Articles

Availability of Supplemental Corn for Sandhill Cranes, Light Geese, and Dabbling Ducks Wintering in New Mexico

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Abstract

The Middle Rio Grande Valley of central New Mexico overwinters the majority of the Rocky Mountain Population of greater sandhill cranes *Antigone canadensis tabida* and numerous Midcontinent Population lesser sandhill cranes *A. c. canadensis*, light geese (i.e., snow *Anser caerulescens* and Ross's geese *Anser rossii*), and dabbling ducks (i.e, *Anas* spp.). Stemming from changes in agricultural practices and loss of habitat, these species have become largely dependent on public lands where corn supplements natural foraging resources, providing a key dietary component while also discouraging crop depredation on private lands. To evaluate if supplemental corn provides a sufficient resource base, we estimated energy available in corn resources and seasonal energy requirements of the sandhill cranes, which consisted of the Rocky Mountain Population and Midcontinent Population. Additionally, we considered energetic requirements for two other wintering guilds, light geese and dabbling ducks. Depletion rates of postmowed corn increased throughout winter from 3,673 $\pm$ 843 kg/ha/d (mean $\pm$ SE) in December to 7,014 $\pm$ 1,884 kg/ha/d in February. The estimated seasonal energetic requirement of the Rocky Mountain Population and Midcontinent Population was 1.14×10^9 kcal (95% CI $= 1.07 \times 10^9$ to 1.21×10^9 kcal). The combined seasonal energetic demand of the Rocky Mountain Population, Midcontinent Population, light geese, and dabbling ducks was 4.23×10^9 kcal (95% CI $= 3.81 \times 10^9$ to 4.53×10^9 kcal) or 911,813 kg of corn (95% CI = 820,821–1,006,894 kg). From 2014 to 2017, corn production on public lands in the Middle Rio Grande Valley was 1,052,006 $\pm$ 58,965 kg grown on an average of 76 ha, sufficient for winter energetic requirements of all guilds. Interagency collaboration, effective planning during the growing season, and strategic schedules for mowing supplemental corn crops that integrate population abundances and their respective energy demands should further promote success of the supplemental corn program in the Middle Rio Grande Valley.

Keywords: *Antigone canadensis tabida*; bioenergetics; greater sandhill crane; migratory birds; supplemental corn

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Introduction

Natural resource organizations (e.g., U.S. Fish and Wildlife Service, Migratory Bird Habitat Joint Ventures, and State Wildlife Agencies) in North America are regularly tasked with establishing habitat objectives for wintering migratory birds that are implemented at regional scales (U.S. Fish and Wildlife Service 2012; Williams et al. 2014). Focused on waterfowl, these initiatives concentrate on linking energetic requirements of a species and the energy base provided from food resources within winter habitats (Fino et al. 2017; Guillemain et al. 2017). Consideration of food resources in the context of energy supply and demand has great practical significance for managing and conserving populations of migratory gamebirds. Determining whether energy availability in food supplies is in equilibrium with population demands can guide habitat management practices, which can be modified to meet population objectives (Davis et al. 2014; Petrie et al. 2016).

Limitation of winter food is an important driver of population dynamics in migratory birds (Sherry et al. 2005; Danner et al. 2013). Access to high-quality food resources during winter can not only influence physiological condition and survival during this period (Duriez et al. 2012; Cooper et al. 2015; Rakhimberdiev et al. 2015) but also dictate timing and successful completion of spring migration (Cooper et al. 2015; Paxton and Moore 2015). Furthermore, energetic gains during winter can be a deciding factor in reproductive performance during the breeding season (Newton 2004; Inger et al. 2010; Sedinger and Alisauskas 2014). Essentially, the potential variation in habitat quality and quantity (i.e., available forage) can influence population dynamics of migratory birds, such as sandhill cranes, ducks, and geese (Sedinger and Alisauskas 2014). Therefore, potential for such cross-seasonal effects requires careful planning and consideration of the availability and quality of food for wintering migratory birds.

In the Middle Rio Grande Valley (MRGV) of central New Mexico, a multiagency program supplements food to wintering migratory gamebirds by growing corn *Zea mays* on public lands that is left standing until manipulated (i.e., mowed) during critical wintering months (December–February). With reductions in food supplies in the MRGV because of changes in agricultural practices (e.g., increased alfalfa production and less corn), drought (e.g., wetland extent loss), and loss of habitat from anthropogenic activities (Pacific Flyway Council and Central Flyway Council 2016; Boggie et al. 2018b), public lands provide crucial habitat for wintering migratory gamebirds. The principal motivation for the supplemental corn program was to provide energetic and nutritional support to the Rocky Mountain Population (RMP) of greater sandhill cranes *Antigone canadensis tabida* that overwinter in the MRGV and reduce crop depredation issues on adjacent private lands (Taylor 1999; U.S. Department of Agriculture 2009; Sanchez and Cline 2020). Approximately 80% of the RMP winter in the MRGV, making it the single most important wintering area for this population (Pacific Flyway Council and Central Flyway Council 2016).

Additionally, the MRGV supports thousands of wintering light geese (lesser snow geese *Anser caerulescens* and Ross's geese *A. rossii*) and a variety of dabbling duck species (i.e., *Anas* spp.), including mallard *Anas platyrhynchos* and northern pintail *A. acuta*. Additionally, an influx of lesser sandhill cranes *A. c. canadensis* from the Midcontinent Population (Krapu et al. 2014; Pacific Flyway Council and Central Flyway Council 2016) has placed greater pressure on food resources, in particular supplemental corn. A general planning structure devised and currently implemented in the MRGV to manage migratory gamebirds is in place (Taylor 1999; Sanchez and Cline 2020). Management actions detailed in the plan have proven successful; however, incorporation of species-specific energetic demands and energy available from corn produced on public lands is lacking.

An evaluation of whether current crop management (e.g., production, depletion, and energetic content) for supplemental corn provides the necessary population energy requirements for each guild (sandhill cranes, light geese, and dabbling ducks) is necessary. We drew from literature to estimate daily energy expenditures and relied on survey data collected seasonally by state and federal agencies to establish winter population estimates for each guild. Our objective was to evaluate whether current crop management for corn produces a sufficient energy base for each of these guilds that overwinter in the MRGV through total corn production, daily depletion rates, and energetic content of grown corn.

Study Area

Our study area was the MRGV of central New Mexico (Figure 1). The MRGV is an area of ~726 km^2, as defined by the Rio Grande and associated floodplain, and spans north of Albuquerque, New Mexico, and approximately 200 km downstream south of Bosque del Apache National Wildlife Refuge (Bosque del Apache NWR). The valley floor has a mean elevation of 1,470 m. Mean precipitation during winter 2014–2017 was 19 mm (range = 0.8–49.8 mm), with a mean temperature of 8°C (range = 1.6–17.3°C). Outward from the riparian zone along the Rio Grande, the area is characterized by Rio Grande cottonwood *Populus deltoides wislizeni* galleries along with dominant native and nonnative vegetation assemblages, including willows (Gooding willow *Salix gooddingii* and coyote willow *S. exigua*), salt cedar *Tamarisk chinensis*, New Mexico privet *Forestiera neomexicana*, and Russian olive *Elaeagnus angustifolia*. The remaining floodplain is a matrix of suburban and urban areas with irrigated agricultural lands consisting of primarily alfalfa *Medicago sativa*, pastures and grass hay, and some small grain silage for livestock (Howe et al. 1991; Swanson et al. 2011). In addition, New Mexico Department of Game and Fish state (Ladd S. Gordon Complex) and federal (Bosque del Apache NWR) properties support sandhill cranes, light geese, and multiple species of dabbling ducks through a matrix of the aforementioned floodplain habitats along with

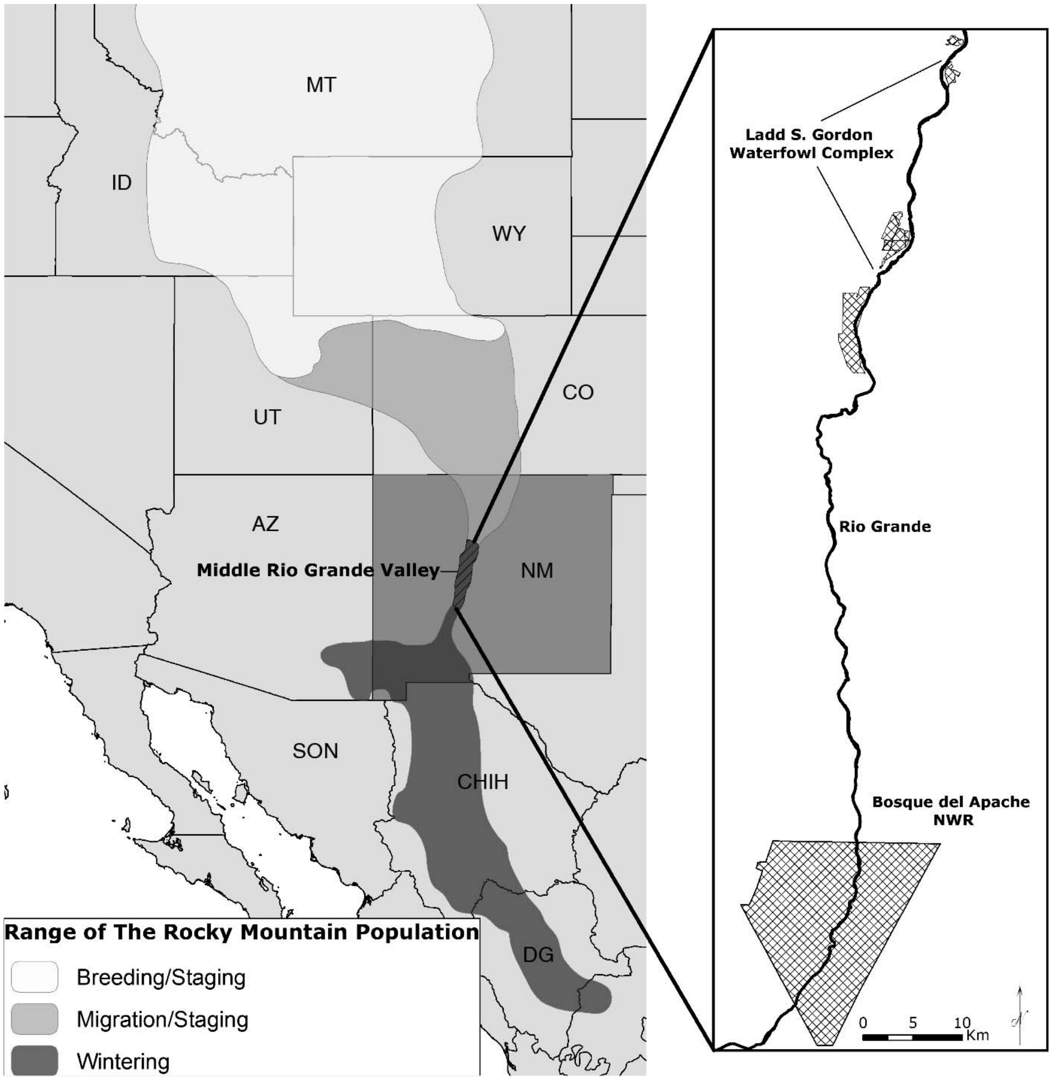

Figure 1. The study area was the Middle Rio Grande Valley of central New Mexico, which overwinters large populations of migratory birds, including most of the Rocky Mountain Population of greater sandhill cranes, on federal (Bosque del Apache National Wildlife Refuge) and state (Ladd S. Gordon Waterfowl Complex) properties from 2014 to 2017.

moist-soil-managed wetlands and corn fields (Boggie et al. 2018a).

Methods

Sandhill crane, light goose, and dabbling duck energetics

Multiple modeling techniques have been developed and implemented for estimating daily energy expenditures of waterfowl. The foundation of these techniques is estimation of resting metabolic rate from respirometry studies for a particular species or generalized linear models that explain variation in resting metabolic rate as a function of body mass across multiple species (Williams et al. 2014; Ringleman et al. 2018). Bioenergetic models, which derive energy expenditures of an individual, account for resting metabolic rate and metabolic cost of daily activities experienced under free-living conditions. However, complexity increases by incorporating other components, such as thermoregulatory costs (McKinney and McWilliams 2005; Ladin et al. 2011; Livolsi et al. 2015; Aagaard et al. 2018) or costs of growth and lipid production (Pearse et al. 2010). More complex bioenergetic models can offer greater insight into the energetic envelope of a species. Transferability of the models to different taxa and data limitations (e.g., zone of thermal neutrality or lower and upper critical temperatures for a particular species) led to use of more simplistic models, albeit with more assumptions and caveats, to determine energetic expenditures for a species and associated energetic carrying capacity of their habitat (Williams et al. 2014; Petrie et al. 2016). For our purposes of approximating a general baseline for energetic carrying capacity of the MRGV, we elected to use more simplistic models to estimate the energetic expenditures of the three guilds of wintering species to maintain consistency between the three guilds due to sandhill cranes not having an established true metabolic energy value. We believe these are suitable given the objectives of this study and maintain consistency among the three guilds of birds.

Our approach for each guild was similar. We used the allometric equation estimated by Miller and Eadie (2006) for all waterfowl to determine the resting metabolic rate (RMR) of representative species in each guild:

$$\mathrm{RMR} = 422(\text{body mass [kg]})^{0.74}.$$

We used mean body mass of greater ($n = 926$ and mean $= 5.2$ kg) and lesser ($n = 419$ and mean $= 3.1$ kg) sandhill cranes, respectively, harvested by hunters and weighed at hunter check stations in central New Mexico (Schmitt and Hale 1997). We used mean body mass of light geese ($n = 64$ and mean $= 1{,}938$ g) wintering at latitudes similar to our study area (Flickinger and Bolen 1979). For dabbling ducks, we used mean body mass of mallards ($n = 2{,}138$ and mean $= 1{,}125$ g), the most abundant dabbling duck wintering in our study area, captured and banded by refuge biologists at Bosque del Apache NWR from 1999 to 2017 (Andersson et al. 2018; Bosque del Apache NWR, unpublished data).

Our central objective was estimating energy requirements for the populations of each guild through winter. Thus, we scaled individual daily energy expenditures to estimated population abundance for each guild. We used surveys flown by New Mexico Department of Game and Fish in fixed-winged aircraft during November, December, and January combined with biweekly ground surveys conducted by U.S. Fish and Wildlife Service on Bosque del Apache NWR to determine mean winter population abundance for sandhill cranes, light geese, and dabbling ducks during the study period (New Mexico Department of Game and Fish and U.S. Fish and Wildlife, unpublished data). We used mean peak abundance indices between the two surveys (monthly aerial and biweekly ground surveys) to represent population abundance, because these values more accurately depicted the number of individuals placing demands on resources through the winter based on our personal observations in the field. We assumed that the proportion of the RMP of greater sandhill cranes wintering in the MRGV was ~80% (Pacific Flyway Council and Central Flyway Council 2016) of the 3-y average from fall population surveys on staging areas that spanned our study period (Thorpe et al. 2016). We subtracted this number from the total number of sandhill cranes counted in surveys conducted in the MRGV to provide an estimate of lesser sandhill cranes that belong to the Midcontinent Population and winter in the MRGV.

Corn production

Each winter, land managers at Bosque del Apache NWR and Ladd S. Gordon Complex estimate production (i.e., yield) for all corn fields. We used these estimates to represent winter corn production on state and federal properties from 2014 to 2017. We used procedures to sample corn yield within fields following standardized methods (Lauer 2002; Nielsen 2004; Thomison 2015). In general, depending on field size and row spacing, we randomly sampled two to six 4.5- to 5.3-m^2 sections of standing corn (corresponds to 1/1,000 acre) within a field. Within these sections, we counted the total number of ears and sampled a subset of ears. We then counted the number of kernels on sampled ears and determined the moisture content of kernels through a moisture analyzer or oven drying and weighing to constant mass. We estimated total dry mass of corn within sample sections and extrapolated to estimate field-specific corn production (dry weight [kg/ha]). We derived the total corn production (dry weight [kg/ha]) at each property for the total area planted per site (Bernardo Wildlife Area, mean $= 50$ ha; Bosque del Apache NWR, mean $= 100$ ha). We used analysis of variance (ANOVA) to determine if corn production varied by year.

Corn energy

In waterfowl bioenergetic studies, true metabolizable energy (amount of energy in a food resource after accounting for metabolic fecal and endogenous urinary losses) is often used as the unit of energy of food resources available to consumers (Miller and Reinecke 1984; Brasher et al. 2007; Williams et al. 2014; Guillemain et al. 2017). To our knowledge, there are no taxa-specific estimates of true metabolizable energy of food resources for cranes, and estimates for the closest species in body mass are geese (Storey and Allen 1982; Petrie et al. 1998). Therefore, rather than assume that these estimates are germane to sandhill cranes and corn varieties grown in the MRGV, we estimated and used gross energy of different varieties of corn grown on state and federal properties to represent energetic availability of corn resources. State and federal agencies have different guidelines governing what types of corn they grow. Specifically, Bosque del Apache NWR is restricted to grow only nongenetically modified crops (NON-GMC) of corn, whereas New Mexico Department of Game and Fish is not. Moreover, throughout the study period, Bosque del Apache NWR grew strains of heirloom corn historically farmed in the MRGV, with the objective to determine if these strains are more resilient to lower soil nutrients and drought than other NON-GMC varieties. During the first year of the study, we sampled all varieties grown on state and federal properties, which included all varieties available to grow throughout the study period. We classified each variety as genetically modified crop (GMC), NON-GMC, or heirloom. We sent samples to Washington State University Wildlife Habitat and Nutrition Laboratory to analyze each variety for gross energy by bomb calorimetry. For each variety, we applied mean caloric content (kcal/g dry mass) to fields growing that variety to estimate total energy availability (kcal) from corn production on state and federal properties. We used

ANOVA to determine if energy content differed among corn varieties.

Corn depletion

In many studies investigating availability and depletion of corn as it relates to consumption by migratory birds, corn availability is residual waste grain from postharvested fields usually owned by private producers (Pearse et al. 2010; Anteau et al. 2011; Sherfy et al. 2011). In our study area, standing corn is available to birds gradually by mechanical manipulation (i.e., tractors pulling commercial rotary mowers) throughout the season. Of note, bumping (knocked down at about 0.75 m off the ground; Post et al. 1998) of corn was historically a management option that was not used during this study period. We were particularly interested in estimating depletion rates of mowed corn; that is, once an area of standing corn was mowed, how long does residual corn from that mowing event persist before it is completely consumed? We could apply such estimates toward mowing schedules used by land managers, and these estimates could provide useful information in determining availability of corn biomass given the area of standing corn mowed while considering energetic demands of migratory gamebird populations that rely on the resource throughout winter.

We coordinated with land managers on state and federal properties to sample mowed corn following their normal mowing schedules beginning in December through February to estimate daily depletion of postmowed corn. We stratified our sampling across December, January, and February. Depending on how many fields still had standing corn, we sampled two to four fields on both state and federal properties within each month. Once land managers identified fields for each sampling occasion, we followed tractors to a field where they mowed 12 rows of corn using two passes within that field. Immediately following mowing and before any granivory, we sampled corn within the mowed area. We used 1-m^2 quadrats to sample corn and sampled 25 quadrats/ha (10 quadrats/acre). We estimated number of hectares per row within each field and then area mowed by multiplying ha/row by number of rows mowed and allocated sampling quadrats proportionally to the mowed area. We used a vehicle-mounted global positioning system antenna (Garmin GPS18x USB) connected to a laptop running a geographic information system (ArcGIS 10.2, ESRI, Redlands, CA) equipped with multispectral high-resolution imagery (1-m^2 pixels) to randomly generate sampling locations for quadrats within the mowed area in real time. We removed all corn (kernels and any intact ears) within each quadrat. For the subsequent 2 d following initial sampling, we repeated the protocol within the mowed area to determine daily change in corn availability. Locations of quadrats within the mowed area were never spatially coincident with quadrats sampled on previous days. Following field collection, we dried and weighed (i.e., corn kernels removed from ears) each sample to a constant mass to the nearest gram. We summed dry weights of corn from all quadrats sampled on the same day within the same field. We then estimated proportional change in amount of corn between subsequent days within each sampling occasion for each field.

To relate daily proportional change in amount of corn to total amount of corn available within the mowed area, we used corn production estimates for each field and field area to derive density of corn (kg/ha) for each field and estimate kg/mowed area on the first day of sampling. We used this as our starting density of corn within the mowed area and to estimate total corn production within the study area. For each subsequent day, we applied the corresponding proportional change between sample days to estimate amount of corn depleted daily. Our estimate of daily depletion rates relied on several assumptions. First, values of standing corn production remain constant throughout the season, and there is little depletion of corn when standing. We felt that this is a fair assumption for our sampling circumstances, as the structural characteristics of an average fully matured corn field (e.g., height and density of corn stalks within a field) in our study area discourages feeding of standing corn by birds. While there is a presence of elk *Cervus canadensis* and mule deer *Odocoileus hemionus*, they typically consume corn before it is made available to the target birds (i.e., cranes, ducks, and geese). Second, changes in amount of corn found in quadrats sampled between days were proportional to changes of depletion of total amount of corn within the mowed area, which we believe is a reasonable assumption given that corn is dispersed in areas that were mowed. We used the lme4 package to fit linear mixed-effects models to explore what factors might explain variation in daily depletion rates (Bates et al. 2015). We square root transformed the response variable to meet assumptions of normality and homogeneity of variance. We considered fields nested within season as random effects, and covariates included day of season, month, and minimum temperature. We performed all statistical analyses in Program R, and we used an α of 0.07 as the threshold to determine statistical significance to capture what we felt were biologically relevant parameter estimates (R Core Team 2017).

Results

Sandhill crane, light goose, and dabbling duck energy expenditures

Fall survey estimates during this study estimated 22,087 RMP sandhill cranes (3-y average; Thorpe et al. 2016). Assuming ~80% of the RMP winters in the MRGV, 17,670 sandhill cranes from the RMP relied on forage resources on state and federal properties. Winter surveys of sandhill cranes in the MRGV conducted by the New Mexico Department of Game and Fish and U.S. Fish and Wildlife Service from 2014 to 2017 estimated a mean

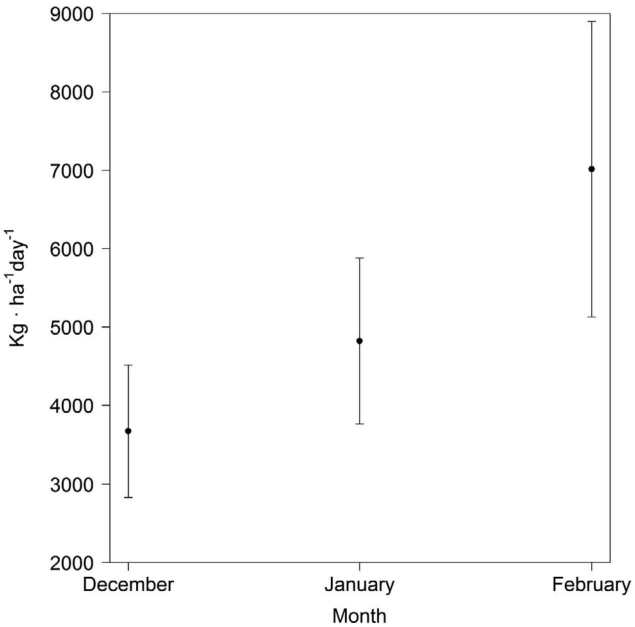

Figure 2. Monthly mean ± standard error daily depletion rates of postmowed corn grown on state and federal properties managed for wintering migratory birds in the Middle Rio Grande Valley of central New Mexico from 2014 to 2017.

population abundance of 20,608 sandhill cranes. After accounting for the 17,670 sandhill cranes from the RMP, we estimated that 2,938 lesser sandhill cranes from the Midcontinent Population wintered in the MRGV. We estimated the mean duration of stay for the RMP in the MRGV from sandhill cranes tagged with satellite transmitters as ~88 d (mean arrival of November 23 ± 2 d, n = 22; mean departure of February 18 ± 1 d, n = 35; Boggie et al. 2018a). Assuming a winter season of 88 d, we estimated the seasonal energetic requirement for the RMP and Midcontinent Population from monthly daily energetic expenditures as 1.14×10^9 kcal (95% CI = 1.07×10^9 to 1.21×10^9 kcal).

Winter surveys of light geese and dabbling duck populations in the MRGV conducted by the New Mexico Department of Game and Fish and U.S. Fish and Wildlife Service from 2014 to 2017 estimated a mean population abundance of 20,608 light geese and 50,935 dabbling ducks. We assumed the same winter period of 88 d for light geese and dabbling ducks for consistency. The estimated mean population-level energy requirement for light geese wintering in the MRGV was 1.61×10^9 kcal (95% CI = 1.39×10^9 to 1.84×10^9 kcal), and the estimated mean population-level energy requirement for dabbling ducks wintering in the MRGV was 1.48×10^9 kcal (95% CI = 1.35×10^9 to 1.62×10^9 kcal).

Corn availability related to energetic demands of wintering sandhill cranes, light geese, and dabbling ducks

Total corn production on state and federal properties ranged from 967,278 to 1,165,408 kg through the winters of 2014 to 2017, with corn acreage planted ranging from 47 to 132 ha between state and federal properties. Mean corn production between state and federal properties over the three winters was 1,052,006 ± 58,965 kg. Estimated caloric energy differed among the three varieties of corn (GMC, heirloom, and NON-GMC) grown on state and federal properties ($F_{2,31}$ = 25.7 and P < 0.001). Estimated caloric content for heirloom varieties (4.74 ± 0.03 kcal/g, n = 15) was slightly greater than NON-GMC (4.52 ± 0.02 kcal/g, n = 5) and GMC varieties (4.57 ± 0.01 kcal/g, n = 15). Although caloric content of corn varieties differed, mean energy availability from corn produced on state and federal properties did not differ by season ($F_{2,78}$ = 1.69 and P = 0.19). Using the mean energy available across all corn varieties (4.6 kcal/g ± 0.019), total energy available from corn production across years was 4.82×10^9 kcal ± 2.72×10^8.

Table 1. Results from linear mixed-effects models describing the influence of covariates on rate of daily depletion (kg/ha) of postmowed standing corn in the Middle Rio Grande Valley of central New Mexico from 2014 to 2017.

Model	Parameter	Estimate	SE	t	P[a]
Day of season	Intercept	42.48	9.05	4.69	<0.001
	Day of season	0.44	0.24	1.81	0.07
Month[b]	Intercept	46.20	7.78	5.99	<0.001
	January	13.60	11.49	1.18	0.30
	February	23.14	13.48	1.72	0.09
Minimum temperature	Intercept	62.42	16.17	3.86	<0.001
	Minimum temperature	−0.27	0.65	−0.25	0.68

[a] Satterthwaite approximations of degrees of freedom were used to calculate P values (Kuznetsova et al. 2017).
[b] Month included December, January, and February. The reference level was December.
SE = standard error.

We sampled corn fields on state and federal properties in December (n = 13), January (n = 12), and February (n = 8) throughout the study period to estimate monthly rates of daily depletion of mowed corn. There was considerable variation in depletion rates within month (Figure 2). We fit several linear mixed-effects models to explain variability in estimates of daily depletion rates. Results suggested that minimum temperature had little effect on depletion rates, and monthly differences in depletion rates were marginal, but differences were detected between December and February (Table 1). Day of season appeared to be the most important effect in explaining depletion rates, which increased as the season progressed (Table 1; Figure 3).

The seasonal corn requirements using the mean gross energy content of all varieties was 245,434 kg (95% CI = 230,481–261,543 kg), 347,242 kg (95% CI = 299,610–396,467 kg), 319,137 kg (95% CI = 290,729–348,884 kg) for sandhill cranes, light geese, and dabbling ducks, respectively. We estimated the energetic requirements of all populations combined to be 4.23×10^9 kcal (95% CI = 3.81×10^9 to 4.53×10^9 kcal), which translates to 911,813

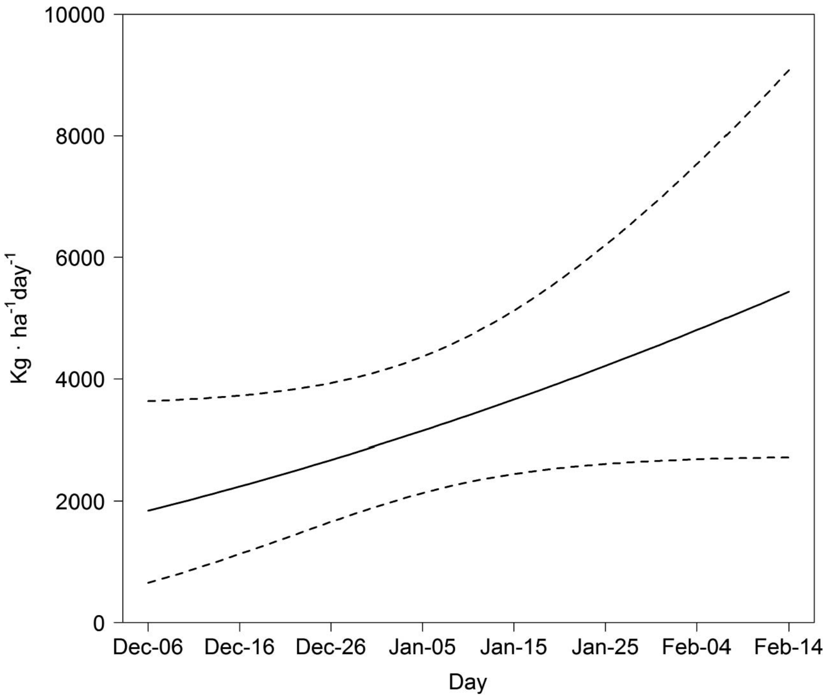

Figure 3. Predicted mean ± 95% confidence interval daily depletion rate of postmowed corn estimated from a linear mixed-effects model increased with day of season in the Middle Rio Grande Valley of central New Mexico from 2014 to 2017.

kg of corn (95% CI = 820,821–1,006,894 kg) required to support energetic demands of these populations throughout winter. At this estimated requirement, mean corn production in the MRGV from 2014 to 2017 (1,052,006 kg) would support joint energetic needs of wintering migratory gamebirds for 101 d (95% CI = 91–113 d).

Discussion

Management of supplemental corn on state and federal properties in the MRGV currently seems to produce sufficient food energy to support energetic requirements of sandhill cranes, light geese, and dabbling ducks from early November to the onset of spring migration in mid-February. Corn has substantial caloric value to migratory birds because of its high energy content (i.e., rich source of carbohydrates) and digestibility (Petrie et al. 1998). Our results suggest that heirloom varieties of corn contain about 150 to 200 kcal/kg more than GMC and NON-GMC varieties. Although this increased caloric content might seem small, NON-GMC corn is already required on Bosque del Apache NWR. Cultivating heirloom varieties may be warranted if the benefits of these varieties (e.g., they are more adapted to arid climate conditions and require less water) outweigh financial costs of purchasing seeds compared with other NON-GMCs. Regardless, maintaining corn production at current levels across state and federal properties should provide sufficient food resources to support current population levels of migratory gamebirds for the duration of the wintering period.

Our calculations of seasonal energetic expenditures used peak abundance of sandhill cranes, light geese, and dabbling ducks in the MRGV. We used peak abundance to avoid underestimation of energetic demands and to establish a corn production objective that accommodates sandhill cranes, light geese, and dabbling ducks at their largest levels during winter. Moreover, many migratory gamebirds use the MRGV as a stopover site at variable times throughout winter (Donnelly et al. 2021), which may place greater energetic demands on corn resources. While using peak abundance to calculate population-level demands might be overly cautious, underestimating corn production may have severe consequences. Unforeseen losses due to crop failure from pests, suboptimal soil conditions (e.g., pH and nutrients), and unaccounted demands placed on corn by other species (e.g., elk and deer) that are not necessarily the primary target for the resource could all reduce or limit corn availability for migratory gamebirds (Sherry et al. 2005; Danner et al. 2013; DeVore et al. 2016). Thus, total corn production objectives within a season should incorporate these potential losses.

Although our estimates of daily energy expenditures for sandhill cranes were similar to previously reported values (Tacha et al. 1987; Rainwater Basin Joint Venture 2013), our estimates did not incorporate energy expenditures related to the synthesis of lipids. Several previous studies have estimated metabolic costs of lipid production to account for the importance of building lipid reserves for migration (Krapu et al. 1985; Tacha et al. 1987; Pearse et al. 2010). Data to estimate lipid production require measurement of lipid content on collected individuals (Iverson and Vohs 1982; Krapu et al. 1985; Afton and Ankney 1991) or prediction of lipid content through body condition indices (Ardia 2005;

Labocha et al. 2014). After adjusting for body size and metabolic efficiencies of lipid production, we can determine changes and metabolic cost of lipid accumulation. Although these estimates do not exist for the RMP, establishing baseline estimates of lipid deposition by sandhill cranes of the RMP may be valuable to include in seasonal energetic costs and to track any changes in physiological condition that might be related to corn quality and availability (Krapu et al. 2005).

The high temporal variability in daily depletion rates of corn is likely due to several confounding factors. First, we could not control for number of birds using supplemental corn resources at any given time, which greatly influences depletion rates. Second, we could not account for the time it takes sandhill cranes, light geese, and dabbling ducks to relocate and begin foraging in a newly mowed area. This is further conflated by how much existing corn remains unconsumed in previously mowed areas before sampling, which could be a product of mowing too much corn within a day given the daily population demands, switching to other available food resources, or changing foraging rates related to weather conditions. Minimum temperature, for example, regulates time spent foraging by migratory birds (Gates et al. 2001; Jónsson and Afton 2009). Although our results suggest that this was not influential in describing variation in daily depletion rates, it may be important and may operate beyond the resolution of our data. Interestingly, Boggie et al. (2018a) found that sandhill crane time–activity budgets indicated a temporal increase in foraging through winter, which corresponded with increasing daily depletion rates of postmowed corn. Increased food intake through winter may be a signal of premigratory fattening where sandhill cranes are steadily acquiring energy reserves needed for spring migration (Rappole 2013; Cooper et al. 2015). This insight could be incorporated into management actions by matching the amount of corn made available to both population abundances and increased monthly dietary requirements.

State and federal agencies do not traditionally begin mowing corn until December 1, which is reflected in our sampling dates. Boggie et al. (2018a) reported the RMP begin to arrive in the MRGV in late November (November 23 $\pm$ 2 d) and that the current initiation date of corn mowing likely satisfies their monthly energetic requirements. However, Boggie et al. (2018a) did have sandhill cranes tagged with satellite transmitters that arrived as early as November 5. Bearing this in mind, managers might want to consider beginning corn mowing in mid-to-late November depending on population abundances and availability of alternative food resources on state and federal properties.

While corn is a dominant dietary component of sandhill cranes (Boggie et al. 2018a) and probably the most important forage energetically, state and federal agencies manage an extensive system of moist-soil impoundments mimicking once naturally occurring wetlands. These moist-soil-managed wetlands support a diversity of natural wetland plants and invertebrate communities that provide essential sources of protein and carbohydrates for sandhill cranes, light geese, and dabbling ducks (Taylor and Smith 2003, 2005a, 2005b). Wetland resources likely fulfill any nutritional requirements beyond corn. Contemporary estimates of wetland food densities should be generated and incorporated into the total energy availability for migratory birds in the MRGV. Our study established winter energetic demands of three guilds of migratory game birds, which we suggest should be used in future conservation planning for the population. Finally, our results demonstrated that current corn production aligns with flyway population objectives for the RMP (Pacific Flyway Council and Central Flyway Council 2016), and supplemental corn in the MRGV can likely meet energetic needs of the RMP and other wintering migratory gamebirds.

Management implications

Active management and manipulation of supplemental corn in the MRGV makes the food resource amendable to support the current RMP while simultaneously serving a multispecies function. Demands on the forage resource are not static and will vary through time with changes in winter habitat condition and population sizes. We encourage Federal and State land managers in the MRGV to maintain interagency coordination for flexibility in applied management actions (i.e., amount of corn grown and mowing schedules as well as variety selection), track population trends of focal species, and consider daily energetic expenditures to meet and link habitat and population objectives.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

Reference S1. Pacific Flyway Council and Central Flyway Council. 2016. Pacific and Central Flyways Management plan for the Rocky Mountain Population of greater sandhill cranes. Vancouver, Washington: Pacific Flyway Council and Central Flyway Council, care of the U.S. Fish and Wildlife Service's Pacific Flyway Representative.

Available: https://doi.org/10.3996/JFWM-22-013.S1 (746 KB PDF)

Reference S2. Rainwater Basin Joint Venture. 2013. The Rainwater Basin Joint Venture implementation plan. Grand Island, Nebraska: Rainwater Basin Joint Venture.

Available: https://doi.org/10.3996/JFWM-22-013.S2 (1.527 MB PDF)

Reference S3. Sanchez J, Cline M. 2020. A plan for the management of waterfowl, sandhill cranes, and other migratory birds in the Middle Rio Grande Valley of New Mexico. Albuquerque, New Mexico: U.S. Fish and Wildlife Service.

Available: https://doi.org/10.3996/JFWM-22-013.S3 (2.898 MB PDF)

Reference S4. Taylor JP. 1999. A plan for the management of waterfowl, sandhill cranes, and other migratory birds in the Middle Rio Grande Valley of New Mexico. Albuquerque, New Mexico: U.S. Fish and Wildlife Service.
Available: https://doi.org/10.3996/JFWM-22-013.S4 (2.208 MB PDF)

Reference S5. Thorpe PP, Donnelly JP, Collins DP. 2016. September 2016 survey of the RMP of greater sandhill cranes. Lakewood, Colorado: Special Report in the files of the Central Flyway Representative.
Available: https://doi.org/10.3996/JFWM-22-013.S5 (152 KB PDF)

Reference S6. U.S. Department of Agriculture. 2009. Environmental assessment of crop damage management in New Mexico. Santa Fe: U.S. Department of Agriculture Animal Plant and Health Inspection Service, New Mexico Wildlife Services Program.
Available: https://doi.org/10.3996/JFWM-22-013.S6 (3.930 MB PDF)

Reference S7. U.S. Fish and Wildlife Service. 2012. North American Waterfowl Management Plan. Washington, D.C.: U.S. Fish and Wildlife Service.
Available: https://doi.org/10.3996/JFWM-22-013.S7 (2.676 MB PDF)

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References

Aagaard KJ, Thogmartin WE, Lonsdorf EV. 2018. Temperature-influenced energetics model for migrating waterfowl. Ecological Modelling 378:46–58.

Afton AD, Ankney CD. 1991. Nutrient-reserve dynamics of breeding lesser scaup: a test of competing hypotheses. Condor 93:89–97.

Andersson K, Davis CA, Harris G, Haukos DA. 2018. Nonbreeding duck use and management contribution trends for Central Flyway refuges. Journal of Fish and Wildlife Management 9:45–64.

Anteau MJ, Sherfy MH, Bishop AA. 2011. Location and agricultural practices influence spring use of harvested cornfields by cranes and geese in Nebraska. Journal of Wildlife Management 75:1004–1011.

Ardia DR. 2005. Super size me: an experimental test of the factors affecting lipid content and the ability of residual body mass to predict lipid stores in nestling European Starlings. Functional Ecology 19:414–420.

Bates D, Maechler M, Bolker B, Walker S. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67:1–48.

Boggie MA, Carleton SA, Collins DP, Vradenburg J, Sroka CJ. 2018a. Using stable isotopes to estimate reliance on agricultural food subsidies and migration timing for a migratory bird. Ecosphere 9:e02083.

Boggie MA, Collins DP, Donnelly JP, Carleton SA. 2018b. Land use, anthropogenic disturbance, and riverine features drive patterns of habitat selection by a wintering waterbird in a semi-arid environment. PLoS ONE 13:e0206222.

Bosque del Apache National Wildlife Refuge. Refuge biweekly waterbird survey data [unpublished]. Located at: Bosque del Apache National Wildlife Refuge, San Antonio, New Mexico.

Brasher MG, Steckel JD, Gates RJ. 2007. Energetic carrying capacity of actively and passively managed wetlands for migrating ducks in Ohio. Journal of Wildlife Management 71:2532–2541.

Cooper NW, Sherry TW, Marra PP. 2015. Experimental reduction of winter food decreases body condition and delays migration in a long-distance migratory bird. Ecology 96:1933–1942.

Danner RM, Greenberg RS, Danner JE, Kirkpatrick LT, Walters JR. 2013. Experimental support for food limitation of a short-distance migratory bird wintering in the temperate zone. Ecology 94:2803–2816.

Davis JB, Guillemain M, Kaminski RM, Arzel C, Eadie JM, Rees EC. 2014. Habitat and resource use by waterfowl in the northern hemisphere in autumn and winter. Wildfowl 4:17–69.

DeVore RM, Butler MJ, Wallace MC, Liley SL, Mertz AA, Sesnie SE, Gipson PS. 2016. Elk resource selection patterns in a semiarid riparian corridor. Journal of Wildlife Management 80:479–489.

Donnelly JP, King S, Knetter J, Gammonley J, Dreitz V, Grisham B, Nowak C, Collins DP. 2021. Migratory efficiency sustains connectivity across agroecological networks supporting sandhill crane migration. Ecosphere 12:e03543.

Duriez O, Ens BJ, Choquet R, Pradel R, Klaassen M. 2012. Comparing the seasonal survival of resident and migratory oystercatchers: carry-over effects of habitat quality and weather conditions. Oikos 121:862–873.

Fino SR, Williams CK, Livolsi MC, Ringelman KM, Coluccy JM, Devers PK, Castelli PM. 2017. Carrying capacity of wintering American black ducks in forested wetlands. Journal of Wildlife Management 81:943–950.

Flickinger EL, Bolen EG. 1979. Weights of lesser snow geese taken on their winter range. Journal of Wildlife Management 43:531–533.

Gates RJ, Caithamer DF, Moritz WE, Tacha TC. 2001. Bioenergetics and nutrition of Mississippi Valley population Canada geese during winter and migration. Wildlife Monographs 146:1–65.

Guillemain M, Elmberg J, Pernollet CA, Arzel C, Eadie JM. 2017. Agent-based modeling may help to merge research traditions in foraging ecology in Europe and North America. Wildlife Society Bulletin 41:170–176.

Howe WH, Knopf FL. 1991. On the imminent decline of Rio Grande cottonwoods in central New Mexico. Southwestern Naturalist 36:218–224.

Inger R, Harrison XA, Ruxton GD, Newton J, Colhoun K, Gudmundsson GA, McElwaine G, Pickford M, Hodgson D, Bearhop S. 2010. Carry-over effects reveal reproductive costs in a long-distance migrant. Journal of Animal Ecology 79:974–982.

Iverson GC, Vohs PA Jr. 1982. Estimating lipid content of sandhill cranes from anatomical measurements. Journal of Wildlife Management 46:478–483.

Jónsson E, Afton A. 2009. Time budget of snow geese (*Chen caerulescens*) and Ross's geese (*Chen rossi*) in mixed flocks: implications of body size, ambient temperature and family associations. Ibis 151:134–144.

Krapu GL, Brandt DA, Buhl DA, Lingle GW. 2005. Evidence of a decline in fat storage in midcontinental sandhill cranes in Nebraska during spring: a preliminary assessment. Pages 179–184 in Chavez-Ramirez F, editor. Proceedings of the Ninth North American Crane Workshop, 17–20 January 2003, Sacramento, California, USA. North American Crane Working Group.

Krapu GL, Brandt DA, Kinzel PJ, Pearse AT. 2014. Spring migration ecology of the mid-continent sandhill crane population with an emphasis on use of the Central Platte River Valley, Nebraska. Wildlife Monographs 189:1–41.

Krapu GL, Iverson GC, Reinecke KJ, Boise CM. 1985. Fat deposition and usage by arctic-nesting sandhill cranes during spring. Auk 102:362–368.

Kuznetsova A, Brockhoff PB, Christensen RHB. 2017. lmerTest package: tests in linear mixed effects models. Journal of Statistical Software 82:1–26.

Labocha MK, Schutz H, Hayes JP. 2014. Which body condition index is best? Oikos 123:111–119.

Ladin ZS, Castelli PM, McWilliams SR, Williams CK. 2011. Time energy budgets and food use of Atlantic brant across their wintering range. Journal of Wildlife Management 75:273–282.

Lauer J. 2002. Methods for calculating corn yield. Agronomy Advice, University of Wisconsin–Madison. Available: http://corn.agronomy.wisc.edu/AA/pdfs/A033.pdf (March 2023)

Livolsi MC, Williams CK, Coluccy JM, DiBona MT. 2015. Morphometrics of mid-Atlantic dabbling ducks for use in thermoregulation models. Condor 117:644–649.

McKinney RA, McWilliams SR. 2005. A new model to estimate daily energy expenditure for wintering waterfowl. Wilson Bulletin 117:44–55.

Miller MR, Eadie JM. 2006. The allometric relationship between resting metabolic rate and body mass in wild waterfowl (Anatidae) and an application to estimate of winter habitat requirements. Condor 180:166–177.

Miller MR, Reinecke KJ. 1984. Proper expression of metabolizable energy in avian energetics. Condor 86:396–400.

New Mexico Department of Game and Fish and U.S. Fish and Wildlife. New Mexico Mid-winter waterfowl survey data [unpublished]. Located at: New Mexico Department of Game and Fish and U.S. Fish and Wildlife, Santa Fe, New Mexico.

Newton I. 2004. Population limitation in migrants. Ibis 146:197–226.

Nielsen RL. 2004. Estimating corn grain yield prior to harvest. Available: https://www.agry.purdue.edu/ext/corn/news/timeless/yldestmethod.html (March 2023)

Pacific Flyway Council and Central Flyway Council. 2016. Pacific and Central Flyways Management plan for the Rocky Mountain Population of greater sandhill cranes. Vancouver, Washington: Pacific Flyway Council and Central Flyway Council, care of the U.S. Fish and Wildlife Service's Pacific Flyway Representative (see *Supplemental Material*, Reference S1)

Paxton KL, Moore FR. 2015. Carry-over effects of winter habitat quality on en route timing and condition of a migratory passerine during spring migration. Journal of Avian Biology 46:495–506.

Pearse AT, Krapu GL, Brandt DA, Kinzel PJ. 2010. Changes in agriculture and abundance of snow geese affect carrying capacity of sandhill cranes in Nebraska. Journal of Wildlife Management 74:479–488.

Petrie MJ, Drobney RD, Graber DA. 1998. True metabolizable energy estimates of Canada goose foods. Journal of Wildlife Management 62:1147–1152.

Petrie MJ, Fleskes JP, Wolder MA, Isola CR, Yarris GS, Skalos DA. 2016. Potential effects of drought on carrying capacity for wintering waterfowl in the Central Valley of California. Journal of Fish and Wildlife Management 7:408–422.

Post DM, Taylor JP, Kitchell JF, Olson MH, Schindler DE, Herwig BR. 1998. The role of migratory waterfowl as nutrient vectors in a managed wetland. Conservation Biology 12:910–920.

Rainwater Basin Joint Venture. 2013. The Rainwater Basin Joint Venture implementation plan. Grand Island, Nebraska: Rainwater Basin Joint Venture (see *Supplemental Material*, Reference S2).

Rakhimberdiev E, Brugge M, Spaans B, van den Hout PJ, Piersma T. 2015. Seasonal mortality and sequential density dependence in a migratory bird. Journal of Avian Biology 46: 332–342.

Rappole J. 2013. The avian migrant: the biology of bird migration. New York: Columbia University Press.

R Core Team. 2017. R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing. Available: https://www.R-project.org/ (March 2023)

Ringelman KM, Williams CK, Castelli PM, Sieges ML, Longenecker RA, Nichols TC, Earsom AD. 2018. Estimating waterfowl carrying capacity at local scales: a case study from Edwin B. Forsythe National Wildlife Refuge, New Jersey. Journal of Fish and Wildlife Management 9(1):106–116; e1944-687X. Available: https://doi.org/10.3996/082017-JFWM-066

Sanchez J, Cline M. 2020. A plan for the management of waterfowl, sandhill cranes, and other migratory birds in the Middle Rio Grande Valley of New Mexico. Albuquerque, New Mexico: U.S. Fish and Wildlife Service (see *Supplemental Material*, Reference S3).

Schmitt CG, Hale B. 1997. Sandhill crane hunts in the Rio Grande Valley and southwest New Mexico. Pages 219–231 in Urbanek RP, Stahlecker DW, editors. Proceedings of the Seventh North American Crane Workshop, 10–13 January 1996, Biloxi, Mississippi, USA. North American Crane Working Group.

Sedinger JS, Alisauskas RT. 2014. Cross-seasonal effects and the dynamics of waterfowl populations. Wildfowl 4:277–304.

Sherfy MH, Anteau MJ, Bishop AA. 2011. Agricultural practices and residual corn during spring crane and waterfowl migration in Nebraska. Journal of Wildlife Management 75:995–1003.

Sherry TW, Johnson MD, Strong AM. 2005. Does winter food limit population of migratory birds? Pages 414–425 in Greenberg R, Marra PP, editors. Birds of two worlds: the ecology and evolution of migration. Baltimore, Maryland: John Hopkins University Press.

Storey ML, Allen NK. 1982. Apparent and true metabolizable energy of feedstuffs for mature, nonlaying female embden geese. Poultry Science 61:739–745.

Swanson BJ, Meyer GA, Coonrod JE. 2011. Historical channel narrowing along the Rio Grande near Albuquerque, New Mexico in response to peak discharge reductions and engineering: magnitude and uncertainty of change from air photo measurements. Earth Surface Processes and Landforms 36:885–900.

Tacha TC, Vohs PA, Iverson GC. 1987. Time and energy budgets of sandhill cranes from mid-continental North America. Journal of Wildlife Management 51: 440–448.

Taylor JP. 1999. A plan for the management of waterfowl, sandhill cranes, and other migratory birds in the Middle Rio Grande Valley of New Mexico. Albuquerque, New Mexico: U.S. Fish and Wildlife Service (see *Supplemental Material*, Reference S4).

Taylor JP, Smith LM. 2003. Chufa management in the MRGV, New Mexico. Wildlife Society Bulletin 31: 56–162.

Taylor JP, Smith LM. 2005a. Migratory bird use of belowground foods in moist-soil managed wetlands in the MRGV, New Mexico. Wildlife Society Bulletin 33:574–582.

Taylor JP, Smith LM. 2005b. Sandhill crane use of managed chufa wetlands in New Mexico. Pages 167–171 in Chavez-Ramirez F, editor. Proceedings of the Ninth North American Crane Workshop, 17–20 January 2003, Sacramento, California, USA. North American Crane Working Group.

Thomison P. 2015. Estimating corn yields. Available: http://agcrops.osu.edu/newsletter/corn-newsletter/2015-25/estimating-corn-yields (March 2023)

Thorpe PP, Donnelly JP, Collins DP. 2016. September 2016 survey of the RMP of greater sandhill cranes. Lakewood, Colorado: Special Report in the files of the Central Flyway Representative (see *Supplemental Material*, Reference S5).

U.S. Department of Agriculture. 2009. Environmental assessment of crop damage management in New Mexico. Santa Fe: U.S. Department of Agriculture Animal Plant and Health Inspection Service, New Mexico Wildlife Services Program (see *Supplemental Material*, Reference S6).

U.S. Fish and Wildlife Service. 2012. North American Waterfowl Management Plan. Washington, D.C.: U.S. Fish and Wildlife Service (see *Supplemental Material*, Reference S7).

Williams CK, Dugger BD, Brasher MG, Coluccy JM, Cramer DM, Eadie JM, Gray MJ, Hagy HM, Livolsi M, McWilliams SR, Petrie M. 2014. Estimating habitat carrying capacity for migrating and wintering waterfowl: considerations, pitfalls and improvements. Wildfowl 4:407–435.