AN ABSTRACT OF THE DISSERTATION OF

Gary L. Ivey for the degree of Doctor of Philosophy in Wildlife Science presented on March 6, 2015.

Title: Comparative Wintering Ecology of Two Subspecies of Sandhill Crane: Informing Conservation Planning in the Sacramento-San Joaquin River Delta Region of California

Abstract approved: ____

Bruce D. Dugger

California's Central Valley agricultural landscapes provide several important wintering regions for Pacific Flyway sandhill crane (*Grus canadensis*) populations; however, the value of those regions is being compromised by urban expansion, other developments, and conversions to incompatible crop types. Greater (*G. c. tabida*) and lesser sandhill cranes (*G. c. canadensis*) both have special conservation status in California; the greater is listed as threatened and the lesser as a bird species of conservation concern by the state. However, basic information about their wintering ecology has been lacking to design biologically sound conservation strategies to maintain their wintering habitats.

My study of sandhill cranes focused on one major Central Valley wintering region, the Sacramento-San Joaquin River Delta (Delta). I compared daily movements and winter site fidelity between the two sandhill crane subspecies, evaluated the timing of crane arrival and departure from the region, assessed foraging habitat choices, measured abundance and distribution in the Delta, documented the characteristics of roost sites, and developed habitat conservation models and decision tools for managers to facilitate habitat conservation and management.

Both crane subspecies showed strong fidelity to my Delta study area. Foraging flights from roost sites were shorter for greaters than lesser (1.2 ± 0.4 km vs. 3.1 ± 0.1 km, respectively) and consequently, mean size of 95% fixed kernel winter home ranges was an order of magnitude smaller for greaters (1.9 ± 0.4 km^2 vs.21.9 ± 1.9 km^2,

respectively). The strong site fidelity of greaters to roost complexes within landscapes in the Delta indicates that conservation planning targeted at maintaining and managing for adequate food resources around traditional roost sites can be effective for meeting sandhill crane habitat needs, while the scale of conservation differs by subspecies. I recommend that conservation planning actions consider all habitats within 5 km of a crane roost as a sandhill crane conservation “ecosystem unit.” This radius encompasses 95% and 69% of the flights from roosts to foraging location (commuting flights) made by greaters and lessers, respectively. For lessers, a conservation radius of 10 km would encompass 90% of the commuting flights. Management, mitigation, acquisition, easement, planning, and farm subsidy programs intended to benefit cranes will be most effective when applied at these scales. Within these radii, conservation and management of wintering habitats should include creating both new roost and feeding areas to ensure high chances of successful use.

Sandhill cranes used major crops and habitat types available in the landscapes surrounding their roost sites and focused most of their foraging in grain crops. They generally avoided dry corn stubble, selected dry rice stubble early in the season, and rarely used dry wild rice stubble. Tilled fields were also usually avoided but were occasionally used shortly after tillage. Mulched corn ranked high in comparison to other corn treatments while mulched rice use was used similarly to dry rice stubble. Both subspecies often highly favored cropland habitats when they were initially flooded. Cranes were attracted to new plantings of pasture and winter wheat. One important difference between the subspecies was that lessers used alfalfa which was generally avoided by greaters. Dry corn stubble was avoided while dry rice stubble was favored early in winter. If wildlife managers want to encourage winter field use by cranes they could provide incentives for favorable practices such as production of grain crops, reduction or delaying tillage and flooding of grain fields, provision of irrigations to some crop types, and increasing the practice of mulching of corn stubble.

Of the 69 crane night roosts I identified, 35 were flooded cropland sites and 34 were wetland sites. I found that both larger individual roost sites and larger complexes of roost sites supported larger peak numbers of cranes. Water depth used by roosting cranes averaged 10 cm (range 3-21 cm, mode 7 cm) and was similar between subspecies. Roosting cranes avoided sites that were regularly hunted or had high densities (i.e., > 1 blind/5 ha) of hunting blinds. Roost site design and management should consider providing and maintaining large roost complexes (100 – 1000 ha) ideally in close proximity (< 5 km) to other roost sites, with large individual sites (> 5 ha) of mostly level topography, dominated by shallow water (5-10 cm depths). The fact that cranes readily use undisturbed flooded cropland sites makes this a viable option for creation of roost habitat. Because hunting disturbance can limit crane use of roost sites I suggest these two uses should not be considered compatible. However, if the management objective of an area includes waterfowl hunting, limiting hunting at low blind densities (i.e., < 1 blind/60 ha) and restricting hunting to early morning may be viable options for creating a crane-compatible waterfowl hunt program.

Radio-marked sandhill cranes arrived in the Delta beginning 3 October, most arrived in mid-October, and the last radio-marked sandhill crane arrived on 10 December. Departure dates ranged from 15 January to 13 March. Mean arrival and departure dates were similar between subspecies. From mid-December through early-February in 2007-2008, the Delta population ranged from 20,000 to 27,000 sandhill cranes. Abundance varied at the main roost sites during winter, likely because sandhill cranes responded to changes in water and foraging habitat conditions. Sandhill cranes used an area of approximately 1,500 km^2 for foraging. Estimated peak abundance in the Delta was more than half the total number counted on recent Pacific Flyway midwinter surveys, indicating the Delta region is a key area for efforts in conservation and recovery of wintering sandhill cranes in California. Based on arrival dates, flooding of sandhill crane roost sites should be staggered with some sites flooded in early September and most sites flooded by early October. Maintaining flooding of at least some roost sites through mid-March would provide essential roosting habitat until most birds have departed the Delta region on spring migration.

Not all 5-km radius ecosystem units are equal in their value to greater sandhill cranes, and the relative foraging value of a particular parcel within an ecosystem unit depends on the numbers of cranes using the focal roost site, the habitat choices they make, and the probability that they will fly to a particular parcel. Additionally, some ecosystem units overlap, and in these overlap zones, the probability of crane use is higher, because of additive effects. To provide a tool to allow managers to further refine management plans, I developed a model which allows more specific focus of crane conservation, mitigation and habitat management, using what my study revealed about greater sandhill cranes. This model considers the abundance of greaters at individual roost sites and the probability that they would fly to a given location. Sites closer to roosts had a higher probability of crane use. I calculated the probability that greaters would fly to a parcel within concentric 1-km intervals as a product of the proportion of commuting flights of individuals that reached that interval, and the proportion of all commuting flights that reached that interval.

Within crane ecosystem units, it is important to protect the existing habitat from further loss and optimize foraging conditions for cranes. I provide a decision matrix to assist with plans to enhance existing crane landscapes, create new crane habitat areas or mitigate habitat losses. This matrix provides a framework for decision-making regarding enhancing sandhill crane foraging and roost site habitats. Wildlife managers could employ a variety of tools to conserve and manage crane habitats, including fee title acquisitions, private conservation easements, and specific cropland management actions to maintain crane-compatible conditions and high food values for cranes (possibly including providing unharvested food plots).

My study has demonstrated that most cranes use a relatively small landscape surrounding their traditional roost sites and that they favor certain crops and post-harvest crop management practices for foraging. However, we need a better understanding of the actual carrying capacity for cranes in these crane management zones to ensure that managers can maintain these sites for cranes in the future.

Title

Comparative Wintering Ecology of Two Subspecies of Sandhill Crane: Informing Conservation Planning in the Sacramento-San Joaquin River Delta Region of California

by

Gary L. Ivey

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APPROVED:

Major Professor, representing Wildlife Science

Head of the Department of Fisheries and Wildlife

Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Gary L. Ivey, Author

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CHAPTER 1

GENERAL INTRODUCTION

Gary L. Ivey

Two subspecies of sandhill cranes (*Grus canadensis*) that winter in the Central Valley of California have special conservation status. The large-bodied greater sandhill crane (*G. c. tabida*; hereafter, greaters) is listed as “threatened” under the California Endangered Species Act (Calif. Dept. of Fish and Game 2013), while the small-bodied lesser sandhill crane (*G. c. canadensis*; hereafter, lessers) is classified as a “Bird Species of Conservation Concern” (Littlefield 2008). These cranes are sympatric during winter and use only a few discrete wintering regions within California’s Central Valley agricultural landscape (Ivey et al. 2014; Fig. 1.1). Although there is much unused agricultural habitat in the Central Valley, the distribution of cranes there has changed little in the past 30 years, apparently because cranes show strong fidelity to wintering regions (Lovvorn and Kirkpatrick 1981, Tacha et al. 1984, Ivey and Herziger 2003).

Traditional Central Valley crane wintering areas are being degraded by habitat loss from urbanization, conversion to incompatible crops (e.g., vineyards and orchards; Central Valley Joint Venture 2006, Ivey 2014), and water development projects, such as proposals to develop water storage reservoirs as part of the Delta Wetlands Project (California Bay-Delta Authority 2003), the North Delta Flood Control and Ecosystem Restoration Project (California Department of Water Resources 2003), and for water diversions facilities in the Bay Delta Conservation Plan (California Department of Water Resources 2013). The Sacramento-San Joaquin River Delta Region (hereafter, Delta) is among the most important crane wintering regions, and is particularly important for greaters (Pogson and Lindstedt 1991). This region is also under the greatest pressure from proposed development and crop conversions.

During the past two decades, agencies and organizations have invested > $70 million to establish refuges and preserves that protect habitats used by sandhill cranes in the Delta, where most of this activity has centered on four major roost complexes: the

Isenberg Sandhill Crane Reserve owned by California Department of Fish and Wildlife (CDFW), Stone Lakes National Wildlife Refuge (NWR) owned by U.S. Fish and Wildlife Service (USFWS), Cosumnes River Preserve, established by The Nature Conservancy (TNC) in partnership with the Bureau of Land Management (BLM) and with multiple agency ownerships, and the more recent acquisition of Staten Island by TNC (Fig. 1.2). All these properties include a portion of habitat managed to provide nocturnal roost sites for sandhill cranes. In some cases, habitats were restored to native habitats such as seasonal wetlands; in the case of Staten Island (3,700 ha), the objective was to foster development and implementation of wildlife friendly farming practices. Understanding how to maximize the value of these properties for cranes requires an understanding of habitat needs and movement patterns of cranes. However, of the roughly 600 publications on Sandhill Cranes, only 11 deal with limited aspects of wintering ecology, only five of those report on Greater and Lesser Sandhill Cranes in California, and only four report habitat use or movements of these subspecies on their wintering grounds. No study has systematically investigated the wintering ecology of sympatric subspecies of cranes.

Cranes require two key habitat components on wintering areas; suitable night roost and foraging habitat (Tacha et al. 1994). The distance cranes can fly from night roosts to forage sites (commuting distance) is limited by energetic costs of flight, which therefore limits their choices of foraging sites within that radius from roosts. Conceptually, crane habitat use during winter can be viewed in the context of central place foraging and refuging theory (Hamilton and Watt 1970, Stephens and Krebs 1986, Frederick et al. 1987; Belanger and Bedard 1990) with individuals spending nights on a centrally located roost site and making one or more round trip flights to forage in surrounding fields during the day (Ivey and Herziger 2003). Therefore, I define an “ecosystem unit” for conservation and management of wintering cranes to include a central roost surrounded by a foraging landscape out to a certain radius to define the population of fields that a crane might use during a single day, and I hypothesized that the foraging landscape available to the two subspecies would be different (Fig. 1.3). However, before my study, data was lacking to parameterize this model.

The ecological unit described above for central place foraging cranes is inconsistent with the irregular boundaries of property ownership in the Delta. Thus, habitat acquisition targeting a key habitat component (e.g., a crane roost) will not likely include the entire foraging area potentially used by the roost population and may not be particularly successful in maintaining these populations of cranes. Habitat management practices often differ between private and public lands as private lands are not typically managed to optimize food availability to cranes. Habitat changes on privately owned fields may change crane abundance at a roost, regardless of management actions at the roost site itself. A primary assumption in my conceptual model is that providing sandhill cranes with better foraging habitat conditions will lead to their increased storage of endogenous fat reserves on the wintering grounds, which will lead to increased fitness for survival and reproduction, and ultimately contribute to their population recovery (Krapu et al. 1985).

Detailed information on crane habitat requirements on their California wintering grounds are needed to understand the critical links between conservation properties where cranes typically roost at night, and surrounding privately owned lands where they often forage. To improve management of agricultural areas for the benefit of cranes, information is needed on which crops they select and which agricultural practices are most crane-friendly. Long term conservation planning will require a program that fundamentally links and understands the relative importance of public and private lands and the best agricultural management practices to meeting the needs of wintering cranes. One goal of my dissertation is to provide basic information on sandhill crane habitat use that would allow conservation planners to develop a meaningful conservation plans and provide recommendations to farmers about how their agricultural operations may contribute to crane conservation.

Also, before this study, little was known about winter use of roost sites and characteristics of roost sites used by wintering cranes that could aid in designing a biologically sound conservation strategy for cranes in the Delta. Other than on the Platte River in Nebraska (e.g., Krapu et al. 1984; Norling et al. 1992; Folk and Tacha 1990; Parrish et al. 2001; Davis 2001, 2003), little work has been done to quantify habitat types used by roosting cranes, with the exception of a recent study in the Sacramento Valley (Shaskey 2012). In the Platte River system, cranes roost in the shallow waters (1-21 cm) and sandbar islands within the river channel. While the water depth information likely has broad applicability, other habitat characteristics of the North Platte River are not found in California. Additionally, there is only one published study about the suitability of flooded agricultural fields (Shaskey 2012) as roost sites for cranes, and no studies with information that quantifies how roost site size correlates with crane abundance at the roost.

Finally, body size has been hypothesized to strongly influence avian foraging behavior (Hockey et al. 1999, Durant et al. 2004, Cope et al. 2005, Mini 2013). Lesser sandhill cranes are smaller-bodied, long distant migrants, whereas greater sandhill cranes are large bodied, short distant migrants (Tacha et al. 1992, 1994, Petrula and Rothe 2005). Differences in body size and migration ecology between these two crane subspecies could translate to important differences in habitat use and movement patterns because of differences in energetic needs, unequal success in competition for foraging sites, and the related effects of dominance of the larger subspecies. However, the influence of body size on the behavior and management of sandhill cranes has not been studied. Thus, conservation plans based on data from one subspecies may not be applicable to the other. My dissertation investigates whether body size and its allometric constraints influence the foraging behavior of greaters and lessers and the implications, if any, of body size differences for movements and habitat selection, and ultimately for conservation planning. My results contribute to our basic understanding of crane ecology, which will help predict how landscape changes could impact the ability of the Delta to support viable populations of wintering cranes.

In Chapter 2, I examined the distribution, abundance and migration timing of each subspecies in my Delta study area. I quantified the timing of arrival, residence time, and timing of departure at major roost sites, tracked changes in roost use from fall through winter, estimated subspecies-specific sandhill crane abundance, and defined the distribution of sandhill cranes in the Delta region. Data on the timing of arrival and expected abundance over time at key roost sites in fall will provide the information needed to justify the timing and size of flooded roost sites to maintain sandhill crane use on traditional sites. When combined with information on habitat use and individual movements, this information will be critical for the development of biologically sound conservation plans for sandhill cranes wintering in the Delta region.

In Chapter 3, I examine winter site fidelity, commuting distance, home range, and survival of greater and lesser sandhill cranes in a habitat conservation and management context and compare movement patterns between large-bodied greaters and small-bodied lessers. I hypothesized that differences in body size would influence subspecies movement patterns. I predicted that lessers would move between wintering regions more often than greaters and travel further to find suitable foraging sites, while greaters would remain at fields close to roost sites. It is important to understand the distances cranes will travel from roosts to find food (commuting distance), to define priority areas for crane habitat conservation and management activities. I address how data on movements can be used to develop a simple model of crane conservation focus, as an “ecosystem unit” to represent the diurnal movement of wintering sandhill cranes from their nocturnal roost sites to neighboring foraging sites during the day, and back to the roost in the evening.

In Chapter 4, I characterize foraging habitat use at the landscape scale and study habitat selection at a local scale, focusing on crane response to post-harvest crop management strategies. I hypothesized that foraging habitat selections would differ among crane subspecies because smaller-bodied lessers have higher mass-specific metabolic requirements than greaters which results in higher energy demands and lower fasting endurance. I predicted that foraging habitat selections would be different for each subspecies and that lessers would tend to shift to more distant fields over time while greaters would tend to remain in proximate fields.

In Chapter 5, I examined the effects of roost site characteristics on the numbers of cranes using roost sites. I hypothesized that more cranes would occur around larger than smaller roost site complexes, and that activity area size would be correlated with the number and or total area of alternate roost sites within a landscape unit, and that crane abundance at roost sites would be correlated with roost area flooded at ideal depths (i.e., < 20 cm). I characterized the features of crane roosts at both the individual site and roost complex scales, correlate roost abundance with roost size, and correlated roost use with recreational waterfowl hunting activity to increase our understanding of crane roosting ecology and support crane habitat conservation and management.

In Chapter 6, the synthesis chapter, I identify priority Central Valley regions to focus sandhill crane winter habitat conservation and management activities, and discuss the need to focus on the most important lands at a local (roost site) scale. To further focus conservation, I present an example of a more complex, GIS-based model design that will allow comparisons of the relative values of individual parcels to greater sandhill cranes, based on the number of birds using a particular roost site and their commuting distances probabilities. I also provide a decision matrix for winter sandhill crane habitat conservation and management. These three tools should have application for sandhill crane wintering and staging areas in agricultural regions across North America. I hope that the findings of this dissertation will provide additional insight and alternative ways for managers across different flyways to think about managing habitats for wintering cranes.

LITERATURE CITED

Belanger, L., and J. Bédard. 1992. Flock composition and foraging behavior of Greater Snow Geese (*Chen caerulescens atlantica*). Canadian Journal of Zoology 70:2410-2415.

California Bay-Delta Authority. 2003. Integrated Storage Investigations—In-Delta Storage Program State Feasibility Study Draft Environmental Evaluations. Sacramento, California.

California Department of Fish and Wildlife [online]. 2013. State and federally listed endangered and threatened animals of California. Sacramento, California. <(http://www.dfg.ca.gov/biogeodata/cnddb/pdfs/TEAnimals.pdf> (1 March 2014).

California Department of Water Resources. 2003. Draft Description of Proposed Alternatives: North Delta Flood Control and Ecosystem Restoration Project. Sacramento, California.

California Department of Water Resources [online]. 2013. Bay Delta Conservation Plan. <http://baydeltaconservationplan.com/AboutBDCP/WhatistheBDCP.aspx> (13 March 2014).

Central Valley Joint Venture. 2006. Central Valley Joint Venture Implementation Plan – Conserving Bird Habitat. U.S. Fish and Wildlife Service, Sacramento, CA.

Cope, D. R., M. J. J. E. Loonen, J. M. Rowcliffe, and R. A. Pettifor. 2005. Larger Barnacle Geese (*Branta leucopsis*) are more efficient feeders: a possible mechanism for observed body size-fitness relationships. Journal of Zoology 265:37–42.

Davis, C. A. 2001. Nocturnal roost site selection and diurnal habitat-use by sandhill cranes during spring in central Nebraska. Proceedings of North American Crane Workshop 8:48-56.

Davis, C. A. 2003. Habitat use and migration patterns of sandhill cranes along the Platte River, 1998-2001. Great Plains Research 13:199-216.

Durant, D., H. Fritz, and P. Duncan. 2004. Feeding patch selection by herbivorous Anatidae: the influence of body size, and of plant quality and quantity. Journal of Avian Biology 35:144–152.

Folk, M. J., and T. C. Tacha. 1990. Sandhill crane roost site characteristics in the North Platte River Valley. Journal of Wildlife Management 54:480–486.

Frederick, R. B., W. R. Clark, and E. E. Klaas. 1987. Behavior, energetics, and management of refuging waterfowl: a simulation model. Wildlife Monographs 96. 33 pages.

Hamilton III, W. J., and K. E. F. Watt. 1970. Refuging. Annual Review of Ecological Systematics 1:263-286.

Hockey, P. A. R., J. K. Turpie, É. E. Plagányi, and T. E. Phillips. 1999. Scaling Patterns in the Foraging Behaviour of Sympatric Plovers: Effects of Body Size and Diet. Journal of Avian Biology 30:40-46.

Ivey, G. L. 2014. Greater sandhill crane. Pages 96-97 in Shuford, W. D., editor. Coastal California (BCR 32) Waterbird Conservation Plan: Encompassing the Coastal Slope and Coast Ranges of Central and Southern California and the Central Valley. U.S. Fish and Wildlife Service, Pacific Southwest Region, Sacramento, California, USA.

Ivey, G. L., and C. P. Herziger. 2003. Sandhill Crane Monitoring at Staten Island, San Joaquin County, California, 2002-03. Unpublished report. The Nature Conservancy, Galt, California, USA.

Ivey, G. L., C. P. Herziger, and D. A. Hardt. 2014. Conservation Priorities and Best Management Practices for Wintering Sandhill Cranes in the Central Valley of

California. Unpublished report. The Nature Conservancy, Sacramento, California, USA.

Krapu, G. L., D. E. Facey, E. K. Fritzell and D. H. Johnson. 1984. Habitat use by migrant sandhill cranes in Nebraska. Journal of Wildlife Management 48:407–417.

Krapu, G. L., G. C. Iverson, K. J. Reinecke, and C. G. Boise. 1985. Fat deposition and usage by arctic-nesting Sandhill Cranes during spring. Auk 102:362-368.

Littlefield, C. D. 2002. Winter foraging habitat of greater sandhill cranes in northern California. Western Birds 33:51-60.

Littlefield, C. D. 2008. Lesser Sandhill Crane. Pages 167-172 *In* Shuford, W. D., and Gardali, T., editors. California Bird Species of Special Concern: A ranked assessment of species, subspecies, and distinct populations of birds of immediate conservation concern in California. Studies of Western Birds 1. Western Field Ornithologists, Camarillo, California, and California Department of Fish and Wildlife, Sacramento, California, USA.

Lovvorn, J. R. and C. M. Kirkpatrick. 1981. Roosting behavior and habitat of migrant Greater Sandhill Cranes. Journal of Wildlife Management 45:842–857.

Mini, A. E. 2013. The Role of Body Size in the Foraging Strategies and Management of Avian Herbivores: A Comparison of Dusky Canada Geese (*Branta canadensis occidentalis*) and Cackling Geese (*B. hutchinsii minima*) Wintering in the Willamette Valley of Oregon. Ph.D. dissertation, Oregon State University, Corvallis, Oregon, USA.

Norling, B. S., S. H. Anderson, and W. H. Hubert. 1992. Roost sites used by sandhill cranes staging along the Platte River, Nebraska. Great Basin Naturalist 52:253-261.

Parrish, T. L, W. A. Hubert, S. H. Anderson, M. J. Pucherelli, and W. Mangus. 2001. Distributions of roosting sandhill cranes as identified by aerial thermography. Prairie Naturalist 33:93-99.

Petrula, M. J., and T. C. Rothe. 2005. Migration chronology, routes, and distribution of Pacific Flyway Population of lesser sandhill cranes. Proceedings North American Crane Workshop 9:53-67.

Pogson, T. H., and S. M. Lindstedt. 1991. Distribution and abundance of large Sandhill Cranes, *Grus canadensis*, wintering in California's Central Valley. Condor 93:266-278.

Shaskey, L. E. 2012. Local and landscape influences on sandhill crane habitat suitability in the northern Sacramento Valley, CA. M.S Thesis, Sonoma State University, Rohnert Park, California.

Stephens, D. W., and J. R. Krebs. 1986. Foraging Theory. Princeton University Press, Princeton, NJ., USA.

Tacha, T. C., P. A. Vohs, and G. C. Iverson 1984. Migration routes of Sandhill Cranes from mid-continental North America. Journal of Wildlife Management 48:1028–1033.

Tacha, T. C., S. A. Nesbit, and P. A. Vohs. 1992. Sandhill Crane (*Grus canadensis*). *In* The Birds of North America, No. 31 (A. Poole, P. Stettenheim, and F. Gill, eds.). Philadelphia: The Academy of Natural Sciences; Washington, DC: The American Ornithologist's Union.

Tacha, T. C., S. A. Nesbitt, and P. A. Vohs. 1994. Sandhill Crane. Pages 77-94 *in* T. C. Tacha and C. E. Braun, editors. Migratory Shore and Upland Game Bird Management in North America. International Association of Fish and Wildlife Agencies, Washington, D.C., USA.

Figure 1.1. Locations of major sandhill crane (*Grus canadensis*) wintering regions within the Central Valley of California. From north to south: Sacramento Valley, Sacramento-

San Joaquin River Delta, San Joaquin River National Wildlife Refuge region, Merced Grasslands, and Pixley National Wildlife Refuge region.

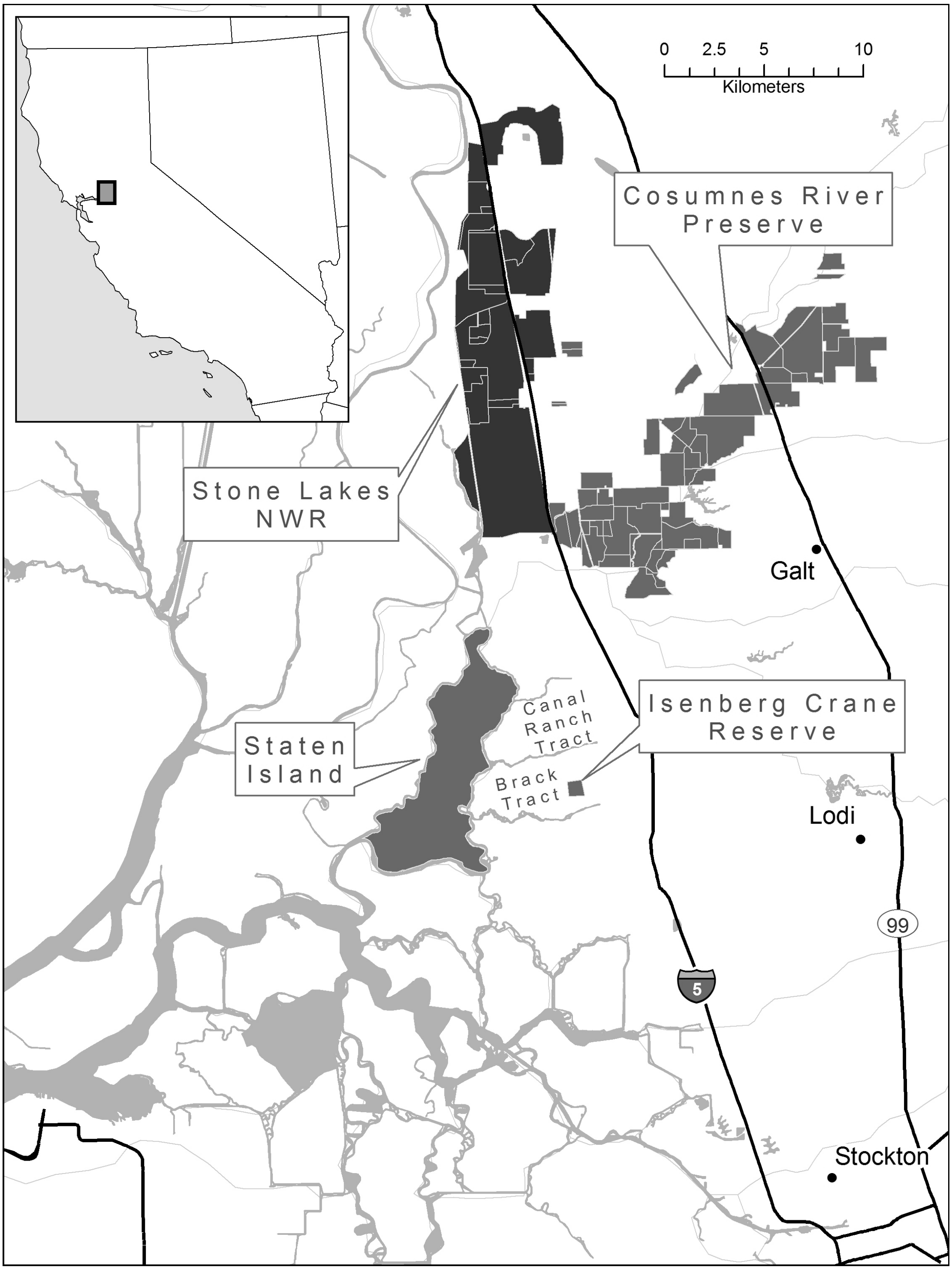

Figure 1. 2 Map of the Sacramento-San Joaquin River Delta of California sandhill crane (*Grus canadensis*) wintering region showing four major crane management areas which provide night roosts.

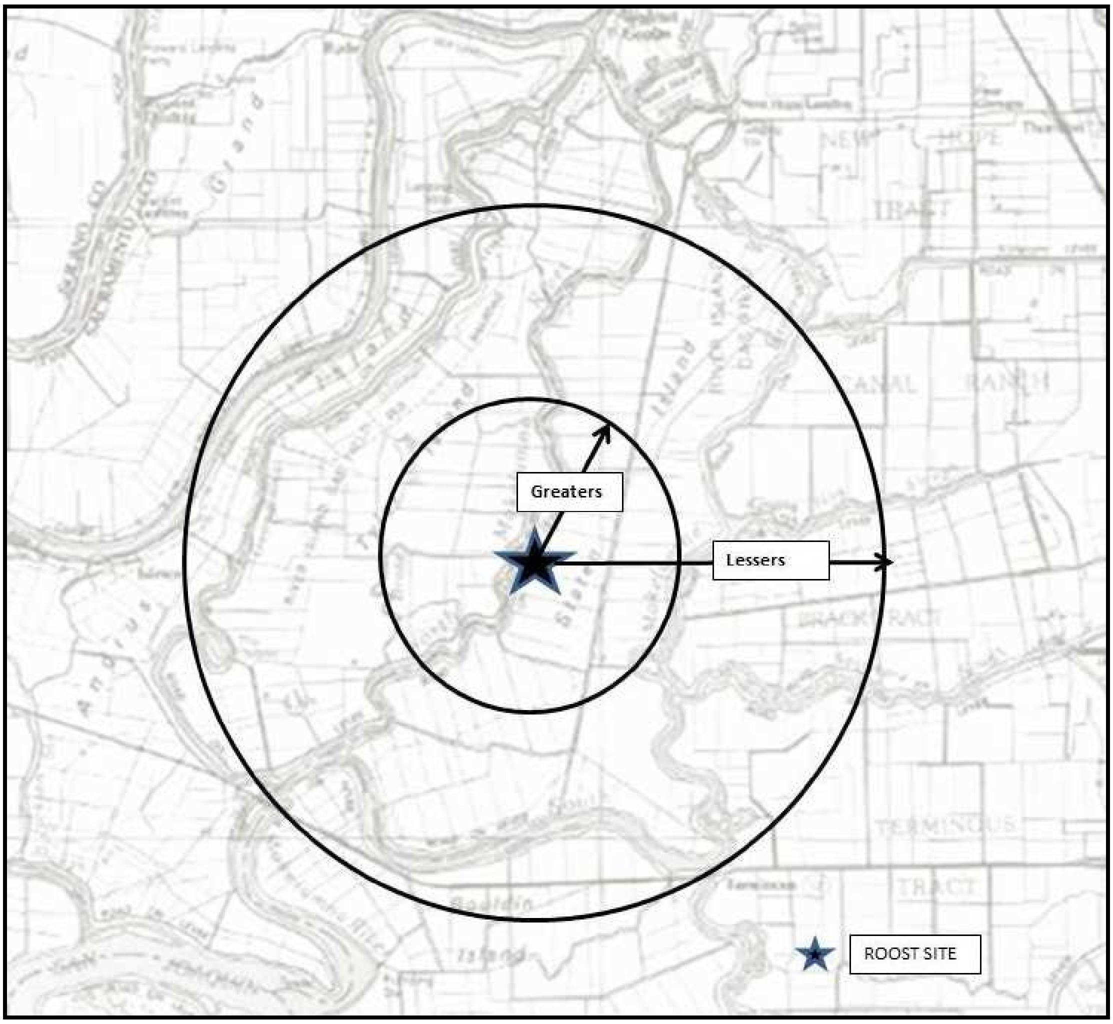

Figure 1.3. Conceptual model of an ecosystem unit for sandhill crane (*Grus canadensis*) conservation which depicts the theoretical foraging landscape available to greater (*G. c. tabida*) and lesser sandhill cranes (*G. c. canadensis*), based on potential differences in their foraging strategies.

Chapter 2

DISTRIBUTION, ABUNDANCE, AND MIGRATION TIMING OF GREATER AND LESSER SANDHILL CRANES WINTERING IN THE SACRAMENTO-SAN JOAQUIN RIVER DELTA REGION OF CALIFORNIA

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ABSTRACT

The Sacramento-San Joaquin River Delta region of California (hereafter, Delta region) is an important wintering region for the Central Valley Population of greater sandhill cranes (*Grus canadensis tabida*) and lesser sandhill cranes (*G. c. canadensis*), but basic information about the ecology of these birds is lacking to design a biologically sound conservation strategy. During the winters of 2007-08 and 2008-09, we conducted roost counts, roadside surveys, aerial surveys, and tracked radio-marked birds to define the geographic area used by sandhill cranes in the Delta region, document migration chronology, and estimate subspecies-specific abundance. Radio-marked sandhill cranes arrived in our study area beginning 3 October, most arrived in mid-October, and the last radio-marked sandhill crane arrived on 10 December. Departure dates ranged from 15 January to 13 March. Mean arrival and departure dates were similar between subspecies. From mid-December through early-February in 2007-2008, the Delta population ranged from 20,000 to 27,000 sandhill cranes. Abundance varied at the main roost sites during winter because sandhill cranes responded to changes in water conditions. Sandhill cranes used an area of approximately 1,500 km^2 for foraging. Estimated peak abundance in the Delta region was more than half the total number counted on recent Pacific Flyway midwinter surveys, indicating the Delta region is a key area for efforts in conservation and recovery of wintering sandhill cranes in California. Based on arrival dates, flooding of sandhill crane roost sites should be staggered with some sites flooded in early September and most sites flooded by early October. Maintained flooding through mid-March would provide essential roosting habitat until most birds have departed the Delta region on spring migration.

INTRODUCTION

California's Central Valley is an important wintering region for sandhill cranes (*Grus canadensis*), both for the Central Valley Population of greater sandhill crane (*G. c. tabida*, hereafter referred to as greaters) and the Pacific Flyway Population of lesser sandhill crane (*G. c. canadensis*, hereafter referred to as lessers) (Pacific Flyway Council 1983, 1997). Sandhill cranes are patchily distributed in the Central Valley using areas where agricultural practices appear to meet their ecological needs and undisturbed roost sites are available (e.g., Pogson and Lindstedt 1991). The Sacramento-San Joaquin River Delta region of California (hereafter Delta region) is a major wintering site for sandhill cranes in the Central Valley, and is particularly important for greaters (Pogson and Lindstedt 1991), listed as threatened in California (California Dept. of Fish and Wildlife 2013).

Because of the importance of the Delta region for wintering sandhill cranes, agencies and conservation groups have acquired, enhanced, and managed lands for use by sandhill cranes. Most of this activity has centered on 5 major roost complexes in the Delta region; the Isenberg Sandhill Crane Reserve owned by California Department of Fish and Wildlife (CDFW), Stone Lakes National Wildlife Refuge (NWR) and San Joaquin River NWR owned by U.S. Fish and Wildlife Service (USFWS), Cosumnes River Preserve, established by The Nature Conservancy (TNC) in partnership with the Bureau of Land Management (BLM) and with multiple agency ownerships, and the more recent acquisition of Staten Island by TNC. All these properties include a portion of habitat managed to provide winter roost sites for sandhill cranes.

Periodic monitoring has confirmed sandhill cranes are using all areas currently managed for roost habitat (Pogson and Lindstedt 1991, Ivey and Herziger 2003), but basic information about the timing of use and subspecies composition are lacking. Moreover, no annual surveys are conducted to estimate crane abundance and define their distribution in the Delta region. Such basic information is necessary for proper sandhill crane management in the face of new environmental threats. For example, the recent spread of West Nile virus into California has caused landowners and managers to reduce the amount of shallow, standing water that might support mosquitoes during summer and early fall (e.g., Calif. Dept. of Fish and Wildlife 2007). Data on the timing of arrival and expected abundance over time at key roost sites in fall will provide the information needed to justify the timing and size of flooded roost sites to maintain sandhill crane use on traditional sites.

Our study addresses key questions about the abundance and distribution of sandhill cranes that winter in the California’s Sacramento-San Joaquin River Delta. Specifically, we quantify the timing of arrival, residence time, and timing of departure at major roost sites, track changes in roost use from fall through winter, estimate subspecies specific sandhill crane abundance, and define the distribution of sandhill crane occurrence in the Delta region during winter. When combined with information on habitat use and individual movements, this information will be critical for the development of biologically sound conservation plans for sandhill cranes wintering in the Delta region.

STUDY AREA

Our study focused on the Delta region but we also collected some information on sandhill crane abundance in the San Joaquin NWR region (Fig. 2.1). Our study concentrated specifically on several properties managed to provide night roost sites for sandhill cranes that subsequently support most of the sandhill cranes that winter in the Delta region (Pogson and Lindstedt 1991, Ivey and Herziger 2003), including Staten Island, Canal Ranch, Cosumnes River Preserve, Brack Tract, and Stone Lakes NWR. The study area was primarily rural agricultural landscapes bordered by urban communities. Agricultural land uses included field and silage corn, fall-planted (winter) wheat, rice, alfalfa, irrigated pasture, dairies, vineyards and orchards. The area also contained tracts of oak savannah and floodplain wetlands along the Cosumnes and Mokelumne rivers. The San Joaquin NWR region (located in Stanislaus County, approximately 12 km west of Modesto) includes the refuge, and private croplands similar to the Delta region.

METHODS

Capture, radio-marking, and tracking

We captured and radio-marked a total of 33 greaters, 46 lessers and one Canadian sandhill crane (*G. c. rowani;* identified morphologically, hereafter referred to as Canadian) on wintering, spring staging, and breeding areas. We captured 33 greaters and 28 lessers using rocket nets baited with corn (Urbanek et al. 1991) and noose-lines (Hereford et al. 2000) at Staten Island or Cosumnes Preserve between 17 October 2007 and 27 February 2008. Additionally, to increase our sample of marked birds, we used rocket nets to capture 6 lessers on a spring staging site (Ladd Marsh Wildlife Management Area) near LaGrande, Oregon in April 2008 and used noose lines to capture 10 lessers on their breeding grounds near Homer, Alaska in August 2008.

For each sandhill crane captured, we determined subspecies based on morphological differences (Johnson and Stewart 1973). We marked each individual with a U.S. Geological Survey aluminum leg band and a unique combination of color bands. Finally, we radio-marked each sandhill crane with a VHF transmitter (Sirtrack, Hawkes Bay New Zealand, Model AVL6171) that was mounted to a tarsal band (Krapu et al. 2011). Transmitters weighed approximately 30 g (< 1% of body mass), had a life expectancy of 730 days, and were equipped with a mortality sensor. The 10 birds captured in Alaska were marked with platform terminal (satellite) transmitters mounted to a tarsal band. All birds were released at their capture site within an hour after capture.

We attempted to locate each radio-marked sandhill crane daily, from October through mid-March, using hand-held 3-element Yagi antennas and a truck-mounted null-peak antenna system (Balkenbush and Hallett 1988, Samuel and Fuller 1996); however, our relocation rate averaged every two days, varied by individual, and primarily depended on sandhill crane movement within our study area. We used a Global Positioning System (GPS), linked to a computer system to enter bird identification number, local site name, truck location, date, time, and bird bearings from multiple locations. We used Program Locate III (Pacer Computing, Tatamagouche, NS, Canada) to triangulate locations (Nams 2005). We conducted 7 aerial searches (Gilmer et al. 1981) over the two winters of our study of areas throughout central California to locate sandhill cranes that left the Delta region. During aerial surveys, we also mapped locations that looked suitable as sandhill crane night roosts.

Our handling of sandhill cranes was conducted under the guidelines of the Oregon State University Animal Care and Use Committee (project #3605) to ensure methods were in compliance with the Animal Welfare Act and United States Government Principles for the Utilization and Care of Vertebrate Animals Used in Testing, Research, and Training policies. Sandhill cranes were captured under CDFW permit SC-803070-02 and U.S. Geological Survey federal banding permit MB#21142.

Migration Chronology

We used telemetry information from our radio-marked sandhill cranes to characterize fall migration arrival and spring migration departure dates relative to our study area during fall 2008 and spring 2009. We defined arrival date as the first date each sandhill crane was found during fall in the study area and departure date as the last date they were detected in late winter. We calculated the number of days our marked sandhill cranes were at our study sites in the Delta region (i.e., winter residency period) from our telemetry records by totaling days that individuals were found at our study sites in the Delta region. We used the Student's t-test to assess if either mean arrival date in fall of 2008 or departure date in spring of 2009 differed by subspecies.

Sandhill Crane Abundance

Roost counts.—We conducted biweekly counts of sandhill cranes at the 5 major night roost complexes in the our study area (Staten Island, Brack Tract, Canal Ranch Tract, Cosumnes River Preserve, and Stone Lakes NWR) between 5 October 2007, and 27 February 2008, to document seasonal patterns of abundance and estimate peak sandhill crane population size in the Delta region. We also conducted roost counts at the San Joaquin River NWR monthly during October 2007 through February 2008. We conducted each count over a period of two or three days but all sites within each roost complex were counted on the same night or morning. We conducted surveys by stationing observers with binoculars at key locations around a roost complex to count all sandhill cranes as they flew into a roost site at sunset or during early morning before they left their roost. We did not have permission to survey the Canal Ranch roost complex on 3 December, so we report estimates only for three dates with complete roost count data.

Aerial surveys.—To generate an unbiased estimate of abundance that included a measure of precision we conducted aerial surveys (e.g., Caughley 1977, Dugger et al. 2005) on 14 and 28 January and 5 February 2008. We first partitioned the study area into high and low density survey blocks based on our understanding of roost site distribution and relative sandhill crane abundance (Ivey and Herziger 2003). In the Delta region, we created three high density survey blocks centered on the major roost complexes at Stone Lakes NWR, Staten Island and adjacent Brack Tract and Canal Ranch, and the Cosumnes River Preserve. The remainder of the Delta region was classified as a low density survey block. In the San Joaquin NWR region, we identified one high density block associated with San Joaquin NWR that was imbedded in a larger, low density, block. We partitioned each survey block into a series of 1 km wide survey strips oriented north-south. We stratified our sample effort by survey block size and randomly selected (without replacement) a sample of transects to survey within each block, adding transects until the total transect area equaled or exceeded 10% of the total block area. We used the same set of transects for each survey.

We conducted surveys from a fixed wing aircraft flying 300 m above the ground and at a speed of 160 km/hr. We used markers on the aircraft window to identify transect boundaries, and two observers counted sandhill cranes out each side of the aircraft while the pilot flew a line down the middle of each survey strip.

For each survey, we estimated sandhill crane abundance as (Caughley 1977):

$\hat{Y} = RZ$

where Z = area of total census

R = average density per unit area = $\Sigma y_{ji}/\Sigma z_i$

where y_{ji} = total sandhill cranes j counted on transect i

z_i = area of transect i

variance was calculated as: $[N(N-n)/n(n-1)]/(\Sigma y^2 + R^2\,\Sigma z^2 - 2R\,\Sigma yz)$

We estimated abundance separately for high and low density survey blocks then combined the two estimates for an estimate of total population size for each survey. We estimated abundance for the Delta and San Joaquin River NWR regions separately, and provide totals for these two regions.

Abundance by subspecies.—Because we could not identify sandhill cranes to subspecies during roost counts or aerial surveys, we conducted roadside surveys at the Cosumnes River Preserve, Staten Island, and Brack Tract to differentiate the subspecies and estimate the relative abundance of greaters and lessers in the Delta region. Counts by roadside surveys were conducted biweekly by 2 experienced observers during morning feeding periods (0700-1000 hrs) from early October through mid-February in 2007-08 and 2008-09. We counted all flocks from vehicles using binoculars and spotting scopes and assigned all sandhill cranes observed as greaters or lessers using morphological characteristics described by Drewien and Bizeau (1974): (1) greaters are approximately

25- 33% taller and more massive; (2) greaters are lighter gray in late fall and winter; (3) greaters have longer and more massive bills in relation to head length; and, (4) greaters have sloping foreheads in comparison to lessers which have rounded foreheads. A few sandhill cranes appeared intermediate in size and were likely Canadians. Our abundance estimates for greaters probably included a few Canadians, but because only 1 of the 60 sandhill cranes that we captured had the morphological measurements of a Canadian (see Johnson and Stewart 1973), this source of bias is likely very low.

We used the estimate of the ratio of greaters to lessers derived from roadside surveys to calculate subspecies-specific abundance for 4 roost count dates (3, 17, 31 December and 14 January 2008). We could not conduct a roadside survey at the Cosumnes River Preserve on 17 December because of poor road conditions; therefore, we took the mean proportion of the roadside surveys for dates immediately before and after 17 December as our estimate to estimate subspecies proportions for that roost count data. Based on the arrival and departure dates of our radio-marked sandhill cranes, our 3 December to 14 January survey interval occurred after all sandhill cranes had arrived and ended before any birds had departed for spring migration. This interval included the period previously known to support peak numbers of greaters in the Delta region (Pogson and Lindstedt 1991). To adjust the total roost count data, we used the proportion estimate generated from the roadside survey that was closest to the roost count date. Finally, because sandhill crane abundance varied by roost complex, we generated proportion estimates (of greaters to lessers) separately for each roost complex and applied that ratio to estimate the number of greaters and lessers at each roost. To derive relative abundances for roosts where we did not have roadside surveys we used proportions from the next nearest roost area: for Stone Lakes NWR we applied the estimate from the Cosumnes River Preserve; and for Canal Ranch we applied the estimate averaged from Staten Island and Brack Track. We then summed estimates from each roost to arrive at the total. We did not have data on subspecies proportions for the San Joaquin NWR region because no roadside surveys were conducted there. We report values as mean ± SE.

Sandhill Crane Distribution

We plotted all locations for radio-marked sandhill cranes on a map of the study area. We supplemented that data with observations of flocks seen from the ground and air during our searches for radio-marked birds. We combined these data sets to generate a map of sandhill crane distribution as well as roost locations in the Delta region.

RESULTS

Migration chronology

Sandhill cranes were reported arriving in our study area as early as 6 September 2007 (M. Ackerman, personal communication), and 9 September 2008 (B. Tadman, personal communication). In 2008 we detected the first radio-marked lesser on 3 October, and the first radio-marked greater on 4 October. Peak arrival occurred slightly earlier for greaters than lessers in 2008 (Fig. 2.2); however, the average arrival date was similar (t =1.22, P = 0.23) between radio-marked greaters (13 Oct ± 2 d) and radio-marked lessers (17 Oct ± 3 d). The average departure date was also similar (t = 1.03; P = 0.30), for greaters (25 Feb ± 1 d) and lessers (22 Feb ± 2 d) (Fig. 2.2). Lessers began departing the study area earlier yet some lingered longer in the Delta region than the greaters (latest departure March 13 versus March 7, respectively). Winter residency was 22% longer for greaters (130 ± 7 d) than for lessers (107 ± 4 d; t_1 = 2.78, P < 0.01).

Abundance

Roost counts.—The total number of roosting sandhill cranes in the Delta region increased from a low of 6,421 (5 Nov 2007) to a high of 27,213 (11 Feb 2008; Fig. 2.3). The season mean was 15,037 ± 4,529. Table 2.1 shows the largest average abundance was recorded at Brack Tract roost complex (7,423 ± 2,129) followed by Staten Island (4,898 ± 1,045), Canal Ranch (4,095 ± 1,425), Cosumnes River Preserve (1,539 ± 339), and Stone Lakes NWR (345 ± 40). Early in the season, most sandhill cranes roosted at Staten Island, however as winter progressed sandhill cranes shifted to Brack Tract and by end of winter most sandhill cranes were roosting in the Brack Tract roost complex. Peak counts recorded at each site included 24,487 at Brack Tract, 10,995 at Staten Island, 7,215 at Canal Ranch, 4,347 at Cosumnes River Preserve, and 598 at Stone Lakes NWR

(Table 2.1). Counts for San Joaquin River NWR averaged 2,310 (± 132), and peaked at 2,895 in February (Table 2.1).

Aerial surveys.—Based on aerial surveys conducted in 2008, we estimated 19,183 ± 1,500 (95% CI: 16,243 - 22,123; Coefficient of Variation [CV]: 0.07) sandhill cranes in the combined Delta and San Joaquin NWR regions on 14 January, 9,028 ± 769 (95% CI: 7,520 – 10,535; CV: 0.01) on 28 January and 21,125 ± 1,903 (95% CI: 17,395 – 24,855; CV: 0.09) on 5 February. Estimates for the Delta region during those same three surveys were 15,687 ± 843 (95% CI: 14,214 – 17,519; CV: 0.05), 8,086 ± 724 (95% CI: 7,362 – 8,810; CV: 0.09), and 18,405 ± 1,795 (95% CI:14,886 – 21,923; CV: 0.10), while estimates for the San Joaquin River NWR region during those three surveys were 3,496 ± 657 (95% CI: 2,208 – 4,783; CV: 0.18), 942 ± 45 (95% CI: 853 – 1,030; CV: 0.05), and 2,720 ± 108 (95% CI: 2,508 – 2,932; CV: 0.04), respectively. In the Delta region, only a few sandhill cranes were observed south of Highway 12 or west of Isleton where we did not conduct roost count surveys, therefore our roost counts included a high percentage of the total Delta region population.

Abundance by subspecies.—The proportion of sandhill cranes that we identified as greaters during roadside surveys varied from 1.0% to 80.4% with higher proportions of greaters generally observed at the Cosumnes River Preserve than other areas (Table 2.2). We estimated that the number of greaters roosting in the Delta Region ranged from 2,166 to 6,866, while the number of lessers ranged from 12,867 to 17,690 (Table 2.3).

Distribution

Sandhill cranes were found primarily in Sacramento and San Joaquin counties, but also in east Yolo, Solano and Contra Costa counties (Fig. 2.4). This area includes both the Central Delta and Cosumnes and Stone Lakes areas, and is approximately 1,500 km^2, bounded on the west by the Sacramento River and the Deep Water Ship Channel, on the north by Elk Grove and South Sacramento, on the south by Highway 4 to Stockton and on the east by Lodi, Galt and rural communities of Herald and Wilton. This area includes the Cosumnes River floodplain (below Wilton), the Mokelumne River floodplain (below Galt), the Sacramento River floodplain (below Freeport), and the Delta tracts and islands which lie east of the Deep Water Ship Channel, east of the Sacramento

River channel between Rio Vista and Antioch, north of Highway 4, and west of Interstate Highway 5.

DISCUSSION

Migration chronology

Sandhill cranes first arrived in our Delta region study area during the first week of September, earlier than the third week of September as reported by Pogson and Lindstedt (1991) in the mid-1980s. The difference may be due to changes in cropping practices that have benefited sandhill cranes. For example, at Staten Island before the mid-1980s, corn harvest was not begun until mid-September and continued to November. With more corn planted due to the falling price of wheat, the start date for harvest was moved up in order to harvest the entire crop early. Earlier crop harvesting has permitted earlier flooding of harvested fields to serve as roost sites on the island (J. Shanks, pers. comm.). Possibly some sandhill cranes learned that resources are available earlier in the Delta region and therefore arrived from migration earlier than they had in the past. Also, the earlier arrival might be attributed to an increasing population of greater sandhill cranes since the mid-1980s (see Littlefield 2002) or because the breeding population has expanded southward in the Sierra Nevada to locations that are shorter migration distances from the Delta region (Ivey and Herziger 2001).

Despite the earlier initial arrival dates of some birds, only a small number of sandhill cranes were present in September. Our radio-marked birds arrived about one month later in October coincident with the arrival of large numbers of sandhill cranes into the region. Despite the considerable difference in the length of migration between subspecies (Pacific Flyway Council 1983, 1997), the arrival chronology of our radio-marked lessers and greaters was similar. These subspecies flocks occasionally share fall staging areas and their movements south may be synchronized by favorable weather conditions for migration to the Central Valley. Arrival dates for lessers to the Delta region were very similar to mean arrival times for lessers to wintering areas in Texas (Krapu et al. 2011), despite the fact that lessers wintering in California use different migration routes and staging areas than birds wintering in Texas (Petrula and Rothe 2005, Krapu et al. 2011).

During our study, sandhill cranes used roosts throughout our study area into early March, much later than reported by Pogson and Lindstedt (1991), who noted sandhill cranes departed Brack Tract, Staten Island, and Canal Ranch in late January. We attribute this difference to changes in management that currently maintains roosts for sandhill cranes later during winter. The general chronology of spring departure was similar for both subspecies. However, lessers tended to begin their departure earlier than greaters but finished departing after the all greaters had left.

Abundance

During mid-winter surveys in the Pacific Flyway in 2008 and 2009, 51,981 and 49,238 sandhill cranes were counted, respectively (Collins and Trost 2010). A comparison of our results with previous work in the Delta region suggests the total abundance of sandhill cranes in the Delta region has increased since the 1980s. Previous aerial counts ranged from 3,380 during 1983-1989 (CDFW, unpublished data) to 17,030 in the late 1990s (Ducks Unlimited, unpublished data) and 11,625 in 2000-2001 (California Department of Fish and Wildlife, unpublished data). Roost count and aerial survey data are not directly comparable, but it is likely that the sandhill crane population in the Delta region is higher today than in the 1980s. The highest estimate from our aerial surveys was similar to the estimate from the air in the late 1990s; however, our methods differed because previous surveys were assumed to be complete counts while our estimates were generated using sampling statistics.

Our population estimates from aerial surveys were relatively precise, with coefficients of variation ranging from 5-10% during all surveys but one. This precision indicates that an aerial-based survey for sandhill cranes in the Delta may be a valid method to estimate their population size or at least derive an index of population size. Such a survey would have to be coupled with ground surveys to derive the percentage of the total population comprised of greaters and lessers. The aerial survey estimates were consistently smaller than the abundance estimates from roost counts (on average 37% less), and the roost count estimates were well above the 95% confidence limits for the aerial survey. Given the large discrepancy, additional work is needed to determine the more accurate method of surveying cranes, but aerial surveys may provide a precise index of crane abundance.

The increase in sandhill crane numbers in the Delta region since the 1980s reflects an overall increase in sandhill cranes in the Pacific Flyway from counts of 10,000 in the 1980s to counts of over 50,000 in recent years (Collins and Trost 2010). A comparison of peak counts for the Delta region relative to the total sandhill crane population in the Pacific Flyway indicates about one-third of all sandhill cranes that wintered in the Pacific Flyway used the Delta region during the 1980s. Our peak roost count of >27,000 sandhill cranes in mid-February indicates that more than half of all sandhill cranes in the Pacific Flyway may currently use the Delta region, so both the absolute and relative importance of this region for wintering sandhill cranes has increased since the 1980s. The increase of sandhill cranes in the Delta region could reflect improved roosting and foraging conditions in the Delta region from the conservation efforts of the past three decades or could be the result of habitat loss and degradation elsewhere which would force the sandhill cranes to increase their presence in the Delta region.

Roost count data indicate that the population of sandhill cranes using the Delta region increased from October through mid-February. Pogson and Lindstedt (1991) noted a similar pattern for greaters during the 1980s. However, our radio-marked greaters had all arrived in the Delta region by the end of November and lessers had all arrived by early December. Furthermore, movement data indicate that once greaters arrived in the Delta region they were relatively sedentary (Chapter 3). This discrepancy between increases in roost counts and movement data may be because our telemetry results were based on a relatively few individuals and may not have encompassed movement trends of the population.

Previous to this study only a few population estimates were made of greaters and lessers wintering in the Central Valley or the Delta region. Pogson and Lindstedt (1991) estimated 6,800 “large cranes” wintered in the Central Valley in 1983 and 1984, while Littlefield (2002) estimated that 6,000 greaters wintered in the Sacramento Valley during the early 1990s. Both estimates apparently combined greaters with the Canadian subspecies which are more common in the Sacramento Valley (. 2014) so their counts are likely biased high. Using roost counts and roadside surveys to allocate total count data to subspecies, our estimate for the number of greaters using the Delta region ranged from 2,166 to 6,800. The maximum number of greaters counted during a single set of roadside surveys in the Delta region was 1,786. Our estimate of 6,800 is likely biased high because in January large flocks of lessers were using Brack Tract for roosting while foraging to the south in areas not covered by our roadside surveys; therefore greaters were over-estimated in our roadside survey proportions. The number of sandhill cranes using Brack Tract during the feeding count in January 2008 was less than three percent of the number roosting, further suggesting our estimates of proportions might be biased. In comparison, our roadside surveys counted 24% and 41% of birds roosting at Brack Tract in mid and late December. Therefore, we think that the true number of greaters in the Delta region was between two and three thousand birds, which is a significant portion of the Central Valley Population. Additional work to develop a more precise survey methodology, including using random sampling of subspecies composition of foraging flocks from ground surveys to assess subspecies composition, and possibly including distance sampling with aerial surveys (see Ridgway 2010), is needed to accurately estimate the population size of each subspecies of sandhill crane wintering in California's Central Valley.

The changing distribution of sandhill cranes among roost complexes in the Delta region was likely in response to changes in roost site conditions. Managers at Staten Island began flooding roost sites relatively early in fall during both years of our study, which attracted early arriving sandhill cranes. As winter proceeded additional roost sites at Brack Tract and Canal Ranch were flooded both years, and sandhill cranes spread out to take advantage of these sites. By mid-winter during both years, managers at Staten Island began drying several large roosts which likely induced birds to shift their roosting to nearby Brack Track. At the Cosumnes River Preserve, roost sites remained available throughout winter and sandhill crane numbers were relatively stable there the entire season. This pattern of habitat use suggests the abundance and distribution of sandhill cranes in the Delta region can be influenced by changing the distribution of their roosts.

In addition to responding to habitat changes, the proportion of greaters to lessers differed by habitat areas. Greaters were proportionately more abundant in the Cosumnes River Preserve and Stone Lakes NWR and lessers dominated in the Central Delta. Reasons for this pattern are not clear but may be related to a preference by lessers for alfalfa (see Chapter 4) which is widely grown in the Central Delta and rarer near the Cosumnes River Preserve and Stone Lakes Refuge. Differences in proportions of the subspecies may have been due to difference in physical characteristics of roosts that favored or constrained use by one subspecies compared to the other. Greaters are also socially dominant over lessers (Ivey, unpublished data) which may have allowed them to dominate proportional use of the Cosumnes River preserve which grew rice, a food resource preferred by both subspecies (Chapter 4).

Distribution

In comparing our data to that from a 1980s study reported in Pogson and Lindstedt (1991), the winter range for sandhill cranes in the Delta region has decreased. While development of conservation areas such as Cosumnes River Preserve and Stone Lakes NWR has improved habitat conditions for wintering sandhill cranes, significant loss of foraging habitat has occurred over the past three decades on private lands in the region (primarily from conversion to vineyards) and such losses are continuing (see Littlefield and Ivey 2000). Within their Delta region winter range, large areas of habitat have been lost primarily due to conversions to incompatible crops (e.g., vineyards and orchards) and to the expansion of the cities of Elk Grove and Galt. Most noticeable has been the increase in grape vineyards, but in more recent years other incompatible crops such as turf farms, olives, and blueberries have further reduced compatible foraging area (Littlefield and Ivey 2000). For example, between 2003 and 2007, approximately 335 hectares of cropland used regularly by sandhill cranes at Canal Ranch was converted to olive trees (G. Ivey, personal observation). If such habitat losses continue, this could further influence sandhill crane use of the Delta region and possibly limit the regional carrying capacity for sandhill crane populations in the future.

MANAGEMENT IMPLICATIONS

Based on arrival dates, flooding of some sites managed for crane roosting should begin slowly in early September and managers should provide larger areas for roosting cranes by early October. Maintaining flooded roosts until mid-March when most birds leave the Delta region for spring migration would provide roosting habitat throughout their wintering period. For areas specifically managed for the welfare of greaters (e.g., Staten Island) our data suggests that maintenance of roost sites through the first week of March would be beneficial, based on departure times for greaters. Our estimates for the population of greaters using the Delta region represent a significant percentage of the total population. Therefore, this region should be considered a key area for efforts in conservation and recovery of this listed subspecies.

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LITERATURE CITED

Balkenbush, J. A., and D. L. Hallett. 1988. An improved vehicle-mounted telemetry system. Wildlife Society Bulletin 16:65-67.

California Dept. of Fish and Wildlife. 2013. State and federally listed endangered and threatened animals of California. Sacramento, California. (http://www.dfg.ca.gov/biogeodata/cnddb/pdfs/TEAnimals.pdf) accessed 3/1/2014.

California Dept. of Fish and Wildlife. 2007. Yolo Bypass Wildlife Area Land Management Plan. Sacramento, California, USA. <http:// http://www.dfg.ca.gov/lands/mgmtplans/ybwa/>. Accessed 12 December 2013.

Caughley, G. 1977. Sampling in aerial survey. Journal of Wildlife Management 41:605-615.

Collins, D. P., and R. E. Trost. 2010. Pacific Flyway Data Book: Waterfowl harvests and status, hunter participation and success in the Pacific Flyway and United States. U.S. Fish and Wildlife Service, Division of Migratory Bird Management, Portland, Oregon, USA.

Drewien, R. C., and E. G. Bizeau. 1974. Status and distribution of greater sandhill cranes in the Rocky Mountains. Journal of Wildlife Management 38:720-742.

Dugger, B. D., S. L. Melvin, R. S. Finger. 2005. Abundance and community composition of waterfowl and wading birds using the channelized Kissimmee River Floodplain, Florida. Southeastern Naturalist 4:435-446.

Gilmer, D. S., L. M. Cowardin, R. L. Duval, L. M. Mechlin, C. W. Shaiffer, and V. B. Kuechle. 1981. Procedures for the use of aircraft in wildlife biotelemetry studies. U.S. Fish and Wildlife Service Resource Publication 140. Washington, D. C., USA.

Hereford, S. G., T. E. Grazia, M. Nagendran, and A. Hussain. 2000. Use of traditional Indian trapping methods to capture sandhill cranes. Proceedings of the North American Crane Workshop 8:220.

Ivey, G. L., and C. P. Herziger. 2001. Distribution of greater sandhill crane pairs in California, 2000. California Dept. Fish and Wildlife, Sacramento, CA, USA.

Ivey, G. L., and C. P. Herziger. 2003. Sandhill crane monitoring at Staten Island, San Joaquin County, California, 2002-03. The Nature Conservancy, Cosumnes River Preserve, Galt, California, USA.

Ivey, G. L., C. P. Herziger, and D. A. Hardt. 2014. Conservation Priorities and Best Management Practices for Wintering Sandhill Cranes in the Central Valley of California. Unpublished report. The Nature Conservancy, Sacramento, California, USA.

Johnson, D. H., and R. E. Stewart. 1973. Racial composition of migrant populations of sandhill cranes in the northern plain states. Wilson Bulletin 85:148-162.

Krapu, G. L., D. A. Brandt, K. L. Jones, and D. H. Johnson. 2011. Geographic distribution of the Mid-Continent Population of sandhill cranes and related management applications. Wildlife Monographs 175:1–38.

Littlefield, C. D. 2002. Winter foraging habitat of greater sandhill cranes in northern California. Western Birds 33:51-60.

Littlefield, C. D., and G. L. Ivey. 2000. Conservation assessment for greater sandhill cranes wintering on the Cosumnes River Floodplain and Delta regions of California. The Nature Conservancy, Cosumnes River Preserve, Galt, California, USA.

Nams, V. O. 2005. LOCATE III. Pacer, Truro, Nova Scotia, Canada.

Nesbitt, S. A., S. T. Schwikert. 2005. Wing-molt patterns - A key to aging sandhill cranes. Wildlife Society Bulletin 33:326-331.

Pacific Flyway Council. 1983. Pacific Flyway Management Plan: Pacific Flyway Population of lesser sandhill cranes. Pacific Flyway Study Committee (c/o Pacific Flyway Representative USFWS), Portland, Oregon, USA.

Pacific Flyway Council. 1997. Pacific Flyway management plan for the Central Valley Population of greater sandhill cranes. Pacific Flyway Study Committee (c/o Pacific Flyway Representative USFWS), Portland, Oregon, USA.

Petrula, M. J., and T. C. Rothe. 2005. Migration chronology, routes, and distribution of Pacific Flyway Population of lesser sandhill cranes. Proceedings of the North American Crane Workshop 9:53-67.

Pogson, T. H., and S. M. Lindstedt. 1991. Distribution and abundance of large sandhill cranes, *Grus canadensis*, wintering in California's Central Valley. Condor 93:266-278.

Ridgway, M. S. 2010. Line transect distance sampling in aerial surveys for double-crested cormorants in coastal regions of Lake Huron. Journal of Great Lakes Research 36:403–410.

Samuel, M. D., and M. R. Fuller. 1996. Wildlife Radiotelemetry. Pages 370-418 *in* T. A. Bookhout, editor. Research and management techniques for wildlife and habitats. Fifth edition. The Wildlife Society, Bethesda, Maryland, USA.

Tacha, T. C., S. A. Nesbitt, and P. A. Vohs. 1992. Sandhill crane *in* A. Poole, P. Stettenheim, and F. Gill, editors. The birds of North America Monograph 31. The Academy of Natural Sciences, Philadelphia and American Ornithologists' Union, Washington, D.C., USA.

Tacha, T. C., S. A. Nesbitt, and P. A. Vohs. 1994. Sandhill Crane. Pages 77-94 *in* T. C. Tacha, and C. E. Braun, editors. Migratory Shore and Upland Game Bird Management in North America. International Association of Fish and Wildlife Agencies, Washington, D.C., USA.

Urbanek, R. P., J. L. McMillen, and T. A. Bookhout. 1991. Rocket-netting greater sandhill cranes on their breeding grounds at Seney National Wildlife Refuge. Pages 241–245 *in* J. T. Harris, editor. Proceedings of the 1987 International Crane Workshop, 10 May 1987, Qiqihar, Heilongjiang Province, China. International Crane Foundation, Baraboo, Wisconsin, USA.

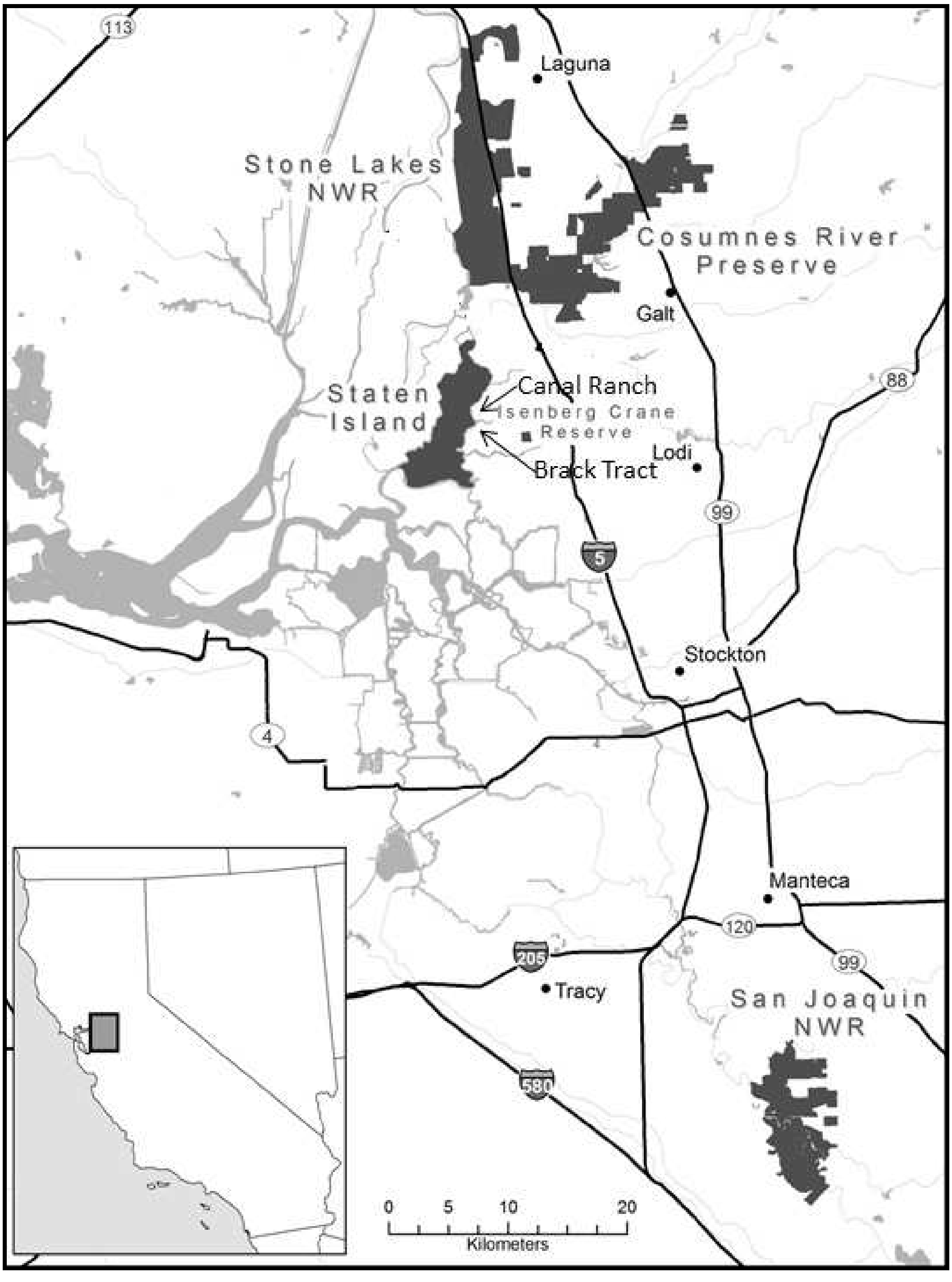
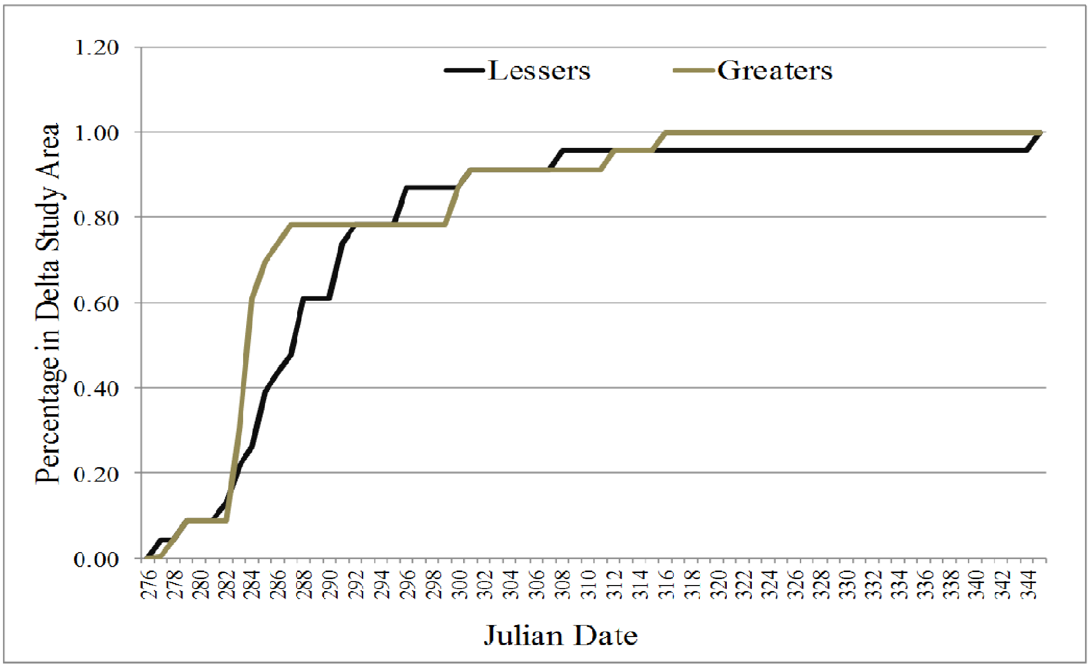


Figure 2.1. Map of the Sacramento-San Joaquin River Delta and the San Joaquin River National Wildlife Refuge where distribution, abundance, and arrival and departure dates of greater (*Grus canadensis tabida)* and lesser (*G. c. canadensis*) sandhill cranes were studied, 2007-2009. Grey areas are waterways.

a.



b.

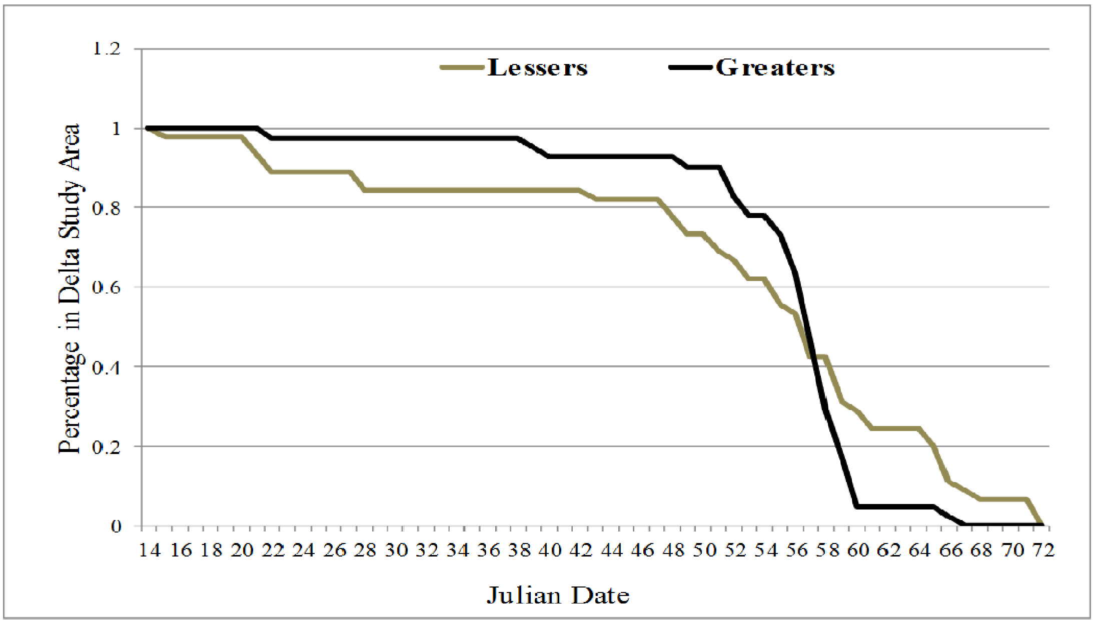


Figure 2.2. Chronology of arrival in fall 2008 (a) and departure in spring 2009 (b) of radio-marked greater (*Grus canadensis tabida*) and lesser sandhill cranes (*G. c. canadensis)* to the Sacramento-San Joaquin River Delta. The lines represent the proportion of radio-marked birds on the study area at each date. Julian date 276 is 2 October, date 344 is 10 December, date 14 is 14 January, date 66 is 7 March, and date 72 is 12 March.

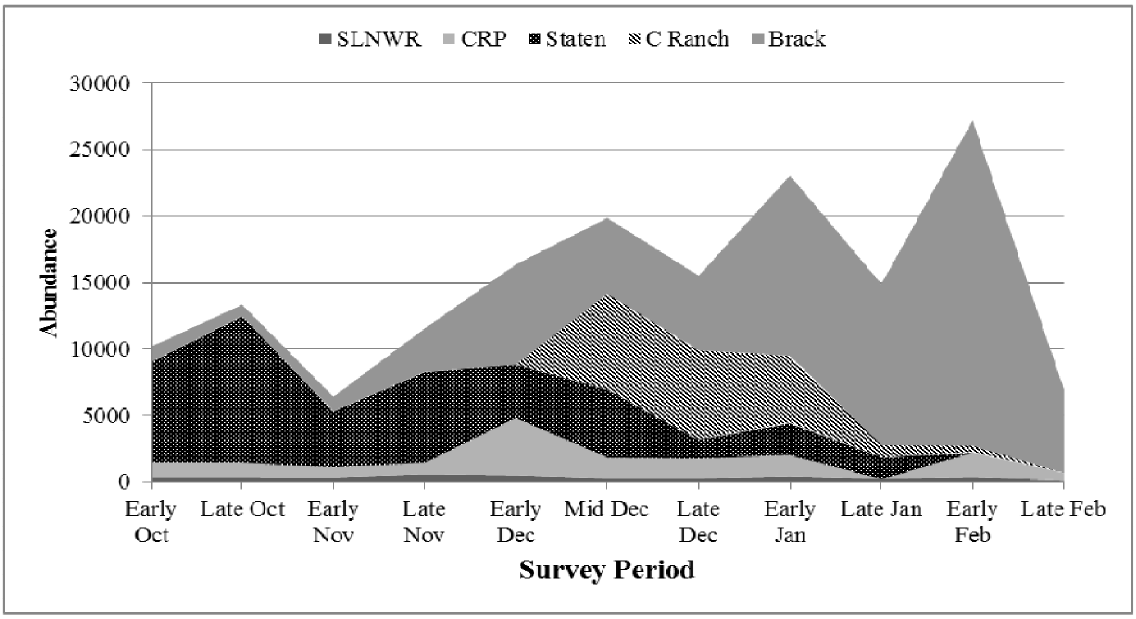


Figure 2.3. Counts of sandhill cranes (*Grus canadensis,* all subspecies combined) at all major roosts sites (Brack Track, Canal Ranch, Staten Island, Cosumnes River Preserve, and Stone Lakes National Wildlife Refuge in the Sacramento-San Joaquin River Delta, California as determined from evening roost counts conducted every two weeks during the winter 2007-08.

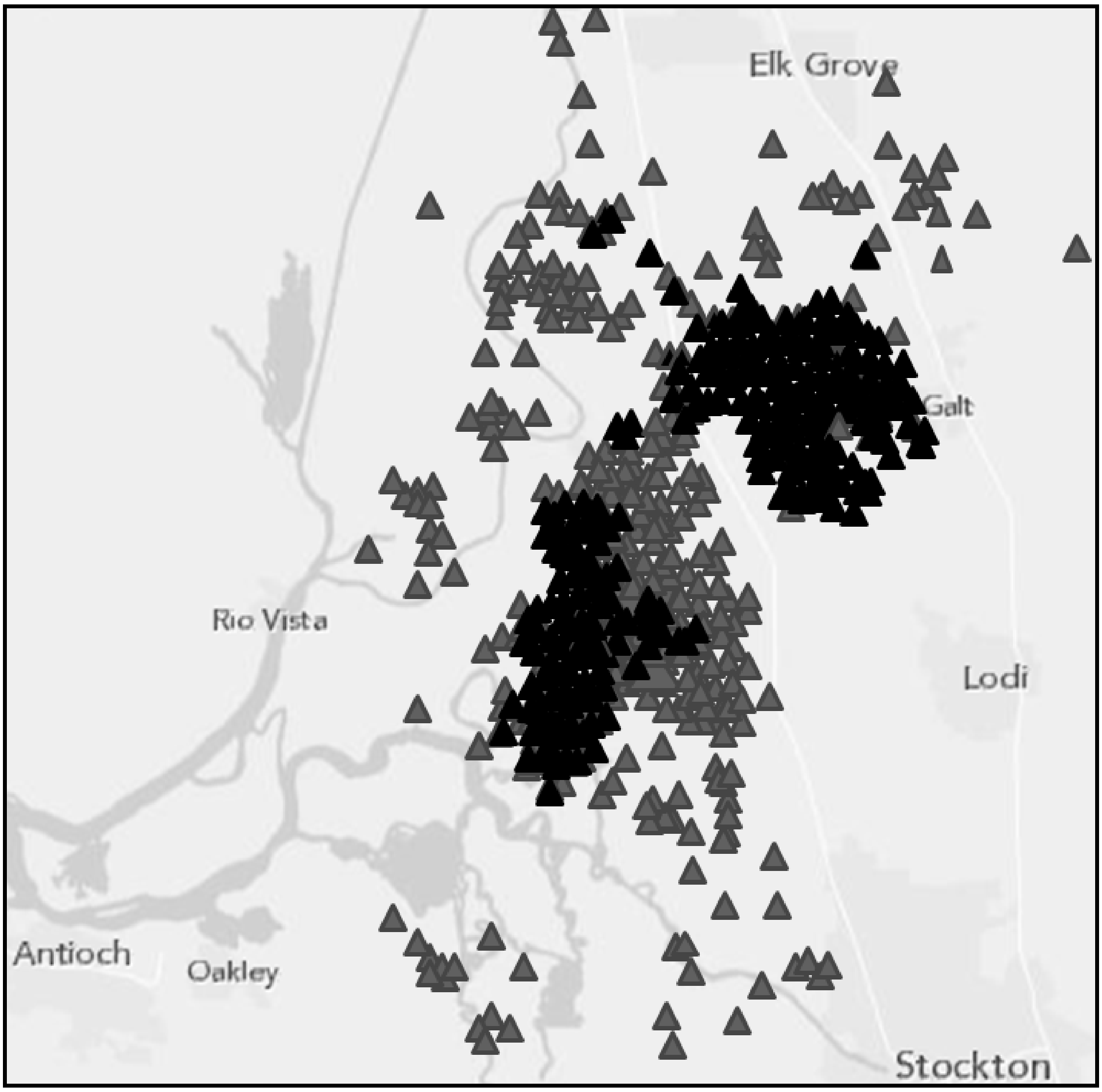


Figure 2.4. Distribution of greater (*Grus canadensis tabida* [black triangles]) and lesser sandhill cranes (*G. c. canadensis* [grey triangles]) winter foraging locations in the Sacramento-San Joaquin River Delta, California, 2007-08 and 2008-09, as determined by locations of radio-marked cranes from ground and air surveys.

Table 2 1. Roost count comparisons of sandhill cranes (*Grus canadensis*) at all major roost sites (Brack Tract [BT], Canal Ranch [CR], Cosumnes River Preserve [CRP], Staten Island [SI], and Stone Lakes National Wildlife Refuge [SLNWR]) in the Sacramento-San Joaquin River Delta region and the San Joaquin National Wildlife Refuge, (SJNWR) California, winter 2007-08.

Week	**BT**	**CR**	**CRP**	**SI**	**SLNWR**	**SJNWR**
08 Oct	1,132	[a]	1,105	7,565	362	[d]
22 Oct	852	[a]	1,137	10,995	358	[d]
05 Nov	1,083	[a]	775	4,230	333	[d]
19 Nov	3,255	[a]	850	6,846	598	2,537
03 Dec	7,540	[b]	4,347	3,986	506	[d]
17 Dec	5,706	7215	1,650	5,041	251	2,264
31 Dec	5,605	6758	1,504	1,397	261	[d]
14 Jan	13,551	5064	1,621	2,403	417	[d]
28 Jan	12,140	915	[c]	1,622	230	2,895
11 Feb	24,487	525	1,834	[a]	367	[d]
25 Feb	6,306	[a]	564	[a]	113	2,484
Average	**7,423**	**4,095**	**1,539**	**4,898**	**345**	**2545**

[a]Roost site was dry.
[b]Did not have permission to survey.
[c]Roads were too wet to survey.
[d]Did not survey on these dates.

Table 2.2. Proportion of greater (*Grus canadensis tabida;* G*)* and lesser sandhill cranes (*G. c. canadensis;* L) observed during four roadside surveys of feeding fields around three major roost complexes in the Sacramento-San Joaquin River Delta, California during 2007-08. "*n*" indicates the total number of cranes observed during surveys at all three sites.

		Roost Complex					
		Brack		**Cosumnes**		**Staten Island**	
Week	***n***	**G**	**L**	**G**	**L**	**G**	**L**
12/03/2007	5,180	0.014	0.986	0.182	0.818	0.083	0.917
12/17/2007	3,788	0.074	0.926	--	--	0.065	0.935
12/31/2007	5,416	0.093	0.907	0.783	0.217	0.093	0.917
01/14/2008	8,152	0.678	0.322	0.804	0.196	0.014	0.986

Table 2.3. Abundance of greater (*Grus canadensis tabida*; G) and lesser sandhill cranes (*G. c. canadensis*; L) at five roost complexes (Brack Track, Cosumnes River, Staten Island, Canal Ranch, and Stone Lakes National Wildlife Refuge [NWR]) in Sacramento-San Joaquin River Delta, California on three dates during winter 2007-08.

	Date					
	Dec. 17		Dec. 31		Jan. 14	
Roost	G	L	G	L	G	L
Brack Tract	422	5,284	521	5,084	3,444	10,107
Cosumnes River	792	858	1,173	331	1,297	324
Staten Island	328	4,713	130	1,267	34	2,369
Canal Ranch	503	6,712	630	6,128	1,757	3,307
Stone Lakes NWR	121	130	204	57	335	83
Total	**2,166**	**17,697**	**2,658**	**12,867**	**6,867**	**16,190**

Chapter 3

WINTERING ECOLOGY OF SYMPATRIC SUBSPECIES OF SANDHILL CRANES: CORRELATIONS BETWEEN BODY SIZE, SITE FIDELITY AND MOVEMENT PATTERNS

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ABSTRACT

Body size is known to correlate with many aspects of life history in birds and this knowledge can be used to manage and conserve bird species, but few studies have compared the wintering ecology of sympatric subspecies that vary significantly in body size. We used radio telemetry to examine the relationship between body size and site fidelity, movements, and home range of 2 subspecies of Sandhill Cranes (*Grus canadensis*) wintering in the Sacramento-San Joaquin Delta of California. Both subspecies showed strong fidelity to the Delta study area between study years, but within years Greater Sandhill Cranes (*G. c. tabida*) showed stronger fidelity to landscapes within our study region and roost complexes within landscapes than Lesser Sandhill Cranes (*G. c. canadensis*). Foraging flights from roost sites were shorter for Greater Sandhill Cranes compared to Lesser Sandhill Cranes (1.2 ± 0.4 km vs 3.1 ± 0.1 km) and consequently, mean size of 95% fixed kernel winter home ranges was an order of magnitude smaller for Greater Sandhill Cranes (1.9 ± 0.4 km^2 vs. 21.9 ± 1.9 km^2). Strong site fidelity indicates that conservation planning to manage for adequate food resources around traditional roost sites can be effective for meeting habitat needs of these cranes, but the scale of conservation differs by subspecies. We recommend that conservation planning consider all habitats within 5 km of a known Greater Sandhill Crane roost and 10 km of a Lesser Sandhill Crane roost when planning for habitat management, mitigation, acquisition, and easements.

Keywords: California, *Grus canadensis*, home range, Sacramento-San Joaquin Delta, Sandhill Crane, site fidelity, wintering ecology, conservation planning, scale

INTRODUCTION

Conservation planning for birds in winter requires estimates of key demographic parameters together with an understanding of habitat needs and movements (e.g., home range size and site fidelity) that can help define the scale at which conservation and management should be focused(Guisan et al. 2006, Thornton and Fletcher 2013). More generally, scale is of fundamental importance to understanding species–environment associations (Levin 1992) because a species response to environmental factors is reliant on the scales that individuals interact with landscapes (Wiens 1989). Body size is often correlated with the scale at which species interact with their environment (Wiens 1989, Mech and Zollner 2002). Mechanisms explaining this association include that body size influences avian energetics (McNab 2001, 2003), social dominance (Bautista et al. 1995), and predation risk (Gotmark and Post 1996), and those factors can influence access to resources and subsequently important life history characteristics like home range size (Shoener 1968, Haskell et al. 2002, Ottaviani et al. 2006), site fidelity (Mini 2013) and survival (Lindstedt and Calder 1976, Sæther 1989, Martin 1995). Knowledge of home range size, and site fidelity inform population performance and the size and frequency of movements that would help define habitat connectivity and the geographic scale at which to target conservation planning.

Much of the comparative work related to body size has focused on interspecies relationships (Western and Ssemakula 1982, Olson et al. 2009, Morales-Castilla et al. 2012) or species with considerable sexual dimorphism (Székely et al. 2002, Krüger 2005). However, some species like Sandhill Cranes (*Grus canadensis*) have large intraspecies variability in body size among subspecies that should be considered when investigating species ecology and conservation planning. For example, Greater (*G. c. tabida*; hereafter Greaters) and Lesser (*G. c. canadensis*) Sandhill Cranes (hereafter, Lessers) are 2 subspecies that breed and winter in western North America. Greaters are large (mean body size for males = 4.9 kg), relatively short distance migrants (mean breeding latitude 45^{o} N) compared to Lessers (mean body size for males = 3.9 kg; mean breeding latitude 65^{o} N; Johnson and Stewart 1973). Such size variation between subspecies is often associated with geographic segregation in winter; however, both subspecies of crane winter sympatrically in the Sacramento-San Joaquin River Delta region of California to the extent that birds share winter roost sites and may forage in the same fields. From a conservation perspective, the Delta is an important wintering region for both subspecies (Pacific Flyway Council 1983, Pacific Flyway Council 1997) and it is under increasing pressure from urbanization, changes in agricultural practices, and water supply limitations (Ivey 2014) that threaten to compromise the capacity of the region to support cranes during fall and winter.

In the case of Sandhill Cranes, individual birds require 2 key habitat components on wintering areas: suitable night roost habitat surrounded by suitable foraging habitats (Tacha et al. 1994). In the context of refuging and central place foraging theories (Hamilton and Watt 1970, Orians and Pearson 1979, Frederick et al. 1987, Belanger and Bédard 1990), crane daily activity patterns can be viewed as one or more round trip flights from a centrally located roost site to one or more foraging sites. Therefore, conceptually, we can define an “ecosystem unit” for conservation and management of cranes to include a central roost surrounded by a foraging landscape out to a certain radius.

Little is known about the wintering ecology of cranes that can be used to parameterize models like we describe above or factors that contribute to variation in winter movements.. However, given that the subspecies differ in body size, we predict that these important metrics will vary between subspecies of cranes wintering in the Delta, which may lead to different conservation recommendations for each subspecies. We use radio telemetry to study movements of Greaters and Lessers wintering in California to compare how body size correlates with important life history traits. Specifically, we quantify site fidelity at several spatial scales and estimate home range size, commuting distance, and survival during winter. Results provide basic insight into how body size correlates specific information that can be used in conservation planning for cranes.

METHODS

Study Area

The vast majority of Pacific Flyway sandhill cranes winter in the Central Valley of California (Pacific Flyway Council 1983, 1997), which extends from Red Bluff to Bakersfield from north to south and between the Coast Range and the Sierra Nevada Mountains from west to east. Their winter range in the valley is primarily focused in five discrete regions which include the Sacramento Valley, the Sacramento-San Joaquin Delta, the San Joaquin River National Wildlife Refuge (NWR) region, the Merced Grasslands, and the Pixley NWR region (Fig. 3.1). These regions support over 95% of the crane use in the valley. Most of our work was concentrated on the Sacramento-San Joaquin Delta region (hereafter, Delta) and was centered on several properties (Staten Island, Cosumnes River Preserve, Isenberg Crane Reserve, and Stone Lakes National Wildlife Refuge) that are managed to provide night roost sites for cranes and subsequently support most of the cranes that winter in the Delta (Pogson and Lindstedt 1991, Ivey and Herziger 2003, U.S. Fish and Wildlife Service 2007; Fig. 3.2). The Delta region is primarily a rural agricultural landscape bordered by urban communities. Agricultural land uses included field and silage corn, fall-planted wheat, rice, alfalfa, irrigated pasture, dairies, vineyards and orchards. The region also contains large tracts of oak savannah and floodplain wetlands along the Cosumnes and Mokelumne rivers.

We captured cranes primarily at Staten Island and Cosumnes River Preserve. Staten Island (3,725 ha) was a large corporate farm that was purchased by The Nature Conservancy (TNC) and is managed as an income-producing farm but with a focus on providing habitat for cranes and other wildlife (Ivey et al. 2003). The Cosumnes River Preserve (9,915 ha within our study area), was established by TNC and is a conglomeration of lands owned or under conservation easements by TNC, Bureau of Land Management (BLM), Ducks Unlimited, California Department of Fish and Wildlife (CDFW), State Lands Commission, California Department of Water Resources, Sacramento County, and various private owners, that provide habitats for cranes including seasonal wetland roost sites, oak savannahs, organic rice and other crops. Isenberg Crane Reserve, located on Brack Tract, is owned and managed by CDFW and consists of 2 seasonal wetland roost sites (totaling 60 ha) that are surrounded by rice fields and other private agricultural lands.

We defined 2 landscapes within our Delta study region (Fig. 3.2) that differed in the composition of habitat types available to wintering cranes (U.S. Fish and Wildlife Service 2007, Kleinschmidt Associates 2008). Previous work suggested that these landscapes were far enough apart to be viewed as distinct by Greaters (Ivey and Herziger 2003). The Cosumnes-Stone Lakes landscape was located in the northern portion of the Delta, which included the Cosumnes River, Mokelumne River and Stone Lakes Floodplains, and contained a greater diversity of habitats, including large areas of seasonal wetlands and native grasslands and oak savannahs. The Central Delta landscape in the east-central portion of the Delta encompassed Staten Island, Isenberg Crane Reserve and other islands north of Highway 4 which were primarily composed of croplands.

Capture, Radio Tagging, and Tracking

We captured and radio tagged a total of 33 Greaters and 46 Lessers. All Greaters and 29 Lessers were captured using rocket nets baited with corn (Urbanek et al. 1991) and noose-lines (Hereford et al. 2000) at Staten Island (4 Greaters and 9 Lessers) or Cosumnes Preserve (21 Greaters and 20 Lessers) between 17 October 2007 and 27 February 2008. We used rocket nets to capture 6 of the Lessers on a spring migration staging site (Ladd Marsh Wildlife Management Area) near LaGrande, Oregon in April 2008 and used noose-lines to capture 10 Lessers on their breeding grounds near Homer, Alaska in August 2008.

For each crane captured, we determined subspecies based on morphological differences (Johnson and Stewart 1973). We marked each individual with a U.S. Geological Survey (USGS) aluminum leg band and a unique combination of color bands. For birds captured in California and Oregon, we attached a very high frequency (VHF) transmitter Model AVL6171 (Sirtrack, Havelock North, New Zealand) that was mounted to a tarsal band (Krapu et al. 2011). Transmitters weighed approximately 30 g (<1% of body mass), had a life expectancy of 730 days, and were equipped with a mortality sensor. The 10 Lessers captured in Alaska were marked with platform terminal (satellite) transmitters (PTTs; Model KiwiSat 202; Sirtrack, Havelock North, New Zealand), mounted to a tarsal band, which weighed 45 grams and had a life expectancy of 180 days. The PTTs were programmed to be on for 4 hours and off for 20 hours, repeatedly, during fall migration (60 days; mid-August – mid-October), then on for 4 hours and off for 116 hours during winter (60 days; mid-October – mid-December); then on for 4 hours and off for 20 hours during spring migration (60 days mid-December – mid-February), afterwards, repeating these cycles. All birds were processed and released at their capture site within an hour after capture.

We used hand-held 3-element Yagi antennas and a truck-mounted null-peak antenna system (Balkenbush and Hallett 1988, Samuel and Fuller 1996) to aid us in visually locating VHF-equipped cranes in fields or at roost sites or to triangulate their location using program Locate III (Nams 2005). We had at least two staff tracking cranes 7 days per week (at least 8 hours per day) from vehicles, searching throughout the study area during the entire study period. Searches were conducted beginning when the first cranes were marked during the first season (October 17, 2007) and continued for a few days after the last marked crane was encountered (March 7, 2008). During the second season, we began monitoring marked cranes on September 29, 2008 (first marked crane encountered October 4, 2008) and continued for three days after the last marked crane was located (through March 9, 2009). Our search for marked cranes was focused primarily on our Delta Study area; however, to locate marked birds missing from our study area, we also conducted periodic searches of other crane wintering regions which included 9 aerial searches (Gilmer et al. 1981; November 6, December 2, 2007, and February 11, 26, October 28, November 4, 10, 18, and December 5, 2008 and 7 ground searches (December 23, 2007, February 11, 19, and December 11, 2008, and January 19, February 4, and 6, 2009).

Statistical Analysis

Winter site fidelity. We used our sample of radio-tagged cranes to study winter movements and site fidelity at 3 spatial scales. First, we calculated regional fidelity as the percentage of cranes individual radio tagged cranes in year one in our Delta study area that returned in year 2 (n = 27 Greaters, 20 Lessers). We defined “region” as major crane roost complexes separated by at least 35 km from other such complexes. In this context, our Delta study area was one of 5 wintering regions in California’s Central Valley (Fig. 3.1). Second, we summarized the number of winter regions used by each radio-tagged crane within each winter, combining the samples for the 2 seasons (n = 55 Greaters, 54 Lessers). Third, as another measure of fidelity at a smaller spatial scale, we compared the number of landscapes (one or 2) used by individual marked cranes of each subspecies within our Delta study region (n = 52 Greaters, 46 Lessers). These 2 landscapes were centered on the major roost complexes (see Study Area section) used by most cranes

(Ivey and Herziger 2003). Lastly, at the smallest spatial scale we compared the number of local roost complexes used (defined as a set of associated roost sites within 5 km of each other) by individuals of each subspecies. We used Fisher's Exact Test, using 2 X 2 frequency tables (Sokal and Rohlf 1981:738) to compare fidelity metrics at each scale.

Movements and home range size. We quantified movements by calculating daily commuting distance and home range size. First, on days when we located the same individual at its night roost and subsequent daytime feeding locations, we used a geographic information system to calculate commuting distance as the linear distance (km) between roost and feeding sites. Second, we calculated winter home range size (km^2) for each crane using the 95% fixed kernel method (Worton 1989, Worton 1995, Kernohan et al. 2001). We used the likelihood cross-validation (CVh) tool in Animal Space Use 1.1 (Horne and Garton 2007) as the smoothing parameter (Rodgers et al. 2005) because it generally produces home range estimates with better fit and less variability when home range is estimated from fewer than 50 locations per animal (Horne and Garton 2006). We report least squared means ± SE for all results.

We estimated home range size for a subset of all cranes that were radio tagged. In cases where we had multiple members of one family unit radio tagged (adults and chicks captured together and remaining together), we only included one member of the family in our analyses. Additionally, home range analyses can be sensitive to small sample size (Seaman et al. 1999). Consequently, we evaluated the effects of the number of locations on changes in home range size and followed the recommendation of Odum and Kuenzler (1955), by only including individuals in our analysis whose home range size stabilized as locations were added (change of <10% for 10 subsequent locations). Home range size stabilized between 35-40 locations for most individuals (smallest was 26); however, home ranges of a few birds did not stabilize, even with > 50 locations. Thus, from our sample of marked birds, we used estimated home range sizes for 27 Greaters and 10 Lessers during the first season and for 23 Greaters and 23 Lessers during the second season.

We used a mixed-effects model (PROC MIXED, SAS/STAT release 9.2, SAS Institute, Cary, North Carolina 2010), using maximum likelihood estimate to examine how commuting distance varied by subspecies, landscape and date during wintering season numbered from 1, beginning October 1(as a continuous variable) and how home range size varied with subspecies and whether having young influenced home range size (pairs + first year immature versus pairs without young and unpaired cranes). We chose this procedure because it accounts for repeated measures. In both analyses we used a square root-transformation of the data to normalize the distribution s, We included year and also individual crane as a random effect because we thought it likely that movements closer to each other in time could be correlated and because estimates of home range size for an individual crane in 2 years were likely not independent. We modeled the covariance structure of the data to control for this possible association and compared among unstructured, compound symmetry (random effects), variance components, and autoregressive covariance models and chose the covariance structure based on the lowest Akaike's Information Criterion corrected for small sample sizes (AIC*c*). Once the appropriate covariance was chosen, we compared how the explanatory variables associated with commuting distance. An increase in commuting distance with date can be an indication of food depletion (Krapu et al. 2004); thus, we investigated whether such a temporal pattern existed in our data for both subspecies.

For the analyses of commuting distance and home range size, we constructed a set of *a priori* models (Tables 1 and 2) and compared model performance using an information theoretic approach (Burnham and Anderson 2002). We selected models based on AIC*c* and resulting model weights. Models within AICc differences of 2 when compared to the best model were considered competitive. We used model averaging, including models within ΔAICc = 2 values of the best model, to estimate parameters and their confidence limits to evaluate the direction and size of the effect for explanatory variables in competitive models. We did not include landscape in our home range models because some cranes used both landscapes.

RESULTS

Winter Site Fidelity

The number of times that we relocated individuals was similar for both subspecies, averaging once every 2.07 ± 0.1 days for Greaters and 2.08 ± 0.1 days for

Lessers. Our sample of Greaters included 5 pairs in 2007, and our sample of Lessers included 3 pairs and 3 family groups of 2 adults and one first year juvenile. Both subspecies showed strong fidelity to the Delta region between years (Fisher's Exact Test, all $P > 0.5$) as 93% of Greaters (25 of 27) and 85% of Lessers (17 of 20) returned to the Delta the second winter. Of the 3 Lessers from year one that did not return to the Delta in year 2, one was juvenile when captured which wintered in the Sacramento Valley the second season, and the other 2 were adults (captured together) that spent the first winter as a pair but who apparently paired with other individuals before returning to California (one wintered in the Sacramento Valley and the other in Merced Grasslands), (a male and a female) that were unpaired when captured, in year one. The 2 Greaters that did not return to the Delta (a male and a female) were both unpaired adults at the time of capture (likely subadults) wintered in different areas in the Sacramento Valley the second winter. All 5 had been captured in our Delta study area.

Within-winter fidelity to the Delta, to landscapes within the Delta, and to roost complexes did not differ for Lessers radio tagged in the Delta during year one versus Lessers radio tagged in Alaska or Oregon that used our Delta study site in year 2 (no difference, Fisher's Exact Test, $P > 0.5$). Compared to all radio-tagged Lessers, Greaters showed stronger fidelity to the Delta, landscapes within the Delta and roost sites within a landscape than Lessers (Fisher's Exact Test, $P < 0.0001$). The vast majority of Greaters (96%) used only one region (2 Greaters used 2 regions); whereas, only 57% of Lessers spent their entire winter in the Delta region, 34% used 2 regions (4 Lessers moved twice between regions), and 9% used 3 regions (each moving between regions 4 times). Within the Delta, 88% of Greaters used only one landscape compared to only 26% of Lessers. Finally, within a landscape, 83% of Greaters used only one roost complex compared to 20% of Lessers.

Commuting Distance

The distribution of commuting flights for each subspecies is illustrated in Fig. 3.3. Our modeling of the covariance structure of the data revealed that the autoregressive heterogeneous structure had the lowest AIC*c*, so we used it in our subsequent modeling to identify factors associated with commuting distance. Our results indicated that 4 competitive models, which together received 83% of model weight (Table 3.1). Models included subspecies and date while the best model included the additive effects of subspecies, date, landscape, and the interaction between subspecies and landscape effects. Mean commuting distance was shorter for Greaters (1.2 ± 0.4 km) than Lessers (3.1 ± 0.1 km). Mean commuting distance for greaters was 2.9 km less than for lessers in the Central Delta Landscape, versus 2.8 km less than for lessers in the Cosumnes-Stone Lakes Landscape. Commuting distance by landscape was 0.43 km and 0.33 km longer in the Cosumnes-Stone Lakes than in the Central Delta landscape for greaters and lessers, respectively. Commuting distance for all cranes increased with date (0.01 ± 0.003 km/day).

Home Range Sizes

The variance components covariance structure had the lowest AIC*c*, so we used it in our subsequent modeling to identify factors associated with home range size. The model which included subspecies and family status received the greatest support among those considered for explaining home range size, although the model which additionally included an interaction between the two subspecies and family and the simpler model including only subspecies were also competitive (Table 3.2). The null model, and the model including only family status, received virtually no support. Models with subspecies and the interaction between subspecies and family received 99.9% of the model weight (Table 2). Model-averaged mean home range size was an order of magnitude smaller for Greaters (1.9 ± 0.4 km^2) than Lessers (21.9 ± 1.9 km^2). Mean home ranges for Lessers pairs with young were smaller than pairs without young (17.1± 3.1 km^2 vs. 25.3± 2.1km^2, respectively). However, for Greaters there was no difference between pairs with or without young.

DISCUSSION

Our study is the first to compare commuting distances and winter home ranges between crane subspecies and provides the first estimate of commuting distance for Greaters. The larger-bodied Greaters exhibited much smaller movements and home ranges, which indicate that management and conservation should occur at a significantly smaller scale than for Lessers, and because of their strong fidelity to winter sites, that conservation should be focused near areas that Greaters traditionally use.

Our estimate of mean commuting distance for Lessers is within the range of estimates reported from other studies in Saskatchewan (Sugden et al. 1988), Texas (Iverson et al. 1985), and Nebraska (Sparling and Krapu 1994, Pearse et al. 2010). Several studies report estimates of home range size for cranes, but methods of estimating home range vary considerably, making comparisons among studies difficult. A previous study in California estimated a much larger average home range for Lessers (342 km^2, Petrula and Rothe 2005) than the 22 km^2 that we report; however, that study used a minimum convex polygon approach for calculating home range and included observations from multiple winter regions, such that polygons included large areas of unsuitable habitat (e.g., urban areas) not used by cranes.

Differences in movement patterns between subspecies are likely partly attributable to a suite of factors that together influence the evolution of crane ecology during winter including body size, dominance, social systems, and possibly diet, similar to what has been shown with geese (Johnson and Raveling 1988, Durant et al. 2004, Jónsson and Afton 2009, Mini 2013). Larger bodied Greaters may meet their higher total energy need by engaging in less energy-intensive activities such as flight (Newton 2010), and they may be able to stay in food patches longer because they can forage to a lower food density and use their larger bills to access foods not available to Lessers (e.g., deeper in the soil). Greaters may be able to extract more energy from lower quality foods than Lessers (Demment and Van Soest 1985), deplete body reserves more slowly and have higher fasting endurance (Afton 1979, Thompson and Raveling 1987), and may take more time to reach starvation thresholds (Afton 1980, Aldrich and Raveling 1983, Johnson and Raveling 1988, Afton and Paulus 1992). Such limitations may translate to the smaller Lessers increasing their foraging time (Gloutney et al. 2001), having higher giving-up food densities (the food density within a patch when the animal will choose to move on to other food patches; Marginal Value Therom; Charnov 1976), and selecting higher quality feeding patches (Demment and Van Soest 1985; Durant et al. 2004), causing them to move among habitat patches more often to seek higher quality patches that may be more dispersed on the landscape. Also, lessers may need to store more energy for their longer migration and harsher conditions upon arrival in their more northern breeding grounds. In our study area, Lessers spent more time foraging than Greaters (86% vs. 67%, respectively; Ivey, unpublished data).

In addition to energetic considerations, smaller Lessers are more likely to be displaced from feeding fields by the dominant Greaters (Shelley et al. 2004; G. L. Ivey, personal observation). Average food intake rate by Common Cranes (*G. grus*) in Spain was positively related to dominance (Bautista et al. 1995). Contributing to displacement of Lessers is the possibility that some Greaters are territorial on our study area during winter as documented for Common Cranes (Alonso et al. 2004) or feed in small groups dispersed on the landscape near roost sites; while Lessers feed in larger flocks. Perhaps Greaters tend to be more territorial on wintering grounds while Lessers tend to be more gregarious and forage in flocks which would contribute to differences in home ranges, as was evidenced by regular observations of isolated pairs of foraging Greaters (not among flocks; G. L. Ivey, personal observation).

Diet preferences may also influence movement patterns. Studies on relationships between body size and home range size indicate that trophic status is correlated with home range size; specifically herbivores tend to have a smaller home range than omnivores (intermediate) and carnivores (largest; Schoener 1968, Harestad and Bunnell 1979). Though cranes are generally omnivores, their diet in the Delta has not been quantified. Lessers preferred to feed in alfalfa fields (Ivey et al. 2011), and research elsewhere has documented a high invertebrate component to the diet when cranes are feeding in alfalfa (Reinecke and Krapu 1979, Krapu et al. 1984, Reineke and Krapu 1986, Rowland et al. 1992).

During winter, Sandhill Cranes are central place foragers, flying out from central night roost sites to forage nearby. Central place foraging theory (Ashmole’s Halo, or refuging theory) predicts that individuals concentrated within a central place will increase distance traveled over time as easily accessed food resources near the central place are depleted (Ashmole 1963, Hamilton and Watt 1970, Cox and Afton 1996, Elliot et al. 2009). We found that commuting distance increased as winter progressed for both subspecies but that the magnitude of the relationship was small (an increase of ~1.5 km through the winter), suggesting food depletion was not pervasive throughout the study area. The fact that Greaters remained sedentary suggests food was not depleted. On the Platte River in Nebraska, a major spring staging area, Sandhill Crane commuting distances increased as spring progressed (Pearse et al. 2010). Also, in that region, commuting distances increased considerably during spring staging between the 1970s and 1990s, apparently due to declines in waste corn availability from increased competition with waterfowl, improved harvest efficiency, and fewer acres planted to corn (Krapu et al. 2004, Krapu et al. 2005, Pearse et al. 2010). Commuting distance may not reflect food depletion for Lessers who might use movement among roost sites as a strategy for mitigating local food depletion.

Periodic observations of marked Greaters indicate some individuals have wintered in the Delta for over 12 years (G. L. Ivey, unpublished data), demonstrating that the pattern we observed during our 2-year study may hold for much longer. Of the 5 cranes from year one that did not return to the Delta in year 2, one was captured as a juvenile Lessers, 2 were adult Lessers, captured together that spent the first winter as a pair but who apparently paired with other individuals before returning to California (they wintered in separate regions), and 2 were adult Greaters (a male and a female) that were unpaired when captured, suggesting they were subadults in year one. All were captured in our Delta study area. Age and pair status likely contributed to their failure to return. A study in Georgia reported that age had a major influence on crane winter site fidelity, as the return rate for adult cranes was 2.4 times greater than that of subadults, and among subadults, birds banded as juveniles exhibited the lowest return rate (Bennett and Bennett 1989). Re-pairing by the Lessers may have resulted in a new pair bond between birds that used different winter regions.

Possible survival and reproductive advantages of cranes returning to the same wintering area include knowledge of the distribution of food resources, roost sites, and predators as reported for waterfowl (Raveling 1969, Nichols et al. 1983, Hestbeck et al. 1991, Iverson and Esler 2006) and other avian species (Rappole and McDonald 1994, Sherry and Holmes 1996, Monroy-Ojeda et al. 2013). Because cranes remain paired for the entire year, they do not need to reunite, so fidelity to the wintering grounds must have some ecological advantage (e.g. familiarity with good foraging areas or safe roosting sites; Raveling 1979). Site fidelity may have the advantage of allowing individuals to maintain social connections among families with long-term pair bonds and extended parental care (Raveling 1969, Robertson and Cooke 1999). Sandhill Cranes exhibit a resource-based mating system, where males secure and maintain the nesting territory and a female chooses a mate partially on the basis of the quality of a male's territory (Nesbitt and Wenner 1987, Nesbitt et al. 2002). The dominance status of the male largely determines the status of a pair (Nesbitt 1981) and his role is as the primary resource defender (Nesbitt et al. 2002). Since the males hold and defend nesting territories it is likely they also take the dominant role in defending wintering resources for pairs and families.

Estimates of winter fidelity by Greater Sandhill Cranes vary among studies, likely reflecting differences in habitat predictability among study areas (Drewien et al. 1999). A study of wintering Greaters in Georgia reported a relatively low return rate (34%), which the authors speculated was caused by variable roost site conditions (Bennett and Bennett 1989). Similarly, Greaters in Florida moved between wintering areas in response to changes in roost water levels and loss of foraging habitats (Wenner and Nesbitt 1987). A previous study of Greaters in the Central Valley of California reported much lower winter region fidelity documenting that 22% of marked birds (compared to 4% in this study) used 2 wintering regions, the Sacramento Valley and the Delta (Pogson and Lindstedt 1991). Perhaps ideal roost site conditions in the Sacramento Valley during the 1980s were less reliable, as most roost sites were on private lands that were not managed to provide ideal conditions for cranes. These patterns suggest that Greaters likely prefer to return to the same areas each winter and that site fidelity could provide an indication of habitat quality or management success, but they are capable of being opportunistic and shifting wintering regions when habitat becomes unsuitable. However, the cost of such movements in terms of survival and reproductive fitness is unknown.

Management Implications

The combination of high winter site fidelity and high winter survival suggests the current landscape composition and roost site management for Sandhill Cranes in the Sacramento-San Joaquin Delta Region of California is providing high quality wintering habitat for both Lesser and Greater Sandhill Cranes. Within the Delta, conservation planners should consider the combination of a roost complex and surrounding agricultural fields as the fundamental ecosystem unit for managing wintering Sandhill Cranes. The extremely strong fidelity of Greaters to roost complexes within landscapes in the Delta indicates that conservation planning targeted at maintaining and managing for adequate food resources around traditional roost sites can be effective for meeting their habitat needs. Most Lessers relied on multiple suitable units (roost complex + fields) spread around the Delta to meet their winter habitat needs.

Our data on commuting distances provide a useful measure of scale for thinking about habitat conservation planning around suitable roost sites. To maintain high use of traditional roosts by Greaters, we recommend that conservation planning and land use zoning actions consider all habitats within 5 km of a known crane roost. That radius encompassed 90% of the commuting flights made by Greaters but only 64% of flights by Lessers. For Lessers, a conservation radius of 10 km would encompass 90% of the commuting flights, and we recommend using this radius in the San Joaquin Valley regions, where flocks are dominated by Lessers (> 97% of flocks; Ivey et al. 2014). Management, mitigation, acquisition, easement, planning, farm subsidy programs, and research intended to benefit cranes will be most effective when applied at these scales. If management plans included a desire to create new crane ecosystem units on the landscape, locating new roosts on the periphery of existing ecosystem units would be most effective as they should be readily discovered, even by the comparatively sedentary Greaters.

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Our handling of cranes was conducted under the guidelines of the Oregon State University Animal Care and Use Committee (project #3605) to ensure methods were in compliance with the Animal Welfare Act and United States Government Principles for the Utilization and Care of Vertebrate Animals Used in Testing, Research, and Training policies. Cranes were captured under CDFW permit SC-803070-02 and USGS federal banding permit MB#21142.

LITERATURE CITED

Afton, A. D. (1979). Time budget of breeding Northern Shovelers. Wilson Bulletin 91:42-49.

Afton, A. D. 1980. Factors affecting incubation rhythms of Northern Shovelers. The Condor 82:132-137.

Afton, A. D. and S. L. Paulus. 1992. Incubation and brood care. In Ecology and Management of Breeding Waterfowl (B. D. J. Batt, A. D. Afton, M. G. Anderson, C. D. Ankney, D. H. Johnson, J. A. Kadlec, and G. L. Krapu, Editors). University of Minnesota Press, Minneapolis, MN. USA. pp. 62-108.

Aldrich, T. W., and D. G. Raveling. 1983. Effects of experience and body weight on incubation behavior of Canada Geese. Auk 100:670-679.

Alonso, J. C., L. M. Bautista, and J. A. Alonso. 2004. Family-based territoriality vs flocking in wintering common cranes *Grus grus*. Journal of Avian Biology 35:434-444.

Ashmole, N. P. 1963. The regulation of numbers of tropical oceanic birds. Ibis 103b: 458-473.

Balkenbush, J. A., and D. L. Hallett. 1988. An improved vehicle-mounted telemetry system. Wildlife Society Bulletin 16:65-67.

Bautista, L. M., J. C. Alonso, and J. A. Alonso. 1995. A field test of ideal free distribution in flock-feeding common cranes. Journal of Animal Ecology 64:747–757.

Belanger, L. and J. Bedard. 1990. Energetic cost of man-induced disturbance to staging snow geese. Journal of Wildlife Management 54:36-41.

Bennett, A. J., and L. A. Bennett. 1989. Wintering population of Greater Sandhill Cranes in the Okefenokee Swamp, Georgia. Wilson Bulletin 101:87-93.

Burnham, K. P., and D. R. Anderson. 2002. Model Selection and Inference—A Practical Information Theoretic Approach. 2nd Edition. Spring-Verlag, NY, USA.

Charnov, E. L. 1976. Optimal foraging, the marginal value theorem. Theoretical Population Biology 9:129-136.

Cox, R. R., Jr., and A. D. Afton. 1996. Evening flights of female Northern Pintails from a major roost site. The Condor 98:810-819.

Demment, M. W., and P. J. Van Soest. 1985. A nutritional explanation for body-size patterns of ruminant and non-ruminant herbivores. American Naturalist 125:641–672.

Drewien, R. C., W. M. Brown, J. D. Varley, and D. C. Lockman. 1999. Seasonal movements of sandhill cranes radiomarked in Yellowstone National Park and Jackson Hole, Wyoming. Journal of Wildlife Management 63:126-136.

Durant, D., H. Fritz, and P. Duncan. 2004. Feeding patch selection by herbivorous Anatidae: the influence of body size, and of plant quantity and quality. Journal of Avian Biology 35:144-152.

Elliott, K., K. Woo, A. J. Gaston, S. Benvenuti, L. Dall'Antonia, and G. Davoren. 2009. Central-place foraging in an arctic seabird lends evidence for Storer-Ashmole's halo. Auk 126:613–625.

Frederick, R. B., W. R. Clark, and E. E. Klaas. 1987. Behavior, energetics, and management of refuging waterfowl: a simulation model. Wildlife Monographs 96. 33pp.

Gilmer, D. S., L. M. Cowardin, R. L. Duval, L. M. Mechlin, C. W. Shaiffer, and V. B. Kuechle. 1981. Procedures for the use of aircraft in wildlife biotelemetry studies. U.S. Fish and Wildlife Service Resource Publication 140.

Gloutney, M. L., R. T. Alisauskas, A. D. Afton, and S. M. Slattery. 2001. Foraging time and dietary intake by breeding Ross' and Lesser Snow Geese. Oecologia 127:78–86.

Gotmark, F., and P. Post. 1996. Prey Selection by Sparrowhawks, Accipiter nisus: Relative Predation Risk for Breeding Passerine Birds in Relation to their Size, Ecology and Behaviour. Philosophical Transactions: Biological Sciences 35:1559-1577.

Guisan, A., A. Lehmann, S. Ferrier, M. Austin, J. Mc. C. Overton, R. Aspinall, and T. Hastie. 2006. Making better biogeographical predictions of species' distributions. Journal of Applied Ecology 43:386–392.

Hamilton, W. J., III, and K. E. F. Watt. 1970. Refuging. Annual Review of Ecology and Systematics 1:263-286.

Harestad, A. S., and F. L. Bunnell. 1979. Home range and body weight–a reevaluation. Ecology 60:389-402.

Haskell, J. P., M. E. Ritchie, and H. Olff. 2002. Fractal geometry predicts varying body size scaling relationships for mammal and bird home range. Nature 418:527-530.

Hereford, S. G., T. E. Grazia, M. Nagendran, and A. Hussain. 2000. Use of traditional Indian trapping methods to capture Sandhill Cranes. Proceedings North American Crane Workshop 8:220.

Hestbeck, J. B., J. D. Nichols, and R. A. Malecki. 1991. Estimates of movement and site fidelity using mark-resight data of wintering Canada Geese. Ecology 72:523-533.

Horne, J. S., and E. O. Garton. 2006. Likelihood cross-validation verses least squares cross-validation for choosing the smoothing parameter in kernel home-range analysis. Journal of Wildlife Management 70:641-648.

Horne, J. S., and E. O. Garton. 2007. Animal Space Use 1.1 http://www.webpages.uidaho.edu/population_ecology/animal_space_use.htm

Iverson, G. C., P. A. Vohs and T. C. Tacha. 1985. Habitat use by Sandhill Cranes wintering in western Texas. Journal of Wildlife Management 49:1074–1083.

Iverson, S. A., and D. Elser. 2006. Site fidelity and the demographic implications of winter movements by a migratory bird, the harlequin duck *Histrionicus histrionicus*. Journal of Avian Biology 37:219-228.

Ivey, G. L. 2014. Greater Sandhill Crane. In Coastal California (BCR 32) Waterbird Conservation Plan: Encompassing the Coastal Slope and Coast Ranges of Central and Southern California and the Central Valley (W. D. Shuford, Editor). U.S. Fish and Wildlife Service, Pacific Southwest Region, Sacramento, CA, USA. pp. 96-97.

Ivey G. L., and C. P. Herziger. 2003. Sandhill Crane Monitoring at Staten Island, San Joaquin County, California, 2002-03. Cosumnes River Preserve, The Nature Conservancy, Galt, CA, USA.

Ivey G. L., C. P. Herziger, and M. Gause. 2003. Farming for wildlife: An overview of agricultural operations at Staten Island, San Joaquin County, California. Cosumnes River Preserve, The Nature Conservancy, Galt, CA, USA.

Ivey, G. L., B. D. Dugger, C. P. Herziger, M. L. Casazza, and J. P. Fleskes. 2011. Sandhill Crane use of agricultural lands in the Sacramento-San Joaquin Delta. Final report submitted to the California Bay-Delta Authority.

Ivey, G. L., C. P. Herziger, and D. A. Hardt. 2014. Conservation Priorities and Best Management Practices for Wintering Sandhill Cranes in the Central Valley of California. Unpublished report. The Nature Conservancy, Sacramento, California, USA.

Johnson, D. H., and R. E. Stewart. 1973. Racial composition of migrant populations of Sandhill Cranes in the northern plain states. Wilson Bulletin 85:148-162.

Johnson, J. C., and D. G. Raveling. 1988. Weak family associations in cackling geese during winter: effects of body size and food resources on goose social organization. In Waterfowl in Winter (M. W. Weller, Editor). University of Minnesota Press, Minneapolis, MN, USA. pp. 71-89.

Jónsson, J. E. and A. D. Afton (2009). Time budgets of Snow Geese *Chen caerulescens* and Ross's Geese *Chen rossii* in mixed flocks: implications of body size, ambient temperatures, and foraging associations. Ibis 151:134-144.

Kernohan, B. J., R. A. Gitzen, and J. J. Millspaugh. 2001. Analysis of animal space use and movements. In Radio Tracking and Animal Populations (J. J. Millspaugh and J. M. Marzluff , Editors). Academic Press, San Diego, CA, USA. pp. 125–166.

Kleinschmidt Associates. 2008. Cosumnes River Preserve Management Plan. Cosumnes River Preserve, Bureau of Land Management, Galt, CA, USA. http://www.blm.gov/pgdata/etc/medialib/blm/ca/pdf/folsom/plans.Par.67798.File.dat/CRP_Final_Mgmt_Plan.pdf

Krapu, G. L., D. A. Brandt, K. L. Jones, and D. H. Johnson. 2011. Geographic distribution of the Mid-Continent Population of Sandhill Cranes and related management applications. Wildlife Monographs 175:1–38.

Krapu, G. L., D. A. Brandt, and R. R. Cox, Jr. 2004. Less waste corn, more land in soybeans, and the switch to genetically modified crops: trends with important implications for wildlife management. Wildlife Society Bulletin 32:127–136.

Krapu, G. L., D. A. Brandt, and R. R. Cox, Jr. 2005. Do arctic-nesting geese compete with Sandhill Cranes for waste corn in the Central Platte River Valley, Nebraska. Proceedings—North American Crane Workshop 9:185–191.

Krapu, G. L., D. E. Facey, E. K. Fritzell and D. H. Johnson. 1984. Habitat use by migrant Sandhill Cranes in Nebraska. Journal of Wildlife Management 48:407–417.

Krüger, O. 2005. The evolution of reversed sexual size dimorphism in hawks, falcons and owls: a comparative study. Evolutionary Ecology19:467–486.

Levin, S. A. 1992. The problem of pattern and scale in ecology. Ecology 73: 1943–1967.

Lindstedt, S. L., and W. A. Calder. 1976. Body size and longevity in birds. The Condor 78:91-145.

Martin, T. E. 1995. Avian Life History Evolution in relation to nest sites, nest predation, and food. Ecological Monographs 65:101-127.

McNab, B. K. 2001. Energetics of toucans, a barbet, and a hornbill: Implications for avian frugivory. Auk: 916-933.

McNab, B. K. 2003. Metabolism: Ecology shapes bird bioenergetics. Nature 426:620-621.

Mech, S. G., and P. A. Zollner. 2002. Using body size to predict perceptual range. Oikos 98:47-52.

Mini, A. E. 2013. The Role of Body Size in the Foraging Strategies and Management of Avian Herbivores: A Comparison of Dusky Canada Geese (*Branta canadensis occidentalis*) and Cackling Geese (*B. hutchinsii minima*) Wintering in the Willamette Valley of Oregon. Ph.D. dissertation, Oregon State University, Corvallis, OR, USA.

Monroy-Ojeda, A., M. Grosselet, G. Ruiz, and E. Del Valle. 2013. Winter site fidelity and winter residency of six migratory Neotropical species in Mexico. Wilson Journal of Ornithology 125:192-196.

Morales-Castilla, I., M. Á. Rodríguez, and B. A. Hawkins. 2012. Deep phylogeny, net primary productivity and the global bird body size gradient. Biological Journal of the Linnean Society 106:880-892.

Nams, V. O. 2005. LOCATE III. Pacer, Truro, Nova Scotia, Canada.

Nesbitt, S. A. 1981. The agonistic repertoire of Sandhill Cranes. Wilson Bulletin 93:99-103.

Nesbitt, S. A., S. T. Schwikert, and M. J. Folk. 2002. Natal dispersal in Florida Sandhill Cranes. Journal of Wildlife Management 66:349-352.

Nesbitt, S. A., and A. S. Wenner. 1987. Pair formation and mate fidelity in Sandhill Cranes. In Proceedings—1985 International Crane Workshop, (J. C. Lewis, Editor). Platte River Trust, Grand Island, NE, USA. pp. 117-122.

Newton, I. 2010. Bird Migration. Collins New Naturalist Library 113. London: Collins. 532 pp.

Nichols, J. D., K. J. Reinecke, and J. E. Hines. 1983. Factors affecting the distribution of Mallards wintering in the Mississippi alluvial valley. Auk 100:932-946.

Odum, E. P. and E. J. Kuenzler. 1955. Measurement of territory and home range size in birds. Auk 72:128-137.

Olson, V. A., R. G. Davies, C. D. L. Orme, G. H. Thomas, S. Meiri, T. M. Blackburn, K. J. Gaston, I. P. F. Owens, and P. M. Bennett. 2009. Global biogeography and ecology of body size in birds. Ecology Letters 12:249-259.

Orians, G. H., and N. E. Pearson. 1979. On the theory of central place foraging. In Analysis of Ecological Systems (B. J. Horn, G. R. Stairs and R. D. Mitchell, Editors). Ohio State University Press, Columbus, Ohio, USA. pp. 155–177.

Ottaviani, D., S. C. Cairns, M. Oliverio, and L. Boitani. 2006. Body mass as a predictive variable of home-range size among Italian mammals and birds. Journal of Zoology 269:317–330.

Pacific Flyway Council. 1983. Pacific Flyway Management Plan: Pacific Flyway Population of Lesser Sandhill Cranes. Pacific Flyway Study Committee (c/o Pacific Flyway Representative USFWS), Portland, OR, USA.

Pacific Flyway Council. 1997. Pacific Flyway Management Plan for the Central Valley Population of Greater Sandhill Cranes. Pacific Flyway Study Committee (c/o Pacific Flyway Representative USFWS), Portland, OR, USA.

Pearse, A. T., G. L. Krapu, D. A. Brandt, and P. J. Kinzel. 2010. Changes in agriculture and abundance of snow geese affect carrying capacity of Sandhill Cranes in Nebraska. Journal of Wildlife Management 74:479–488.

Petrula, M. J., and T. C. Rothe. 2005. Migration chronology, routes, and distribution of Pacific Flyway Population of Lesser Sandhill Cranes. Proceedings—North American Crane Workshop 9:53-67.

Pogson, T. H., and S. M. Lindstedt. 1991. Distribution and abundance of large Sandhill Cranes, *Grus canadensis*, wintering in California's Central Valley. The Condor 93:266-278.

Rappole, J. H., and M. V. McDonald. 1994. Cause and effect in population declines of migratory birds. Auk 111:652–660.

Raveling, D. G. 1969. Roost sites and flight patterns of Canada Geese in winter. Journal of Wildlife Management 33:19-330.

Raveling, D. G. 1979. Traditional use of migration and winter roost sites by Canada Geese. Journal of Wildlife Management 43:229-235.

Reinecke, K. J., and G. L. Krapu. 1979. Spring food habits of Sandhill Cranes in Nebraska. In Proceedings—1978 Crane Workshop (J. C. Lewis, Editor). Colorado State University, Fort Collins, CO, USA. pp. 13-19.

Reinecke, K. J., and G. L. Krapu. 1986. Feeding ecology of Sandhill Cranes during migration in Nebraska. Journal of Wildlife Management 50:71-79.

Robertson, G. J., and F. Cooke. 1999. Winter philopatry in migratory waterfowl. Auk 116:20-34.

Rodgers, A. R., A. P. Carr, L. Smith, and J. G. Kie. 2005. HRT: Home Range Tools for ArcGIS. Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario, Canada.

Rowland, M. W., L. Kinter, T. Banks, and D. C. Lockman 1992. Habitat use by Greater Sandhill Cranes in Wyoming. In Proceedings—1988 North American Crane Workshop (D. A. Wood, Editor). Florida Game and Fresh Water Fish Commission, Nongame Wildlife Program Technical Report 12, Tallahassee, FL, USA. pp. 82-85.

Sæther, B. E. 1989. Survival rates in relation to body weight in European birds. Ornis Scandinavica 20:13-21.

Samuel, M. D., and M. R. Fuller. 1996. Wildlife Radiotelemetry. In Research and Management Techniques for Wildlife and Habitats (T. A. Bookhout, Editor). Fifth edition. The Wildlife Society, Bethesda, MD, USA. pp. 370-418.

Schoener, T. W. 1968. Sizes of feeding territories among birds. Ecology 49:123-141.

Seaman, D. E., J. J. Millspaugh, B. J. Kernohan, G. C. Brundige, K. J. Raedeke and R. A. Gitzen. 1999. Effects of sample size on kernel home range estimates. Journal of Wildlife Management 63:739-747.

Shelley, E. L., M. Y. U. Tanaka, A. R. Ratnathicam, and D. T. Blumstein**.** 2004. Can Lanchester's laws help explain interspecific dominance in birds? The Condor 106:39-400.

Sherry, T. W., and R. T. Holmes. 1996. Winter habitat quality, population limitation, and conservation of neotropical-nearctic migrant birds. Ecology 77:36–48.

Shoener, T. W. 1968. Sizes of feeding territories among birds. Ecology 49:123-141.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry, Second Edition. W. H. Freeman Company, San Francisco, CA, USA.

Sparling, D. W., and G. L. Krapu. 1994. Communal roosting and foraging behavior of staging Sandhill Cranes. Wilson Bulletin 106:62-77.

Sugden, L. G., R. G. Clark, E. J. Woodsworth, and H. Greenwood. 1988. Use of cereal fields by foraging Sandhill Cranes in Saskatchewan. Journal of Applied Ecology 25:111-124.

Székely, T., Reynolds, J. D. and J. Figuerola. 2000. Sexual size dimorphism in shorebirds, gulls, and alcids: the influence of sexual and natural selection. Evolution 54:1404–1413.

Tacha, T. C., S. A. Nesbitt, and P. A. Vohs. 1994. Sandhill Cranes. In Migratory Shore and Upland Game Bird Management in North America (T. C. Tacha and C. E. Braun, Editors). International Association of Fish and Wildlife Agencies, Washington, DC, USA. pp. 76-94.

Thompson, S. C., and D. G. Raveling. 1987. Incubation behavior of emperor geese compared to other geese: interactions of predation, body size and energetics. Auk 104:707-716.

Thornton, D. H., and R. J. Fletcher, Jr. 2013. Body size and spatial scales in avian response to landscapes: a meta-analysis. Ecography 37:001–010.

Urbanek, R. P., J. L. McMillen, and T. A. Bookhout. 1991. Rocket-netting Greater Sandhill Cranes on their breeding grounds at Seney National Wildlife Refuge. Proceedings—1987 International Crane Workshop, Qiqihar, Heilongjiang Province, China (J. T. Harris, Editor). International Crane Foundation, Baraboo, WI, USA.

U.S. Fish and Wildlife Service. 2007. Stone Lakes National Wildlife Refuge Comprehensive Conservation Plan. Stone Lakes National Wildlife Refuge, Elk Grove, CA, USA.

Wiens, J. A. 1989. Spatial scaling in ecology. Functional Ecology 3:385–397.

Wenner, A. S. and S. A. Nesbitt. 1987. Wintering of Greater Sandhill Cranes in Florida. In Proceedings—1985 International Crane Workshop (J. C. Lewis, Editor). Platte River Trust, Grand Island, NE, USA. pp. 196-200.

Western, D., and J. Ssemakula. 1982. Life history patterns in birds and mammals and their evolutionary interpretation. Oecologia 54:281-290.

Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home range studies. Ecology 70:164-168.

Worton, B. J. 1995. Using Monte Carlo simulation to evaluate kernel-based home range estimators. Journal of Wildlife Management 59:794-800.

Figure 3.1. Major sandhill crane (*Grus canadensis*) wintering regions within the Central Valley of California. From north to south: Sacramento Valley, Sacramento-San Joaquin River Delta, San Joaquin River National Wildlife Refuge region, Merced Grasslands, and Pixley National Wildlife Refuge region.

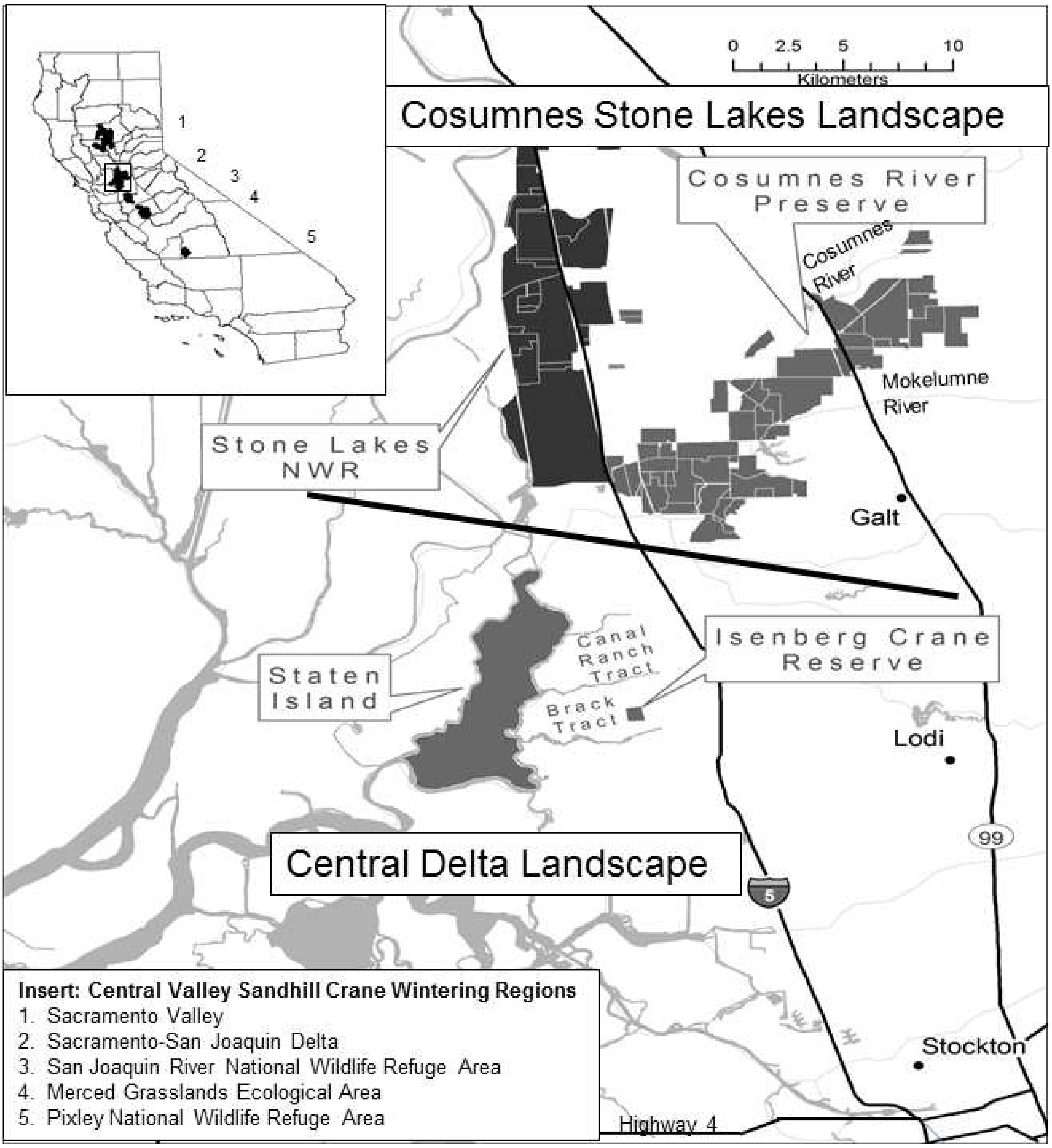

Figure 3 2. Locations of major sandhill crane wintering regions within the Central Valley of California (insert) and our study area of winter crane ecology, the Sacramento-San Joaquin Delta region, comprised of 2 landscapes (bold line inserted to show approximate border between the 2 landscapes). Also shown are key sandhill crane (*Grus canadensis*) roost site areas within each landscape.

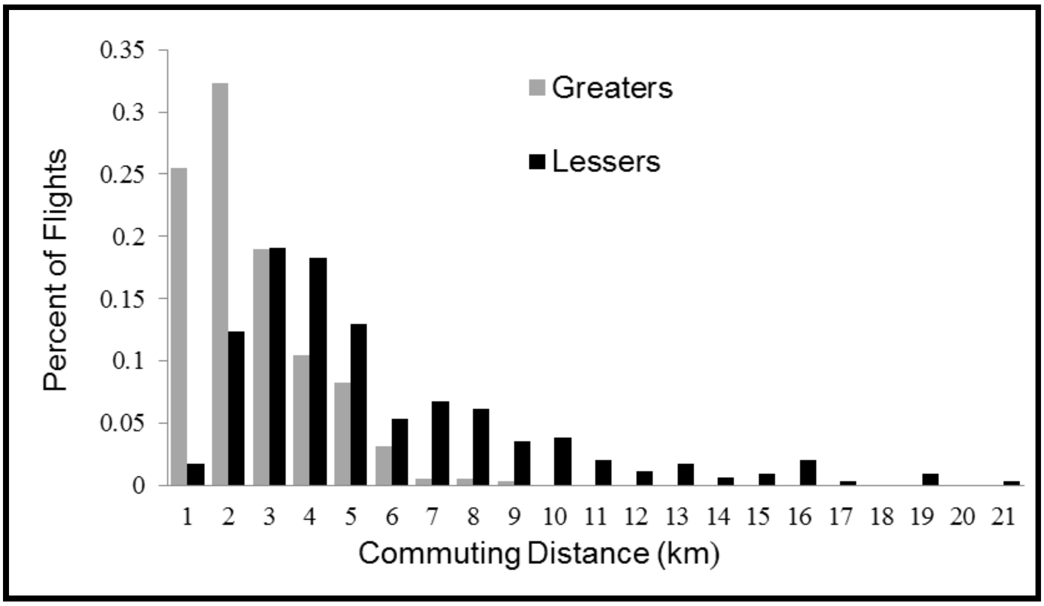

Figure 3.3. Distribution of winter commuting flights (1 km intervals) of Greater (*Grus canadensis tabida*) and Lesser (*G. c. canadensis*) Sandhill Cranes during 2007-2008 and 2008-2009 in the Sacramento-San Joaquin Delta, California.

Table 3.1. Models to identify factors influencing commuting distance of Greater (*Grus canadensis tabida)* and Lesser (*G. c. canadensis*) Sandhill Cranes wintering in the Sacramento-San Joaquin Delta, 2007-2008 and 2008-2009. Models are ranked according to Akaike's information criterion adjusted for small sample size (AIC*c*). The number of parameters (*k*), change in AIC*c* (ΔAIC*c*), and AIC*c* weights (w_i) are given for all models. Models with ΔAIC*c* < 2 were used in model averaging to calculate mean commuting distance.

Model structure[a]	*K*	ΔAICc[b]	w_{i}
S D	5	0	0.29
S D L S*L	7	0.5	0.23
S D L	6	1.3	0.15
S D S*D	6	1.3	0.15
S D L S*D	7	2.7	0.08
S D L D*L	7	3.3	0.06
S D L S*D S*L	8	4.1	0.04
S L	5	13.9	0.01
S L S*L	6	15.9	0.01
D	4	68.3	0.00
L	4	79.6	0.00
NULL	3	82.1	0.00

[a]S = subspecies as Greater or Lesser Sandhill Crane; D = continuous date (15 Oct -28 Feb); L = Landscape (Cosumnes-Stone Lakes or Central Delta); NULL = no effects model
[b]Lowest AIC*c* = 1296.3

Table 3.2. Models to identify factors influencing 95% fixed kernel home range sizes of Greater (*Grus canadensis tabida)* and Lesser Sandhill Cranes (*G. c. canadensis*) wintering in the Sacramento-San Joaquin Delta, 2007-2008 and 2008-2009. Models are ranked according to Akaike's information criterion adjusted for small sample size (AIC*c*). The number of parameters (*k*), and AIC*c* weights (w_{i}) are given for all models. Models with ΔAIC*c* < 2 were used in model averaging to calculate mean home range size.

Model structure[a]	*K*	ΔAIC*c*[b]	w_{i}
S F	5	0	0.40
S F S*F	6	0.5	0.31
S	4	0.6	0.29
F	4	103.6	0.000
NULL	3	101.8	0.000

[a]S = subspecies as Greater or Lesser Sandhill Crane; F = cranes with chicks versus adults and subadults without chicks; NULL = no effects model.
[b]Lowest AIC*c* = 248.5

Chapter 4

HABITAT USE BY SANDHILL CRANES WINTERING IN THE AGRICULTURAL LANDSCAPE OF THE SACRAMENTO-SAN JOAQUIN RIVER DELTA OF CALIFORNIA

Gary L. Ivey

ABSTRACT

The Sacramento-San Joaquin River Delta region of California is an important wintering region for sympatric greater (*Grus canadensis tabida*) and lesser (*G. c. canadensis*) sandhill cranes. Basic information about sandhill crane use of habitats in their winter landscape is needed to design biologically driven conservation strategies. I monitored radio-tagged birds of each subspecies for two winters and conducted foraging counts to document their habitat use. With the exception of vineyards and orchards, cranes used the major crops and habitat types that were available in the landscapes surrounding their roost sites, but focused most of their foraging in grain crops. Cranes generally avoided dry corn stubble, selected dry rice stubble early in the season, and rarely used dry wild rice (*Zizania palustris*) stubble. Tilled fields were usually avoided but were occasionally used shortly after tillage. Mulched corn ranked high in comparison to other corn treatments while mulched rice was used similarly to dry rice stubble. Both crane subspecies often showed high selection of croplands when fields were initially flooded. Cranes were also attracted to new plantings of pasture and winter wheat. One important difference between the subspecies was that lessers used alfalfa which was generally avoided by greaters. If wildlife managers want to favor winter field use by foraging cranes they could provide incentives for favorable practices such as for production of grain crops, to reduce or delay tillage and flooding of grain fields, to periodically irrigate pasture and grain stubble crop types, and to increase the practice of mulching of corn stubble.

INTRODUCTION

The Central Valley of California is the major wintering area for populations of two subspecies of Sandhill crane (*Grus canadensis*) that winter in the Pacific Flyway of western North America (Pacific Flyway Council 1983, 1997). While cranes are a focus for conservation in the Sacramento-San Joaquin River Delta (hereafter, Delta) region, most actions have centered on acquisition and management of roosting habitat. Thus, most major crane roost sites occur on public lands such as National Wildlife Refuges, State Wildlife Areas, or conservation reserves, while considerable foraging occurs on adjacent private lands (Littlefield 2002, Ivey and Herziger 2003). These private lands are not typically managed to optimize food availability for cranes, and are under increasing pressure from urbanization, changes in agricultural practices, and water supply limitations (Ivey 2014) that threaten to compromise the capacity of the Delta region to support cranes during fall and winter.

Historically, cranes likely depended on the vast floodplain and basinal wetlands of the Central Valley to provide foraging and roosting habitat, but those wetlands have been reduced by > 90% since European settlement (Frayer et al. 1989). However, like some species of waterfowl (e.g., Foster et al. 2010) cranes have adapted to use agricultural habitats and now commonly feed in grain fields and some row crops (Lovvorn and Kirkpatrick 1982; Krapu et al. 1984; Iverson et al. 1985; Reinecke and Krapu 1986; Iverson et al. 1987; Walker and Schemnitz 1987; Sugden et al. 1988; Sparling and Krapu 1994; Ballard and Thompson 2000; Littlefield 2002; Davis 2003). Although it is common knowledge that cranes will use agricultural habitats during migration and winter, few studies have quantified how they use habitats or how post-harvest field treatments impact field use by sandhill cranes, and most studies have focused on wintering and staging in Nebraska and Texas, where the agricultural landscape differs considerably from California. Two studies documented crane use of agricultural habitats in the rice-dominated landscape of the northern Sacramento Valley of California (Littlefield 2002, Shaskey 2012); however, no such crane habitat use information is available for the more diverse agricultural landscapes within the crane wintering regions of the Delta or the San Joaquin Valley.

No studies have compared habitat use between subspecies of sandhill cranes. The greater (*G. c. tabida*) and lesser (*G. c. canadensis*) subspecies are sympatric during winter in the Central Valley to the extent that they share winter roost sites and often forage in the same fields. Greaters are large (mean body size for males = 4.9 kg), and relatively short distance migrants (mean breeding latitude 45^{o} N) compared to lessers (mean body size for males = 3.9 kg; mean breeding latitude 65^{o} N; Johnson and Stewart 1973). These differences in body size may influence the foraging choices of the subspecies, as body size influences the scale that birds respond to landscapes (Thornton and Fletcher 2014) and avian energetics (McNab 2001, 2003). Consequently, assuming habitat use is similar between subspecies is inappropriate, and research on habitat use of these two subspecies is essential to their habitat conservation and management planning.

Here, I report results from a study of crane habitat use in the region of California. My objectives were to compare foraging habitat types across two major landscapes used by each crane subspecies, and also assess habitat selection by crop type and post-harvest field treatment for each subspecies. Results will both improve our basic understanding of crane winter foraging ecology and contribute to developing recommendations for optimizing sandhill crane use of croplands.

STUDY AREA

My study area was the San Joaquin-Sacramento River Delta Region, one of the major wintering regions for cranes in the Central Valley (Fig. 4.1) which included several properties managed to provide night roost sites for cranes (Staten Island, Canal Ranch, Cosumnes River Preserve, Brack Tract, and Stone Lakes National Wildlife Refuge [NWR]; described below) that subsequently support most of the cranes that winter in the Delta (Pogson and Lindstedt 1991, USFWS 2007, Chapter 2; Fig. 4.2). The Delta is particularly important for greaters of the Central Valley Population (Pogson and Lindstedt 1991, Pacific Flyway Council 1997). This region consists primarily of an agricultural landscape bordered by expanding urban communities. Major agricultural land uses include field and silage corn, fall-planted (winter) wheat, rice (organic and conventionally grown), alfalfa, irrigated pasture, dairies, vineyards and orchards. The region also contained some relatively pristine tracts of oak savannah and floodplain wetlands along the Cosumnes and Mokelumne rivers.

Staten Island (3,725 ha) is a large corporate farm that was purchased by The Nature Conservancy (TNC) in 2002. TNC continues to manage Staten Island as a profitable farm but with a focus on providing habitat for cranes and other wildlife and developing wildlife-friendly farming practices that can serve as a demonstration to other farmers in the region (Ivey et al. 2003). The island primarily provided field corn with some fall-planted wheat and irrigated pasture. Some of the fields are flooded in early autumn and managed as crane roost sites through most of the winter.

The Cosumnes River Preserve (9,915 ha within my study area), located along the Cosumnes River Floodplain, was established in 1987 by TNC and is a conglomeration of lands owned or under conservation easements by TNC and its agency partners (Bureau of Land Management [BLM], California Department of Fish and Wildlife [CDFW], California Department of Water Resources, California State Lands Commission, Ducks Unlimited, Inc., Galt Joint Union Elementary School District, Natural Resource Conservation Service and Sacramento County Department of Regional Parks). The Cosumnes River Preserve manages habitats for cranes including seasonal wetland roost sites and organic rice fields. BLM owns most of the Preserve's wetland habitats and manages them as well as the farming program.

Brack Tract is approximately 4,050 ha and includes important crane roosts on both public and private lands. Public land on the Brack Tract includes the Isenberg Ecological Reserve, owned and managed by CDFW. The Reserve consists of two seasonal wetlands totaling 60 ha that provide night roost sites. These sites were purchased in the mid-1980s because they were traditional winter roosts for cranes. They are surrounded by private agricultural lands, including a large area of rice fields, which were winter flooded and also provided night roosts for cranes.

Stone Lakes NWR (7,140 ha) has developed 410 ha of seasonal wetland sites that are used as sandhill crane nocturnal roosts and which are near private agricultural lands. The refuge also provides croplands such as irrigated pasture, alfalfa, and occasionally grain crops for cranes and other wildlife.

I partitioned my Delta study region into two landscapes (Fig. 4.2) that differed in habitat types available to wintering cranes (USFWS 2007, Kleinschmidt Associates 2008). These landscapes were far enough apart to be viewed as distinct by greaters (Chapter 3). The northern landscape included the Cosumnes River, Mokelumne River and Stone Lakes Floodplains (hereafter, Cosumnes - Stone Lakes landscape) and contained a high diversity of habitats, including large areas of seasonal wetlands, native grassland and oak savannah. The southern landscape encompassed Staten Island, Brack Tract, Canal Ranch and other Delta Islands (hereafter, Central Delta landscape) and is primarily composed of croplands on Delta tracts and islands.

METHODS

Capture, radio-tagging, and tracking

I captured and radio tagged a total of 33 greaters and 45 lessers. All greaters and 29 lessers were captured using rocket nets baited with corn (Urbanek et al. 1991) and noose-lines (Hereford et al. 2000) at Staten Island (4 greaters and 10 lessers) or Cosumnes Preserve (28 greaters and 21 lessers) between 17 October 2007 and 27 February 2008. Additionally, I rocket netted six lessers on a spring staging site (Ladd Marsh Wildlife Management Area near LaGrande, Oregon) in April 2008 and captured ten lessers with noose-lines on their breeding grounds near Homer, Alaska in August 2008. I identified mated pairs by observing their behavior before capture and confirmed pair status during later tracking and observation; pairs and family groups remained together through the winter period and remained associated as a family unit within flocks.

For each crane captured, I determined subspecies based on morphological differences (Johnson and Stewart 1973). I marked each individual with a U.S. Geological Survey (USGS) aluminum leg band and a unique combination of color bands. For birds captured in California and Oregon, I attached a very high frequency (VHF) transmitter Model AVL6171 (Sirtrack, Havelock North, New Zealand) that was mounted to a tarsal band (Krapu et al. 2011). Transmitters weighed approximately 30 g (<1% of body mass), had a life expectancy of 730 days, and were equipped with a mortality sensor. The 10 lessers captured in Alaska were marked with both a VHF transmitter (as described above) and a platform terminal (satellite) transmitter (PTT; model KiwiSat 202; Sirtrack, Havelock North, New Zealand), mounted to a tarsal band, which weighed 45 grams and had a life expectancy of 180 days. The PTTs were programmed to be on for 4 hours and off for 20 hours, repeatedly, during fall migration (60 days), then on for 4 hours and off for 116 hours during winter (60 days); then on for 4 hours and off for 20 hours during spring migration (60 days). All birds were processed and released at their capture site within an hour after capture.

My handling of cranes was conducted under the guidelines of the Oregon State University Animal Care and Use Committee (project #3605) to ensure methods were in compliance with the Animal Welfare Act and United States Government Principles for the Utilization and Care of Vertebrate Animals Used in Testing, Research, and Training policies. Cranes were captured under CDFW permit SC-803070-02 and USGS federal banding permit MB#21142.

Habitat use by radio-tagged cranes in two Delta landscapes

I used hand-held 3-element Yagi antennas and a truck-mounted null-peak antenna system (Balkenbush and Hallett 1988, Samuel and Fuller 1996) to aid us in visually locating VHF-equipped cranes in fields or at roost sites or to triangulate their location using program Locate III (Nams 2005). I used my radio-tagged cranes as a random sample to characterize broad patterns of habitat use in the Delta region of my study area. Habitat types available included corn, wheat, rice (organic and conventionally grown), wild rice, pasture, alfalfa, savannah, fallow, wetland, Sudan grass, and safflower. For each radio-tagged crane, I summarized the habitats used during morning (0700 - 1000 hrs) and afternoon (1600-1830 hrs) foraging periods as the percentage of all observations that occurred in each habitat type and compared habitat use by subspecies in each landscape (Cosumnes-Stone Lakes vs. Central Delta).

I used a likelihood-ratio chi-square test (PROC FREQ, SAS/STAT release 9.2, SAS Institute, Cary, North Carolina 2010) to compare habitat use between the subspecies and habitat use by each subspecies between the Cosumnes-Stone Lakes and Delta landscapes. I compared only habitats that were available in both landscapes for the subspecies by landscape comparison.

Influence of agricultural practices on habitat selection

I used radio-tagged birds to provide a broad characterization of habitat use as telemetry permitted documenting locations when cranes were out of visual range. However, I could not assign post-harvest cropping practices for all fields used by radio-tagged birds. Consequently, I conducted roadside surveys on Cosumnes River Preserve, Brack Tract, and Staten Island (which are separate roost site complexes) to compare habitat use versus habitat availability for various agricultural cropping practices and management strategies (e.g., till, mulch, or flood). These areas included the most heavily used crane roost complexes and differed in the composition of habitats available to cranes. Two experienced observers conducted biweekly (representing 14 day periods (defined as early Oct., late Oct., early Nov., late Nov., etc.) surveys during morning feeding periods (0700-1000 hrs) between 9 October 2007 and 13 February 2008, and between 8 October 2008 and 11 February 2009. At the Cosumnes River Preserve, surveys covered the agricultural fields used for organic rice production (404 ha). On Brack Tract, I was limited to Woodbridge Road, the county road that transects the area and surveyed the 850 ha which were clearly visible from the road. At Staten Island, I surveyed the entire 3,725 ha agricultural land base.

I counted all flocks from vehicles using binoculars and spotting scopes and identified all cranes observed as greaters or lessers using morphological characteristics described by Drewien and Bizeau (1974). Some cranes appeared intermediate in size and were probably the Canadian subspecies (*G. c. rowani*). However, only one of the cranes (1.5%) that I captured during this study measured as a Canadian, suggesting this source of bias is very low. For approximately 20% of flocks that were too distant to identify subspecies, I assumed the same overall subspecies ratio as flocks where subspecies could be assigned for a given count interval.

During each survey I mapped habitat as alfalfa, corn, rice, wild rice, fall-planted wheat, safflower, irrigated pasture (as newly planted or formerly established), fallow fields, vineyards, and orchards. Additionally, I mapped associated habitats that were used by cranes, including temporary water management levees, the sides of main levees at Staten Island and unpaved (i.e., dirt and gravel) roads. I also recorded the post-harvest condition of each field during each survey as dry stubble (harvested and no post-harvest stubble treatment), mulched (harvested and stubble knocked down and chopped or ground), tilled (plowed or disced), and flooded (flooded stubble and flooded in addition to other post-harvest treatments). Additionally, for wheat and pasture I distinguished between crops established from the previous growing season and those newly planted in the fall. By recording habitat conditions during surveys, I was able to track how habitat availability changed over time. I calculated the area available in each habitat type by management category during each survey using ArcGIS version 9.2 (ESRI, Redlands, California).

Habitat selection is a process of behavioral choices that may result in a disproportionate use of habitats to influence survival and ultimate fitness of individuals (Johnson 1980, Block and Brennan 1993). To compare habitat selection for each subspecies during each survey period, I used a log-linear analysis of categorical data based on saturated models (PROC GENMOD, SAS version 9.1; Heisey 1985, Erickson et al. 2001). I analyzed data separately for the three habitat survey areas. The offset variable was the natural log of the proportion of available habitat. Selection or odds ratios with 95% confidence intervals were generated for each habitat type (Erickson et al. 2001). Ratios overlapping 1 indicated no selection, ratios below 1 indicated less selection (avoidance), and ratios above 1 indicated higher selection (preferred or favored). I calculated these ratios for habitat types by management condition (e.g., mulched corn or tilled corn) category during each survey date at each site. It was necessary to calculate selection coefficients separately for each survey as habitat availability and bird abundance changed over time. The relative desirability of each habitat was assessed by the ratio of two selection ratios (Erickson et al. 2001).

RESULTS

Habitat use by Radio-tagged cranes

Radio-tagged cranes were recorded in 1,645 foraging locations during the two years of this study and documented crane use of 12 habitat types during morning and afternoon feeding periods, including fields of corn, rice, wheat, alfalfa, safflower, Sudan Grass, and fallow fields, pastures, seasonal wetlands, oak savannahs. In addition to these habitats, cranes also used field levees and dirt and gravel roads. Agricultural croplands and pastures accounted for 84% and 93% of the use by greaters and lessers, respectively. For the entire study area, the highest use by greaters was in corn (33.1%) followed by rice (27.7%), pasture (10.0%), oak savannah (8.8%), fallow fields (7.6%), wetlands (5.8%), wheat (2.8%), Sudan grass (2.0%), and other habitats (1.5%; Fig. 4.3). For lessers, the highest use was also in corn (52.9%), followed by alfalfa (15.0%), pasture (9.8%), rice (7.5%), wheat (5.0%), oak savannah (3.9%), wetlands (1.7%), fallow fields (1.7%), levees (1.1%), and other habitats (1.7%; Fig. 4.3). The two subspecies used similar proportions of cereal grains (63.6% use of grains by greaters vs. 65.4% by lessers; χ^2 = 0.55, p = 0.46) and most other habitats, with the exception of the high use of alfalfa by lessers (0.6% use by greaters vs. 15.0% use by lessers; χ^2 = 145.6 p < 0.01). Cranes were never located in orchards, vineyards, blueberry fields, turf farms, or nursery crops even though these crops were common in the study area.

Use of foraging habitats differed between subspecies in both the Cosumnes-Stone Lakes (χ^2 = 85.7, p < 0.0001) and Central Delta (χ^2 = 88.0, p < 0.0001) landscapes. In the Cosumnes-Stone Lakes landscape, greaters used rice, followed by corn, pasture, savannah, and fallow fields. Their use of rice and fallow fields was higher than lessers. In contrast, lessers most often used corn followed by pasture, and rice and their use of corn and pasture was higher than greaters (Fig. 4.4).

In the Central Delta, corn was the most common habitat used during the foraging periods by both subspecies, but it was used more by greaters, while lessers used alfalfa and pasture more than greaters (Fig. 4.4).

Use of foraging habitats differed between landscapes for both greaters (χ^2 = 280.8, p < 0.0001) and lessers (χ^2 = 139.4, p < 0.0001). For both subspecies, the number of habitats used was higher in the Cosumnes-Stone Lakes landscape than in the Central Delta landscape (Fig. 4.5). For greaters, corn comprised over 75% of habitat use in the Central Delta landscape compared to only 21% in the Cosumnes-Stone Lakes landscape. Use of wheat by greaters was also higher in the Central Delta. Greaters used cereal grains in higher proportions than other habitats in both landscapes, with the highest use in rice in the Cosumnes-Stone Lakes landscape, while lessers focused on corn in the both landscapes (Fig. 4.5). Greaters in the Cosumnes-Stone Lakes landscape offset lower corn use with higher use of rice, pasture, savannah and fallow. Corn use was similar for lessers in both landscapes; it comprised about half of locations, but use of alfalfa and wheat was relatively high in the Central Delta, while use of pasture, savannah, fallow and wetland was higher in the Cosumnes-Stone Lakes.

Influence of agricultural practices on selection of foraging habitats

I conducted 23 surveys in 2007-2008 (of 30 possible; 3 roost complexes, 10 survey periods) and 27 surveys in 2008-2009. A few survey periods were missed for some roost complexes because of inclement weather that muddied roads and prevented access. The availability of foraging habitats varied around each roost complex and changed during winter as fields were subjected to different management actions associated with post-harvest field treatments, fall plantings, and field flooding. Patterns of habitat selection were complex and sometimes differed between landscapes for a specific crop type/field treatment combination, trends were identified. Appendix A details selection ratios for each survey.

Grain crops.—Crane response to management of dry corn habitats varied. Dry corn stubble was generally not used by cranes of either subspecies in either year and when used, use was almost always less than available (i.e., avoided; Table 4.1). Both subspecies avoided tilled corn stubble during the first winter but occasionally selected (i.e., used at higher rate than available) this habitat type the second winter. Mulched corn stubble was selected much more often than other dry stubble conditions, as both subspecies regularly selected this condition, particularly during the second half of each season.

Use of flooded corn stubble treatments was also mixed. The initial flooding of any previously harvested corn field often resulted in selection (Table 4.1). Greaters consistently selected flooded-tilled fields, whereas use of flooded stubble quickly declined to be avoided or not used. Flooded stubble and tilled stubble treatments were selected more often than dry conditions, while dry mulched stubble was selected more often than when this treatment was flooded. During the second winter, late season irrigation of mulched corn stubble fields at Staten Island was very attractive to cranes, resulting in frequent selection and very high selection ratios (Appendix A-Table A1).

In contrast to corn, dry rice stubble was more consistently used by both species in both years with periodic selection throughout winter, and tilled dry rice fields were rarely used by either species in either year (Table 4.2). Like corn, dry mulched rice was regularly used by both subspecies and the highest selection occurred during November, after which it was generally avoided. Flooding generally resulted in increased selection of rice in both years, regardless of field treatment. Selection for flooded organic rice stubble and flooded mulched rice stubble was particularly strong early during their availability in both years (Appendix A-Table A4), while flooded tilled stubble was primarily selected when it was first flooded and generally avoided otherwise. Flooded organic rice types were often selected throughout the season at Cosumnes River Preserve, in contrast to tilled conventional rice at Brack Tract, which was favored when initially flooded, but was generally avoided after that.

Tilled wheat stubble, dry or flooded, was rarely used by either subspecies except dry tilled wheat in year 2 (Table 4.3). In that year, both subspecies selected this habitat early in fall, but generally avoided it thereafter. Flooded tilled wheat was only selected one time for each subspecies, early during its availability and otherwise avoided. Crane use of fall planted wheat varied by location. At Staten Island, greaters selected new wheat during the first survey that this habitat was available, but at Brack Track they avoided this crop. The general pattern was that cranes favored fall planted wheat early during its availability and used it less as the season progressed.

Other habitats.—Greaters only used alfalfa during one survey in either year and generally avoided this crop (Table 4.3), whereas, lessers regularly used alfalfa and often selected for it throughout winter. Established pasture (≥ 1 year since planting) was unused at Brack Tract; it was more commonly used by each subspecies on Staten Island, but largely avoided (only selected once, by greaters). Newly-planted pasture was only available at Staten Island where it was regularly selected by greaters in both years and by lessers in year 2 (Table 4.3).

Dry safflower stubble was never used, while tilled safflower stubble was only used once, by greaters, and was otherwise avoided (Table 4.4). When initially flooded, tilled safflower stubble was selected by both subspecies. Fallow fields on Bract Tract were never used, while tilled fallow fields at Cosumnes River Preserve were infrequently used and never selected.

Although dirt roads comprised a small percentage of the available habitat and were used sporadically, when used, they were often selected by both subspecies (Table

4.5). Temporary field levees at Staten Island were favored very early each winter by both subspecies, but were generally avoided or used in proportion to their availability as winter progressed and the use pattern was similar to newly tilled fields. The main levee at Staten Island was rarely used and generally avoided by greaters; while in contrast, lessers used it regularly and often selected this habitat, especially in the second year.

DISCUSSION

Habitat use by radio-tagged cranes differed by landscape within the Delta. Cranes using the Cosumnes-Stone Lakes landscape were in a more diverse landscape and consequently, used a greater diversity of foraging habitat types than cranes in the Central Delta landscape. Foraging habitat availability is dictated by location relative to roost sites and the distance birds are willing to travel to find food. Lessers often travel farther to feed (Chapter 3) and therefore a different composition of habitats was available to lessers than greaters.

Cereal grains provide the major source of energy for migrating and wintering sandhill cranes (Tacha et al. 1987, Iverson et al. 1987). The high proportion of use of cereal grains I documented is consistent with findings of other studies of wintering and staging sandhill cranes (Lewis 1979, Lovvorn and Kirkpatrick 1982, Krapu et al. 1984, Iverson et al. 1985, Reinecke and Krapu 1979, 1986, Sugden et al. 1988, Sparling and Krapu 1994, Davis 2001, Littlefield 2002, Davis 2003). Grain crops were very important to cranes in both landscapes. For example, greaters using the Cosumnes-Stone Lakes landscape were found most often in rice grown on the Cosumnes River Preserve (likely because of their shorter foraging flights; Chapter 3) while lessers using that region were found most often in more distant corn fields. Similarly, winter studies of common cranes (*G. grus*) in Spain and black-necked cranes (*G. nigricollis*) in Tibet reported a preference for cereal grains (Alonso et al. 1994, Bishop et al. 1998, Guzman et al. 1999, Aviles et al. 2002).

Despite the fact that cranes use a wide range of habitats, I never documented cranes using orchards, vineyards, blueberries, turf farms, or nursery areas. Cranes likely avoid these habitats because trees and shrubs make it difficult to see approaching predators and offer limited food value. These habitats were common in the study area, and in the case of vineyards, their relative abundance has increased considerably during the past 25 years (e.g., from 1989-2013 San Joaquin County vineyard acreage increased 105%; Reed 1989, Schwieger and Gonsalves 2013). If the abundance of these incompatible crops continue to increase within the Delta crane wintering region, the capacity of the landscape to support wintering cranes will likely decrease.

Cranes tended to select corn and rice more often and generally throughout the winter seasons in their foraging choices, while wheat was selected less often and for shorter duration, suggesting that wheat is less valuable in supporting crane use or that grain availability in wheat fields is depleted faster. Most crane use of post-harvest and fall-planted wheat occurred early during the period they were available and subsequently, use rapidly declined. Post-harvest wheat at Staten Island was harvested in August and was tilled in September which likely reduced availability to cranes before their arrival, as much of the available grain was likely consumed by other species before cranes arrived. Crane use of wheat fields may have persisted longer if fields had not been tilled. Cranes appeared to be attracted to newly planted wheat only for a short period after planting while the seeds are still available, and generally lost interest in this crop after the growing sprouts reach about 5 cm (G. Ivey, personal observation). Studies of sandhill crane habitat use in Michigan and in the Sacramento Valley noted a similar pattern of wheat use (Hoffman 1976, Littlefield 2002).

Both the telemetry data and the foraging surveys indicated subspecies choices differed. In the Central Delta landscape, lessers showed high use and preference for alfalfa fields at Brack Tract, and lessers at Staten Island favored the grassy sides of the main levees, while both of these habitats were avoided by greaters. Alfalfa was rarely used by greaters, even though large fields were in very close proximity to roost sites. I investigated soils on the main levees where lessers had been digging and found an abundance of ground beetle larvae (Order: Coleoptera, Family: Carabidae) which was likely what the lessers were eating. Lessers also used pastures and wetlands slightly more than greaters. These habitat types are likely important sources of invertebrates, small vertebrates, and green plant material, which are rich sources of protein and calcium, nutrients essential for daily maintenance requirements that are lacking in corn (Baldassarre et al. 1983, Reinecke and Krapu 1986).

My finding of relatively high use by lessers of alfalfa is consistent with other studies (Krapu et al. 1984, Iverson et al. 1987, Davis 2001, Davis 2003). Although they did not distinguish subspecies, those studies occurred within the range of the Midcontinent Population of cranes which is dominated by lessers (Johnson and Stewart 1973). Similar to this study, Nebraska studies of spring crane use documented a preference for alfalfa (Iverson et al. 1987, Sparling and Krapu 1994, Davis 2003). Cranes foraging in alfalfa in Wyoming in late summer were reported to be consuming grasshoppers and weevils (Rowland et al. 1992), while studies during spring in Nebraska reported them to primarily consume earthworms (Reinecke and Krapu 1979, 1986, Krapu et al. 1984). A subsequent study reported that invertebrates made up more than 75% of the diet in alfalfa fields and that the remaining portion of their diet was primarily alfalfa which had high protein content (33.5%; Reineke and Krapu 1986). Therefore, alfalfa fields tend to be a protein source for foraging cranes. The lesser's choice of alfalfa may be related to physiological differences between this smaller-bodied, long distance migrant and the larger, short-distance migrant greater, which may translate into different protein needs.

Crane use of specific crops was strongly influenced by post-harvest field treatments. Treatment of post-harvest stubble influenced use of corn and rice fields as such treatments likely differed in waste grain availability (Sherfy et al. 2011). In rice fields, my documentation of early selection by cranes and subsequent avoidance suggests that food in dry rice habitat types may be rapidly depleted or that more desirable habitats became available. While cranes were generally attracted to newly tilled areas to take advantage of exposed foods, such use was short-lived, as expected, because tillage is known to reduce the availability of waste grain (Baldassarre et al. 1983, Iverson et al. 1985, Miller et al. 1989, Sherfy et al. 2011), cranes largely avoided tilled grain fields in this study. Similarly, untilled rice stubble was selected and tilled rice stubble was avoided by wintering sandhill cranes in the Sacramento Valley (Littlefield 2002), and in a study of red-crowned (*G. japonensis*) and white-naped cranes (*G. vipio*) in South Korea, tilled rice stubble was also used much less than untilled stubble, resulting in authors recommending delaying autumn tillage until spring (Lee et al. 2007). An Indiana study reported that in autumn, cranes avoided tilled corn stubble and favored stubble that had not been altered (Lovvorn and Kirkpatrick 1982), while a study of spring use in Nebraska reported that cranes were least likely to use corn fields that were idle (unmanipulated dry stubble) or tilled (Anteau et al. 2011). However, tilled corn was recorded as being favored early and late during the wintering season in the Sacramento Valley (Littlefield 2002).

Mulched corn tended to be used and regularly selected, while dry corn stubble was universally avoided, as it also was in the Sacramento Valley (Littlefield 2002). A Nebraska study also documented a strong preference of cranes in spring for mulched corn stubble (Anteau et al. 2011). The avoidance of unmulched corn stubble may be because cranes feel less secure from approaching predators in the taller cover it provides. The mulched corn litter covers much of the available waste grain which makes it less visible to competitive geese and other birds. Geese were least likely to use mulched corn in Nebraska (Anteau et al. 2011). Perhaps mulching gives the cranes an advantage, since they are skilled at digging through litter to find food. Mulching also likely increases densities of invertebrates at the soil surface which provide additional food and nutrients for cranes (Anteau et al. 2011). Additionally, mulching of corn stubble provides benefits to the agricultural producer such as limiting winter weed growth and retaining soil moisture (Ivey et al. 2003).

Both subspecies often showed high selection of cropland habitats when they were initially flooded. I also observed this pattern of attraction in the seasonal wetlands at Cosumnes River Preserve as they were flooded through the fall season. Flooding and irrigation are common practices for crop management and can be used to provide forage benefits to cranes. For example, I observed that cranes were very attracted to pastures when they were being irrigated and after heavy rains, and also to late-season mulched corn stubble when it was being irrigated to provide soil moisture before spring planting. Even though the irrigated area was large, this habitat was selected by both subspecies as they responded to the irrigation. Cranes were attracted to newly-flooded wetlands, corn, rice, and even safflower fields (which received little use otherwise), regardless of the treatment. As fields flooded, I observed cranes feeding on invertebrates (e.g., earthworms and arthropods [including crayfish; *Procambarus clarkia*]) and small rodents that were exposed as they moved to escape rising water. Rice fields typically support populations of crayfish which burrow into the soil when fields are dry and become available when they are re-flooded. Similar to my findings, a Sacramento Valley study found cranes to favor partially flooded (hence shallow) fields both when they were initially flooded and during drawdown (Shaskey 2012).

While flooding of grainfields provides night roost sites and foraging opportunities for cranes, such flooding likely also reduces grain availability to cranes and attracts ducks that deplete grain. In this study, habitat selection tended to be high when fields were first flooded; however, on a field by field basis, use generally dropped rapidly after the first week of flooding (Ivey, personal observation). This pattern has been reported by other researchers in the Sacramento Valley rice lands (Elphick and Oring 1998, Littlefield 2002, Shaskey 2012). Flooded organic rice at Cosumnes River Preserve was an exception to this pattern as it tended to be favored more often through most of the winter. This was primarily because of the staggered flooding of individual fields through the winter season which maintained high use in this habitat type. Also, crane's higher attraction to flooded rice at Cosumnes River Preserve appeared to be due in part to an abundance of yellow nut sedge (*Cyperus esculentus*) which I observed sprouting shortly after flooding. Yellow nut sedge was more abundant as a crane food source in the organic rice fields on the Cosumnes River Preserve, in comparison to the rice on Brack Tract, where herbicides were used (G. Ivey, personal observation). This plant has been shown to be an important food of sandhill cranes in other areas (Guthery 1976, Taylor and Smith 2005).

Established irrigated pastures received use by cranes primarily when they were being irrigated and after heavy rains, otherwise, they were generally avoided. In contrast, newly planted pasture at Staten Island was often selected by both subspecies. I suspect this was because the cranes were attracted to newly sprouting plants, which are high in protein. Crane use and selection of dirt roads and temporary levees is difficult to explain. They may be attracted to roads as a source of grit, which is rare in the peat-dominated soils of the Delta. Some grain was spilled along roads during harvest operations which may have contributed to their attraction. Crane use of the temporary field levees might have been because they were attracted to the disturbed soil (from levee construction) which likely temporarily enhanced invertebrate availability. Also, temporary levees and roadsides may concentrate invertebrates after adjacent fields are flooded.

Although my study documented important patterns of crane habitat use, I don't have a complete understanding of how management of croplands affects food availability. Further research that examines relationships between harvest method, post-harvest treatment, and grain availability would help inform post-harvest treatment decisions to benefit foraging opportunities for wintering cranes (Elphick and Oring 1998, Miller et al. 2010). Also, using my habitat use information and studying food availability would inform an energetics approach to crane conservation planning (e.g., Pearse et al. (2010).

MANAGEMENT IMPLICATIONS

My data suggest that if wildlife managers want to favor winter field use by foraging cranes they could provide incentives for favorable practices such as production of grain crops (particularly corn and rice), reduction or delaying tillage and flooding of grain fields, provision of irrigations to some crop types (particularly during late winter, when food may become scarce), and increasing the practice of mulching of corn stubble. Flooding of crops should be delayed as late as possible (beginning in December) to allow cranes and other wildlife access to waste grains. If large areas need to be flooded, I recommend that the flooding of individual fields and wetlands be staggered over winter rather than all at once to spread out the feeding opportunities that flood-up provides. I also recommend providing periodic irrigations to facilitate use by cranes. For pastures, irrigations during the dry period of early fall would be beneficial, but for croplands, I recommend that irrigations be provided later in winter (January-early March), when possible to facilitate use by cranes. While cranes are attracted by new crop plantings, these plantings are often subject to damage by cranes and farmers can suffer significant depredation losses. To avoid such damage, I suggest that farmers delay planting until after cranes migrate (after late March) or consider heavier seeding of new crops to accommodate the damage (Ivey et al. 2003). Other crops and habitats that are used by sandhill cranes include alfalfa (primarily for lessers), irrigated pasture, seasonal wetlands, native grasslands and oak savannahs, and these should be maintained and could be included in habitat conservation and mitigation planning where possible. Cranes did not use orchards, vineyards, blueberries, turf farms, or nursery areas, so conversion of crane suitable crops to these habitat types should be avoided within areas specifically being managed for cranes.

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LITERATURE CITED

Afton, A. D. 1979. Time budget of breeding Northern Shovelers. Wilson Bulletin 91: 42-49.

Afton, A. D. 1980. Factors affecting incubation rhythms of Northern Shovelers. Condor 82:132-137.

Afton, A. D. and S. L. Paulus. 1992. Incubation and brood care. Pages 62-108 *in* B. D. J. Batt, A. D. Afton, M. G. Anderson, C. D. Ankney, D. H. Johnson, J. A. Kadlec, and G. L. Krapu, editors. Ecology and management of breeding waterfowl. University of Minnesota Press, Minneapolis, Minnesota, USA.

Aldrich, T. W., and D. G. Raveling. 1983. Effects of experience and body weight on incubation behavior of Canada geese. Auk 100:670-679.

Alonso, J. C., J. A. Alonso, and L. M. Bautista. 1994. Carrying capacity of staging areas and facultative migration extension in Common Cranes. Journal of Applied Ecology 31:212-222.

Anteau, M. J., M. H. Sherfy, and A. A. Bishop. 2011. Location and agricultural practices influence spring use of harvested cornfields by cranes and geese in Nebraska. Journal of Wildlife Management 75:1-8.

Aviles, J. M., Sanchez J. M. and D. Parejo. 2002. Food selection of wintering common cranes (*Grus grus*) in holm oak (*Quercus ilex*) dehesas of southwest of Spain in a rainy season. Journal of Zoology, London 256:71–79.

Baldassarre, G. A., R. J. Whyte, E. E. Quinlan, and E. G. Bolen. 1983. Dynamics and quality of waste corn available to postbreeding waterfowl in Texas. Wildlife Society Bulletin 11:25-31.

Balkenbush, J. A., and D. L. Hallett. 1988. An improved vehicle-mounted telemetry system. Wildlife Society Bulletin 16:65-67.

Ballard, B. M., and J. E. Thompson. 2000. Winter diets of sandhill cranes from central and coastal Texas. Wilson Bulletin 112:263-268.

Bishop, M. A., C. Zhouma, S. Yanling, J. Harkness, and G. Binyuan. 1998. Winter habitat use by black-necked cranes *Grus nigricollis* in Tibet. Wildfowl 49:228-241.

Black, J. M., J. Prop, and K. Larsson. 2007. Wild Goose Dilemmas: Population Consequences of Individual Decisions in Barnacle Geese. Branta Press, Groningen, the Netherlands.

Block, W. M., and L. A. Brennan. 1993. The habitat concept in ornithology: theory and applications. Current Ornithology 11:35–91.

Davis, C. A. 2001. Nocturnal roost site selection and diurnal habitat-use by sandhill cranes during spring in central Nebraska. Proceedings of the North American Crane Workshop 8:48-56.

Davis, C. A. 2003. Habitat use and migration patterns of sandhill cranes along the Platte River, 1998-2001. Great Plains Research 13:199-216.

Day, J. H. and M. A. Colwell. 1998. Waterbird communities in rice fields subjected to different post-harvest treatments. Colonial Waterbirds 21:185-197.

Demment, M. W., and P. J. Van Soest. 1985. A nutritional explanation for body-size patterns of ruminant and non-ruminant herbivores. American Naturalist 125:641–672.

Drewien, R. C. and E. G. Bizeau. 1974. Status and distribution of greater sandhill cranes in the Rocky Mountains. Journal of Wildlife Management 38:720-724.

Durant, D., H. Fritz, and P. Duncan. 2004. Feeding patch selection by herbivorous Anatidae: the influence of body size, and of plant quantity and quality. Journal of Avian Biology 35:144-152.

Elphick, C. S., and L. W. Oring. 1998. Winter management of Californian rice fields for waterbirds. Journal of Applied Ecology 35:95-108.

Erickson, W. P., T. L. McDonald, K. G. Gerow, S. Howlin, and J. W. Kern. 2001. Statistical issues in resource selection studies with radio-marked animals. Pages 209–242 *in* J. J. Millspaugh and J. M. Marzluff, editors. Radio Tracking and Animal Populations. Academic Press, San Diego, California. USA.

Foster, M. A., M. J. Gray, and R. M. Kaminski. 2010. Agricultural seed biomass for migrating and wintering waterfowl in the Southeastern United States. Journal of Wildlife Management 74:489-495.

Frayer, W. E, D. E. Peters, and H. R. Pywell. 1989. Wetlands of the California Central Valley: status and trends – 1939 to mid-1980s. U.S. Fish and Wildlife Service, Portland, OR. http://www.fws.gov/wetlands/Documents/Wetlands-of-the-California-Central-Valley-Status-and-Trends-1939-to-mid-1980s.pdf

Gloutney, M. L., R. T. Alisauskas, A. D. Afton, and S. M. Slattery. 2001. Foraging time and dietary intake by breeding Ross’ and Lesser Snow Geese. Oecologia 127:78–86.

Guthery, F. S. 1976. Foods and feeding habitat of sandhill cranes in Southern Texas. Pages 117-125 *in* J. C. Lewis, editor. Proceedings of the 1975 International Crane Workshop. Oklahoma State University. Publishing and Printing, Stillwater, Oklahoma, USA.

Guzman, J. M. S., A. S. Garcia, C. C. Amado, and A. M. del Viejo. 1999. Influence of farming activities in the Iberian Peninsula on the winter habitat use of common crane (*Grus grus*) in areas of its traditional migratory routes. Agriculture, Ecosystems and Environment 72:207-214.

Heisey, D. M. 1985. Analyzing selection experiments with log-linear models. Ecology 66:1744-1748.

Hereford, S. G., T. E. Grazia, M. Nagendran, and A. Hussain. 2000. Use of traditional Indian trapping methods to capture sandhill cranes. Proceedings of the North American Crane Workshop 8:220 (abstract only).

Hoffman, R. H. 1976. Field usage by sandhill cranes in southern Michigan. Pages 35-43 *in* J. C. Lewis, editor. Proceedings of the 1975 International Crane Workshop. Oklahoma State University. Publishing and Printing, Stillwater, Oklahoma, USA.

Iverson, G. C., P. A. Vohs and T. C. Tacha. 1985. Habitat use by sandhill cranes wintering in western Texas. Journal of Wildlife Management 49:1074–1083.

Iverson, G. C., P. A. Vohs, and T. C. Tacha. 1987. Habitat use by midcontinent sandhill cranes during spring migration. Journal of Wildlife Management 51:448–458.

Ivey, G. L. 2014. Greater Sandhill Crane. In Coastal California (BCR 32) Waterbird Conservation Plan: Encompassing the Coastal Slope and Coast Ranges of Central and Southern California and the Central Valley (W. D. Shuford, Editor). U.S. Fish and Wildlife Service, Pacific Southwest Region, Sacramento, CA, USA. pp. 96-97.

Ivey, G. L., and C. P. Herziger. 2003. Sandhill crane monitoring at Staten Island, San Joaquin County, California, 2002-03. Unpublished report. The Nature Conservancy, Galt, California. http://deltarevision.com/2002_docs/2002staten-cranes%5B1%5D.pdf. Accessed 11-27-2013.

Ivey, G. L., C. P. Herziger, and M. Gause. 2003. Farming for wildlife: an overview of agricultural operations at Staten Island, San Joaquin County, California. The Nature Conservancy, Galt, California.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65–71.

Johnson, D. H., and R. E. Stewart. 1973. Racial composition of migrant populations of sandhill cranes in the northern plain states. Wilson Bulletin 85:148-162.

Johnson, J. C., and D. G. Raveling. 1988. Weak family associations in cackling geese during winter: effects of body size and food resources on goose social organization. Pages 71-89 *in* M. W. Weller, editor. Waterfowl in winter. University of Minnesota Press, Minneapolis, Minnesota, USA.

Kendeigh, S. C. 1970. Energy requirements for existence in relation to size of a bird. Condor 72:60-65.

Kleinschmidt Associates. 2008. Cosumnes River Preserve Management Plan. Cosumnes River Preserve, Galt, California. http://www.blm.gov/pgdata/etc/medialib/blm/ca/pdf/folsom/plans.Par.67798.File.dat/CRP_Final_Mgmt_Plan.pdf. Accessed 11-27-2013.

Krapu, G. L., D. A. Brandt, K. L. Jones, and D. H. Johnson. 2011. Geographic distribution of the Mid-Continent Population of sandhill cranes and related management applications. Wildlife Monographs 175:1–38.

Krapu, G. L., D. E. Facey, E. K. Fritzell and D. H. Johnson. 1984. Habitat use by migrant sandhill cranes in Nebraska. Journal of Wildlife Management 48: 407–417.

Lasiewski, R. C., and W. R. Dawson. 1967. A re-examination of the relation between standard metabolic rate and body weight in birds. Condor 69:13-23.

Lee, S. D., P. G. Jablon´ski and H. Higuchi. 2007. Winter foraging of threatened cranes in the Demilitarized Zone of Korea: Behavioral evidence for the conservation importance of unplowed rice fields. Biological Conservation 138: 286-289.

Lewis, J. C. 1979. Taxonomy, food, and feeding habitat of sandhill cranes, Platte Valley, Nebraska. Pages 21-27 *in* J. C. Lewis, editor. Proceedings of the 1978 Crane Workshop. Colorado State University, Fort Collins, Colorado, USA.

Littlefield, C. D. 2002. Winter foraging habitat of greater sandhill cranes in northern California. Western Birds 33:51-60.

Littlefield, C. D., and G. L. Ivey. 2000. Conservation Assessment for Greater Sandhill Cranes wintering on the Cosumnes River Floodplain and Delta regions of California. Unpublished report. The Nature Conservancy, Galt, California.

Lovvorn, J. R. and C. M. Kirkpatrick. 1982. Field use by staging eastern greater sandhill cranes. Journal of Wildlife Management 46:99–108.

Manly B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals, statistical design and analysis for field studies. Second Edition. Kluwer Academic Publishers, Dordrecht, The Netherlands.

McNab, B. K. 2001. Energetics of toucans, a barbet, and a hornbill: Implications for avian frugivory. Auk 118:916-933.

McNab, B. K. 2003. Metabolism: Ecology shapes bird bioenergetics. Nature 426:620-621.

Meine, C. D., and G. W. Archibald (Editors). 1996. The cranes: Status survey and conservation action plan. IUCN, Gland, Switzerland, and Cambridge, U.K. 294 pp. Northern Prairie Wildlife Research Center Online. http://www.npwrc.usgs.gov/resource/birds/cranes/index.htm (Version 02MAR98).

Miller, M. R., D. E. Sharp, D. S. Gilmer, and W. R. Mulvaney. 1989. Rice available to waterfowl in harvested fields in the Sacramento Valley, California. California Fish and Game 75:113-123.

Miller, M. R., J. D. Garr, and P. S. Coates. 2010. Changes in the status of harvested rice fields in the Sacramento Valley, California: Implications for Wintering Waterfowl. Wetlands 30:939–947.

Møller, A. P. 2009. Basal metabolic rate and risk-taking behaviour in birds. Journal of Evolutionary Biology 22:2420–2429.

Nams, V. O. 2005. LOCATE III. Pacer, Truro, Nova Scotia, Canada.

Nesbitt, S. A., S. T. Schwikert. 2005. Wing-molt patterns - A key to aging sandhill cranes. Wildlife Society Bulletin 33:326-331.

Pacific Flyway Council. 1983. Pacific Flyway Management Plan: Pacific Flyway Population of Lesser Sandhill Cranes. Pacific Flyway Study Committee (c/o Pacific Flyway Representative USFWS), Portland, Oregon, USA.

Pacific Flyway Council. 1997. Pacific Flyway management plan for the Central Valley Population of Greater Sandhill Cranes. Pacific Flyway Study Committee (c/o Pacific Flyway Representative USFWS), Portland, Oregon, USA.

Pearse, A. T., G. L. Krapu, D. A. Brandt, and P. J. Kinzel. 2010. Changes in agriculture and abundance of snow geese affect carrying capacity of sandhill cranes in Nebraska. Journal of Wildlife Management 74:479–488.

Petrula, M. J., and T. C. Rothe. 2005. Migration chronology, routes, and distribution of Pacific Flyway Population of Lesser Sandhill Cranes. Proceedings North American Crane Workshop 9:53-67.

Pogson, T. H., and S. M. Lindstedt. 1991. Distribution and abundance of large sandhill cranes, *Grus canadensis,* wintering in California's Central Valley. Condor 93:266-278.

Reed, T. 1989. San Joaquin County 1989 Agricultural Crop Report. San Joaquin Agricultural Commissioner's Office, Stockton, CA.

Reinecke, K. J., and G. L. Krapu. 1979. Spring food habits of sandhill cranes in Nebraska. Paged 13-19 *in* J. C. Lewis, editor. Proceedings of the 1978 Crane Workshop. Colorado State University, Fort Collins, Colorado, USA.

Reinecke, K. J., and G. L. Krapu. 1986. Feeding ecology of Sandhill Cranes during migration in Nebraska. Journal of Wildlife Management 50:71-79.

Robbins, C. T. 2001. Wildlife Feeding and Nutrition. Second edition. Academic Press, Inc., San Diego, California.

Rowland, M. W., L. Kinter, T. Banks, and D. C. Lockman. 1992. Habitat use by greater sandhill cranes in Wyoming. Pages 82-85 *in* D.A. Wood, editor. Proceedings of the 1988 North American Crane Workshop. Florida Game and Fresh Water Fish Commission, Nongame Wildlife Program Technical Report 12, Tallahassee, FL, USA.

Samuel, M. D., and M. R. Fuller. 1996. Wildlife Radiotelemetry. Pages 370-418 *in* T.A. Bookhout, editor. Research and management techniques for wildlife and habitats. Fifth edition. The Wildlife Society, Bethesda, Maryland, USA.

Schwieger, R., and T. Gonsalves. 2013. San Joaquin County 2013 Crop Report. San Joaquin Agricultural Commissioner's Office, Stockton, CA.

Shaskey, L. E. 2012. Local and landscape influences on sandhill crane habitat suitability in the northern Sacramento Valley, CA. M.S Thesis, Sonoma State University, Rohnert Park, California.

Sherfy, M. H., M. J. Anteau, and A. A. Bishop. 2011. Agricultural Practices and Residual Corn During Spring Crane and Waterfowl Migration in Nebraska. Journal of Wildlife Management 75:995-1003.

Sparling, D. W., and G. L. Krapu. 1994. Communal roosting and foraging behavior of staging sandhill cranes. Wilson Bulletin 106:62-77.

Sugden, L. G., R. G. Clark, E. J. Woodsworth, and H. Greenwood. 1988. Use of cereal fields by foraging sandhill cranes in Saskatchewan. Journal of Applied Ecology 25:111-124.

Taylor, J. T., and L. M. Smith. 2005. Sandhill Crane use of managed chufa wetlands at Bosque del Apache NWR, New Mexico. Proceedings of the North American Crane Workshop 9:167-171.

Tacha, T. C., S. A. Nesbitt, and P. A. Vohs. 1994. Sandhill Cranes. Pages 76-94 *in* T. C. Tacha and C. E. Braun, editors. Migratory Shore and Upland Game Bird Management in North America. International Association of Fish and Wildlife Agencies, Washington, D. C.

Thornton, D. H., and R. J. Fletcher, Jr. 2014. Body size and spatial scales in avian response to landscapes: a meta-analysis. Ecography 37:454–463.

U.S. Fish and Wildlife Service. 2007. Stone Lakes National Wildlife Refuge Draft Comprehensive Conservation Plan. Stone Lakes National Wildlife Refuge, Elk Grove, California. USA.

Urbanek, R. P., J. L. McMillen, and T. A. Bookhout. 1991. Rocket-netting greater sandhill cranes on their breeding grounds at Seney National Wildlife Refuge. Page 241 *in* J. T. Harris, editor. Proceedings 1987 International Crane Workshop, Qiqihar, Heilongjiang Province, China. International Crane Foundation, Baraboo, Wisconsin, USA.

Walker, D. L., and S. D. Schemnitz. 1987. Food habits of sandhill cranes in relationship to agriculture in central and southwestern New Mexico. Pages 201-212 *in* J. C. Lewis, editor. Proceedings 1985 Crane Workshop. Platte River Whooping Crane Habitat Maintenance Trust, Grand Island, NE.

Figure 4.1. Major sandhill crane (*Grus canadensis*) wintering regions within the Central Valley of California. From north to south: Sacramento Valley, Sacramento-San Joaquin River Delta, San Joaquin River National Wildlife Refuge region, Merced Grasslands, and Pixley National Wildlife Refuge region.

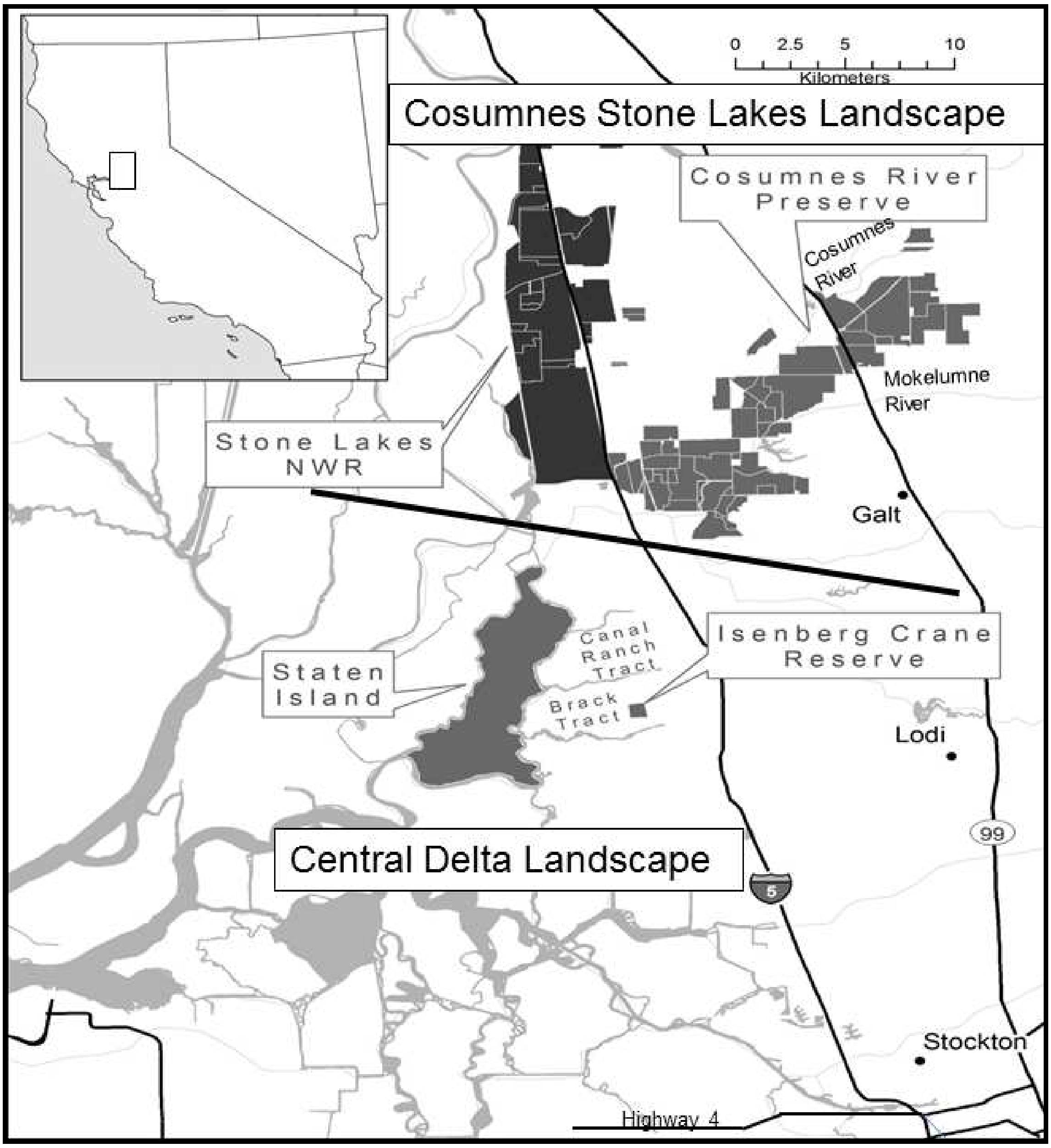


Figure 4.2. Map of the Sacramento-San Joaquin River Delta study area that also shows landscapes (separated by dashed line) for this sandhill crane (*Grus canadensis*) research project, 2007-2009.

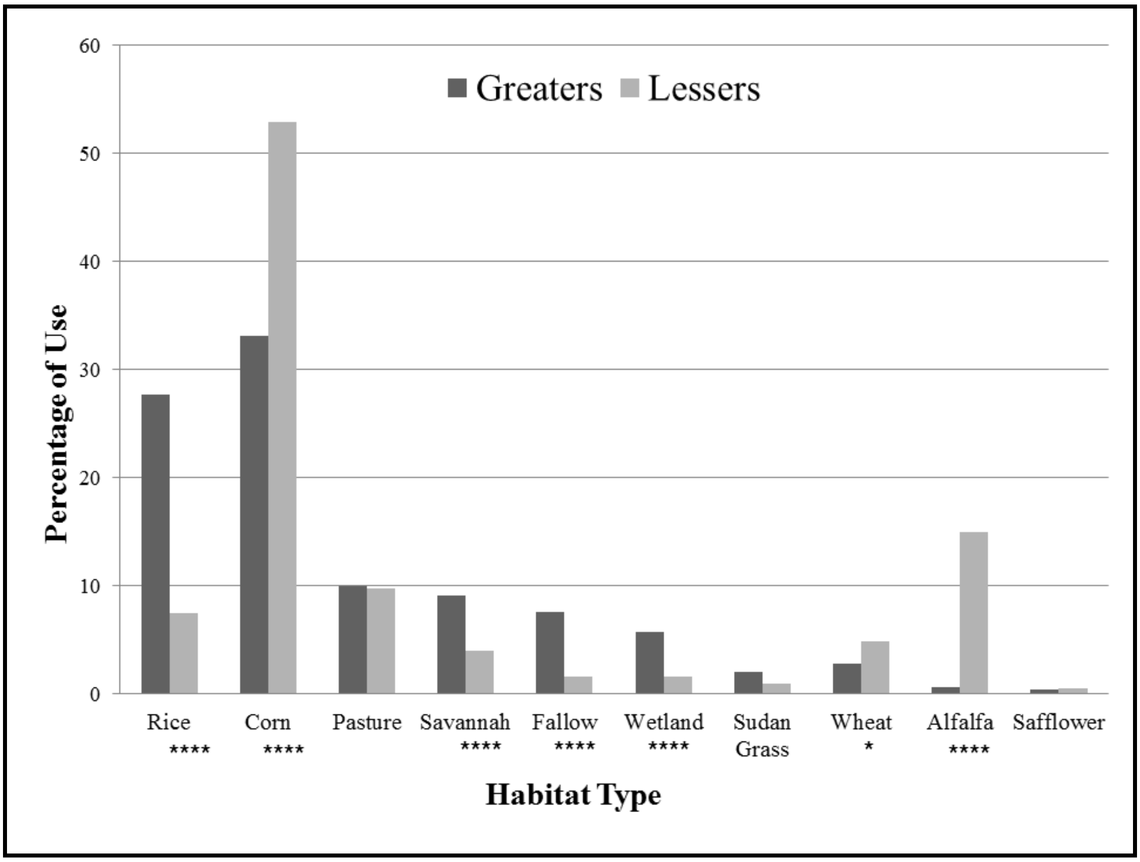
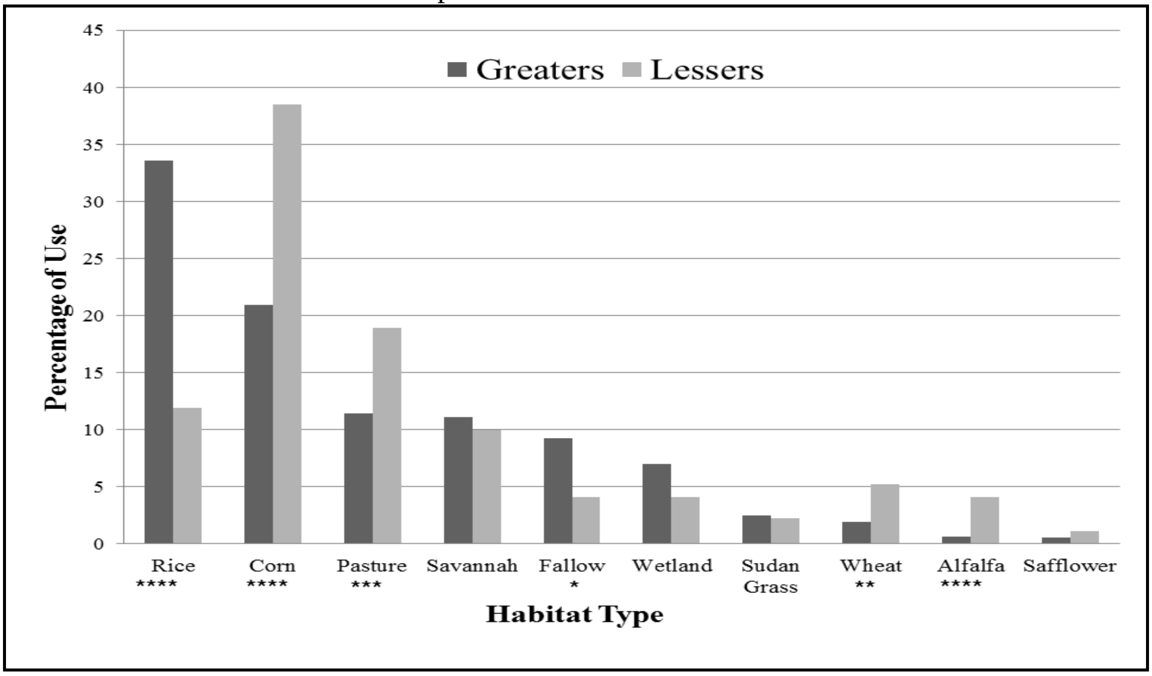


Figure 4.3. Habitat use by greater (*Grus canadensis tabida*) and lesser sandhill cranes (*G. c. canadensis*) radio-tagged in the Sacramento-San Joaquin River Delta, California region (entire study area) during winters 2007-2008 and 2008-2009. Chi-square P-Values: * = P < 0.05, **** = P < 0.0001.

a. Cosumnes-Stone Lakes Landscape



b. Central Delta Landscape

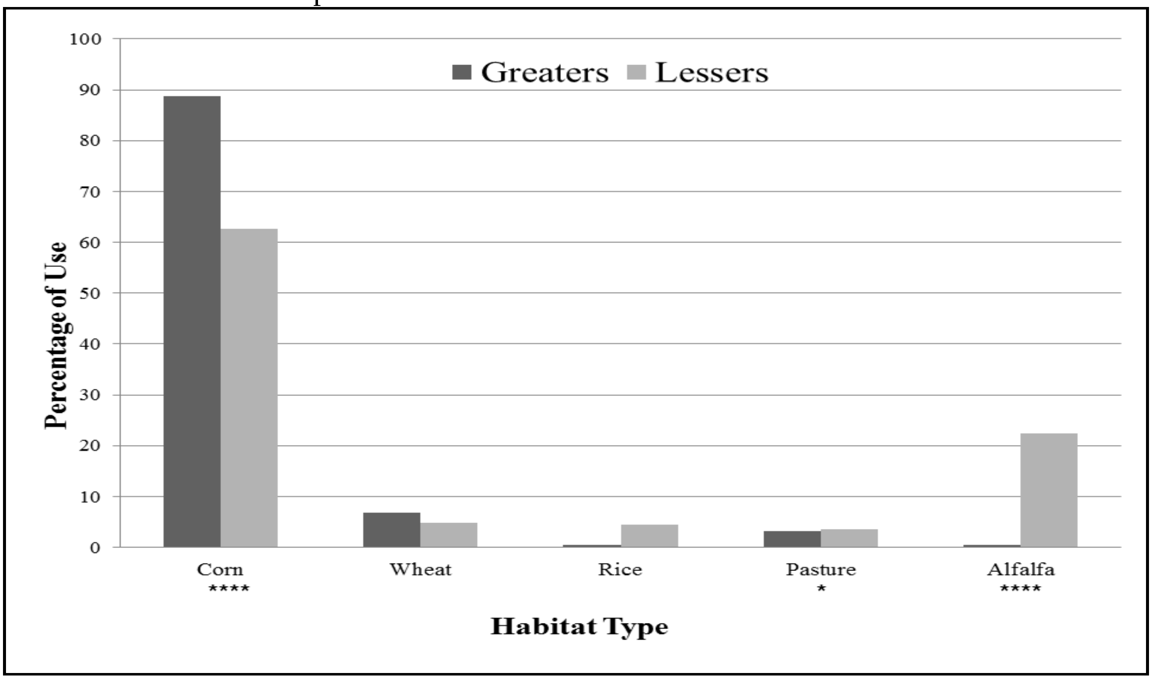
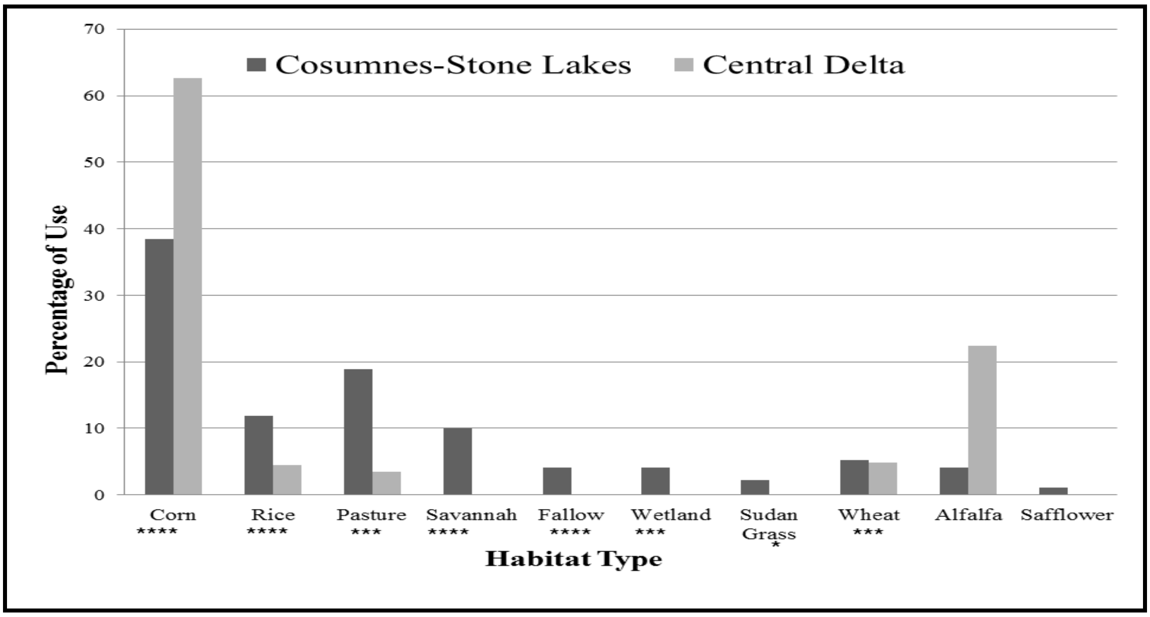


Figure 4.4. Habitat use by sandhill crane (*Grus canadensis*) subspecies (greater [*G. c. tabida*] vs. lesser sandhill cranes [*G. c. canadensis*]) radio-tagged in the Cosumnes-Stone Lakes (a) and the Central Delta landscapes (b) in the Sacramento-San Joaquin River Delta, California during winters 2007-2008 and 2008-2009. Chi-square P-Values: * = P < 0.05, ** = P < 0.01, ** = P < 0.001, **** = P < 0.0001.

a. Greaters



b. Lessers

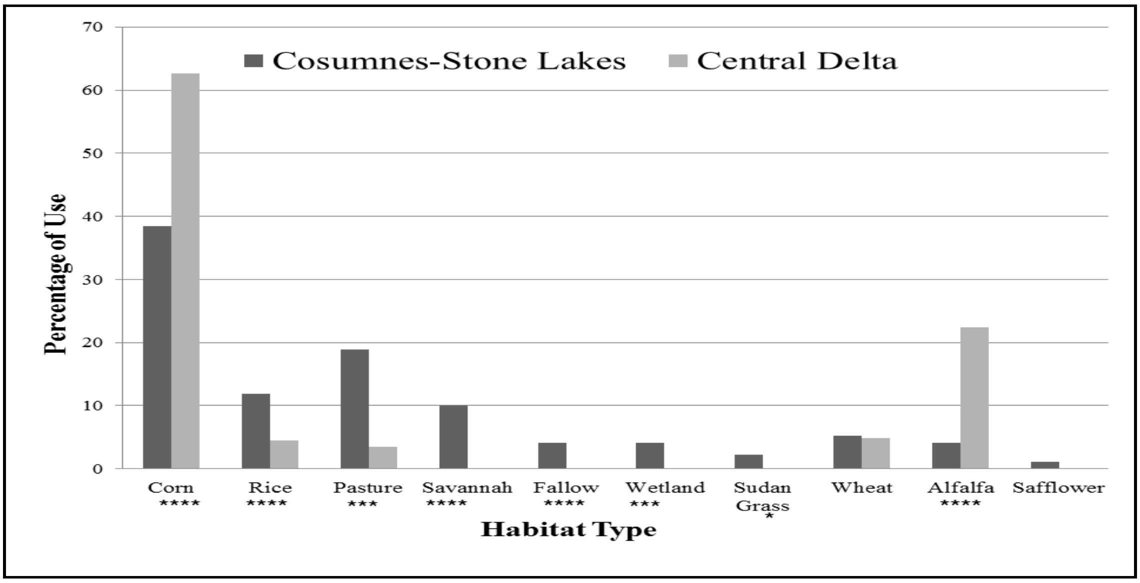


Figure 4.5. Habitat use by landscape (Cosumnes-Stone Lakes vs. Central Delta) by radio-tagged greater (*Grus canadensis tabida*; a) and lesser sandhill cranes (*G. c. canadensis*; b) in the, Sacramento-San Joaquin River Delta study area, California during winters 2007-2008 and 2008-2009. Chi-square P-Values: * = P < 0.05, ** = P < 0.01, ** = P < 0.001, **** = P < 0.0001.

Table 4.1. Summary of greater(*Grus canadensis tabida*) and lesser sandhill cranes (*G. c. canadensis*) selection of corn habitats by management conditions during winters of 2007-08 and 2008-09 at three sites in the Sacramento-San Joaquin River Delta, California (S = selected, a = avoided, u = unused, * = neither selected or avoided, - = no survey, ~ = not available).

			Survey Period									
Post-Harvest Condition	**Year-Site[1]**	**Subspecies[2]**	**Early Oct**	**Late Oct**	**Early Nov**	**Mid Nov**	**Early Dec**	**Mid Dec**	**Early Jan**	**Mid Jan**	**Late Jan**	**Mid Feb**
dry stubble	1-BT	G	-	-	u	u	u	~	~	~	~	~
	2-BT	G	u	a	u	u	u	u	~	~	~	~
	1-SI	G	u	~	~	~	~	~	~	~	~	~
	2-SI	G	a	u	u	u	u	u	u	u	u	u
	1-BT	L	-	-	**S**	u	u	~	~	~	~	~
	2-BT	L	u	a	u	u	u	u	~	~	~	~
	1-SI	L	u	~	~	~	~	~	~	~	~	~
	2-SI	L	a	u	u	u	u	u	u	u	u	u
dry tilled stubble	1-BT	G	-	-	a	a	~	~	~	~	~	~
	2-BT	G	**S**	**S**	*	u	**S**	*	u	u	~	~
	1-SI	G	~	-	a	a	u	a	u	u	a	*
	2-SI	G	u	**S**	**S**	~	~	~	~	~	~	~
	1-SI	L	~	-	a	a	u	a	u	u	u	a
	2-SI	L	u	a	a	~	~	~	~	~	~	~
	1-BT	L	-	-	a	a	~	~	~	~	~	~
	2-BT	L	a	**S**	a	a	a	**S**	u	u	~	~
dry mulched stubble	1-BT	G	~	~	~	u	**S**	**S**	**S**	~	~	~
	1-SI	G	**S**	-	a	a	a	*	**S**	a	**S**	**S**
	2-SI	G	u	**S**	a	a	a	**S**	**S**	**S**	**S**	a
	1-BT	L	~	~	~	u	a	**S**	a	~	~	~
	1-SI	L	a	-	a	a	a	**S**	**S**	**S**	**S**	**S**
	2-SI	L	a	a	a	**S**	*	**S**	**S**	**S**	**S**	a
flooded stubble	1-BT	G	~	~	u	u	u	u	u	u	u	u
	1-SI	G	**S**	-	**S**	*	**S**	u	a	u	a	u
	2-SI	G	**S**	*	**S**	a	a	a	a	a	a	a
	1-BT	L	~	~	u	u	u	u	u	**S**	u	u
	1-SI	L	**S**	-	**S**	a	a	u	a	u	a	u
	2-SI	L	a	a	a	a	u	u	u	a	a	a
flooded tilled stubble	1-BT	G	~	~	~	~	~	*	**S**	**S**	**S**	**S**
	2-BT	G	~	~	~	**S**	**S**	**S**	**S**	*	**S**	**S**
	1-BT	L	~	~	~	~	~	a	**S**	*	a	**S**
	2-BT	L	~	~	~	**S**	**S**	**S**	a	**S**	u	*
flooded mulched stubble[3]	1-SI	G	~	~	~	~	**S**	u	u	u	u	u
	2-SI	G	~	~	~	~	**S**	**S**	u	u	**S**	**S**
	1-SI	L	~	~	~	~	**S**	u	u	u	u	u
	2-SI	L	~	~	~	~	**S**	u	u	**S**	**S**	**S**

[1] 1 = 2007-08, 2 = 2008-09, BT = Brack Tract, SI = Staten Island; [2]G = Greater subspecies; L = Lesser subspecies. [3]flooded in year 1, irrigated in year 2.

Table 4.2. Summary of greater (*Grus canadensis tabida*) and lesser sandhill cranes (*G. c. canadensis*) selection of rice habitats by management conditions during winters of 2007-08 and 2008-09 at three sites in the Sacramento-San Joaquin River Delta, California (S = selected, a = avoided, u = unused, * = neither selected or avoided, - = no survey, ~ = not available).

			Survey Period									
Post-Harvest Condition	**Year-Site[1]**	**Subspecies[2]**	**Early Oct**	**Late Oct**	**Early Nov**	**Mid Nov**	**Early Dec**	**Mid Dec**	**Early Jan**	**Mid Jan**	**Late Jan**	**Mid Feb**
dry stubble	2-BT	G	u	**S**	~	~	~	~	~	~	~	~
	1-CP	G	**S**	-	*	**S**	u	-	u	~	~	~
	2-CP	G	**S**	**S**	a	u	u	-	-	~	~	~
	2-BT	L	a	**S**	~	~	~	~	~	~	~	~
	1-CP	L	*	-	a	u	u	-	u	~	~	~
	2-CP	L	**S**	**S**	u	u	u	-	-	~	~	~
	2-CP[3]	G	**S**	u	u	u	-	-	-	~	~	~
	2-CP[3]	L	*	u	u	u	-	-	-	~	~	~
tilled stubble	1-BT	G	-	-	u	u	~	~	~	~	~	~
	2-BT	G	u	u	**S**	a	u	u	u	u	u	u
	1-CP	G	u	-	u	u	u	-	u	~	~	~
	1-BT	L	-	-	u	u	~	~	~	~	~	~
	2-BT	L	u	u	a	a	u	u	u	u	u	u
	1-CP	L	**S**	u	u	u	u	-	u	~	~	~
mulched stubble	1-BT	G	-	-	a	**S**	~	~	~	~	~	~
	1-CP	G	~	-	**S**	*	u	-	*	~	~	~
	2-CP	G	a	*	a	a	-	-	-	~	~	~
	2 BT	G	*	~	~	~	~	~	~	~	~	~
	1-BT	L	-	-	**S**	**S**	~	~	~	~	~	~
	1-CP	L	~	-	a	a	a	-	a	~	~	~
	2-CP	L	~	u	u	a	u	-	-	~	~	~
	2-BT	L	**S**	~	~	~	~	~	~	~	~	~
flooded stubble	1-CP	G	~	~	**S**	**S**	**S**	-	a	**S**	-	-
	2-CP	G	~	~	~	~	**S**	-	-	**S**	u	-
	1-CP	L	~	~	**S**	**S**	**S**	-	**S**	**S**	-	-
	2-CP	L	~	~	~	~	**S**	-	-	a	u	-
	2-CP[3]	G	~	~	~	~	~	~	~	**S**	**S**	-
	2-CP[3]	L	~	~	~	~	~	~	~	u	**S**	-
flooded tilled stubble	1-BT	G	~	~	~	**S**	u	a	*	a	a	u
	2-BT	G	~	~	~	**S**	a	u	u	u	**S**	u
	1-CP	G	u	-	u	~	~	~	~	~	~	~
	1-BT	L	~	~	~	**S**	a	a	a	*	u	u
	1-CP	L	u	-	u	~	~	~	~	~	~	~
	2-BT	L	~	~	~	a	u	*	a	u	u	u
flooded mulched stubble	1-CP	G	~	~	~	~	*	-	**S**	*	-	-
	2-CP	G	~	~	**S**	**S**	**S**	-	-	a	a	-
	1-CP	L	~	~	~	~	**S**	-	**S**	*	-	-
	2-CP	L	~	~	**S**	**S**	**S**	-	-	**S**	u	-

[1] 1 = 2007-08, 2 = 2008-09; BT = Brack Tract, CP = Cosumnes River Preserve; [2]G = Greater subspecies; L = Lesser subspecies; [3]Wild rice.

Table 4.3. Summary of greater (*Grus canadensis tabida*) and lesser sandhill cranes (*G. c. canadensis*) selection of wheat, alfalfa and irrigated pasture habitats by management conditions during winters of 2007-08 and 2008-09 at three sites in the Sacramento-San Joaquin River Delta, California (**S** = selected, a = avoided, u = unused, * = neither selected or avoided, - = no survey, ~ = not available).

			Survey period									
Habitat Condition	**Year-Site[1]**	**Subspecies[2]**	**Early Oct**	**Late Oct**	**Early Nov**	**Mid Nov**	**Early Dec**	**Mid Dec**	**Early Jan**	**Mid Jan**	**Late Jan**	**Mid Feb**
tilled wheat	1-SI	*G*	a	-	a	u	u	u	u	u	u	u
	2-SI	*G*	a	**S**	**S**	a	u	a	a	*	u	u
	1-SI	*L*	u	-	a	u	u	u	u	u	u	u
	2-SI	*L*	**S**	**S**	*	a	u	a	a	a	a	a
flooded tilled wheat	1-SI	*G*	u	-	u	u	u	u	u	u	u	u
	2-SI	*G*	u	**S**	u	u	u	u	u	u	u	u
	1-SI	*L*	**S**	-	u	u	u	u	u	u	u	u
	2-SI	*L*	a	u	u	u	u	u	u	u	u	u
fall planted wheat	1-BT	G	-	-	*	a	u	a	u	a	u	u
	2-BT	G	~	~	u	u	a	u	u	u	u	u
	1-SI	G	~	~	~	**S**	*	**S**	*	u	u	a
	2-SI	G	~	~	~	**S**	a	u	**S**	a	a	u
	1-BT	L	-	-	a	*	*	a	a	*	a	u
	2-BT	L	~	~	**S**	a	**S**	**S**	**S**	a	u	u
	1-SI	L	~	~	~	**S**	**S**	a	a	a	u	u
	2-SI	L	~	~	~	a	a	u	a	u	u	u
alfalfa	1-BT	*G*	-	-	u	u	u	a	u	u	u	u
	2-BT	*G*	u	u	u	u	u	u	u	u	u	u
	1-BT	*L*	-	-	**S**	a	**S**	**S**	**S**	u	**S**	u
	2-BT	*L*	**S**	u	**S**	a	**S**	u	**S**	**S**	**S**	**S**
established irrigated pasture	1-BT	*G*	-	-	u	u	u	u	u	u	u	u
	2-BT	*G*	u	u	u	u	u	u	u	u	u	u
	2-SI	*G*	*	a	a	**S**	a	u	a	a	a	*
	1-BT	*L*	-	-	u	u	u	u	u	u	u	u
	2-BT	*L*	u	u	u	a	u	u	u	u	u	u
	2-SI	*L*	**S**	a	u	a	*	u	a	a	u	u
newly-planted pasture	1-SI	*G*	~	~	~	~	**S**	u	*	**S**	**S**	*
	2-SI	*G*	~	~	~	~	**S**	**S**	**S**	**S**	**S**	**S**
	1-SI	*L*	~	~	~	~	*	a	a	**S**	*	u
	2-SI	*L*	~	~	~	~	**S**	**S**	a	**S**	**S**	**S**

[1] 1 = 2007-08, 2 = 2008-09; BT = Brack Tract, SI=Staten Island; [2]G = Greater subspecies; L = Lesser subspecies.

Table 4.4. Summary of greater (*Grus canadensis tabida*) and lesser sandhill cranes (*G. c. canadensis*) selection of safflower and fallow habitats by management conditions during winters of 2007-08 and 2008-09 at three sites in the Sacramento-San Joaquin River Delta, California (S = selected, a = avoided, u = unused, * = neither selected or avoided, - = no survey, ~ = not available).

			Survey Period									
Habitat Condition	**Year-Site**[1]	**Subspecies**[2]	**Early Oct**	**Late Oct**	**Early Nov**	**Mid Nov**	**Early Dec**	**Mid Dec**	**Early Jan**	**Mid Jan**	**Late Jan**	**Mid Feb**
dry safflower stubble	2-CP	*G*	u	u	u	~	~	~	~	~	~	~
	2-CP	*L*	u	u	u	~	~	~	~	~	~	~
tilled safflower stubble	2-CP	*G*	u	u	u	a	u	-	-	~	~	~
	2-CP	*L*	u	u	u	u	u	-	-	~	~	~
flooded safflower stubble	2-CP	*G*	~	~	~	~	u	-	-	u	u	-
	2-CP	*L*	~	~	~	~	u	-	-	u	u	-
tilled flooded safflower	2-CP	*G*	~	~	~	**S**	u	-	-	u	u	-
	2-CP	*L*	~	~	~	**S**	u	-	-	u	u	-
fallow	1-BT	*G*	u	u	u	u	u	u	u	u	u	u
	1-BT	*L*	u	u	u	u	u	u	u	u	u	u
fallow tilled	1-CP	*G*	u	-	u	u	u	-	u	u	-	u
	2-CP	*G*	u	u	u	a	a	-	-	u	*	-
	1-CP	*L*	u	-	u	u	u	-	u	u	-	u
	2-CP	*L*	u	u	u	a	a	-	-	u	u	-

[1] 1 = 2007-08, 2 = 2008-09; BT = Brack Tract; CP = Cosumnes River Preserve. [2]G = Greater subspecies; L = Lesser subspecies

Table 4.5. Summary of greater (*Grus canadensis tabida*) and lesser sandhill cranes (*G. c. canadensis*) selection of field levees, main levees and dirt road habitats during winters of 2007-08 and 2008-09 at three sites in the Sacramento-San Joaquin River Delta, California (S = selected, a = avoided, u = unused, * = neither selected or avoided, - = no survey, ~ = not available).

			Survey Period									
Habitat Condition	**Year-Site**[1]	**Subspecies**[2]	**Early Oct**	**Late Oct**	**Early Nov**	**Mid Nov**	**Early Dec**	**Mid Dec**	**Early Jan**	**Mid Jan**	**Late Jan**	**Mid Feb**
field levees	1-SI	*G*	a	-	**S**	u	u	u	u	u	u	u
	2-SI	*G*	u	u	**S**	u	u	u	u	u	u	u
	1-SI	*L*	a	-	**S**	u	u	u	u	u	u	u
	2-SI	*L*	u	u	u	u	u	u	u	u	u	u
permanent levees	1-SI	*G*	u	-	u	a	u	u	u	u	u	u
	2-SI	*G*	u	a	a	*	u	u	u	a	u	*
	1-SI	*L*	u	-	**S**	*	a	*	a	u	a	u
	2-SI	*L*	u	**S**	**S**	**S**	**S**	a	a	**S**	a	a
dirt roads	1-BT	*G*	-	-	**S**	*	**S**	**S**	u	**S**	u	u
	2-BT	*G*	u	u	u	u	**S**	**S**	**S**	**S**	*	u
	1-SI	*G*	u	-	u	u	u	u	u	u	u	u
	2-SI	*G*	u	a	**S**	**S**	u	a	u	u	u	a
	1-BT	*L*	-	-	**S**	*	a	*	u	*	u	u
	2-BT	*L*	u	u	u	**S**	*	*	*	u	u	u
	1-SI	*L*	u	-	u	u	u	u	u	u	a	u
	2-SI	*L*	u	u	u	u	u	u	u	a	u	u

[1] 1 = 2007-08, 2 = 2008-09; BT = Brack Tract, SI=Staten Island; [2]G = Greater subspecies; L = Lesser subspecies.

Chapter 5

CHARACTERISTICS OF SANDHILL CRANE ROOSTS IN THE SACRAMENTO-SAN JOAQUIN RIVER DELTA OF CALIFORNIA

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ABSTRACT

The Sacramento-San Joaquin River Delta (Delta) region of California is an important wintering region for 2 subspecies of Pacific Flyway sandhill cranes (*Grus canadensis*): the Central Valley Population of the greater sandhill crane (*G. c. tabida*) and the Pacific Flyway Population of the lesser sandhill crane (*G. c. canadensis*). During the winters of 2007-08 and 2008-09 we conducted roost counts, roadside surveys, aerial surveys, and tracked radio-marked birds to locate and assess important habitats for roosting cranes in the Delta. Of the 69 crane night roosts we identified, 35 were flooded cropland sites and 34 were wetland sites. We found that both larger individual roost sites and larger complexes of roost sites supported larger peak numbers of cranes. Water depth used by roosting cranes averaged 10 cm (range 3-21 cm, mode 7 cm) and was similar between subspecies. We found that cranes avoided sites that were regularly hunted or had high densities of hunting blinds. The fact that cranes readily use undisturbed flooded cropland sites makes this a viable option for creation of roost habitat. Because hunting disturbance can limit crane use of roost sites we suggest these two uses should not be considered readily compatible. However, if the management objective of an area includes waterfowl hunting, limiting hunting to low blind densities and restricting hunting to early morning may be viable options for creating a crane-compatible waterfowl hunt program.

INTRODUCTION

The Sacramento-San Joaquin River Delta (hereafter, Delta) is an important wintering region for 2 subspecies of Pacific Flyway sandhill cranes (*Grus canadensis*); the Central Valley Population of the greater sandhill crane (*G. c. tabida*, hereafter, greaters) and the Pacific Flyway Population of the lesser sandhill crane (*G. c. canadensis*, hereafter, lessers) (Pacific Flyway Council 1983, Pacific Flyway Council 1997). Greaters, which are listed as threatened in California (California Department of Fish and Wildlife [CDFW] 2013), are a priority for conservation actions, while lessers are considered a California Species of Conservation Concern (Littlefield 2008). However, little is known about winter use of roost sites and characteristics of roost sites used by wintering cranes that could aid in designing a biologically sound conservation strategy for cranes in the Delta.

Other than on the Platte River in Nebraska (e.g., Krapu et al. 1984; Norling et al. 1992; Folk and Tacha 1990; Parrish et al. 2001; Davis 2001, 2003), little work has been done to quantify habitat types used by roosting cranes. In the Platte River system, cranes roost in the shallow waters (1-21 cm) and sandbar islands within the river channel. While the water depth information likely has broad applicability, other habitat characteristics of the North Platte River are not found in California. Additionally, there are no published studies about the suitability of flooded agricultural fields as roost sites for cranes or information that quantifies how roost site size correlates with crane abundance at the roost. In this study, we characterize the features of crane roosts at both the individual site and roost complex scales, correlate roost abundance with roost size, and correlate roost use with recreational waterfowl hunting activity to increase our understanding of crane roosting ecology and support crane habitat conservation and management.

STUDY AREA

We centered our study on several properties in the Delta that are specifically managed to provide night roost sites for cranes, and which subsequently support most of the cranes that winter in the region (Pogson and Lindstedt 1991, Ivey and Herziger 2003, U.S. Fish and Wildlife Service 2007), including Cosumnes River Preserve, Staten Island and adjacent Canal Ranch and Bract Tracts (which includes the Isenberg Crane Reserve), and Stone Lakes National Wildlife Refuge (NWR) (Fig. 5.1). The Delta region is primarily rural agricultural landscapes bordered by urban communities. Agricultural land uses include field and silage corn, fall-planted wheat, rice, alfalfa, irrigated pasture, dairies, vineyards, and orchards. The region also contains large tracts of oak savannah and floodplain wetlands along the Cosumnes and Mokelumne river floodplains.

We trapped cranes at Cosumnes River Preserve and Staten Island. The Cosumnes River Preserve (9,915 ha within our study area) was established by The Nature Conservancy (TNC) and is a conglomeration of lands owned or under conservation easements by TNC and its agency partners. It provides habitats for cranes including seasonal wetland roost sites, oak savannahs, organic rice, and other crops. Staten Island (3,725 ha) was a large corporate farm that was purchased by TNC and was managed as an income-producing farm but with a focus on providing habitat for cranes and other wildlife and developing wildlife-friendly farming practices that can serve as a demonstration to other farmers in the region (Ivey et al. 2003). Cranes use roosts at Staten Island and adjacent Canal Ranch and Brack Tracts as a complex. We define a complex as an association of flooded fields and wetlands in close proximity to each other (none > 1 km from another flooded site). Brack Tract contains Isenberg Crane Reserve, owned and managed by the California Department of Fish and Wildlife, and consisted of 2 seasonal wetland sites (totaling 60 ha) that were surrounded by private agricultural lands, including a large area of flooded rice fields that also provided roosts. Stone Lakes NWR has developed 410 ha of seasonal wetland sites that were used as night roosts and which were also adjacent to private agricultural lands. The refuge also managed croplands such as irrigated pasture, alfalfa, and occasionally grain crops for cranes and other wildlife.

METHODS

We defined a roost as a site used by cranes at night. We cataloged locations of sandhill crane roost sites in the Delta during 2007-08 and 2008-09 by tracking radio-tagged cranes and through observations from the ground. We captured and radio-tagged a total of 77 sandhill cranes during 17 October 2007 and 27 February 2008 in the Delta, and during April and August 2008 at northern breeding and staging areas before they returned to the Delta (see Ivey et al. 2014 for detailed methods of crane capture, handling, and tracking). Our handling of cranes was conducted under the guidelines of the Oregon State University Animal Care and Use Committee (project #3605) to ensure methods were in compliance with the Animal Welfare Act and United States Government Principles for the Utilization and Care of Vertebrate Animals Used in Testing, Research, and Training policies. Cranes were captured under CDFW permit SC-803070-02 and U.S. Geological Survey federal banding permit MB#21142.

We mapped each roost site, categorized the habitat as either wetland or flooded cropland, noted whether the site was used for waterfowl hunting, calculated the density of hunting blinds, and estimated the size (ha) of each using ArcGIS version 9.2 (ESRI, Redlands, California). Many of the individual sites were directly adjacent to each other (separated by dikes or secondary roads) and individual cranes tended to shift their choices for roosting among adjacent sites. We mapped adjoining sites of the same type (i.e., agriculture or wetland) as 1 site, rather than each field or wetland separately. Sites either >200 m apart, separated by paved roads or rivers, or adjacent to roosts of different habitat types were mapped separately. We calculated the mean ± SE size for wetland and agricultural roosts sites and complexes of associated roost sites, and compared the means using a Student's *t*-test.

We conducted biweekly counts of cranes using the 3 major night roost complexes in our study area (Staten Island [including the adjacent Brack and Canal Ranch Tracts], Cosumnes River Preserve, and Stone Lakes NWR) between 5 October 2007 and 27 February 2008 to document seasonal abundance of cranes and compare abundance with roost site size (ha) and type (wetland versus agricultural). We conducted each count over a period of 2 or 3 days, but all sites within each roost complex were counted on the same night. We conducted surveys by stationing observers with binoculars at key locations around a roost complex to count all cranes as they flew into a roost site at sunset or during early morning before they left their roost. We used roost counts at our major roost sites to relate roost size with peak roost site counts in 2007-08. We used linear regression to test the hypothesis that size of the roost site or complex was an important determinant of crane population size at a roost site or complex. Count data were not normally distributed, so we used a square-root transformation to normalize the data. We combined our roost counts and roost site areas for each of 4 habitat complexes (Cosumnes Preserve, Staten-Brack-Canal Ranch, and Stone Lakes NWR) and used peak counts at roost complexes for each roost complex size, which changed over time. We used a Student's *t*-test to compare crane densities between the 2 roost site categories (wetland versus flooded cropland).

We used observations of cranes at night roost sites to characterize water depths chosen by cranes. Roosts were visited during early morning periods, before all cranes had departed the roost. Because roosting cranes are not all independent (e.g., family groups and flocks roost together) our unit of analysis was subgroups or individual cranes of the same subspecies within a flock roosting at the same depth. For example, within a cluster of cranes, a group of cranes of the same subspecies standing together at the same depth were measured as 1 sample, while other groups or individuals standing at different depth were measured as a separate samples, which included several or single individuals. Water depth measurements were estimated visually as the proportion of a crane's tarsometatarsus that was submerged. Values were recorded to the nearest 10% increment. We converted the percentage value to water depth by multiplying each by the average tarsometatarsus length for each subspecies (from Johnson and Stewart 1973) adjusting values by 1.5 or 2 cm to account for height of the foot for lessers and greaters, respectively. We hypothesized that flooded croplands would support higher densities of cranes as field topography is relatively level compared with wetlands, so a larger percentage of the area would provide optimal depths for roosting. We used a Student's *t*-test to compare roost water depths between the subspecies and between the 2 roost site types (wetland habitat versus cropland). All means are reported ± SE.

We qualitatively assessed the impact of waterfowl hunting disturbance on roost site use by cranes by observing crane behavior at roosts before, during, and after the waterfowl hunting season relative to the density of hunter blinds and frequency at which hunting occurred at each roost site. Waterfowl hunting occurred on portions of all roost complexes that we surveyed, including the Cougar Wetlands Unit of the Cosumnes Preserve, the wetlands of the Sun River Unit of Stone Lakes NWR, and most of the flooded sites at Staten Island. Hunting at the Cougar Wetlands was administered by the Bureau of Land Management (BLM), that permitted all-day hunting from 6 permanent blinds, every Saturday during waterfowl season at a comparably high density (4 ha/blind). Hunting on the Sun River Unit roost site was administered by the U.S. Fish and Wildlife Service (USFWS) on a reservation system for 7 permanent blinds at a density of 5 ha of water area per blind. Hunting was allowed from a half hour before sunrise until noon on Wednesdays and Saturdays during the season (early October - late January). At Staten Island, the hunt program was administered by the property manager. Hunting was limited to 12 permanent blinds placed at low density (63 ha/blind). Waterfowl hunting was allowed from a half hour before sunrise until 10 AM on Wednesdays, Saturdays, and Sundays.

RESULTS

We mapped 69 sites used as night roosts in the Delta (Fig. 5.2): 35 sites in flooded croplands and 34 sites in seasonal wetlands. Most wetland roosts were managed as seasonal or semipermanent wetlands and typically flooded through fall and winter; fields were primarily post-harvest grain fields (e.g., rice, corn, or wheat) flooded after harvest through winter. Timing and duration of flooded fields varied considerably, primarily to meet the objectives of farmers, with the exception of fields on the conservation areas which were generally flooded most of the fall and winter period specifically to provide for crane and waterfowl use. Managed roost sites were typically flooded through fall and winter, while other sites were temporarily available following heavy rains, or because of flooding for cropland management. Of the wetland roost sites, approximately 90% were constructed wetlands. Roost sizes ranged between 27 and 2,068 ha and averaged 117 ± 20 ha (median 52 ha). Cropland roost sites were larger (191 ± 33 ha) than wetland roost sites (49 ± 10 ha; $t = 4.32$; $P < 0.0001$).

We collected data on peak roost site population size for 19 roosts within our 5 main roost complexes. Larger roost sites supported larger peak numbers of cranes ($R^2 = 0.54$; $t = 3.09$, $P < 0.1$). Similarly, larger roost complexes supported larger peak numbers of cranes ($R^2 = 0.58$; $t = 4.56$, $P < 0.01$). For all sites, the mean density was 1.4 ± 0.26 cranes/ha and the slope of the relationship between density and roost site size was zero ($R^2 = 0.01$; $P > 0.05$), indicating that crane density did not change with roost size. The mean density of cranes using cropland roost sites (1.9 ± 0.31 cranes/ha) was higher than for wetland roost sites (1.0 ± 0.22) ($t = 2.55$; $P < 0.05$).

We estimated water depth on 94 individual or groups of cranes ($n = 46$ lessers and 48 greaters) at 19 different roosts on 16 different days between 1 February 2008 and 20 November 2008. Mean roost water depth was similar between agricultural and wetland roost sites ($P > 0.60$) and mean roost depth used was similar between greaters (10.3 ± 0.6 cm) and lessers (10.6 ± 0.6 cm; $t = 0.33$, $P = 0.75$).

The impact of hunting intensity varied by roost complex. We never observed cranes roosting at the *Cougar Wetlands* Unit, which had a high density of hunting blinds and was hunted all day, every Saturday during waterfowl season. Cranes used the Sun

River Unit for roosting in early October during 2007 and 2008, before waterfowl season opened; however, they left the site after opening day both years, and were only infrequently found roosting there following the initial hunting disturbance, each hunting season. In 2008, before the hunting season started, we recorded a peak of 286 cranes roosting in the Sun River Unit, while no cranes roosted there the night of opening day of hunting, and we only found cranes roosting there twice (totaling 31 and 38 cranes) out of 9 subsequent bi-weekly counts (7 during hunting season). Also, one of our radio-tagged greaters was roosting there from its arrival in the region on 5 October, through the night before the opening of waterfowl hunting on 18 October. Following the opening day hunt, it moved with other cranes at the site to the Cosumnes River Preserve. Cranes continued to use hunted roost sites throughout the waterfowl season at Staten Island. The number of cranes roosting on Staten Island actually increased (by 36%), immediately after opening day of waterfowl season, suggesting that Staten Island recruited birds that were displaced from other hunted roost sites in the area.

DISCUSSION

The typical roost site in our study was a large expanse of open, shallow water that was mostly isolated from disturbance. A North Dakota study identified large expanses of shallow water not close to shore as the most important roost site characteristics (Soine 1982), while studies along the Platte River in Nebraska determined that areas of wider river channels received higher crane use (Krapu et al. 1984; Norling et al. 1992; Folk and Tacha 1990; Parrish et al. 2001; Davis 2001, 2003). Along the Platte River, roost sites disturbed by nearby roads or bridges supported lower densities of roosting cranes (Krapu et al. 1984, Parrish et al. 2001). Also, an Indiana study report that the nearer a roost was to another roost the more likely that it would be used (Lovvorn and Kirkpatrick 1981).

A high percentage (48%) of the roost sites that we documented were flooded croplands, a habitat type that has rarely been reported in other winter studies. Cropland roost sites were mentioned as being used during migration in Indiana (Lovvorn and Kirkpatrick 1981). Other studies reported cranes roosting on managed and natural wetlands in Indiana, North Dakota, Colorado, Nebraska, Alaska, Georgia, and California (Lovvorn and Kirkpatrick 1981, Soine 1982, Kauffeld 1982, Iverson et al. 1987, Bennett and Bennett 1989, Pogson and Lindstedt 1991), flooded playas and shallow lakes in Texas and North Dakota (Lewis 1976, Carlisle and Tacha 1983, Iverson et. al 1985), and shallow riverine sites along the Platte River in Nebraska (Krapu et al. 1984, Norling et al. 1992, Folk and Tacha 1990, Parrish et al. 2001, Davis 2001, 2003). In California, a previous study in the Delta also documented cranes using flooded fields for roosting (Ivey and Herziger 2003), but a study in the early 1980s did not document such use in the Delta (Pogson and Lindstedt 1991). Flooding of grain fields as a general practice has increased in northern California over the past 2 decades (Fleskes et al. 2005), primarily for agricultural purposes, but also to provide waterfowl hunting opportunities and in specific cases on our study area in an effort to provide roost sites for cranes. Our results suggest that sandhill cranes will readily adapt to using flooded agricultural fields as roost sites and that flooding cropland is one option for creating sandhill crane roosts.

The mean density of cranes roosting in flooded croplands was higher than in wetlands. We believe this was because flooded croplands tend to provide more area of ideal roost water depths due to their flat topography, and also because they were usually adjacent to unflooded grain field foraging sites. However, wetland roost sites likely provide additional values beyond just water depth to cranes, such as providing alternate foods like macroinvertebrates. A Nebraska study reported that cranes preferred wetlands during the day (Iverson et al. 1987), and a previous study in the Delta also documented preference for wetlands (Ivey and Herziger 2003). During our study the majority of cranes roosted at cropland sites because, on average, roosts in agricultural fields were larger than wetland roosts and crane density was highest in agricultural roosts.

We found positive relationships between roost site size and crane abundance at a roost at both the individual roost site and roost complex scales. An Indiana study (Lovvorn and Kirkpatrick 1981) found that roost sites were more likely to be used if they were near other roost sites, but no other study has examined the relationship between roost size and either peak count or crane density. In landscapes managed for wintering and staging cranes, it is important to understand how much roost water should be available, as there is a trade-off between increasing the size of a roost site versus maximizing suitable foraging habitat. Areas inundated to provide roost habitat are not generally good foraging habitat for cranes. Roost size only explained about half the variation in our data; other likely factors influencing bird use of roosts include food availability in the foraging landscape around roost complexes, migration timing, disturbance (e.g., hunting), and changing conditions at other roost sites (e.g., dewatering, disturbance increase). These additional factors could be explored in greater depth if a more complete understanding of crane roosts is desired.

The water depths used by cranes at each roost in our study was similar to what cranes have used in other regions that are thought to provide high quality habitat. Cranes in our study used depths ranging from 3 to 21 cm, with a mode of 7 cm. Similarly, along the Platte River in Nebraska, cranes were reported to prefer depths of 1–13 cm for roosting, with the highest proportions of depths used being between 1 and 7 cm (Norling et al. 1992), and $\leq$ 21 cm by Folk and Tacha (1990). Other studies in Nebraska, Indiana, and Oregon have reported that cranes roosted in water less than 20 cm deep (Frith 1976, Lovvorn and Kirkpatrick 1981, Latka and Yahnke 1986, Littlefield 1986, Armbruster and Farmer 1992, Norling et al. 1992). In one exception to this pattern, a study along the North Platte River in Nebraska documented 14% of the cranes using depths from 21 to 35.6 cm (Folk and Tacha 1990).

Although our data are qualitative, when cranes have a choice, it appears they prefer to avoid sites used for waterfowl hunting as night roosts. Some temporarily used roost sites were only used before or after waterfowl season. Our results are similar to findings in Indiana (Lovvorn and Kirkpatrick 1981), while a study in Saskatchewan documented that cranes would not tolerate repeated hunting disturbance at roosts (Stephen 1967). Even with very limited waterfowl hunting at the Sun River Unit, cranes immediately left the site for a few weeks and were only found roosting there on 2 of 7 surveys later during the waterfowl season. Cranes in Michigan and Wisconsin also abandoned roosts on or immediately after the opening day of waterfowl hunting season (Walkinshaw and Hoffman 1974, Bennett 1978). Most hunted sites in the Delta are hunted all day, usually 3 days a week (Wednesday, Saturday, and Sunday), which limits opportunities for cranes to roost or loaf during the day at these sites. Based on our observations of the hunting program at Staten Island, cranes seem particularly sensitive to hunting disturbance in the late afternoon when they are flying to roost sites and also during mid-day when they often use roost sites for loafing.

Staten Island was an exception to the general rule that cranes avoided hunted sites as roosts. This is likely in part because most of the permitted hunters were only able to hunt on Sundays, resulting in low hunting frequency. Similar to other hunted roost sites, cranes are flushed from Staten Island roosts when shooting begins, but because hunting is only allowed until 10:00 AM, cranes have a chance to return to the sites undisturbed to loaf in late mornings (they usually return about 11:00 AM) and to roost in the evenings. Cranes at Staten Island may also tolerate the hunting disturbance better, because of lower hunter density and larger roost sites. The pattern of increased roosting numbers at Staten Island following opening day was also noted in a previous study (Ivey and Herziger 2003).

MANAGEMENT IMPLICATIONS

Considerations for design and management of wetlands and flooded cropland roosts include providing large roost site complexes (100-1000 ha, depending on the number of cranes to support) because larger sites likely give crane more security from predators. Individual sites within a managed roost complex should be >5 ha, of mostly level topography, and dominated by shallow water (5-10 cm depths). The depth of water used by cranes may be a reasonable indicator of roost site availability. We suggest that if cranes are commonly seen roosting where water depths are greater than 20 cm, it is an indication that ideal roost sites are limited. Seasonal wetlands will provide more values to cranes than flooded croplands, but flooded croplands may be a better option for building crane habitat into a working agricultural farm. Flooding of croplands to provide temporary roost sites might also be of value to expand crane roosting habitat options in other crane wintering or staging regions.

Disturbance caused by waterfowl hunting appears to limit crane use of roost sites; thus, we suggest these 2 uses should not be considered readily compatible. However, if the management objective of an area includes waterfowl hunting, then the Staten Island program of very low hunter densities and limited, early morning hunting, can serve as a model for a crane-compatible waterfowl hunt program.

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LITERATURE CITED

Armbruster, M. J., and A. H. Farmer. 1982. Draft sandhill habitat suitability model. Pages 136-43 *in* J. C. Lewis, editor. Proceedings of the 1981 crane workshop. National Audubon Society, Tavernier, Florida, USA.

Bennett, A. J. 1978. Ecology and status of greater sandhill cranes in southeastern Wisconsin. Thesis, University of Wisconsin, Stevens Point, USA.

Bennett, A. J., and L. A. Bennett. 1989. Wintering population of greater sandhill cranes in the Okefenokee Swamp, Georgia. Wilson Bulletin 101:87-93.

California Dept. of Fish and Wildlife. 2013. State and federally listed endangered and threatened animals of California. Sacramento, California, USA. (http://www.dfg.ca.gov/biogeodata/cnddb/pdfs/TEAnimals.pdf) accessed 3/1/2014.

Carlisle, M. J., and T. C. Tacha. 1983. Fall migration of sandhill cranes in west central North Dakota. Journal of Wildlife Management 47:818-821.

Davis, C. A. 2001. Nocturnal roost site selection and diurnal habitat-use by sandhill cranes during spring in central Nebraska. Proceedings of North American Crane Workshop 8:48-56.

Davis, C. A. 2003. Habitat use and migration patterns of sandhill cranes along the Platte River, 1998-2001. Great Plains Research 13:199-216.

Fleskes, J. P., W. M. Perry, K. L. Petrik, R. Spell, and F. Reid. 2005. Change in area of winter-flooded and dry rice in the northern Central Valley of California determined by satellite imagery. California Fish and Game 91:207-215.

Folk, M. J., and T. C. Tacha. 1990. Sandhill crane roost site characteristics in the North Platte River Valley. Journal of Wildlife Management 54:480–486.

Frith, C. R. 1976. Crane habitat of the Platte River. Pages 151-156 *in* J. Lewis, editor. Proceedings of the [1975] international crane workshop. Oklahoma State University Publishing and Printing, Stillwater, USA.

Iverson, G. C., P. A. Vohs, and T. C. Tacha. 1985. Habitat use by sandhill cranes wintering in western Texas. Journal of Wildlife Management 49:1074–1083.

Iverson, G. C., P. A. Vohs, and T. C. Tacha. 1987. Habitat use by midcontinent sandhill cranes during spring migration. Journal of Wildlife Management 51:448–458.

Ivey, G. L., B. D. Dugger, C. P. Herziger, M. L. Casazza, and J. P. Fleskes. 2014. Distribution, abundance, and timing of arrival and departure of greater and lesser sandhill cranes wintering in the Sacramento-San Joaquin River Delta region of California. Proceedings of the North American Crane Workshop 12:1-11.

Ivey, G. L., and C. P. Herziger. 2003. Sandhill crane monitoring at Staten Island, San Joaquin County, California, 2002-2003. The Nature Conservancy, Cosumnes River Preserve, Galt, California, USA.

Ivey, G. L., C. P. Herziger, and M. Gause. 2003. Farming for wildlife: an overview of agricultural operations at Staten Island, San Joaquin County, California. The Nature Conservancy, Cosumnes River Preserve, Galt, California, USA.

Johnson, D. H., and R. E. Stewart. 1973. Racial composition of migrant populations of sandhill cranes in the northern plain states. Wilson Bulletin 85:148-162.

Kauffeld, J. D. 1982. Management of migratory crane habitat on Alamosa and Monte Vista National Wildlife Refuges. Pages 117-121 *in* J. C. Lewis, editor. Proceedings of the 1981 crane workshop. National Audubon Society, Tavernier, Florida, USA.

Krapu, G. L., D. E. Facey, E. K. Fritzell, and D. H. Johnson. 1984. Habitat use by migrant sandhill cranes in Nebraska. Journal of Wildlife Management 48:407–417.

Latka, D. C., and J. W. Yahnke, 1986. Simulating the roosting habitat of sandhill cranes and validation of suitability-of-use indices. Pages 19-22 *in* J. Verner, M. L Morison, and C. J. Ralph, editors. Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. University of Wisconsin Press, Madison, USA.

Lewis, J. C. 1976. Roost habitat and roosting behavior of sandhill cranes in the southern Central Flyway. Pages 93-104 *in* J. C. Lewis, editor. Proceedings of the 1975 Crane Workshop. Oklahoma State University Publishing and Printing, Stillwater, Oklahoma, USA.

Littlefield, C. D. 1986. Autumn sandhill crane habitat use in southeast Oregon. Wilson Bulletin 98:131-137.

Littlefield, C. D. 2008. Lesser Sandhill Crane. Pages 167-172 *in* Shuford, W. D., and Gardali, T., editors. California Bird Species of Special Concern: A ranked assessment of species, subspecies, and distinct populations of birds of immediate conservation concern in California. Studies of Western Birds 1. Western Field Ornithologists, Camarillo, California, and California Department of Fish and Wildlife, Sacramento, California.

Lewis, J. C. 1976. Roost habitat and roosting behavior of sandhill cranes in the southern central flyway. Pages 93-104 *in* J. C. Lewis, editor. Proceedings of the [1975] international crane workshop. Oklahoma State University Publishing and Printing, Stillwater, USA.

Lovvorn, J. R., and C. M. Kirkpatrick. 1981. Roosting behavior and habitat of migrant greater sandhill cranes. Journal of Wildlife Management 45:842–857.

Norling, B. S., S. H. Anderson, and W. H. Hubert. 1992. Roost sites used by sandhill cranes staging along the Platte River, Nebraska. Great Basin Naturalist 52:253-261.

Pacific Flyway Council. 1983. Pacific Flyway Management Plan: Pacific Flyway Population of Lesser Sandhill Cranes. Pacific Flyway Study Committee (c/o Pacific Flyway Representative USFWS), Portland, Oregon, USA.

Pacific Flyway Council. 1997. Pacific Flyway management plan for the Central Valley Population of Greater Sandhill Cranes. Pacific Flyway Study Committee (c/o Pacific Flyway Representative USFWS), Portland, Oregon, USA.

Parrish, T. L, W. A. Hubert, S. H. Anderson, M. J. Pucherelli, and W. Mangus. 2001. Distributions of roosting sandhill cranes as identified by aerial thermography. Prairie Naturalist 33:93-99.

Pogson, T. H., and S. M. Lindstedt. 1991. Distribution and abundance of large sandhill cranes, *Grus canadensis*, wintering in California's Central Valley. Condor 93:266-278.

Sidle, J. G., H. G. Nagel, R. Clark, C. Gilbert, D. Stuart, K. Wilburn, and M. Orr. 1993. Aerial thermal infrared imaging of sandhill cranes on the Platte River, Nebraska. Remote Sensing of Environment 43:333-341.

Soine, P. J. 1982. Roost habitat selection by sandhill cranes in central North Dakota. Pages 88-94 *in* J. C. Lewis, editor. Proceedings of the 1981 crane workshop. National Audubon Society, Tavernier, Florida, USA.

Stephen, W. J. D. 1967. Bionomics of the sandhill crane. Canadian Wildlife Service Report Series 2, Ottawa, Ontario, Canada.

U.S. Fish and Wildlife Service. 2007. Stone Lakes National Wildlife Refuge Comprehensive Conservation Plan. Stone Lakes National Wildlife Refuge, Elk Grove, California, USA.

Walkinshaw, L. H., and R. H. Hoffman. 1974. Southern Michigan sandhill crane survey. Jack-Pine Warbler 52:102-114.

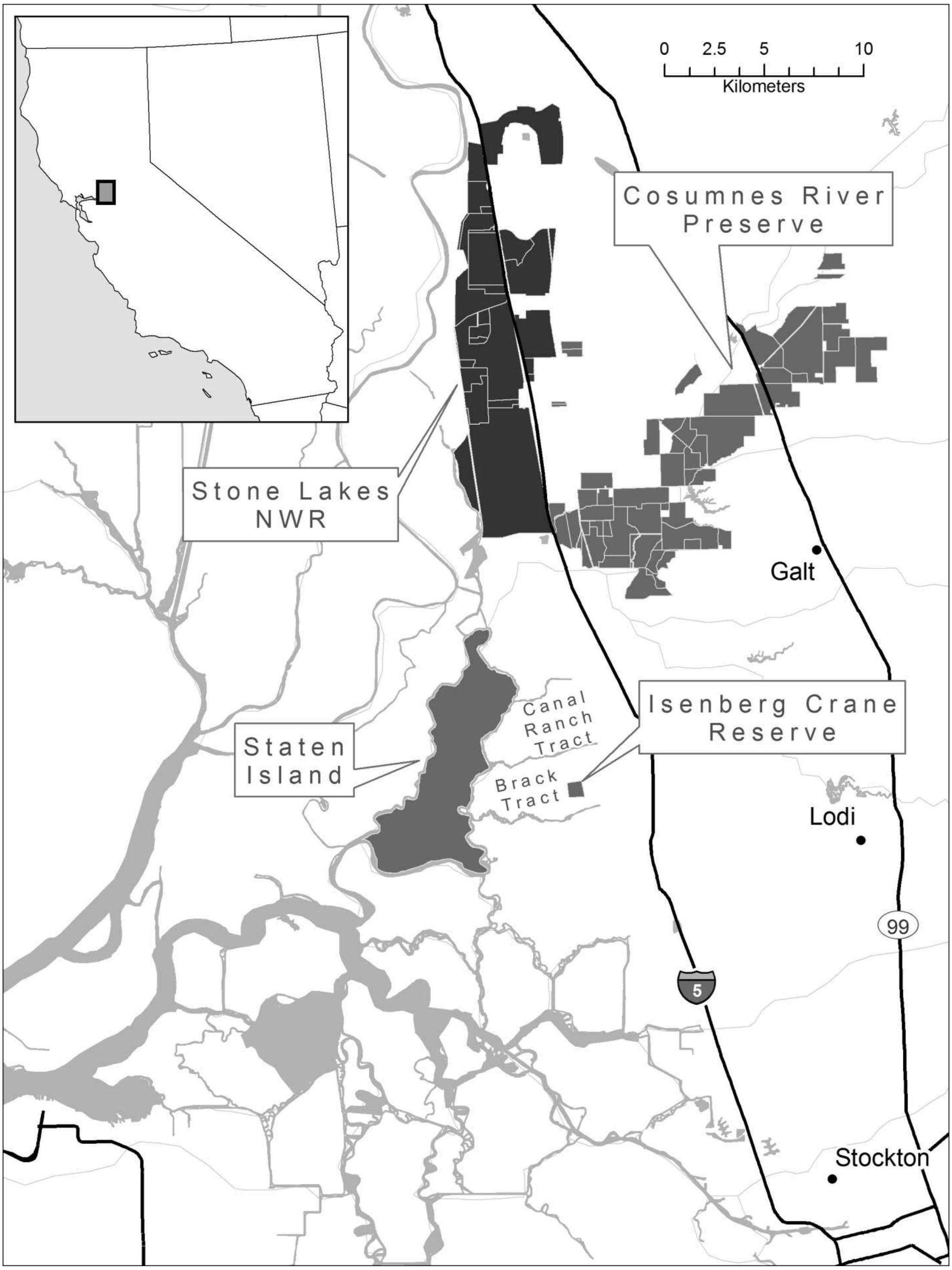

Figure 5.1. Map of the Sacramento-San Joaquin River Delta study area where characteristics of sandhill crane (*Grus canadensis*) winter night roosts were studied, 2007-2009.

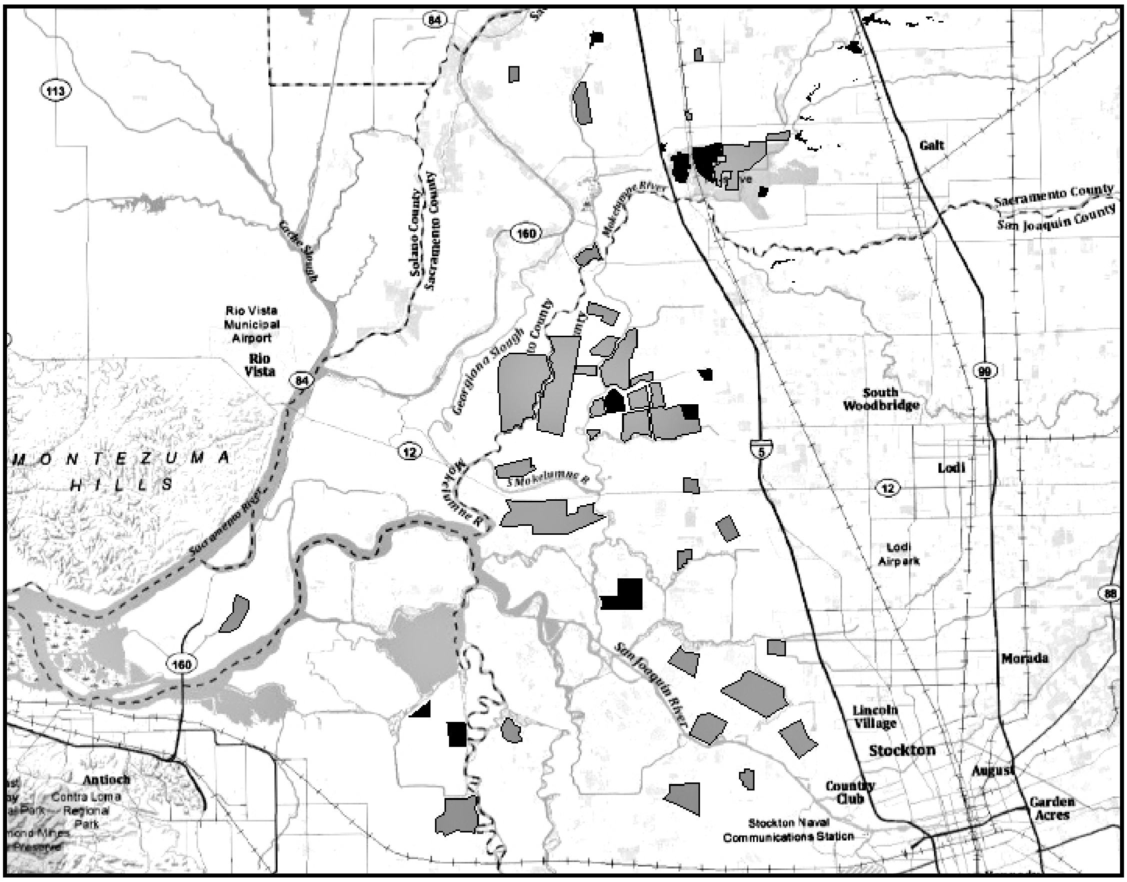

Figure 5.2. Locations of winter night roost sites used by sandhill cranes (*Grus canadensis*) in the Sacramento-San Joaquin River Delta, 2007-08 and 2008-09 (Black = wetland roosts; Dark Grey = flooded cropland roosts).

Chapter 6

GENERAL CONCLUSIONS

Gary L. Ivey

The Central Valley of California includes important wintering regions for two subspecies of sandhill cranes (*Grus canadensis*; Fig. 6.1). Both subspecies are priorities for conservation in the state, where greater sandhill cranes (*G. c. tabida*) are listed as threatened (California Department of Fish and Wildlife 2013), and lesser sandhill cranes (*G. c. canadensis*) are listed as a Species of Conservation Concern (Littlefield 2008). Because greaters are threatened, they are the focus of most crane habitat conservation activities in California. The majority of sandhill crane night roost sites within these wintering regions are on protected areas such as National Wildlife Refuges (NWRs), State Wildlife Areas, or conservation reserves, but considerable foraging occurs on adjacent private lands (Littlefield 2002, Ivey and Herziger 2003, Chapter 5). Private lands are vulnerable to changes in land use, and habitat loss on private lands within these wintering regions has concentrated crane at remaining sites (Pogson and Lindstedt 1991). Continuing changes in land uses, especially conversion to incompatible crops such as orchards or vineyards, and loss to urbanization (Central Valley Joint Venture 2006) will likely reduce future sandhill crane carrying capacity of these regions and could limit populations. Therefore, conservation planning is important for preserving and managing habitat for wintering sandhill cranes.

In this chapter, I identify priority Central Valley regions to focus sandhill crane winter habitat conservation and management activities, and discuss the need to focus on the most important lands at a local (i.e., roost site) scale. I present a model based on refuging theory (Frederick et al. 1987; Belanger and Bedard 1990) to represent the diurnal movement of wintering sandhill cranes from their nocturnal roost sites to neighboring foraging sites during the day, and back to the roost in the evening. Because sandhill cranes use their winter roosts as central place foragers, I would define a “crane ecosystem unit” for conservation and management of cranes to include a central roost surrounded by a foraging landscape out to a certain radius. This combination of a suitable roost site surrounded by adequate foraging habitat is the basis for crane habitat conservation. A primary assumption in this conceptual model is that providing sandhill cranes with improved foraging habitat conditions will lead to their increased storage of endogenous fat reserves on the wintering grounds which will lead to increased fitness for survival and reproduction, and ultimately contribute to population recovery (Krapu et al. 1985). I address how data on sandhill crane commuting distances, foraging choices, and population estimates for roost sites can be used to inform this simple model, and also derive a more complex, but more informative model. Additionally, I provide a decision matrix which considers roost site characteristics, crane foraging choices and conservation choices for winter sandhill crane habitat conservation and management. Both of these tools should have application for sandhill crane wintering and staging areas in agricultural regions across North America.

Greaters and lessers are sympatric at all major wintering areas in California, but the proportions of greaters found in crane flocks decreases from north to south in the Central Valley (Ivey et al. 2014). I recommend consideration of the following for prioritizing of sandhill crane conservation among winter regions: the proportions of the population of greaters present, the proportions of the total populations of all sandhill cranes present, and the relative risk of habitat loss. On the first consideration, the highest numbers of greaters occur in the Sacramento Valley Region, followed by the Sacramento-San Joaquin River Delta Region (hereafter, Delta); the Delta supported highest total numbers of all sandhill cranes, followed by the Merced Grasslands, Pixley National Wildlife Refuge (NWR), Sacramento Valley, and the San Joaquin River NWR regions (Ivey et al. 2014). The threat of habitat loss is highest in the Delta, primarily because of the added pressures of urban expansion in this region (Central Valley Joint Venture 2006). Ideally, future sandhill crane habitat conservation will occur in all regions in the Central Valley; however, if prioritization is necessary, I recommend the Delta be considered the highest priority region for conservation focus.

In Chapter 3, I found greaters to have smaller winter home ranges than lessers and very high fidelity to their wintering regions; therefore, habitat conservation activities would more likely be successful if they occur in proximity to traditional roost sites.

Lessers were also very loyal to their wintering regions, but were more likely to move between regions. Within their wintering regions, sandhill cranes use very specific landscapes around traditional roost sites where they have adapted to forage in agricultural fields (Chapter 4). I reported that a habitat conservation radius of 5 km from roost sites encompassed 90% of the commuting flights made by greaters and 64% of flights by lessers. Therefore, focusing conservation activities on the 5 km radius as a crane ecosystem unit would benefit all three subspecies. I have described a relatively simple model of a series of sandhill crane roost sites, each surrounded by habitat options for crane foraging to a radius of 5 km (Fig. 6.2). It is important to maintain compatible roost site characteristics and a crane-compatible foraging landscape in these ecosystem units to support local sandhill crane wintering flocks and maintain each area's crane carrying capacity. Roost site design and management (Chapter 5) should consider providing and maintaining large roost complexes (> 100 ha, depending on the number of cranes that a site is intended to support), ideally in close proximity (< 5 km) to other roost sites, with large individual sites (> 5 ha) of mostly level topography, dominated by shallow water (5-10 cm depths).

Not all habitat parcels within 5 km of a roost site are used equally by greater sandhill cranes. Their value depends on the numbers of cranes using the focal roost site, the habitat choices they make, and the probability that they will fly to a particular parcel. Additionally, some of these ecosystem units overlap, and in these overlap zones, probabilities of crane use are higher, because of additive effects. To provide a tool to allow managers to further refine their plans, I have developed a more spatially explicit model that allows for a more biologically complex, but focused crane conservation, mitigation and habitat management strategy. The intent of this model is to allow comparison of relative values of parcels to help prioritize crane conservation and management activities. Avian foragers tend to exploit patches to a greater extent that are closer to their central place (e.g., a winter roost; van Gils et al. 2008), as in my study, where sites closer to roosts had a higher probability of crane use as they supported higher percentages of the total commuting flights (Fig. 6.3A). Also, commuting distances of individuals were quite variable and the proportions of marked individuals that flew out to

1 km intervals declined with distance (Fig. 6.3B). I calculated the probability that greaters would fly to a concentric 1 km intervals as a product of the proportion of individual greaters that had commuting distances that reached that interval, and the percentages of all that subspecies' commuting flights to that interval (Fig. 6.3C). Those estimated values were then multiplied by the number of cranes using the roost site to give an estimate of abundance, relative to other polygons. Where the concentric polygons overlap, those numbers were added together

An important consideration in selection of conservation sites is the abundance of greater sandhill cranes using a particular roost complex. My survey data allows a general estimate of their numbers at roost site complexes in my study area from peak counts during roadside surveys. It makes sense to use my peak counts, because this subspecies is highly sedentary (Chapter 3). For example, the highest counts of greater sandhill cranes were 1,523 on Staten Island, followed by 549 on Brack Tract, 360 on Stone Lakes NWR, and 156 at Cosumnes River Preserve. Using such relative abundance information and the usage probabilities in Fig. 6.3C, I have provided an example of how such information could be used to develop a GIS tool that ranks the landscape by the relative site importance to greater sandhill cranes (Fig. 6.4). Such a tool could guide planning of conservation and management actions towards more important parcels and to avoid negative impacts to more important sites from developments that result in habitat loss or which may increase mortality risk to cranes (i.e., new power lines).

Once priority sites have been selected, I provide a decision matrix to assist with plans to enhance existing crane landscapes, create new crane habitat areas or mitigate habitat losses (Table 6.1). This matrix provides a framework for decision-making about increasing sandhill crane foraging and roost site habitats. Foraging habitat suitability is affected by habitat type, distance from roost sites, the size of the parcel, and disturbance factors.

An easement program could pay farmers within crane management zones to maintain compatible crops for sandhill cranes, alter their post-harvest management to be more favorable to crane use, and to tolerate any reduction in yield that might result from crane visitation. They should also be required to minimize crane disturbance on such designated land (e.g., Owen 1990, Vickery et al. 1994). However, tracking disturbance might be difficult, so further incentives might be provided as a reward for documented high use by cranes of their lands. Restoration of vineyards and orchards to compatible foraging habitat may be necessary to achieve habitat objective in some management zones. Parcels with no or minimal disturbance issues should be considered priority for including in an easement program. Larger parcels are better than smaller ones (Armbruster and Farmer 1981), as they will buffer disturbance from neighboring operations. Parcels adjacent to existing conservation parcels have some added value for connecting to a larger conservation landscape. Sandhill cranes generally avoid occupied dwellings and foraging areas within 100 m of these sites should not be considered suitable (Armbruster and Farmer 1981).

My matrix also outlines an alternative strategy that entails providing new roost sites towards the edge of existing management zones. This strategy would give cranes access to additional foraging lands. I observed that cranes readily use newly flooded areas for foraging, and if managed properly, they would likely use these sites for night roosting. I would expect cranes using such a new roost site to forage out to an additional 5 km zone where suitable habitat is available. This strategy could also be used to move cranes away from areas at higher risk of habitat loss (e.g., where the existing habitat is below sea level and at risk to sea level rise). Systematically providing new roost sites, allowing cranes to accommodate them for a year or so, and then adding another site within the 5 km zone is a viable strategy to shift them in directions where their habitat is more sustainable.

My study has demonstrated that greater sandhill cranes use a relatively small landscape surrounding their traditional roost sites and that they favor certain crops and post-harvest crop management practices for foraging. However, we need a better understanding of the actual carrying capacity for cranes in these crane management zones to ensure that managers can maintain these sites for cranes in the future. I recommend that further research in this region pursue studies of food availability in various crop types and post-harvest management practices and relate that information to develop a crane energetics model which includes estimates of carrying capacity of the various habitat conditions (see Alonso et al. 1994 and Pearse et al. 2011).

LITERATURE CITED

Alonso, J. C, J. A. Alonso, and L. M. Bautista. 1994. Carrying capacity of staging areas and facultative migration extension in common cranes. Journal of Applied Ecology 31:212-222.

Armbruster, M. J., and A. H. Farmer. 1981. Draft sandhill crane habitat suitability model. Pages 136-143 *in* J. C. Lewis, ed. Proceedings 1981 crane workshop. National Audubon Society, Tavernier, FL.

Belanger, L. and J. Bedard. 1990. Energetic cost of man-induced disturbance to staging snow geese. Journal of Wildlife Management 54:36-41.

California Dept. of Fish and Wildlife. 2013. State and federally listed endangered and threatened animals of California. Sacramento, California. (http://www.dfg.ca.gov/biogeodata/cnddb/pdfs/TEAnimals.pdf) accessed 3/1/2014.

Central Valley Joint Venture, 2006. Central Valley Joint Venture Implementation Plan – Conserving Bird Habitat. U.S. Fish and Wildlife Service, Sacramento, CA.

Frederick, R. B., W. R. Clark, and E. E. Klaas. 1987. Behavior, energetics, and management of refuging waterfowl: a simulation model. Wildlife Monographs 96. 33pp.

Ivey, G. L., and C. P. Herziger. 2003. Sandhill Crane Monitoring at Staten Island, San Joaquin County, California, 2002-03. Cosumnes River Preserve, The Nature Conservancy, Galt, California.

Ivey, G. L., C. P. Herziger, and D. A. Hardt. 2014. Conservation Priorities and Best Management Practices for Wintering Sandhill Cranes in the Central Valley of California. Unpublished report. The Nature Conservancy, Sacramento, California, USA.

Krapu, G. L., G. C. Iverson, K. J. Reinecke, and C. G. Boise.1985. Fat deposition and usage by arctic-nesting Sandhill Cranes during spring. Auk 102:362-368.

Littlefield, C. D. 2002. Winter foraging habitat of greater sandhill cranes in northern California. Western Birds 33:51-60.

Littlefield, C. D. 2008. Lesser Sandhill Crane. Pages 167-172 *in* Shuford, W. D., and T. Gardali, editors. California Bird Species of Special Concern: A ranked assessment of species, subspecies, and distinct populations of birds of immediate conservation concern in California. Studies of Western Birds 1. Western Field Ornithologists, Camarillo, California, and California Department of Fish and Game, Sacramento, California.

Owen, M. 1990. The damage-conservation interface illustrated by geese. Ibis 132:238–252.

Pearse, A. T., G. L. Krapu, D. A. Brandt, and P. J. Kinzel. 2010. Changes in agriculture and abundance of snow geese affect carrying capacity of sandhill cranes in Nebraska. Journal of Wildlife Management 74:479–488.

Pogson, T. H., and S. M. Lindstedt. 1991. Distribution and abundance of large Sandhill Cranes, *Grus canadensis*, wintering in California's Central Valley. Condor 93:266-278.

van Gils, J. A., J. H. Beekman, P. Coehoorn, E. Corporaal, T. Dekkers, M. Klaassen, R. van Kraaij, R. de Leeuw, and P. P. de Vries. 2008. Longer guts and higher food quality increase energy intake in migratory swans. Journal of Animal Ecology 77:1234–1241.

Vickery, J. A., W. J. Sutherland, and S. J. Lane. 1994. The management of grass pastures for Brent Geese. Journal of Applied Ecology 31:282–290.

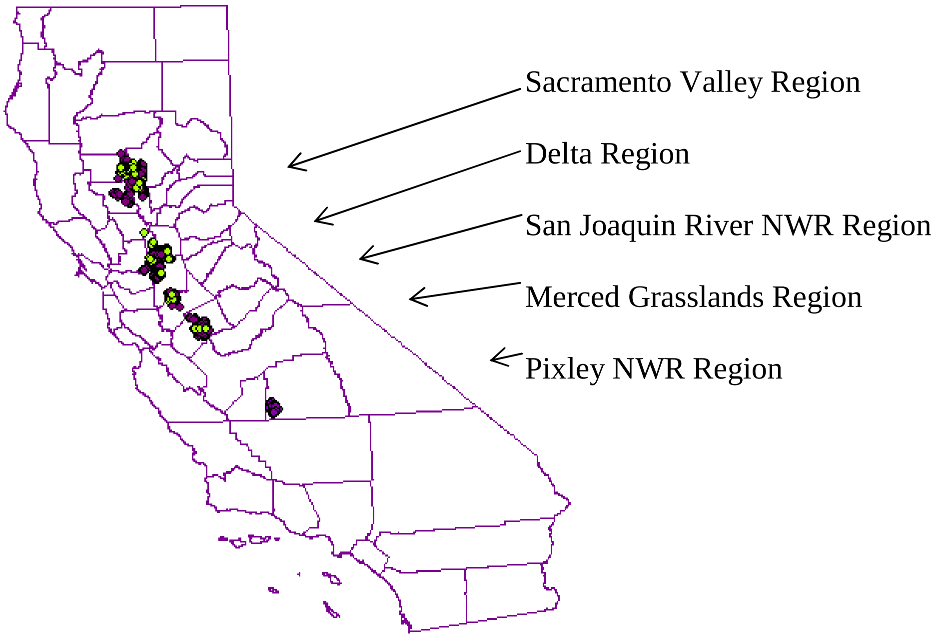

Figure 6.1. General locations of major sandhill crane (*Grus canadensis*) wintering regions in the Central Valley of California (based on geospatial data on distribution of crane flocks mapped in 2013; Ivey et al. 2014).

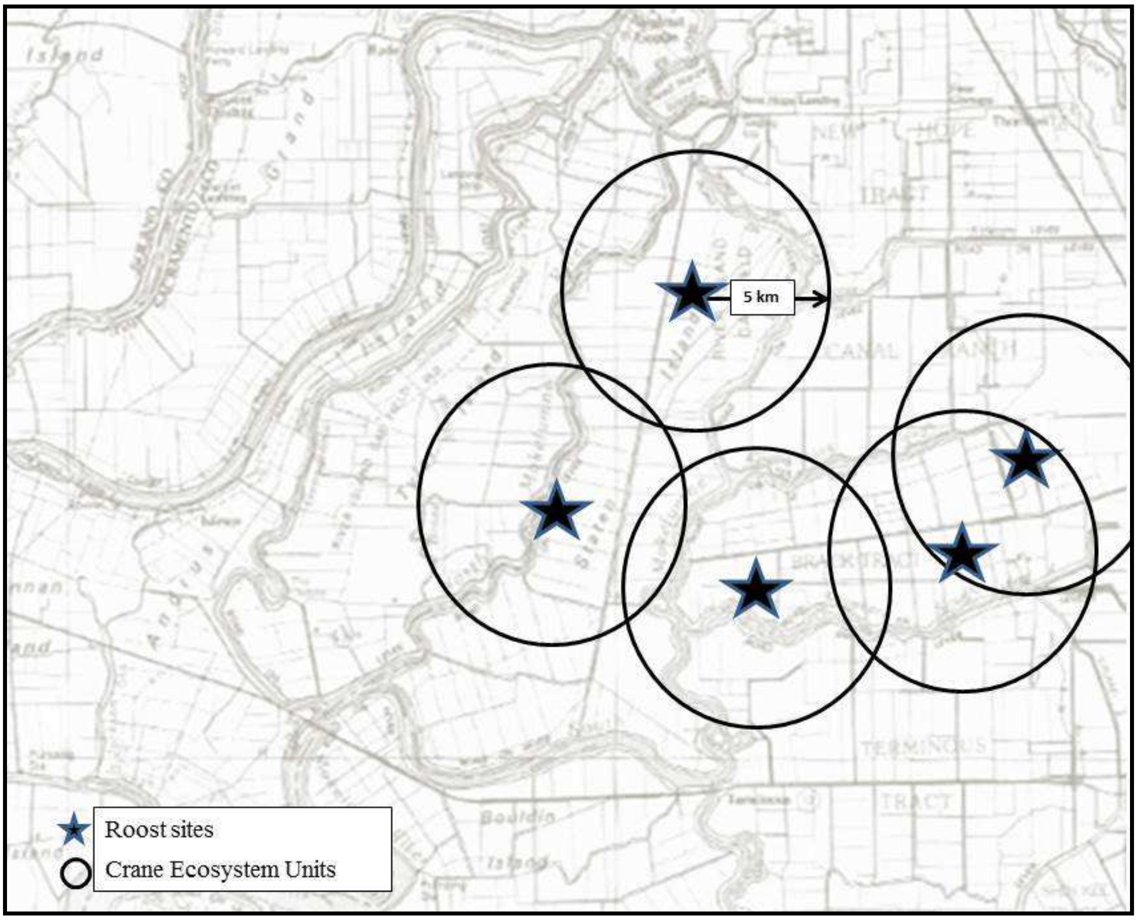

Figure 6.2. Simple conceptual model of sandhill crane (*Grus canadensis*) ecosystem units, consisting of central roost sites surrounded by a 5 km radius of foraging habitat, as focal areas for conservation and management of wintering habitat.

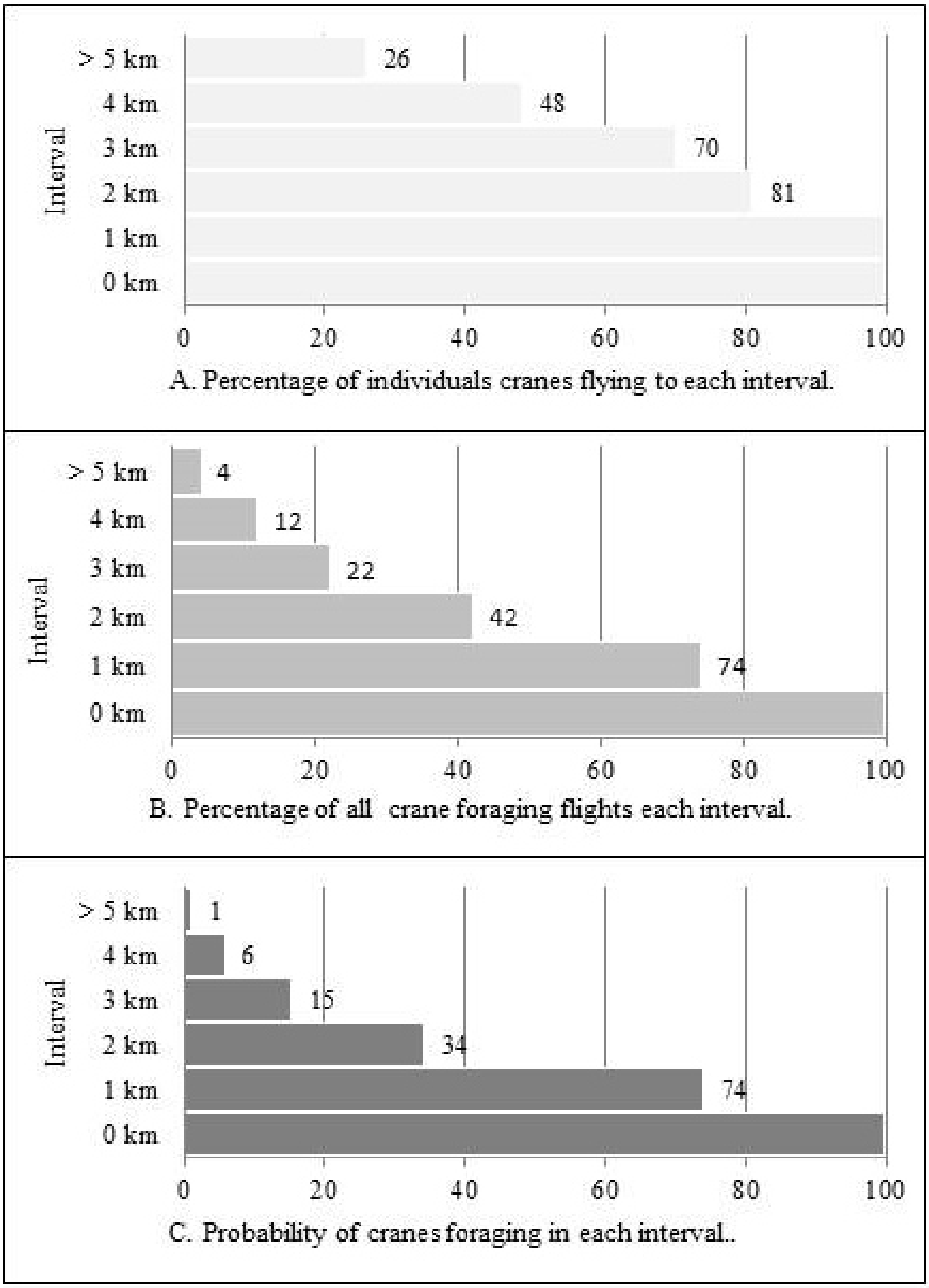

Figure 6.3. A. Percentatage of individual greater sandhill cranes (*Grus canadensis tabida*) that foraged in each 1 km interval; B. Percentatge of all foraging flights by greater sandhill cranes that reached each 1 km interval, and C. Probability of greater sandhill cranes using each interval, calculated as a product of A and B.

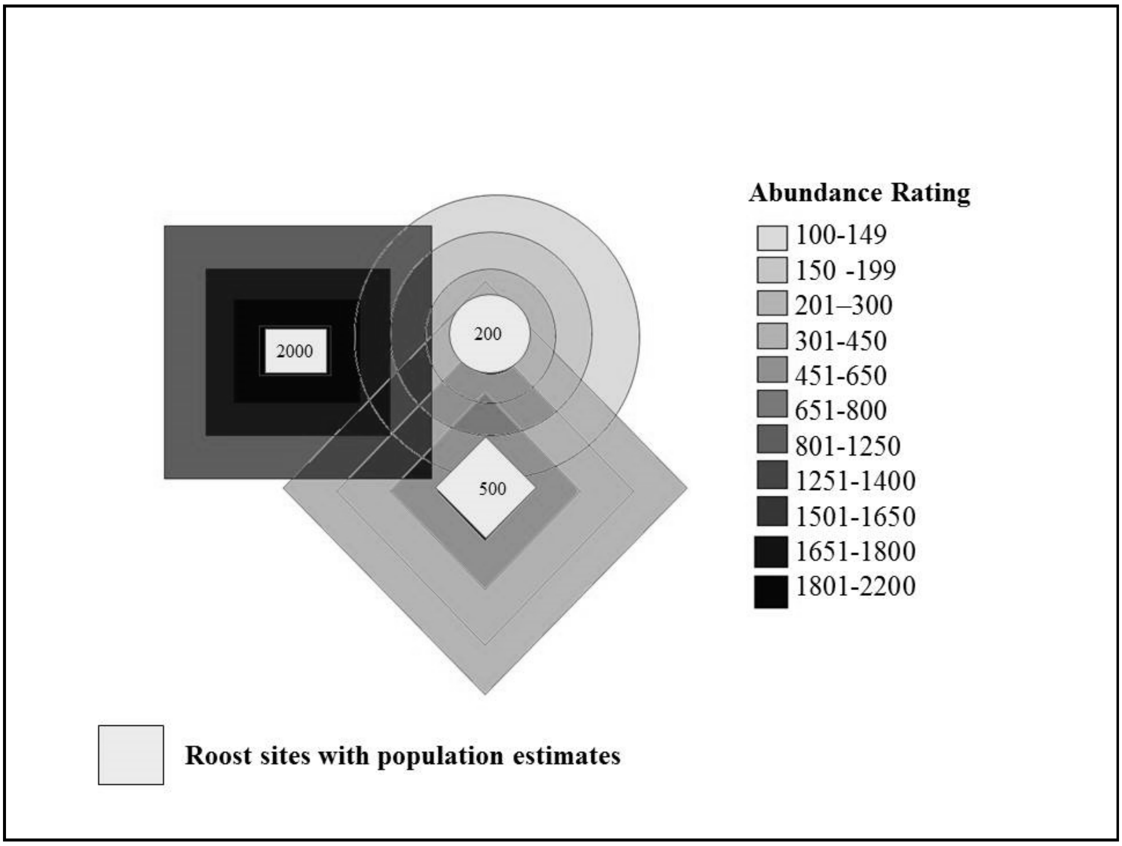

Figure 6.4. An example of a GIS model to show relative importance of landscape areas to greater sandhill cranes (*Grus canadensis tabida*), based on numbers using roost sites and the probabilities that they would use 1 km intervals (derived from data on commuting distances) to display the relative importance of locations.

Table 6.1. Decision matrix for conservation and management of sandhill crane (*Grus canadensis*) wintering habitats.

Crane Habitat Management Decision Matrix	
Strategy1: Protect and enhance foraging habitat within priority crane landscapes, 3 to 5 km from existing roost sites.	**Strategy 2**: Provide new roost sites at edge of priority crane landscapes (3 km) to increase food availability by increasing their access to additonal lands.
Options: Private land sites • Conservation easements on private lands to: o limit development and incompatible cropping o prioritize grain crops in the landscape o guide postharvest management favored by cranes o pay for providing food plots (unharvested grains) o restore incompatible habitat (e.g, restore vineyards and orchards to grain fields) Public and private conservation sites • Employ post harvest grainfield practices favored by cranes o avoid or delay tillage o mulch corn stubble o late season irrigations (shallow flooding) • Provide food plots (unharvested grain crops) o manipulate availability	**Options:** Public or private land sites • seasonal wetland (a "permanent" feature) or flooded cropland o could be temporary (1 season) o or winter flooded annualy • Could be combined with an easement program as in Strategy 1 • Some lands within the new foraging zone could also be added to refuges or wildlife areas to make this strategy more sustainable. • Roost site design should consider providing large complexes (100 – 1000 ha, depending on the objective number of cranes to support), ideally in close proximity (< 5 km) to other roost sites, with large individual sites (> 5 ha) of mostly level topography, dominated by shallow water (5-10 cm depths).
Advantages • Uses existing crane use landscape o much of these areas are already conserved and managed (e.g., on refuges) o Cranes already have a tradition of using these landscapes • Should reduce depredation problems on private lands • Provides long-term protection of lands • Likely a more sustainable strategy	**Advantages** • less expensive • relies more on existing private lands with less need for easements and reduce costs • this strategy could be used to shift cranes away from areas that are at > risk of loss by providing more distant roost sites over time.
Disadvantages • More expensive • Cranes may be at risk in some current priority landscapes (e.g., from sea level rise)	**Disadvantages** • Could increase depredation problems on private lands • New use areas may be at risk to loss from development unless they were officially included in an easement program or added to an existing conservation area • May be less sustainable

APPENDIX A

GREATER AND LESSER SANDHILL CRANE HABITAT SELECTION RATIOS IN THE SACRAMENTO-SAN JOAQUIN RIVER DELTA REGION OF CALIFORNIA DURING WINTERS OF 2007-08 AND 2008-09.

Table A1. Greater (*Grus canadensis tabida*) and lesser sandhill crane (*G. c. canadensis*) habitat selection ratios for dry post-harvest corn habitat conditions on Brack Tract (BT) and Staten Island (SI) in the Sacramento-San Joaquin River Delta Region of California during winters of 2007-08 and 2008-09. SR represents the Wald 95% confidence intervals for selection ratios. Intervals above 1 indicate selection, intervals below 1 indicate avoidance, and intervals including 1 indicate no preference. Habitats that were not used are coded NU. Date intervals represent the survey periods (every two weeks) when a particular habitat condition was available.

	Date	**Site**	**Greater SR**	**Lesser SR**	**Date**	**Site**	**Greater SR**	**Lesser SR**
stubble	11-07-07	BT	NU	1.0, 1.3***	10-09-08	SI	0.01, 0.2***	0.3, 0.3**
	11-19-07	BT	NU	NU	10-23-08	SI	NU	NU
	12-07-07	BT	NU	NU	11-05-08	SI	NU	NU
	10-08-08	BT	NU	NU	11-19-08	SI	NU	NU
	10-21-08	BT	0.4, 0.9***	NU	12-02-08	SI	NU	NU
	11-06-08	BT	NU	0.5, 0.7***	12-16-08	SI	NU	NU
	11-18-08	BT	NU	NU	12-28-08	SI	NU	NU
	12-03-08	BT	NU	NU	01-12-09	SI	NU	NU
	12-17-08	BT	NU	NU	01-26-09	SI	NU	NU
	10-09-07	SI	NU	NU	02-10-09	SI	NU	NU
tilled	11-07-07	BT	0.4, 0.8***	0.2, 0.3***	10-08-08	BT	3.7, 3.7***	0.4, 0.5***
	11-19-07	BT	0.04, 0.2***	0.09, 0.1***	10-21-08	BT	1.3, 1.8***	2.0, 2.2***
	11-06-07	SI	0.3, 0.5***	0.2, 0.3***	11-06-08	BT	0.5, 2.8***	0.3, 0.4***
	11-20-07	SI	0.01, 0.1***	0.3, 0.6***	11-18-08	BT	NU	0.3, 0.4***
	12-04-07	SI	NU	0.2, 0.3***	12-03-08	BT	2.0, 2.4***	0.04, 0.2***
	12-18-07	SI	0.04-1.4***	0.1, 0.3***	12-17-08	BT	0.6, 1.5***	2.3, 3.1***
	12-31-07	SI	NU	NU	01-02-09	BT	NU	NU
	01-16-08	SI	NU	NU	01-14-09	BT	NU	NU
	01-30-08	SI	NU	NU	10-09-08	SI	NU	NU
	02-12-08	SI	0.4, 1.8***	NU	10-23-08	SI	4.3, 7.5***	0.03, 0.6***
					11-05-08	SI	1.5, 2.2***	0.2, 0.7***
mulched	11-19-07	BT	NU	NU	02-12-08	SI	2.0, 2.0***	2.2, 2.2***
	12-07-07	BT	7.8, 8.6***	0.2, 0.4***	10-09-08	SI	NU	0.03, 0.1***
	12-19-07	BT	4.6, 5.0***	3.5, 3.9***	10-23-08	SI	1.2, 1.4***	0.9, 0.95***
	01-03-08	BT	1.0, 2.2***	0.2, 0.4***	11-05-08	SI	0.5, 0.9***	0.2, 0.6***
	10-09-07	SI	1.1, 1.2***	0.6, 0.8***	11-19-08	SI	0.8, 0.9***	1.2, 1.2***
	11-06-07	SI	0.02, 0.1***	0.02, 0.07***	12-02-08	SI	0.8, 0.8	0.97, 1.0***
	11-20-07	SI	0.1, 0.2***	0.1, 0.4*	12-16-08	SI	1.5, 1.6***	1.9, 1.9***
	12-04-07	SI	0.3, 0.9***	0.7, 0.8***	12-28-08	SI	1.7, 1.8***	1.9, 1.9***
	12-18-07	SI	1.1, 1.2***	1.9, 1.9***	01-12-09	SI	1.5, 1.5***	1.8, 1.8***
	12-31-07	SI	1.6, 1.7***	1.5, 2.2***	01-26-09	SI	1.5, 1.5***	1.7, 1.8***
	01-16-08	SI	0.7, 0.9***	1.6, 1.6***	02-10-09	SI	0.5, 0.8***	0.9, 0.98***
	01-30-08	SI	1.8, 1.8***	1.9, 2.0***				

*= P < 0.05; ** = P < 0.01; *** = P < 0.001

Table A2. Greater (*Grus canadensis tabida*) and lesser sandhill crane (*G. c. canadensis*) habitat selection ratios for flooded post-harvest corn habitat conditions on Brack Tract (BT) and Staten Island (SI) in the Sacramento-San Joaquin River Delta Region of California during winters of 2007-08 and 2008-09. SR represents the Wald 95% confidence intervals for selection ratios. Intervals above 1 indicate selection, intervals below 1 indicate avoidance, and intervals including 1 indicate no preference. Habitats that were not used are coded NU. Date intervals represent the survey periods (every two weeks) when a particular habitat condition was available.

	Date	Site	Greater SR	Lesser SR	Date	Site	Greater SR	Lesser SR
flooded	11-07-07	BT	NU	NU	01-16-08	SI	NU	NU
	11-19-07	BT	NU	NU	01-30-08	SI	0.3, 0.5***	0.0003, 0.1***
	12-07-07	BT	NU	NU	02-12-08	SI	NU	NU
	12-19-07	BT	NU	NU	10-09-08	SI	4.2, 4.3***	0.5, 0.6***
	01-03-08	BT	NU	NU	10-23-08	SI	1.0, 1.2***	0.01, 0.03***
	01-14-08	BT	NU	83.4, 108.3***	11-05-08	SI	1.2, 1.4***	0.02, 0.2***
	01-31-08	BT	NU	NU	11-19-08	SI	0.1, 0.4***	0.02, 0.1***
	02-13-08	BT	NU	NU	12-02-08	SI	0.8, 0.9***	NU
	10-09-07	SI	2.3, 2.4***	2.5, 2.5***	12-16-08	SI	NU	NU
	11-06-07	SI	3.7, 3.8***	2.0, 2.0***	12-28-08	SI	0.01, .04***	NU
	11-20-07	SI	0.9, 1.0***	0.2, 0.4***	01-12-09	SI	0.1, 0.2***	0.003, 0.03***
	12-04-07	SI	1.6, 1.9***	0.04, 0.1***	01-26-09	SI	0.1, 0.3***	0.003, 0.04***
	12-18-07	SI	NU	NU	02-10-09	SI	0.1, 0.3***	0.04, 0.2***
	12-31-07	SI	0.4, 0.6***	0.1, 0.1***				
tilled flooded	12-19-07	BT	0.2, 13***	0.3. 0.6***	12-03-08	BT	1.6, 2.4***	1.2, 2.1***
	01-03-08	BT	6.3, 6.8***	1.2, 1.6***	12-17-08	BT	4.1, 5.0***	1.4, 2.3***
	01-14-08	BT	3.3, 3.4***	0.7, 1.1***	01-02-09	BT	1.5, 2.4***	0.3, 0.6***
	01-31-08	BT	4.3, 4.3***	0.4, 0.8***	01-14-09	BT	0.9, 1.4***	1.7, 2.3***
	02-13-08	BT	4.4, 4.4***	4.4, 4.4***	01-28-09	BT	2.8, 3.1***	NU
	11-18-08	BT	6.1, 7.2***	8.7, 8.8***	02-11-09	BT	4.2, 4.2***	0.99, 2.8***
mulched flooded	12-04-07	SI	1.8, 9.5***	7.3, 10.0***	01-16-08	SI	NU	NU
	12-18-07	SI	NU	NU	01-30-08	SI	NU	NU
	12-31-07	SI	NU	NU				
mulched irrigated	12-02-08	SI	73.0, 113.9***	54.8, 68.5***	01-12-09	SI	NU	1.4, 3.5***
	12-16-08	SI	11.5, 21.3***	NU	01-26-09	SI	6.3, 14.9***	8.2, 15.1***
	12-28-08	SI	NU	NU	02-10-09	SI	6.2, 6.7***	4.2, 4.6***

*** = P < 0.001

Table A3. Greater (*Grus canadensis tabida*) and lesser sandhill crane (*G. c. canadensis*) habitat selection ratios for dry post-harvest rice and wild rice habitat conditions on Brack Tract (BT) and Cosumnes River Preserve (CP) in the Sacramento-San Joaquin River Delta Region of California during winters of 2007-08 and 2008-09. Crops on CP were organic, while crops on BT were conventionally grown. SR represents the Wald 95% confidence intervals for selection ratios. Intervals above 1 indicate selection, intervals below 1 indicate avoidance, and intervals including 1 indicate no preference. Habitats that were not used are coded NU. Date intervals represent the survey periods (every two weeks) when a particular habitat condition was available.

	Date	**Site**	**Greater SR**	**Lesser SR**	**Date**	**Site**	**Greater SR**	**Lesser SR**
stubble	10-08-08	BT	NU	0.1, 0.2***	01-01-08	CP	NU	NU
	10-21-08	BT	3.5, 4.4***	2.9, 5.1***	10-10-08	CP	2.9, 3.1***	1.5, 2.0***
	10-09-07	CP	1.8, 1.8***	1.0, 1.3***	10-20-08	CP	3.1, 3.1***	3.4, 3.4***
	11-05-07	CP	0.8, 1.0***	0.02, 0.1***	11-07-08	CP	0.1, 0.9**	NU
	11-19-07	CP	2.1, 2.9***	0.02, 0.1***	11-18-08	CP	NU	NU
	12-03-07	CP	NU	NU	12-05-08	CP	NU	NU
wild rice stubble	10-10-08	CP	1.6, 3.0***	0.2, 1.5***	11-07-08	CP	NU	NU
	10-20-08	CP	NU	NU	11-18-08	CP	NU	NU
tilled	11-07-07	BT	NU	NU	11-06-08	BT	3.7, 4.1***	0.1, 0.1***
	11-19-07	BT	NU	NU	11-18-08	BT	0.1, 0.99**	0.003, 0.1***
	10-09-07	CP	NU	1.7, 2.2***	12-03-08	BT	NU	NU
	11-05-07	CP	NU	NU	12-17-08	BT	NU	NU
	11-19-07	CP	NU	NU	01-02-09	BT	NU	NU
	12-03-07	CP	NU	NU	01-14-09	BT	NU	NU
	01-01-08	CP	NU	NU	01-28-09	BT	NU	NU
	10-08-08	BT	NU	NU	02-11-09	BT	NU	NU
	10-21-08	BT	NU	NU				
mulched	11-07-07	BT	0.7, 1.1***	2.9, 2.9***	10-08-08	BT	0.4, 1.3***	4.3, 5.3***
	11-19-07	BT	3.7, 5.7***	2.1, 2.5***	10-20-08	CP	0.4, 0.9***	NU
	11-05-07	CP	1.0, 5.1**	0.4, 0.9***	11-07-08	CP	0.8, 2.4***	NU
	11-19-07	CP	0.8, 1.5***	0.2, 0.4***	11-18-08	CP	0.1, 0.5***	0.1, 0.6***
	12-03-07	CP	NU	0.2, 0.3***	12-05-08	CP	0.5, 0.9***	NU
	01-01-08	CP	0.03, 1.4***	0.5, 3.0***				

**= P < 0.01; *** = P < 0.001

Table A4. Greater (*Grus canadensis tabida*) and lesser sandhill crane (*G. c. canadensis*) habitat selection ratios for flooded post-harvest rice and wild rice habitat conditions on Brack Tract (BT) and Cosumnes River Preserve (CP) in the Sacramento-San Joaquin River Delta Region of California during winters of 2007-08 and 2008-09. SR represents the Wald 95% confidence intervals for selection ratios. Intervals above 1 indicate selection, intervals below 1 indicate avoidance, and intervals including 1 indicate no preference. Habitats that were not used are coded NU. Date intervals represent the survey periods (every two weeks) when a particular habitat condition was available.

	Date	**Site**	**Greater SR**	**Lesser SR**	**Date**	**Site**	**Greater SR**	**Lesser SR**
flooded	11-05-07	CP	18.6, 66.7***	98.0, 98.4***	01-18-08	CP	2.1, 2.4***	2.6, 3.0***
	11-19-07	CP	2.7, 3.7***	7.2, 7.3***	12-05-08	CP	9.0, 51.8***	13.7, 23.3***
	12-03-07	CP	4.2, 4.2***	3.2, 3.3***	01-13-09	CP	1.1, 3.7***	0.3, 0.99***
	01-01-08	CP	0.04, 0.7***	2.6, 3.0***	01-29-09	CP	NU	NU
wild rice flooded	01-13-09	CP	7.1, 8.5***	NU	01-29-09	CP	8.5, 10.2***	15.1, 15.1***
tilled flooded	11-19-07	BT	5.2, 5.4***	4.4, 4.5***	11-19-07	CP	NU	NU
	12-07-07	BT	NU	0.02, 0.1***	11-18-08	BT	2.9, 4.4***	0.2, 0.3***
	12-19-07	BT	0.1, 0.8***	0.03, 0.1***	12-03-08	BT	0.5, 0.9***	NU
	01-03-08	BT	0.95, 1.3***	0.2, 0.3***	12-17-08	BT	NU	0.6, 1.1***
	01-14-08	BT	0.1, 0.4***	0.7, 1.2***	01-02-09	BT	NU	0.03, 0.1***
	01-31-08	BT	0.03, 0.3***	NU	01-14-09	BT	NU	NU
	02-13-08	BT	NU	NU	01-28-09	BT	1.2, 2.4***	NU
	10-09-07	CP	NU	NU	02-11-09	BT	NU	NU
mulched flooded	12-03-07	CP	0.9, 1.8***	2.5, 2.9***	11-18-08	CP	12.5,13.1***	10.4, 11.6***
	01-01-08	CP	3.9, 4.1***	1.7, 2.7***	12-05-08	CP	1.1, 3.5***	6.1, 6.2***
	01-18-08	CP	0.8, 1.3***	0.3, 1.2***	01-13-09	CP	0.3, 0.7***	13.7, 14.0***
	11-07-08	CP	27.1, 32.7***	43.5, 43.5***	01-29-09	CP	0.04, 0.9***	NU

*** = P < 0.001

Table A5. Greater (*Grus canadensis tabida*) and lesser sandhill crane (*G. c. canadensis*) habitat selection ratios for wheat habitat conditions on Brack Tract (BT) and Staten Island (SI) in the Sacramento-San Joaquin River Delta Region of California during winters of 2007-08 and 2008-09. SR represents the Wald 95% confidence intervals for selection ratios. Intervals above 1 indicate selection, intervals below 1 indicate avoidance, and intervals including 1 indicate no preference. Habitats that were not used are coded NU. Date intervals represent the survey periods (every two weeks) when a particular habitat condition was available.

	Date	Site	Greater SR	Lesser SR	Date	Site	Greater SR	Lesser SR
tilled	10-09-07	SI	0.01, 0.2***	NU	10-23-08	SI	1.3, 2.3***	1.5, 22.5***
	11-06-07	SI	0.1, 0.4***	0.08, 0.4***	11-05-08	SI	1.4, 1.8***	0.7, 1.0***
	11-20-07	SI	NU	NU	11-19-08	SI	0.5, 0.9***	0.3, 0.7***
	12-04-07	SI	NU	NU	12-02-08	SI	NU	NU
	12-18-07	SI	NU	NU	12-16-08	SI	0.4, 0.8***	0.1, 0.2***
	12-31-07	SI	NU	NU	12-28-08	SI	0.2, 0.3***	0.04, 0.1***
	01-16-08	SI	NU	NU	01-12-09	SI	0.8, 1.0***	0.2, 0.4***
	01-30-08	SI	NU	NU	01-26-09	SI	NU	0.3, 0.6***
	02-12-08	SI	NU	NU	02-10-09	SI	NU	NU
	10-09-08	SI	0.3, 0.7***	1.5, 2.7***				
tilled flooded	10-09-07	SI	NU	2.3, 3.5***	10-09-08	SI	NU	NU
	11-06-07	SI	NU	NU	10-23-08	SI	6.8, 18.4***	0.5, 1.9***
	11-20-07	SI	NU	NU	11-05-08	SI	NU	NU
	12-04-07	SI	NU	NU	11-19-08	SI	NU	NU
	12-18-07	SI	NU	NU	12-02-08	SI	NU	NU
	12-31-07	SI	NU	NU	12-16-08	SI	NU	NU
	01-16-08	SI	NU	NU	12-28-08	SI	NU	NU
	01-30-08	SI	NU	NU	01-12-09	SI	NU	NU
	02-12-08	SI	NU	NU	01-26-09	SI	NU	NU
newly planted	11-07-07	BT	0.7, 1.1***	0.6, 0.8***	11-06-08	BT	NU	4.3, 4.5***
	11-19-07	BT	0.1,0.2***	0.99, 1.1***	11-18-08	BT	NU	0.1, 0.2***
	12-07-07	BT	NU	1.0, 1.3***	12-03-08	BT	0.1, 0.7***	2.5, 2.6***
	12-19-07	BT	0.1, 0.4***	0.6, 0.9***	12-17-08	BT	NU	1.1, 1.4***
	01-03-08	BT	NU	0.2, 0.3***	01-02-09	BT	NU	1.2, 6.7***
	01-14-08	BT	0.1, 0.3***	0.9, 1.2***	01-14-09	BT	NU	0.2, 0.9***
	01-31-08	BT	NU	0.2, 0.6***	01-28-09	BT	NU	NU
	02-13-08	BT	NU	NU	02-11-09	BT	NU	NU
	11-20-07	SI	5.8, 9.1***	5.0, 12.1***	11-19-08	SI	3.4, 6.7***	0.04, 0.2***
	12-04-07	SI	0.9, 1.7***	2.5, 11.3***	12-02-08	SI	0.1, 0.8***	0.06, 0.2***
	12-18-07	SI	3.2, 6.7***	0.2, 0.3***	12-16-08	SI	NU	NU
	12-31-07	SI	0.7, 1.2***	0.2, 0.3***	12-28-08	SI	1.1, 1.7*	0.4, 0.8***
	01-16-08	SI	NU	0.01, 0.04***	01-12-09	SI	0.3, 0.7***	NU
	01-30-08	SI	NU	NU	01-26-09	SI	0.2, 0.6***	NU
	02-12-08	SI	0.1, 0.5***	NU	02-10-09	SI	NU	NU

* = P < 0.05; *** = P < 0.001

Table A6. Greater (*Grus canadensis tabida*) and lesser sandhill crane (*G. c. canadensis*) habitat selection ratios for alfalfa and established and newly planted irrigated pasture on Brack Tract (BT) and Staten Island (SI) in the Sacramento-San Joaquin River Delta Region of California during winters of 2007-08 and 2008-09. SR represents the Wald 95% confidence intervals for selection ratios. Intervals above 1 indicate selection, intervals below 1 indicate avoidance, and intervals including 1 indicate no preference. Habitats that were not used are coded NU. Date intervals represent the survey periods (every two weeks) when a particular habitat condition was available.

	Date	**Site**	**Greater SR**	**Lesser SR**	**Date**	**Site**	**Greater SR**	**Lesser SR**
alfalfa	11-07-07	BT	NU	1.2, 1.6***	10-21-08	BT	NU	NU
	11-19-07	BT	NU	0.4, 0.6***	11-06-08	BT	NU	3.1, 4.0***
	12-07-07	BT	NU	6.8, 7.0***	11-18-08	BT	NU	0.2, 0.4***
	12-19-07	BT	0.1, 0.8***	2.2, 3.3***	12-03-08	BT	NU	2.8, 3.3***
	01-03-08	BT	NU	9.0, 9.1***	12-17-08	BT	NU	NU
	01-14-08	BT	NU	NU	01-02-09	BT	NU	6.6, 6.8***
	01-31-08	BT	NU	7.5, 7.5***	01-14-09	BT	NU	1.2, 10.0*
	02-13-08	BT	NU	NU	01-28-09	BT	NU	10.6, 10.6***
	10-08-08	BT	NU	7.5, 7.5***	02-11-09	BT	NU	5.0, 8.2***
established pasture	11-07-07	BT	NU	NU	01-02-09	BT	NU	NU
	11-19-07	BT	NU	NU	01-14-09	BT	NU	NU
	12-07-07	BT	NU	NU	01-28-09	BT	NU	NU
	12-19-07	BT	NU	NU	10-09-08	SI	0.9, 1.7***	5.4, 9.9***
	01-03-08	BT	NU	NU	10-23-08	SI	0.6, 0.98***	0.6, 0.8***
	01-14-08	BT	NU	NU	11-05-08	SI	0.02, 0.4***	NU
	01-31-08	BT	NU	NU	11-19-08	SI	1.8, 4.0***	0.03, 0.1*
	02-13-08	BT	NU	NU	12-02-08	SI	0.06, 0.3***	0.8, 1.1***
	10-08-08	BT	NU	NU	12-16-08	SI	NU	NU
	10-21-08	BT	NU	NU	12-28-08	SI	0.5, 0.9***	0.2, 0.4***
	11-06-08	BT	NU	NU	01-12-09	SI	0.3, 0.6***	0.03, 0.2***
	11-18-08	BT	NU	0.1, 0.2***	01-26-09	SI	0.2, 0.7***	NU
	12-03-08	BT	NU	NU	02-10-09	SI	0.8, 1.5***	NU
	12-17-08	BT	NU	NU				
newly planted pasture	12-04-07	SI	2.3, 6.4***	0.8, 1.0***	12-02-08	SI	1.1, 2.0***	9.0, 11.8***
	12-18-07	SI	NU	0.1, 0.2***	12-16-08	SI	6.3, 10.6***	3.3, 5.1***
	12-31-07	SI	0.5, 1.3***	0.2, 0.4***	12-28-08	SI	1.8, 3.0***	0.2, 0.6***
	01-16-08	SI	12.1,13.2***	4.3, 4.8***	01-12-09	SI	6.7, 9.2***	1.0, 1.9***
	01-30-08	SI	1.2, 2.3***	0.9, 1.4***	01-26-09	SI	11.2, 7.9***	4.0, 6.8***
	02-12-08	SI	0.8, 1.0***	NU	02-10-09	SI	3.1, 7.7***	3.5, 9.5***

* = P < 0.05; *** = P < 0.001

Table A7. Greater (*Grus canadensis tabida*) and lesser sandhill crane (*G. c. canadensis*) habitat selection ratios (SR) for safflower and fallow field conditions on Cosumnes River Preserve (CP) in the Sacramento-San Joaquin River Delta Region of California during winters of 2007-08 and 2008-09. SR represents the Wald 95% confidence intervals for selection ratios. Intervals above 1 indicate selection, intervals below 1 indicate avoidance, and intervals including 1 indicate no preference. Habitats that were not used are coded NU. Date intervals represent the survey periods (every two weeks) when a particular habitat condition was available.

	Date	Site	Greater SR	Lesser SR	Date	Site	Greater SR	Lesser SR
safflower stubble	10-09-07	CP	NU	NU	12-03-07	CP	NU	NU
	11-05-07	CP	NU	NU	01-01-08	CP	NU	NU
	11-19-07	CP	NU	NU				
safflower tilled	10-10-08	CP	NU	NU	11-18-08	CP	0.1, 0.5***	NU
	10-20-08	CP	NU	NU	12-05-08	CP	NU	NU
	11-07-08	CP	NU	NU				
safflower flooded	12-05-08	CP	NU	NU	12-05-08	CP	NU	NU
	01-13-09	CP	NU	NU	01-13-09	CP	NU	NU
	01-20-09	CP	NU	NU	01-20-09	CP	NU	NU
	11-18-08	CP	1.2, 6.6***	7.7, 14.2***				
fallow	10-08-08	BT	NU	NU	12-17-08	BT	NU	NU
	10-21-08	BT	NU	NU	01-02-09	BT	NU	NU
	11-06-08	BT	NU	NU	01-14-09	BT	NU	NU
	11-18-08	BT	NU	NU	01-28-09	BT	NU	NU
	12-03-08	BT	NU	NU	02-11-09	BT	NU	NU
fallow tilled	10-09-07	CP	NU	NU	10-20-08	CP	NU	NU
	11-05-07	CP	NU	NU	11-07-08	CP	NU	NU
	11-19-07	CP	NU	NU	11-18-08	CP	0.1, 0.5***	0.1, 0.7***
	12-03-07	CP	NU	NU	12-05-08	CP	0.1, 0.7***	0.1, 0.2***
	01-01-08	CP	NU	NU	01-13-09	CP	NU	NU
	01-18-08	CP	NU	NU	01-20-09	CP	0.9, 1.4***	NU
	10-10-08	CP	NU	NU				

*** = P < 0.001

Table A8. Greater (*Grus canadensis tabida*) and lesser sandhill crane (*G. c. canadensis*) habitat selection ratios (SR) for dirt roads, temporary and permanent levees on Brack Tract (BT) and Staten Island (SI) in the Sacramento-San Joaquin River Delta Region of California during winters of 2007-08 and 2008-09. SR represents the Wald 95% confidence intervals for selection ratios. Intervals above 1 indicate selection, intervals below 1 indicate avoidance, and intervals including 1 indicate no preference. Habitats that were not used are coded NU. Date intervals represent the survey periods (every two weeks) when a particular habitat condition was available.

	Date	Site	Greater SR	Lesser SR	Date	Site	Greater SR	Lesser SR
dirt levees	10-09-07	SI	0.2, 0.5***	0.1, 0.4***	10-23-08	SI	NU	NU
	11-06-07	SI	18.5, 30.5***	2.7, 8.1***	11-05-08	SI	7.1, 20.2***	NU
	11-20-07	SI	NU	NU	11-19-08	SI	NU	NU
	12-04-07	SI	NU	NU	12-02-08	SI	NU	NU
	12-18-07	SI	NU	NU	12-16-08	SI	NU	NU
	12-31-07	SI	NU	NU	12-28-08	SI	NU	NU
	01-16-08	SI	NU	NU	01-12-09	SI	NU	NU
	01-30-08	SI	NU	NU	01-26-09	SI	NU	NU
	02-12-08	SI	NU	NU	02-10-09	SI	NU	NU
	10-09-08	SI	NU	NU				
permanent levees	10-09-07	SI	NU	NU	10-23-08	SI	0.3, 0.97**	1.2, 17.8***
	11-06-07	SI	NU	10.3, 14***	11-05-08	SI	0.1, 0.7***	11.5, 28.0***
	11-20-07	SI	0.1, 0.5***	0.6, 1.0***	11-19-08	SI	0.4, 1.3***	7.7, 9.2***
	12-04-07	SI	NU	0.3, 0.6***	12-02-08	SI	NU	1.6, 2.3***
	12-18-07	SI	NU	1.0, 1.4***	12-16-08	SI	NU	0.4, 0.8***
	12-31-07	SI	NU	0.01, 0.1***	12-28-08	SI	NU	0.2, 0.4***
	01-16-08	SI	NU	NU	01-12-09	SI	0.1, 0.4***	1.8, 2.2***
	01-30-08	SI	NU	0.2, 0.8***	01-26-09	SI	NU	0.1, 0.3***
	02-12-08	SI	NU	NU	02-10-09	SI	0.7, 1.5***	0.2, 0.6***
	10-09-08	SI	NU	NU				
dirt road	11-07-07	BT	36.6,41.0***	1.2, 2.1***	11-06-07	SI	NU	NU
	11-19-07	BT	0.3, 1.5***	0.9, 1.4***	11-20-07	SI	NU	NU
	12-07-07	BT	2.6, 18.6***	0.03,0.1***	12-04-07	SI	NU	NU
	12-19-07	BT	7.9, 24.9***	0.3, 1.1***	12-18-07	SI	NU	NU
	01-03-08	BT	NU	NU	12-31-07	SI	NU	NU
	01-14-08	BT	9.7, 19.1***	0.4, 4.3***	01-16-08	SI	NU	NU
	01-31-08	BT	NU	NU	01-30-08	SI	NU	0.1, 0.6***
	02-13-08	BT	NU	NU	02-12-08	SI	NU	NU
	10-08-08	BT	NU	NU	10-09-08	SI	NU	NU
	10-21-08	BT	NU	NU	10-23-08	SI	0.02, 0.4***	NU
	11-06-08	BT	NU	NU	11-05-08	SI	2.0, 5.0***	NU
	11-18-08	BT	NU	1.6, 2.9***	11-19-08	SI	1.4, 4.0***	NU
	12-03-08	BT	11.2, 31.5***	0.97, 2.9***	12-02-08	SI	NU	NU
	12-17-08	BT	16.0, 24.6***	0.9, 5.8***	12-16-08	SI	0.3, 0.96***	NU
	01-02-09	BT	55.8, 61.2***	1.0, 2.9***	12-28-08	SI	NU	NU
	01-14-09	BT	55.5 ,60.2***	NU	01-12-09	SI	NU	0.2, 0.6***
	01-28-09	BT	0.95, 8.9***	NU	01-26-09	SI	NU	NU
	02-11-09	BT	NU	NU	02-10-09	SI	0.05,0.82***	NU
	10-09-07	SI	NU	NU				

*** = P < 0.001