1991, Alisauskas and Ankney 1992, Baker et al. 2004, Blums et al. 2005, Morrison et al. 2007, Ryder 1970).

ACKNOWLEDGEMENTS

We thank the Natural Resources Conservation Service for funding. W. Barrow, M. Baldwin, and L. Randall at the USGS National Wetlands Research Center provided MBHI site boundary data and valuable input on the study design. We also thank J. Gautreaux, R. Lyon, and D. Greene for screening radar data.

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