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Importance of flood irrigation for foraging colonial waterbirds

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Abstract

For a colonial-nesting bird, like the white-faced ibis (*Plegadis chihi*), the landscape surrounding the breeding colony can be important. White-faced ibis must rely on areas outside their breeding colony for foraging, but this part of their life history has received little attention, and the management of this landscape even less so. To address this knowledge gap, we conducted road-based driving surveys and a randomly selected, spatially balanced sample survey of agricultural fields within a 22-km radius of the 2 largest white-faced ibis breeding colonies in Idaho, USA: Market Lake Wildlife Management Area and Mud Lake Wildlife Management Area. Our study took place in 2012 and the primary objective was to quantify patterns of foraging habitat use of this marsh-nesting species, particularly associations with specific irrigation practices and crop types. We documented the majority of foraging birds in flood-irrigated and wheel-line sprinkler-irrigated agricultural fields (76%) and natural wetlands (13%), which were limited in our study area (3% of land cover). Even though 70% of the agricultural landscape included center pivot sprinkler irrigation, only 11% of foraging observations came from this irrigation type. Most agricultural fields (>85%) used by foraging ibis were flood-irrigated and all had standing water or recent moisture at the time of use. Though ibis used many crop types when foraging in flooded agricultural fields, ibis use of alfalfa (58%) was greater than availability (38%). We also observed distinct distribution patterns around the 2 breeding colonies. Whereas birds foraged in all directions around Mud Lake (~80%) within a 12-km radius from the colony, we observed over half of birds around Market Lake foraging within 12–22 km, and almost exclusively to the south and southeast of the colony, reflecting the distribution of flood-irrigated agriculture in the area. The most common foraging distance (12–22 km) around Market Lake is greater than found in existing literature, suggesting that the foraging habitat is limited within 12 km of the colony and that the birds may need to travel farther to find adequate foraging habitat. Flood-irrigated agriculture and natural wetlands provide foraging habitats for white-faced ibis in eastern Idaho and should be considered in future management and conservation of wetland birds.

KEYWORDS

flood irrigation, foraging, Idaho, *Plegadis chihi*, white-faced ibis

If left unchecked, the continued loss and degradation of natural wetlands poses a threat to global waterbird populations (Dahl 1990, 2006). Wetland losses from the 1780s to the 1980s in individual states across the western United States ranged from 27–91% (Dahl 1990), largely driven by various human uses, such as agricultural infrastructure, dam construction, and residential development (McKinstry 2004, Donnelly and Vest 2012). The Intermountain West is a predominantly dry region with a variety of wetland types that, except for several large and iconic wetlands (e.g., Great Salt Lake), are limited in extent and widely scattered, and many are only seasonally flooded (Donnelly and Vest 2012). An important question to consider is whether irrigation in agricultural fields can provide at least a partial substitute for the loss of seasonally flooded wetlands that many aquatic bird species rely upon (Strum et al. 2013). There are many examples of waterbirds using irrigated agricultural fields as foraging habitats (Fasola and Ruiz 1996, Czech and Parsons 2002), yet some researchers indicate that natural wetlands may still be used more for foraging than agricultural fields (Toureng et al. 2001, Richardson and Taylor 2003). In highly altered working landscapes, such as the Snake River Plain, restoration of natural wetlands may be particularly challenging and economically infeasible. An additional consideration is that many agricultural areas in the central and western United States have undergone conversion from traditional flood-irrigated systems to more efficient sprinkler-irrigated systems (Maupin et al. 2014, Dieter et al. 2018). This conversion may reduce important foraging habitat for many waterbirds and might also affect the ground water supply and maintenance of nearby wetlands (Peck and Lovvorn 2001, Ward and Pulido-Velazquez 2008). Generally, sprinkler-irrigated systems leave much less surface water after the irrigation turns off and this leaves significantly less water to slowly descend through the soil to underlying aquifers. In addition to providing less potential for aquifer recharge, the reduced surface water associated with sprinkler irrigation almost certainly affects habitat suitability for various wildlife species, including wetland birds (Shuford et al. 2016, Donnelly et al. 2021). Thus, an important component of waterbird conservation is understanding how waterbirds use agricultural fields near wetlands, and how irrigation practices affect forage availability.

White-faced ibis (*Plegadis chihi*; ibis) is a species of colonial-breeding waterbird that nests in tall emergent perennial wetlands of the Intermountain West. In Idaho, USA, this species is listed as a species of greatest conservation need because of its reliance on relatively few breeding sites and concerns about pesticide exposure (Capen and Leiker 1979, Steele 1984, Earnst et al. 1998, Idaho Department of Fish and Game [IDFG] 2017, Ryder and Manry 2020). Though historically uncommon as breeders in Idaho, ibis established breeding colonies in eastern Idaho on managed wetlands at Market Lake Wildlife Management Area (WMA) in 1973 and Mud Lake WMA in

1977 (Booser and Sprunt 1980, Taylor et al. 1989, Taylor 1992, Trost 1994). At the time of this study, these colonies comprised one of the largest breeding concentrations throughout their range (IDFG 2017). These 2 colonies comprised about 25% of the known breeding population of ibis in the western United States, with approximately 12,300 and 4,000 ibis nests at Market Lake and Mud Lake WMAs, respectively (Cavitt et al. 2014).

Although ibis breed primarily in state and federally managed marshes (palustrine emergent deep marsh), they rely heavily on nearby wet meadows (palustrine emergent wet meadow) and agricultural landscapes for foraging and resting (Cowardin et al. 1979). Ibis feed on moist-soil invertebrates (e.g., earthworms, crustaceans), which they can obtain most readily in shallowly flooded areas such as flooded agricultural fields (Ryder and Manry 2020). Thus, both publicly managed wetlands and private agricultural lands, often predominantly located on sites of historical natural wetlands, are important for ibis populations. The degree to which they forage in fields of different irrigation practices and crops has not been quantified in any parts of its range since the 1980s (Bray and Klebenow 1988, Ryder and Manry 2020). When Bray and Klebenow (1988) studied ibis in Nevada, USA, all agricultural fields in their study area were flood irrigated, and they documented alfalfa, clay or clay-loam soils, active irrigation, larger field size (>30 ha), and proximity to the breeding colony as important to feeding flocks of ibis.

Because Idaho's landscape now includes a significant sprinkler irrigation (primarily center pivot) component, we wanted current data about which agricultural landscapes are most important to ibis feeding ecology. Therefore, we designed a descriptive study to examine foraging behavior and habitat use patterns of ibis breeding on managed wetlands in the eastern Snake River Plain of Idaho, using a combination of field-specific surveys, to directly assess use of the agricultural landscape, and driving route surveys that traversed agricultural areas and the limited natural wetlands available on the landscape (3% of our study area). Based on previous observations by local biologists, we predicted ibis would use flood-irrigated agriculture more than fields with sprinkler irrigation; but, given the variety of crops in our study area, we did not have any expectations for crop choices beyond knowing alfalfa was heavily used in Nevada (Bray and Klebenow 1988).

STUDY AREA

We conducted this study during the 2012 ibis breeding season (Apr–Jul) in eastern Idaho on the eastern Snake River Plain, a relatively flat (1,445–1,700 m elevation) and open landscape situated north and west of the towns of Idaho Falls and Rexburg (Figure 1). The 259,000-ha study area included lands within a 22-km buffer around ibis breeding colonies at Market Lake WMA (43.7792°N, 112.1459°W) and Mud Lake WMA (43.8914°N, 112.4167°W). Bray and Klebenow (1988) reported that ibis foraged ≤18 km from colonies in the Great Basin in Nevada, but we expanded our buffer to encompass additional natural wetlands and agricultural lands where ibis had previously been observed (R. A. Cavallaro, IDFG, personal observation).

This area had a desert climate that consists of cold winters (Dec–Feb) with variable snowfall; cool, windy, dry springs (Mar–May); hot, dry summers (Jun–Aug); and warm autumns (Sep–Nov). Monthly average temperatures ranged from −8°C in January (coldest month; min. −14.6°C, max. −1.5°C) to 20.2°C in July (warmest month; min. 9.4°C, max. 31°C; National Oceanic and Atmospheric Administration [NOAA] 2021). Average annual precipitation was 24.43 cm, with fairly even but low seasonal totals (5.21 cm in winter, 7.57 cm in spring, 6.60 cm in summer, and 5.05 cm in autumn; NOAA 2021).

Land cover was a mix of high desert shrub-steppe (54%), cultivated cropland and pasture and hay (40%), emergent herbaceous and woody wetlands (e.g., natural wetlands, 3%), open water (1%), and urban and rural development (2%; U.S. Geological Survey 2019). Nearly half (48%) of the study area consisted of private land where the predominant land use was irrigated agriculture with deeper soils and nearby perennial water. Several large, public wetland complexes lie adjacent to the agricultural land, including 3 state-managed wildlife areas: Cartier Slough (43.8128°N, 111.9184°W), Market, and Mud Lake WMAs, and the Camas National Wildlife Refuge (43.9639°N, 112.2645°W). These state and federally managed wetlands represented almost all of the natural wetlands available in our study area. The rest of the study area consisted of federally managed rangelands. Our study focused exclusively on wetlands and irrigated

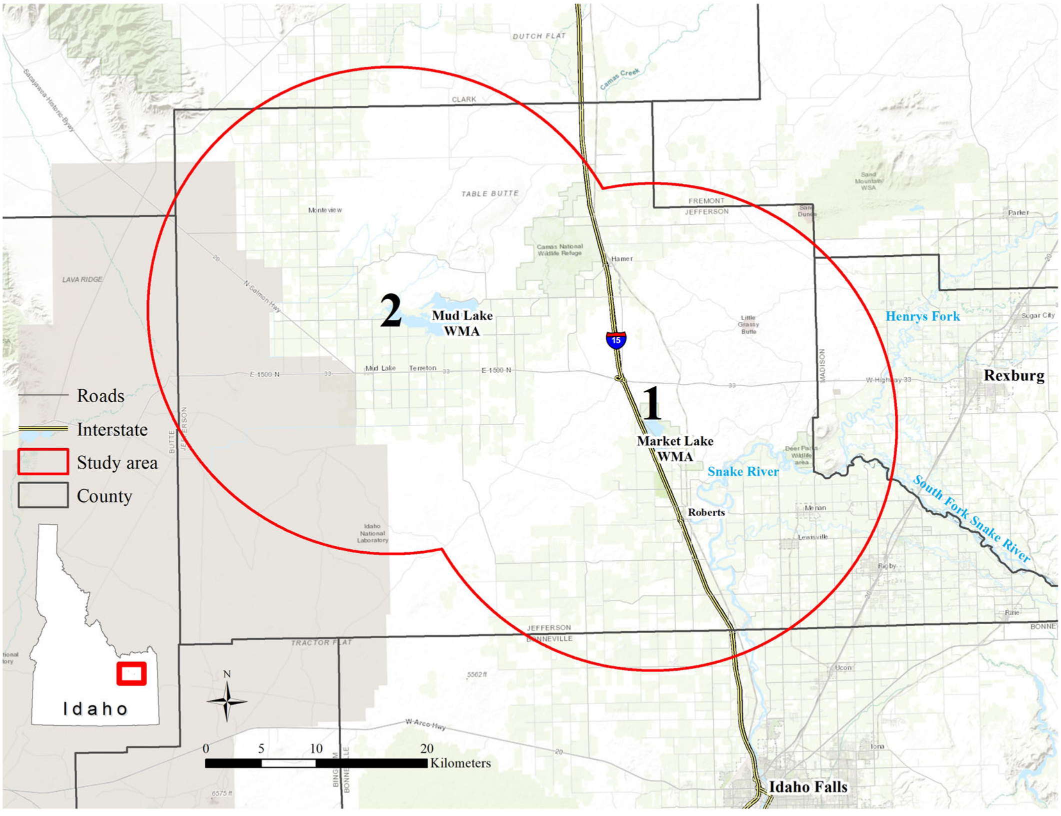

FIGURE 1 Location of a white-faced ibis foraging study in eastern Idaho, USA, 2012. The red line represents a 22-km buffer around each breeding colony at Market Lake Wildlife Management Area (1) and Mud Lake Wildlife Management Area (2).

agricultural lands (43% of study area). Wetland flora were dominated by bulrushes (primarily hardstem [*Schoenoplectus acutus*]), cattail (*Typha latifolia*), Baltic rush (*Juncus balticus*), and saltgrass (*Distichlis spicata*). Predominant crops grown in the area included alfalfa, barley, wheat (spring and winter), and potatoes. Associated wetland major fauna included many bird species, such as Franklin's gull (*Leucophaeus pipixcan*), American coot (*Fulica americana*), Canada goose (*Branta canadensis*), eared grebe (*Podiceps nigricollis*), western grebe (*Aechmophorus occidentalis*), ruddy duck (*Oxyura jamaicensis*), and yellow-headed blackbird (*Xanthocephalus xanthocephalus*).

Irrigated agricultural land within the study area is commonly watered by center pivots and there is an on-going trend of conversion from flood irrigation to center pivot irrigation. Flood irrigation involves canals that bring water near agricultural fields and gates that allow water to flow into and over a field. In eastern Idaho, farmers typically flood irrigate crops once every 2 weeks, with water permeating 1.2–1.5 m; in comparison, center pivot fields receive water weekly and water permeates 5–8 cm (R. R. Watson, Rhett Watson Farms, personal communication). Center pivot crop irrigation involves sprinkler equipment that is anchored in the center of a field and mechanically rotated around a central pivot point, creating a circular footprint (Figure 2). Wheel line and hand move sprinkler systems are also portable sprinkler systems but require more manual effort to move sprinklers at regular intervals. They tend to be used in smaller, or rectangular and irregularly shaped fields. Water is typically pumped from underground wells but may also come from a river or reservoir. Center pivot systems, like all sprinkler irrigation, use less water than traditional flood-irrigation practices, and thus do not create widespread flooding; the only standing water typically present is usually in wheel ruts

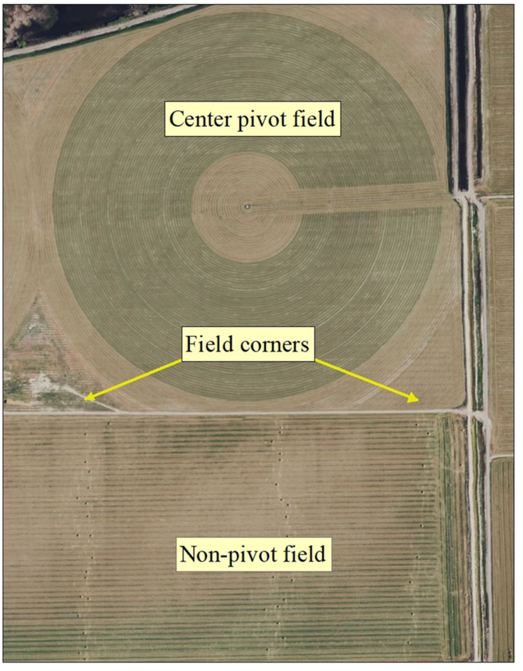

FIGURE 2 Aerial imagery illustrating layout of center pivot and non-pivot fields in eastern Idaho, USA, 2012. The corners of center pivot fields were often flood-irrigated. Although primarily flood-irrigated, non-pivot fields also included wheel line and hand move sprinkler-irrigated fields that were not easily discernible from flood-irrigated fields through aerial imagery.

or if there is a leak. In areas where the flood-irrigation infrastructure (canals, gates) is still functional, farmers that convert to center pivot irrigation often still flood field corners that center pivot sprinklers do not reach.

METHODS

We digitized onscreen all agricultural fields within the study area using 2009 1-m color infrared orthorectified aerial imagery for Idaho (U.S. Department of Agriculture Farm Service Agency Aerial Photography Field Office 2009; the most current statewide data source at the time) and ArcGIS 10.3.1 (Esri, Redlands, CA, USA). We classified irrigation method as center pivot (inferred from its circular shape and infrastructure that is often evident in the imagery) or non-pivot; non-pivot fields consisted of flood irrigation, wheel line sprinklers, or other portable, hand-move sprinklers because it proved difficult to differentiate these methods using imagery alone. We estimated approximately 100,700 ha of cultivated cropland, 68% of which was irrigated by center pivot sprinkler systems. We then assigned each field a crop type using 2011 Cropscape cropland data or a primary and secondary crop type if there was no clear majority (U.S. Department of Agriculture National Agricultural Statistics Service 2012). We validated irrigation method and crop type for all fields at which we conducted field-specific ibis surveys in 2012, but we did not ground-truth additional fields.

Field-specific surveys

We used a spatially balanced sample design to study ibis foraging patterns in agricultural fields surrounding the Market Lake WMA and Mud Lake WMA breeding colonies, stratifying by distance from colony and irrigation method. We divided the study area into 3 distance bands to represent short- (0–6 km), moderate- (>6–12 km), and long-distance (>12–22 km) commutes from each breeding colony. Using Bray and Klebenow's (1988) reports that ibis had a strong preference for fields >30 ha, we established a similar but slightly smaller minimum field size of 20 ha, which resulted in 1,690 potential agricultural fields to survey. We used general randomized Tessellation stratified sampling (GRTS; Stevens and Olsen 2004) to create an ordered list of fields to sample such that an equal number of fields (*n* = 50/strata; 300 total) would be surveyed from each distance band and irrigation combination (0–6 km center pivot, 0–6 km non-pivot, >6–12 km center pivot, >6–12 km non-pivot, >12–22 km center pivot, >12–22 km non-pivot) while ensuring even spatial coverage throughout the entire study area, regardless of the number of fields sampled. We followed this survey protocol from late April to mid-May, but when ground-truthing fields for irrigation practice during early season visits, we soon found that some non-pivot fields had either been misclassified or recently converted to a center pivot irrigation system. Additionally, we observed very little use of center pivot fields by ibis and determined a reduced sample size of center pivot fields was appropriate to allocate more effort in non-pivot fields with a goal of generating a sufficient sample size. Thus, on 21 May we implemented a 70:30 ratio of non-pivot (*n* = 210 overall; *n* = 70/distance band) versus center pivot (*n* = 90 overall; *n* = 30/distance band) fields for the remainder of the survey season. We did not observe any changes in irrigation frequency (i.e., rate of water application) over the course of the season; thus, we do not believe our shift in survey effort introduced bias when comparing earlier season surveys using the original ratio and later season surveys that enabled more of a focus on non-pivot fields.

When a selected field was not accessible (e.g., no road access, private property issue) or of the wrong irrigation type, we removed it from the sample and replaced it with the next field in the sampling sequence from the same distance band and irrigation category. Overall, we replaced 6 fields because of access issues, 3 fields where irrigation method was misclassified, and 24 fields (11% of ground-truthed non-pivot fields) that had been converted to center pivot sometime between 2009 and the start of the survey period.

We timed surveys during the core ibis breeding season of late April through mid-July 2012 (Ryder and Manry 2020). As fields are typically flood-irrigated every 2 weeks, and center pivot-irrigated weekly, our goal was to survey each field approximately every 3 weeks for a total of 4 surveys. Though we recognize that 4 visits to an individual field might not be sufficient to sample the full range of habitat conditions over a 3-month period, we think that all field surveys combined allow for a representative assessment of the full range of habitat conditions. A single observer conducted field surveys between 30 minutes and 7 hours after sunrise. Because observers were not able to enter these privately owned fields, they chose the best, publicly accessible vantage point that allowed visual access to the largest portion of each field to be surveyed. In rare cases where visibility was restricted from the vantage point (<5% of fields), the observer also surveyed from an additional vantage point to ensure as much coverage as possible. From 23 April to 20 May, observers spent 30 minutes at each field looking for and counting ibis, and we quickly noticed that counts rarely changed during the 30-minute duration. Beginning on 21 May, when we increased our sampling effort in non-pivot fields, we also reduced the survey window to 5 minutes; this allowed us to survey more fields each day. Observers spent 5 minutes looking for and counting ibis within the field and recorded group size during the first and fifth minutes of the count period for ibis, if present. Observers also recorded the predominant behavior by scanning the entire flock several times and choosing 1 of 6 behavior categories that was exhibited by the highest proportion of birds in the flock: aggression (fighting or displacement behavior), alertness (body usually motionless but head moving, looking up or around for potential predators), foraging (active pursuit of food, probing, pecking), locomotion (walking, running, flying without actively seeking food), preening (actively cleaning or arranging feathers with bill), and resting (not moving, often with bill tucked in feathers; includes sunning [standing with wings out-stretched to the side]).

During each survey, we recorded crop type, irrigation method, approximate water depth (if any), and weather conditions. Crop types included alfalfa, small grain (barley or wheat), potatoes, and pasture. To assess whether ibis showed a preference for crop type, we conducted a chi-square test for independence.

We estimated water depths to nearest 2.5 cm when possible. Recognizing that flood-irrigated fields are usually not perfectly level, observers estimated an average water depth for each field (when standing water was present). For analyses, we binned these values into depth categories.

We surveyed the majority of fields (218; 58%) 4 times between late April and mid-July. Because of the change in sampling protocol in mid-May, in which we dropped some center pivot fields and added other non-pivot fields, we surveyed 75 center pivot fields only once. Other exceptions to the 4 surveys/field rule were 2 fields that we surveyed twice (<1%), 81 fields (21%) surveyed 3 times, and 1 field (<1%) surveyed 5 times. Of the 300 fields we surveyed ≥3 times, 92 (31%) were center pivot and 208 (69%) were non-pivot. Of the non-pivot fields, 153 (74%) were flood irrigated, whereas 55 (26%) were sprinkler-irrigated via an array of linear drive, wheeled, and piped ground sprinkler systems.

Driving route surveys

To increase detections of ibis foraging in our study area, and to include the relatively limited natural wetlands, we established 26 road-based survey routes, ranging from 28 km to 80 km in length that covered all public, improved and maintained roads in potential ibis habitat within the study area. We delineated routes within areas of agriculture and natural wetlands, and avoided upland rangeland. Though our routes passed by many of the fields in our field-specific surveys, we surveyed these routes independently of field surveys and we aimed to survey each route at least once a month for 3 surveys. We recognize the potential for differences in detectability both between natural wetlands and agricultural fields, and throughout the season as vegetation grew taller in crops and natural wetlands. The driving routes, however, allowed for multiple views into the natural wetlands and each agricultural field we passed; we expect the issue of taller vegetation as summer progressed was similar across the study area.

Two observers (driver, passenger) conducted driving route surveys between 30 minutes after sunrise and 30 minutes before sunset. Most routes took approximately 2 hours to complete. We varied start times for each survey to account for potential differences in activity patterns throughout the day. Likewise, we alternated the driving direction of the route. We drove as slowly as safely possible and searched for ibis on either side of the road. We recorded all ibis that we observed regardless of distance. Observers stopped only if they detected ibis or to more thoroughly scan possible sightings. We recorded all on-ground observations of ibis, including group size, global positioning system coordinates, land cover type (natural wetland, agricultural), crop type, irrigation type, approximate water depth where birds were located, and the dominant behavior of the flock. As with the field surveys, we recorded water depth to the nearest 2.5 cm when possible, and categorically binned for data analyses. We surveyed all but 1 route 4 times ($n = 25$). We surveyed the remaining route 3 times.

Incidental observations

When we observed ibis on the ground during travel between fields and routes, we recorded them as incidental observations. In these cases, we recorded the same variables as those collected during driving route surveys. Because these data added valuable sample size to our formal survey efforts, we report these in the results in their own section and as part of combined observations.

RESULTS

We estimated that as of 2009, nearly 47,700 ha of center pivot cropland and 24,800 ha of non-pivot cropland occurred within 22 km of the ibis colony at Market Lake, and 39,800 ha of center pivot cropland and 9,300 ha of non-pivot cropland occurred within 22 km of the Mud Lake colony (Table 1; Figure 3). Overall, we classified 30% of

TABLE 1 Number of fields and hectares in center pivot and non-pivot (includes wheel-line sprinkler and flood irrigation) within 6 km, 12 km, and 22 km of the Market Lake and Mud Lake white-faced ibis colonies, eastern Idaho, USA, 2012. Irrigation type was inferred from 2009 aerial imagery.

		Market Lake WMA		Mud Lake WMA	
Distance	Irrigation	*n*	ha	*n*	ha
0–6 km	Non-pivot	81	2,354	63	1,860
	Center pivot	4	187	105	5,704
>6–12 km	Non-pivot	239	4,140	215	5,180
	Center pivot	116	6,295	252	13,882
>12–22 km	Non-pivot	1,028	18,352	157	2,254
	Center pivot	851	41,168	392	20,200

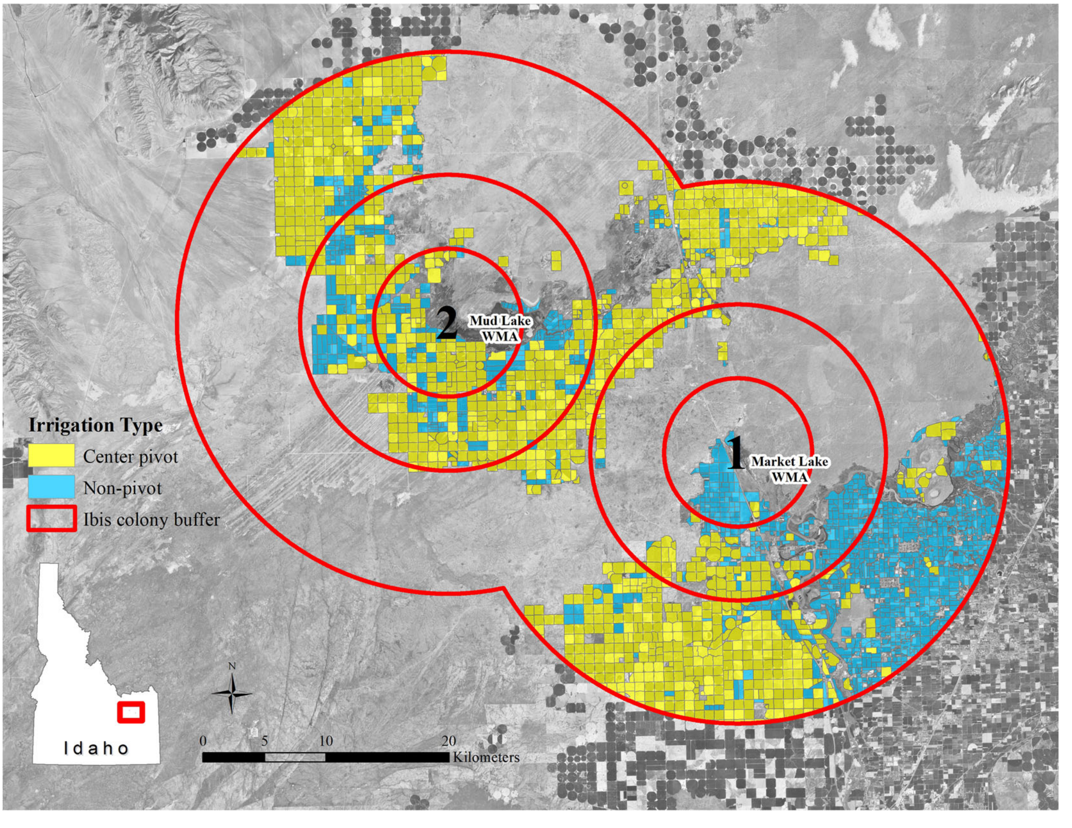

FIGURE 3 Distribution of center pivot and non-pivot fields within the white-faced ibis foraging study area in eastern Idaho, USA, 2012. The concentric circles represent 6-km, 12-km, and 22-km distance bands around the Market Lake Wildlife Management Area and Mud Lake Wildlife Management Area colonies.

agricultural fields in the study area as non-pivot. The area and number of non-pivot fields were similar within 12 km of each colony, but most (73%) of the non-pivot fields surrounding Market Lake, the colony with the larger breeding population during our study, were >12 km away. During ground-truthing of sampled fields, we observed that of non-pivot fields, 73% were in flood irrigation and 27% were in wheel line or hand move sprinkler irrigation.

Field-specific surveys

We conducted 1,200 surveys at 377 different agricultural fields throughout the study area and detected ibis at 42 fields during field-specific surveys. Overall, foraging flocks ranged in size from 3 to 680 birds ($\bar{x}$ = 107, median = 42). We observed foraging behavior at 29 of these fields; 1 (3%) was in center pivot, 3 (10%) were in the flooded-corners of a center pivot field, and 25 (86%) were in non-pivot fields. For the 1 observation in a center pivot, 6 birds flew in during a survey and foraged where water from a leak in the sprinkler system was creating a small flooded pool.

Crop types recorded during field surveys included alfalfa, small grain (barley, wheat), pasture, potatoes, and corn. Of the fields for which we could determine crop type, we observed ibis foraging mostly in alfalfa (58%). We also observed foraging in small grain and pasture. Proportion of use differed from availability (Figure 4), with ibis showing a strong preference for alfalfa (χ^2_5 [n = 100] = 23.19, P < 0.001; Figure 5).

We observed standing water up to approximately 10 cm deep within agricultural fields, and we never observed ibis foraging in dry fields. We documented water depths for 21 fields in which ibis were foraging, and, although >85% of foraging observations were in fields with standing water up to 5 cm deep, we observed foraging in 3 fields with water depths >5 cm.

Driving route surveys

We conducted 103 driving surveys and recorded 134 ibis observations, including 87 ibis foraging observations. Two of these foraging observations consisted of an insufficient level of habitat detail and thus we excluded them from analyses. Similar to field surveys, we observed ibis foraging in flooded corners of center pivot fields and under center pivots themselves infrequently (7 and 3 times, respectively). Twenty-one (25%) foraging observations occurred in natural wetlands, mostly located within Camas National Wildlife Refuge, Market Lake WMA, and Mud Lake WMA. The remaining 54 observations (64%) consisted of ibis foraging in non-pivot agricultural fields. Six (11%) of these fields were sprinkler-irrigated (ground and wheeled), while the remaining 48 (89%) were flood-irrigated. Of

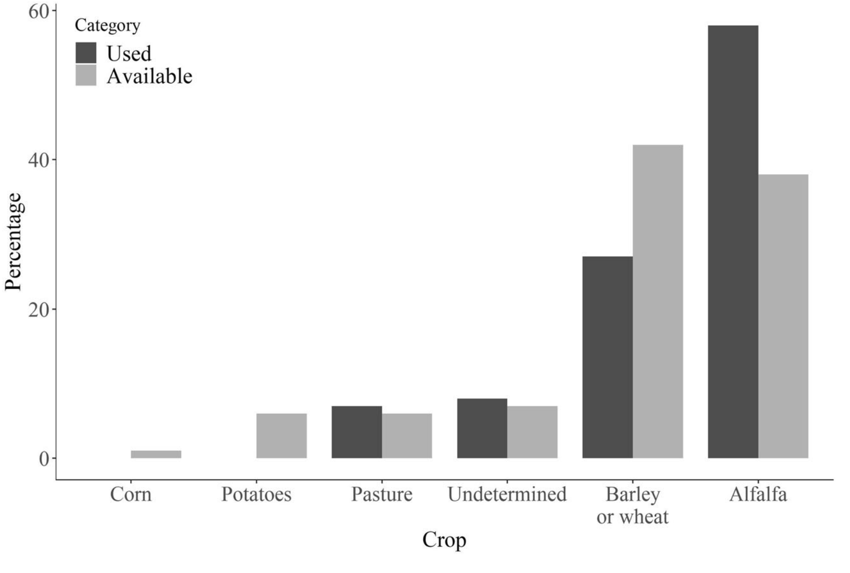

FIGURE 4 Used versus available crop types for white-faced ibis foraging observations collected during field surveys within 22 km of the Market Lake Wildlife Management Area and Mud Lake Wildlife Management Area colonies in eastern Idaho, USA, 2012.

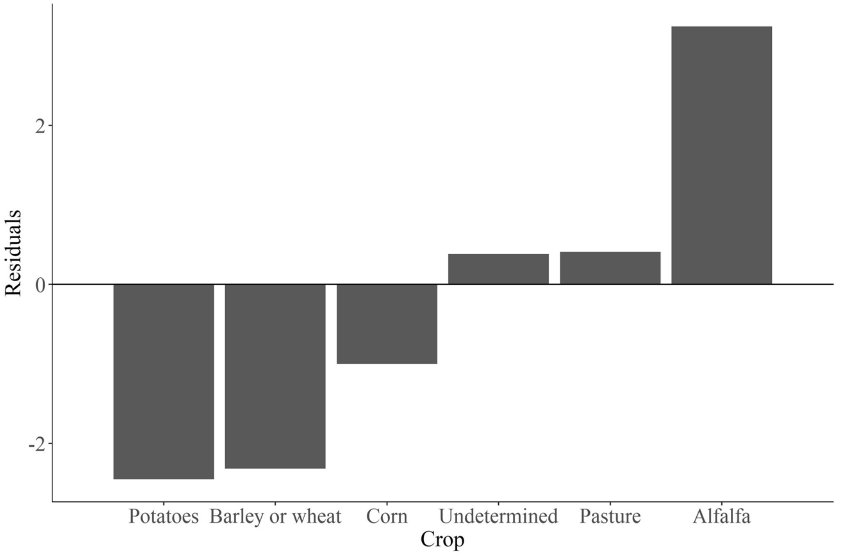

FIGURE 5 Crop type preference (χ^2_5 [n = 100] = 23.19, P < 0.001) of white-faced ibis observed foraging in agricultural fields within 22 km of the Market Lake Wildlife Management Area and Mud Lake Wildlife Management Area colonies in eastern Idaho, USA, 2012. Residuals represent the dis-proportionate use based upon availability, revealing degree of preference or avoidance.

the fields for which we could determine the crop type, 24 foraging observations were in small grain, 18 in pasture or hay, 16 in alfalfa, and 2 in corn.

Incidental observations

Of 94 incidental observations of ibis on the ground, we recorded 70 (74%) observations of foraging birds; the rest were preening, resting, in alert mode, or moving across a field. The majority (89%) of incidental foraging observations were from non-pivot fields, while 5 were in flooded corners of center pivot fields, 2 were in canals between non-pivot fields, and just 1 under a center pivot. No incidental observations of foraging birds occurred in natural wetlands. Of the fields for which we could determine crop type, 25 foraging observations were in alfalfa, 19 in small grain, and 12 in pasture or hay.

Combined observations

We analyzed all observations collectively, combining data from field surveys, driving route surveys, and incidental observations. We recognize this approach likely underestimates the importance of natural wetlands because they were only sampled during road surveys, but we found it useful for summarizing general trends. Combining survey types, we collected 186 observations of foraging ibis in the study area (Figure 6), 181 of which we recorded enough habitat detail for analyses. Foraging flocks ranged in size from 1 to 700 birds. They predominantly occurred in non-pivot agricultural fields (140; 77%) but also in natural wetlands (21; 12%), flooded edges of center pivot fields (14; 8%), and within center pivot fields (6; 3%). Within agricultural fields, 87.5% of foraging observations were in non-pivot and 12.5% were in center pivot-irrigated fields. Of 145 foraging observations in cultivated fields for which we had data on crop types, alfalfa was the most common crop type used by foraging birds (57; 39%), but we also frequently observed foraging birds in small grain (34%) and pasture or hay (21%). The other 9 observations were in

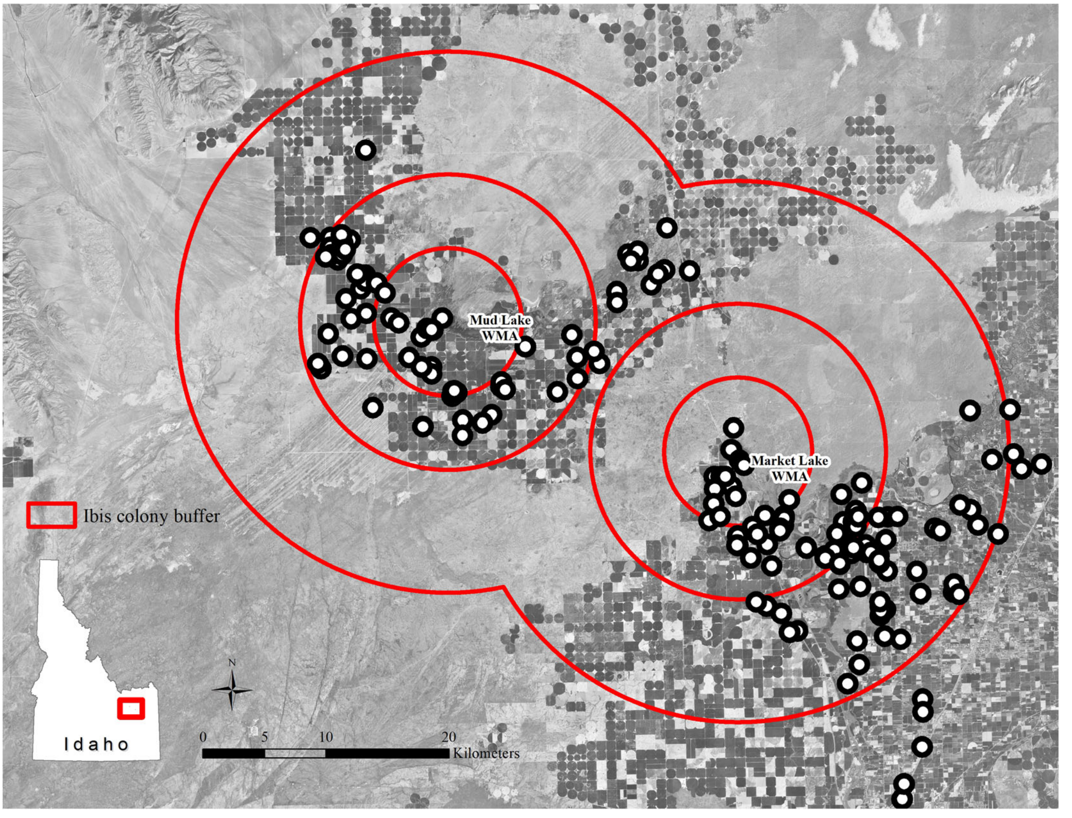

FIGURE 6 Foraging white-faced ibis observations, from all survey methods combined, around the Market Lake Wildlife Management Area and Mud Lake Wildlife Management Area colonies in eastern Idaho, USA, 2012. The concentric circles represent 6-km, 12-km, and 22-km distance bands around the 2 colonies.

all other crop types (i.e., corn, potatoes, a mix, fallow). Of the 45 fields for which we had area information, we observed ibis foraging in fields that ranged from 8 ha to 80 ha, with an average field size of 38 ha. We recorded 75 and 129 foraging ibis observations within 22 km of the Mud Lake and Market Lake colonies, respectively. Only 33 observations (16.2%) were within 6 km of the colonies, while 78 observations (38.2%) were >6–12 km from colonies, and the rest (83 observations, 40.7%) were >12–22 km from colonies. This proportion varied between colonies, with over 51% of observations around Market Lake being >12–22 km from colonies versus only 22.7% of similar distance observations around Mud Lake. Although we typically detected ibis only once in any particular field, we did detect foraging ibis at 10 agricultural fields in the study area on >1 occasion. These fields were flood-irrigated, with the exception of 1 field that was being irrigated by wheel line sprinklers. The distribution of observations differed between the 2 colonies. We recorded 79% of the foraging observations (59/75) around Mud Lake within 12 km of the colony. In contrast, >50% of our foraging observations around the Market Lake colony were between 12 km and 22 km (76; 59%); the majority (47; 62%) were east and southeast of the colony.

DISCUSSION

This study generated novel data on the spatial distribution and habitat use patterns of foraging ibis during the breeding season. There were consistent patterns across all observations and survey methods, namely that ibis used non-pivot fields (predominantly in flood irrigation) at a much higher frequency than available in the agricultural landscape. In addition, we observed birds within a 22-km radius of the Market Lake WMA colony almost exclusively to the south and southeast of the colony, consistent with the distribution of flood-irrigated agriculture in the area.

In examining use versus availability, irrigation type was more important than crop type in determining ibis presence. Although non-pivot fields make up only 30% of the cultivated fields in the study area, and 63% of the fields we sampled in our field surveys, 88% of foraging ibis observations in agriculture occurred in non-pivot fields. Our observations of water depth associations further support the reliance of ibis on agricultural fields with standing water. Though these agricultural landscapes cannot fully replace the ecological complexity and ecosystem services of natural wetlands, they appear to serve as a partial surrogate for permanent or seasonally flooded wetlands in providing foraging habitat (Safran et al. 2000). In particular, ibis prefer standing water of up to 5 cm deep in fields, which is more than would normally be present from sprinkler-irrigated agriculture.

Within field surveys, our data suggests that ibis prefer alfalfa fields for foraging over other crop types available in our study area. Similarly, Bray and Klebenow (1988) observed ibis using alfalfa fields 86–100% of the time in Nevada and concluded that ibis had a preference for alfalfa. Availability of alfalfa in their study area was much higher than observed in ours (68–79% vs. 38%), and their observation could reflect alfalfa representing most of the agriculture available. Our study provides confirmation that ibis have a preference for alfalfa when foraging in flooded agricultural fields. As Bray and Klebenow (1988) speculated, this may be a result of alfalfa's nitrogen-fixing properties. High soil nitrogen promotes growth and increases protein content in earthworms (Evans and Guild 1948, Brady 1990). It is also possible that ibis are selecting for a combination of vegetation height and specific hydrology, as opposed to a particular plant or crop type.

Throughout the course of this study, we observed ibis foraging in the same fields only a handful of times. Because a flooded field is only likely to be suitable foraging habitat for a few days until standing water recedes, ibis need to shift their foraging locations frequently throughout the breeding season, keying in on recently flooded fields (Bray and Klebenow 1988). This indicates the importance of having a mosaic of flooded fields available within 22 km of a breeding colony throughout the breeding season.

Although we observed birds in agricultural areas in all expected directions and distances around Mud Lake, we observed an unusual distribution around Market Lake. Specifically, we observed a higher proportion of ibis in the >12–22 km band around Market Lake than Mud Lake. For those that were not also within the >6–12 km band around Mud Lake (an area of overlap in which proximity to Mud Lake suggests that these birds likely originated from the Mud Lake colony), almost all of these observations were concentrated to the east and southeast, with the remainder concentrated around Camas National Wildlife Refuge. Our observations of flying flocks in the morning and evening (leaving and returning to Market Lake) confirmed that most birds were flying in generally southeast or northwest directions. As there were no other known nesting colonies in the vicinity, the birds observed >12 km southeast of the Market Lake colony were most likely breeding birds commuting from Market Lake. Thus, many birds were foraging notably farther from the colony than is reported in the literature. In addition, although the amount of flooded agriculture within 12 km of Market Lake is similar to that of Mud Lake, Market Lake was a much larger breeding colony than Mud Lake in 2012. Therefore, the amount of foraging area needed by such a large colony may be greater than what was currently available within 12 km.

In ground-truthing sampled fields, we observed a conversion of 24 fields from non-pivot to center pivots since 2009, which represents a potential loss of 1,100 ha of flood-irrigated cropland. A follow-up analysis of 2019 imagery revealed a conversion >7,000 non-pivot ha to center pivot in our study area between 2009 and 2019 (S. J. Knetter, IDFG, unpublished data). Our ground-truthing activities documented that 73% of non-pivot fields were flood-irrigated. Therefore, this conversion represents a loss of approximately 5,000 ha of flood-irrigated cropland—a 16% decline. This aligns with regional trends, which include a 13% increase in sprinkler irrigation and a 17% decline in flood irrigation between 2000 and 2010 across the 17 most western states (Maupin et al. 2014), a trend that continued through 2015 (Dieter et al. 2018). Combined with additional threats, such as subdivision development, the impacts to foraging aquatic birds in the Market and Mud lake area could be substantial (McWethy and Austin 2009). Though we observed ibis, gulls, and other waterbird species (especially migratory waterfowl and shorebirds) feeding in the flood-irrigated corners bordering center pivot fields, flock sizes were generally lower than those found in non-pivot fields. Thus, while these flooded corners are used, if conversion to center pivot were to continue, it is unlikely that flooded corners alone will provide enough foraging habitat to support the current population of these species.

Finally, breeding colony surveys at Market and Mud Lake WMAs suggested a 27% drop in breeding ibis between 2010 and 2012 (C. E. Moulton, IDFG, unpublished data). Since our study, managers noted a complete abandonment of the Market Lake colony in 2018, and no nesting has resumed as of 2021. Without having studied this colony carefully in recent years, we can only speculate as to the cause(s) of this abandonment. Several factors that warrant consideration are the innately nomadic nature of ibis, a reduction in suitable agricultural foraging habitat, increased water scarcity (drought or increased use for irrigation), and groundwater depletion. White-faced ibis are nomadic and parts of the population could have shifted to other colonies to take advantage of favorable habitat conditions elsewhere; ibis first colonized our study area approximately 35–40 years prior to our study. Given the rate of conversion we observed, and that we documented birds traveling much farther to forage than noted in prior literature, it is plausible that changes in foraging opportunities are affecting viability of these colonies. Surface water loss, combined with decreasing groundwater, from climate and water management practices may be exacerbating the loss of functional wetland habitat in an already arid environment (Donnelly et al. 2020). Therefore, we suggest that it is important to continue to monitor these colonies and to work to conserve adequate foraging habitat to ensure these breeding populations can be sustained.

MANAGEMENT IMPLICATIONS

Our study indicates that maintenance of flooded agricultural lands, particularly those planted in alfalfa and, to a lesser degree, pasture, within 22 km of these 2 ibis nesting colonies is important for their persistence. Maintaining natural wetlands with emergent vegetation is critical and restoring or creating additional wetlands where feasible and appropriate, particularly within 12 km of the colonies, could partially offset losses of flood-irrigated fields to conversion.

As conversion to center pivots is prevalent throughout the West, the potential impacts to other nesting colonies of ibis and other wetland species that are reliant on flooded habitats, should be of significant concern. If the patterns we observed in this study are similar elsewhere, it speaks to the importance of flood-irrigated agriculture as a partial surrogate for seasonally flooded wetlands in providing foraging habitat, especially in areas where natural wetlands have been lost. We suggest considering the current policies on irrigation practices relative to wildlife conservation goals (e.g., potential conflicts with river flows, fisheries, and other wildlife issues) and that maintaining some level of flood irrigation on the landscape is likely highly beneficial for migratory waterbirds. Private landowners will play an important role in the future management of these species, while state and federal wildlife managers will need to manage these species on a landscape scale, beyond the borders of the wetlands within which the birds breed.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

ETHICS STATEMENT

While our sampling protocol was completely observational, we followed guidelines approved by the Boise State University Institutional Animal Care and Use Committee (permit 006-AC11-004).

DATA AVAILABILITY STATEMENT

Data are available on request because of privacy or ethical restrictions.

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