2014

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Wildlife Monographs 189:1–41; 2014; DOI: 10.1002/wmon.1013

Spring Migration Ecology of the Mid-Continent Sandhill Crane Population with an Emphasis on Use of the Central Platte River Valley, Nebraska

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ABSTRACT We conducted a 10-year study (1998–2007) of the Mid-Continent Population (MCP) of sandhill cranes (*Grus canadensis*) to identify spring-migration corridors, locations of major stopovers, and migration chronology by crane breeding affiliation (western Alaska–Siberia [WA–S], northern Canada–Nunavut [NC–N], west-central Canada–Alaska [WC–A], and east-central Canada–Minnesota [EC–M]). In the Central Platte River Valley (CPRV) of Nebraska, we evaluated factors influencing staging chronology, food habits, fat storage, and habitat use of sandhill cranes. We compared our findings to results from the Platte River Ecology Study conducted during 1978–1980. We determined spring migration corridors used by the breeding affiliations (designated subpopulations for management purposes) by monitoring 169 cranes marked with platform transmitter terminals (PTTs). We also marked and monitored 456 cranes in the CPRV with very high frequency (VHF) transmitters to evaluate length and pattern of stay, habitat use, and movements. An estimated 42% and 58% of cranes staging in the CPRV were greater sandhill cranes (*G. c. tabida*) and lesser sandhill cranes (*G. c. canadensis*), and they stayed for an average of 20 and 25 days (2000–2007), respectively. Cranes from the WA–S, NC–N, WC–A, and EC–M affiliations spent an average of 72, 77, 52, and 53 days, respectively, in spring migration of which 28, 23, 24, and 18 days occurred in the CPRV. The majority of the WA–S subpopulation settled in the CPRV apparently because of inadequate habitat to support more birds upstream, although WA–S cranes accounted for >90% of birds staging in the North Platte River Valley. Crane staging duration in the CPRV was negatively correlated with arrival dates; 92% of cranes stayed >7 days. A program of annual mechanical removal of mature stands of woody growth and seedlings that began in the early 1980s primarily in the main channel of the Platte River has allowed distribution of crane roosts to remain relatively stable over the past 2 decades. Most cranes returned to nocturnal roost sites used in previous years. Corn residues dominated the diet of sandhill cranes in the CPRV, as in the 1970s, despite a marked decline in standing crop of corn residues. Only 14% (10 of 74) of PTT-marked migrant cranes stayed at stopovers for ≥5 days before arriving in the CPRV, which limited the contribution of sites south of the CPRV for fat accumulation needed for migration and reproduction. Body masses of cranes (after adjusting for body size [an index of fat]) at arrival in the CPRV varied widely among years (1998–2006), indicating the importance of maintaining productive habitats on the wintering grounds to condition cranes for migration and reproduction. Average rates of fat gain by adult females while in the CPRV remained similar from 1978–1979 to 1998–1999 but declined among males. Distances cranes flew to feeding grounds in the CPRV increased as the percentage of cropland planted to soybeans increased and as density of cranes on nocturnal roosts increased. These results suggest that as habitats of limited or no value to cranes increase on the landscape, more flight time and higher maintenance costs may reduce fat storage. An estimated 40% of diurnal use occurred north of Interstate 80 (I-80) where ≤5% of lands dedicated to crane conservation are located. Seventy-four and 40% of PTT-marked EC–M and WC–A cranes had spring migrations that included staging in eastern South Dakota for an average of 11 and 10 days, respectively. Cranes of the NC–N, WA–S, and WC–A subpopulations staged an average of 25, 17, and 12 days in central and western Saskatchewan/eastern Alberta. Females in these affiliations increased their fat reserves after leaving Nebraska by an estimated 450, 451, and 452 g, respectively, underscoring the key role of these staging areas in preparing the 3 subpopulations for reproduction. After departing Nebraska, MCP cranes roosted primarily in basin wetlands. Most of these wetlands are in private ownership and lack adequate protection, emphasizing the need for effective laws and policies to ensure their long-term protection. The continued success of the current management goal of maintaining the MCP at approximately its current size and providing diverse recreational opportunities over a wide area of midcontinent and western North America is predicated on the ability of MCP cranes to continue to store large fat reserves in the CPRV in advance of breeding. For the CPRV to remain a key fat storage site, active channel maintenance (e.g., clearing of woody vegetation) likely will need to

Received: 2 October 2012; Accepted: 24 February 2014

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continue, along with establishing minimum stream flows. These actions would help ensure nocturnal roosting habitat remains sufficiently dispersed to provide cranes with daily intake of high-energy food adequate for major fat storage and limit risk of high mortality from storms and disease. Published 2014.

KEY WORDS body mass, Central Platte River Valley (CPRV), fat reserves, food habits, *Grus canadensis*, habitat use, Mid-Continent Population (MCP), migration chronology, roost-site use, sandhill crane, Saskatchewan, satellite telemetry, spring staging areas, subspecies, subpopulations, time budgets.

Ecologia de la Migracion de Primavera de la Poblacion Centro-Continental de la Grulla Canadiense con Enfasis en el Uso del Valle del Central Platte River en Nebraska

RESUMEN Llevamos a cabo un estudio de 10 años (1998–2007) de la Población Centro-Continental (MCP) de grulla canadiense (*Grus canadensis*) para identificar los corredores utilizados durante la migración de primavera, la localización de los principales sitios de parada migratoria y la cronología de migración por afiliación reproductiva (oeste de Alaska–Siberia [WA–S], norte de Canadá–Nunavut [NC–N], centro oeste de Canadá–Alaska [WC–A] y centro este de Canadá–Minnesota [EC–M]). En el Valle del Central Platte River (CPRV) de Nebraska, evaluamos los factores que influencian la cronología de los sitios de escala, los hábitos alimenticios, las reservas de grasa corporal y el uso del hábitat de las grullas canadienses. Comparamos nuestros hallazgos con los resultados del estudio de ecología del Platte River llevado a cabo durante 1978–1980. Determinamos los corredores utilizados durante la migración de primavera por las afiliaciones reproductivas (designadas subpoblaciones para el propósito de manejo) monitoreando 169 grullas marcadas con transmisores PTT (platform transmitter terminal). También marcamos y monitoreamos 456 grullas en el CPRV con transmisores very high frequency (VHF) para evaluar la duración y el patrón de estancia, el uso del hábitat y los movimientos. Se estima que el 42% y el 58% de las grullas que hicieron escala en el CPRV eran grullas canadienses mayores (*G. c. tabida*) y grullas canadienses menores (*G. c. canadensis*), y que se mantuvieron en el área un promedio de 20 y 25 días (2000–2007), respectivamente. Las grullas de las afiliaciones WA–S, NC–N, WC–A, y EC–M estuvieron un promedio de 72, 77, 52, y 53 días migrando durante la primavera, respectivamente, de los cuales 28, 23, 24, y 18 días ocurrieron en el CPRV, respectivamente. La mayoría de la subpoblación WA–S se instaló en el CPRV, debido aparentemente al insuficiente hábitat para mantener más aves río arriba, si bien las grullas de la WA–S representaron >90% de las aves que hicieron escala en el valle del North Platte River. La duración de la escala de las grullas en el CPRV se correlacionó negativamente con la fecha de llegada; el 92% de las grullas se quedaron >7 días.

Un programa anual de remoción mecánica de árboles maduros y plántulas que empezó a principios de los años 80 ante todo en el canal principal del Platte River, ha permitido que la distribución de dormideros de grullas se mantenga relativamente estable durante las 2 últimas décadas. La mayoría de las grullas regresaron a los dormideros nocturnos utilizados en años anteriores. El maíz residual dominó la dieta de las grullas canadienses en el CPRV, al igual que en los años 70, a pesar de una disminución marcada del desecho residual de maíz posterior a la cosecha. Solamente el 14% (10 de 74) de las grullas marcadas con transmisores PTT se quedaron en los sitios de parada migratoria durante ≥5 días antes de llegar al CPRV, lo cual limitó la contribución de los sitios al sur del CPRV a la acumulación de la grasa corporal necesaria para la migración y la reproducción. Las masas corporales de las grullas (después de compensar por el tamaño del cuerpo [un índice de grasa corporal]) a la llegada al CPRV variaron ampliamente entre años (1998–2006), indicando la importancia de mantener hábitats productivos en las áreas de invernada para preparar a las grullas para la migración y la reproducción. El promedio de grasa corporal ganada por hembras adultas durante su estancia en el CPRV permaneció similar desde 1978–1979 hasta 1998–1999, pero disminuyó en los machos. Las distancias que las grullas volaron hasta las áreas de alimentación en el CPRV aumentaron a medida que el porcentaje de soya plantada y la densidad de grullas en los dormideros nocturnos aumentaron. Estos resultados sugieren que a medida que los hábitats con un valor reducido o nulo para las grullas aumentan en el paisaje, el aumento de la duración del vuelo y costo de mantenimiento pueden reducir las reservas de grasa corporal. Se estima que el 40% del uso diurno ocurrió al norte de la autopista interestatal 80 (I-80) donde se localizan ≤5% de los terrenos dedicados a la conservación de grullas. Setenta y cuatro y 40% de las grullas marcadas con transmisores PTT de las afiliaciones EC–M y WC–A respectivamente, realizaron migraciones de primavera que incluyeron sitios de escala al este de Dakota del Sur por un promedio de 11 y 10 días respectivamente. Grullas de las subpoblaciones NC–N, WA–S, y WC–A pararon un promedio de 25, 17, y 12 días en el centro y el oeste de Saskatchewan/este de Alberta. Se estima que a partir de Nebraska, las hembras de estas afiliaciones aumentaron sus reservas de grasa corporal en 450, 451, y 452 g respectivamente, enfatizando la importancia de estas áreas de escala

en la preparación de las 3 subpoblaciones para la reproducción. Al dejar Nebraska, las grullas de la MCP durmieron principalmente en lagunas de cuenca. Muchas de estas lagunas se encuentran en propiedades privadas y carecen de protección adecuada, enfatizando la necesidad de implementar leyes y políticas efectivas que aseguren su protección a largo plazo. La continuidad del éxito de la actual gestión de la MCP, con el objetivo de mantener aproximadamente su tamaño actual y proveer diversas oportunidades recreativas a través de una amplia área del centro y oeste de Norte América, está ligada a la habilidad de las grullas de la MCP de almacenar grandes reservas de grasa corporal en anticipación a la reproducción. Para que el CPRV se mantenga como un sitio importante para la acumulación de grasa corporal en las grullas canadienses, se proponen el mantenimiento activo del canal (e.g., remoción de árboles) y el establecimiento de un flujo mínimo en el río. Estas acciones ayudarían a asegurar que suficientes dormideros nocturnos permanezcan disponibles para que las grullas se puedan dispersar adecuadamente y puedan acceder a su dieta, limitando de esta manera el riesgo de alta mortalidad asociado con tormentas y enfermedades.

Écologie de la Migration Printaninière de la Population Mi-Continentale des Grues du Canada avec un Accent sur L'utilisation de la Vallée Centrale de la Rivière Platte, Nebraska

RÉSUMÉ Nous avons conduit une étude sur une période de 10 ans (1998–2007) sur la population mi-continentale (MCP) des grues du Canada (*Grus canadensis*) pour identifier les couloirs de migration printaniers, les escales principales et la chronologie de migration selon l'affiliation reproductive des grues observées (Ouest de l'Alaska-Sibérie [WA–S], Nord Canadien-Nunavut [NC–N], Centre Ouest Canadien [WC–A], et le Centre Est Canadien-Minnesota [EC–M]). Nous avons évalué les facteurs qui influencent la chronologie des périodes de repos, les habitudes alimentaires, le surplus de gras et l'utilisation de l'habitat des grues du Canada dans la vallée de la rivière Platte au Nebraska (CPRV). Nous avons comparé nos résultats avec l'étude sur l'écologie de la rivière Platte conduite entre 1978–1980. Les couloirs migratoires printaniers utilisés dans l'affiliation reproductive (sous-populations désignées ci-haut pour aider à la gestion) ont été déterminés après avoir surveillé et suivi 169 grues identifiées par une borne de transmission plate-forme (PTT). Nous avons également identifié et surveillé 456 grues dans la région de la rivière Platte (CPRV) avec des transmetteurs ayant une très haute fréquence de transmission (VHF) dans le but d'évaluer la durée et leur tendance de séjour, l'utilisation de l'habitat et leurs mouvements. Entre 42% et 58% de l'aire de repos des grues du Canada (*Grus canadensis tabida*) dans la région de la rivière Platte était plus grande que celle des grues du Canada (*Grus canadensis*) qui elles sont restées respectivement en moyenne entre 20 et 25 jours (2000–2007). Les grues appartenant aux régions WA–S, NC–N, WC–A, et EC–M ont voyagé lors de leur migration printanière en moyenne 72, 77, 52, et 53 jours et ils ont passé respectivement en moyenne 28, 23, 24, et 18 jours dans la région de la rivière Platte (CPRV). La majorité de la sous-population WA–S s'est installée dans la région de la rivière Platte (CPRV) à case d'un habitat inadéquat en amont pour supporter plus d'oiseaux, même si les grues WA–S représentaient >90% des oiseaux qui ont choisi la rivière Platte comme aire de repos. Le temps passé dans la région de la rivière Platte (CPRV) est négativement corrélée avec leurs dates d'arrivées, 92% des grues sont restées >7 jours.

Un programme annuel de désherbage mécanique des plantules et des plantes ligneuses matures qui a commencé au début des années 1980 a aider la distribution des gîtes de grue à rester relativement stable au cours des 2 dernières décennies. La plupart des grues sont retournées dans leurs perchoirs nocturnes utilisées les années précédentes. Les résidus de maïs ont dominé le régime des grues dans la vallée de la Rivière Platte (CPRV), tout comme dans les années 1970, malgré une baisse considérable de la récolte des résidus des plants de maïs. Seulement 14% (10 sur 74) des grues identifiées par le système PTT sont restées dans un aire de repos ≥5 jours avant d'arriver dans la vallée de la rivière Platte (CPRV), ce qui limite la contribution des sites au sud de la CPRV pour aider à l'accumulation des gras nécessaires pour la migration et la reproduction. Les masses corporelles des grues (après avoir été ajusté pour la taille corporelle [un indice de masse grasses]) à leur arrivée dans la CPRV variaient considérablement selon les années étudiées (1998–2006), ce qui indique l'importance de maintenir des habitats productifs dans les aires de repos pour inciter la migration et la reproduction des grues du Canada. Les taux moyens d'accumulation de graisses par les femelles adultes lors de leur séjour dans la CPRV est demeuré stable de 1978–1979 à 1998–1999, mais a diminué chez les males. Les distances voyagées par les grues pour se rendre dans des aires d'alimentation dans la région de la CPRV ont augmenté ainsi que le pourcentage des terres arables plantées de soja et la densité des grues sur les racines nocturnes. Ces résultats suggèrent que les habitats de peu ou sans valeurs pour les grues se sont multipliées dans la région, plus de temps de vol est nécessaire, ce qui augmente les coûts de maintenance tout en réduisant les réserves de

gras. On estime que 40% de l'utilisation diurne est survenue au nord de l'Interstate 80 (I-80) où ≤5% des terres vouées à la conservation des grues sont situées. Lors de la migration printanière des grues EC–M et WC–A, 74% et 40% de celles-ci se sont reposées dans le sud-est du Dakota du Sud pour une moyenne respective de 11 et 10 jours. Les grues des sous-populations NC–N, WA–S, et WC–A se sont reposées en moyenne 25, 17, et 12 jours dans le centre et l'ouest de la Saskatchewan et l'est de l'Alberta. Les femelles de ces affiliations ont augmenté leurs réserves de gras respectives d'environ 450, 451, et 452g lors de leur repos au Nebraska, ce qui souligne l'importance clé de ces aires de repos dans le cycle préparatoire pour la reproduction de ces trois sous-populations. Après s'avoir envolé du Nebraska, les grues de la mi-continentale se sont principalement perchés dans des bassins et des zones humides. La plupart de ces terres humides et ces bassins se retrouvent sur des propriétés privées et elles manquent de protection adéquate pour protéger les grues. Ceci met l'emphase sur la nécessité de lois et politiques efficaces pour assurer la protection à long terme des grues du Canada. Le succès continue de l'objectif actuel de gestion pour maintenir la population mi-continentale des grues du Canada à sa taille actuelle ainsi que d'offrir diverses possibilités de loisirs sur une large zone mi-continentale et de l'Ouest de l'Amérique du Nord repose sur la capacité des grues de faire de grandes réserves de gras avant la saison d'élevage. Pour que la région de la vallée de la rivière Platte (CPRV) demeure un site important pour faire des réserves de gras, le maintien des terres doit être actif, ce qui inclut la continuation du défrichement des zones de végétation ligneuses ainsi que l'établissement minimal des débits d'eau. Ces mesures contribueraient à assurer que suffisamment d'aire de repos nocturnes demeurent à la disponibilité des grues du Canada lors de leur migration et assureraient de satisfaire leurs besoins alimentaires ce qui aidera les grues à se disperser et en conséquence limitera le risque de mortalité élevé dû aux tempêtes et aux maladies.

Экология Весенней Миграции Средне-Континентальной Популяции Канадского Журавля с Акцентом на Транзитной Остановке в Центральной Долине Реки Платт в Небраске

АННОТАЦИЯНами проведены 10-летние исследования (1998–2007 гг.) по изучению весенних миграционных коридоров, основных мест транзитных остановок, хронологии миграций средне-континентальной популяции (СКП) канадского журавля (*Gruscanadensis*) из различных мест размножения вида (Западная Аляска - Сибирь [ЗА–С], Северная Канада–Нунавут[СК–Н], Западно-центральная Канада–Аляска [ЗК–А], и Восточно-центральная Канада–Миннесота [ВК–М]; Крапу и др. 2011). В Центральной долине реки Плат (ЦДРП) в штате Небраска нами оценены факторы, влияющие на хронологию перемещений канадских журавлей, их пищевые предпочтения, накопление жира и использование местообитаний. Результаты наших исследований были сравнены с результатами работ по Исследованию Экологии Реки Плат, проводившимися в 1978–1980 гг. (Служба рыбы и дичи США, 1981). Коридоры весенних миграций, используемые журавлями с различных мест размножения (выявленные для целей управления субпопуляциями) были определены путем спутникового мониторинга 169 журавлей с датчиками PTT (PlatformTransmitterTerminals). Также в ЦДРП нами были помечены 456 птиц высокочастотными спутниковыми датчиками VHF (VeryHighFrequency) для оценки продолжительности и характера их пребывания, использования местообитаний, и передвижений. Отмечено, что 42 и 58% журавлей на транзитной остановке в ЦДРП были представлены двумя подвидами, соответственно, большим (*G. c. tabida*), и малым канадским журавлями (*G. c. canadensis*), которые держались на территории в среднем 20– 25 дней (2000–2007 гг.).Журавли из ЗА–С, СК–Н, ЗК–А и ВК–М потратили в среднем 72, 77, 52 и 53 дней, соответственно, на весеннюю миграцию, из которых 28, 23, 24 и 18 дней провели в ЦДРП. Вероятно, что большая часть особей субпопуляции ЗА–С держались в ЦДРП из-за нехватки подходящих местообитаний, необходимых для поддержания большого количества птиц, выше по течению, хотя журавли субпопуляции ЗА–С составляли >90% птиц, отмеченных в Северной Долине Реки Плат. Продолжительность остановки журавлей в ЦДРП имеет отрицательную корреляцию с датами прибытия; 92% журавлей пребывали на местах остановки >7 дней.

Программа ежегодного механического удаления зрелых насаждений деревьев и саженцев, которая началась в 1980-х, позволила распределению мест кормления журавлей в течение последних двух десятилетий оставаться относительно стабильным. Большинство журавлей возвращались в места кормления, используемые ими в предыдущие годы. Остатки кукурузы преобладали в рационе канадских журавлей в ЦДРП, как и в 1970-х гг., несмотря на заметное снижение урожая кукурузы. Только 14% (10 из 74) PTT-меченых мигрирующих журавлей держались на остановках в течение ≥5 дней до прибытия в ЦДРП, что ограничивало вклад южных от ЦДРП территорий для накопления жира, необходимого для миграции и размножения птиц. Масса тела журавлей (с поправкой на размер тела [индекс жира])

по прибытии в CPRV различалась по годам (1998–2006), что указывает на важность сохранения продуктивных местообитаний на зимовках, необходимых для миграционного и репродуктивного состояния журавлей. Средние темпы роста жира у взрослых самок в ЦДРП оставались одинаковыми с 1978–1979 по 1998–1999, но снизились среди самцов. Дистанции полетов журавлей на места кормежек в ЦДРП увеличились в связи с увеличением доли соевых угодий на данной территории, также наблюдалось повышение плотности журавлей на ночных местах кормления. Эти результаты позволяют предположить, что некачественные и не имеющие ценности обширные угодья требуют больше времени на перелет, и эти энергетические затраты могут уменьшить накопление жира. По нашим оценкам, 40% суточного использования территорий происходило к северу от внутреннего штата 80 (I-80), где ≤5% земель определены под охрану журавлей. 74 и 40% PTT-меченых ВК–М и ЗК–А журавлей во время весенних миграций останавливались в восточной части Южной Дакоты в среднем на 11 и 10 дней соответственно. Журавли субпопуляций СК–Н, ЗА–С и ЗК–А останавливались в среднем на 25, 17 и 12 дней в центральном и западном Саскачеване/восточной Альберте. Самки из данных группировок увеличили свои жировые запасы на 450, 451, и 452 г соответственно, что подчеркивает ключевую роль кормовых угодий Небраски в подготовке трёх субпопуляций для размножения. После отлета из Небраски, СКП журавлей кормились, прежде всего, в водно-болотных угодьях. Многие из этих водно-болотных угодий находятся в частной собственности и не имеют адекватной охраны, что подчеркивает необходимость эффективных законов и политики для обеспечения их долговременной защиты. Продолжающееся успешное управление по поддержанию СКП канадского журавля примерно соответствует целям управления в полном размере, и предоставляет разнообразные рекреационные возможности на большой территории средне-континентальной и западной части Северной Америки, которое основано на возможности СКП канадского журавля накапливать большие запасы жиры перед периодом размножения.

Для того, чтобы ЦДРП продолжала оставаться важным местом накопления жира журавлями, нужна дальнейшая активная работа по поддержке доступности водного канала, которая включает очистку древесной растительности, а также установление минимального количества водных потоков. Эти меры помогут обеспечить достаточное количество ночных мест кормления, доступных журавлям, чтобы птицы могли быть адекватно распределены по территории для удовлетворения своих кормовых потребностей, с целью сокращения риска высокой смертности от неблагоприятных погодных условий и болезней.

Contents

INTRODUCTION

Sandhill cranes (*Grus canadensis*) of the Mid-Continent Population (MCP; see Appendix A for an index of acronyms and abbreviations) occur across a vast geographic area of central and western North America and northeastern Asia (Krapu et al. 2011). In March of each year, an estimated 500,000 sandhill cranes representing approximately 80% of the MCP gather in the Central Platte River Valley (CPRV) of Nebraska for several weeks (Kinzel et al. 2006), forming the largest concentration of cranes in the world. This unique annual gathering of cranes in 1991 attracted an estimated 80,000 crane watchers to the CPRV

(Lingle 1992). Ecotourism associated with wildlife watching, and particularly the crane spectacle, contributes an estimated $25.1–$53.1 million annually to the economy of Nebraska (Eubanks et al. 1998). Studies conducted in the late 1970s documented that MCP cranes staged in the CPRV for about 4 weeks in late winter and early spring (U.S. Fish and Wildlife Service 1981), and fed primarily on corn residues to accumulate large fat reserves, which the birds used during migration to the breeding grounds and reproduction (Krapu et al. 1985, Reinecke and Krapu 1986). These studies established the key role of the CPRV in meeting the needs of the MCP during migration and reproduction.

Sandhill crane use of the CPRV in spring migration began before recorded human history as the braided channels provided preferred roosting habitat, and surrounding wet meadows and grasslands were well suited for feeding and resting (Krapu 1999). Before agriculture became the dominant land use in the Great Plains, high-energy foods sought by cranes were less concentrated and their abundance probably fluctuated widely among years at any particular site in response to differences in precipitation including recurring droughts (Wishart 2004). In natural environments, cranes probably returned to the same sites from 1 spring to the next less consistently, and when returning to these sites occurred in smaller numbers, and stayed for shorter time periods than has occurred over the past 60 years.

After Euro-American settlement began in the late 19th century, uncontrolled spring hunting probably disrupted sandhill crane use of the CPRV during spring. Spring hunting was prohibited starting in 1918 with passage of The Migratory Bird Treaty Act, but full implementation of the ban took several decades to accomplish and some spring shooting continued as late as the 1940s (Youngworth 1947). By this time, crane use of the CPRV was increasing rapidly. In a letter dated 25 August 1943, A. M. Brooking wrote "My observations which extend over a period of fifty years are that [sandhill] cranes are much more common in the past ten years [along the Platte River] than previous to this" (from Walkinshaw 1949:129). Plentiful channel roosting habitat and abundant corn residues (Reinecke and Krapu 1986), attracted growing numbers of cranes during the second half of the 20th century. Quantitative estimates of crane abundance in the CPRV first became available in 1959–1964, when an estimated 135,000 were present at the peak of spring migration (Stephen 1967; letter dated 29 July 1964 from R. J. Buller, U.S. Bureau of Sport Fisheries and Wildlife, Albuquerque, New Mexico). The MCP was estimated to contain a minimum of 200,000 to 270,000 cranes in 1973 (Lewis 1977), 560,000 cranes by the late 1980s (Tacha et al. 1994), and 600,000 by the early 21st century (Krapu et al. 2011). By the 1970s, an estimated 80% of the MCP was stopping annually in early spring in the CPRV (U.S. Fish and Wildlife Service 1981); and by 1982, an estimated 490,000 cranes were present in late March (Benning and Johnson 1987).

Rapid growth in numbers of sandhill cranes stopping in the CPRV in spring from the 1950s to the late 1970s occurred concurrent with massive destruction of channel roosting habitat. The upper Platte River was lost to cranes in the first 2 decades after 1,300 million m^3 of annual flows were diverted into the Tri-County Canal in 1941 to fill stream reservoirs, irrigate cropland, and operate power plants (Fig. 1). The diversion left 493 million m^3 (38%) of annual flows remaining in the upper Platte River at Brady (Missouri River Basin Commission 1975). Wetted channel width at Brady and Cozad (Fig. 1) declined from 340 m and 440 m in 1938 before the diversion to 45 m and 40 m, respectively, in 1965. The former wetted channel area rapidly became riparian woodland (Williams 1978). In 1953 and 1954, Walkinshaw (1956) surveyed sandhill cranes in the Platte River Valley upstream from Lexington and found that by 1953 the species was largely absent from the reach upstream from Cozad to the confluence of the North Platte and South Platte rivers. He also noted that although thousands of sandhill cranes still staged in the Cozad area in 1954, this was the last report of significant crane use west of Lexington on the Platte River. Studies in the 1970s revealed cranes avoided channel widths of <50 m in the CPRV (Krapu et al. 1984), suggesting that reduction in channel width was a major cause of cranes abandoning the upper Platte River.

In 1957, an estimated 60% of the sandhill crane population was located in the reach between the J-2 discharge site, which emptied return flows from the Tri-County Canal into the Platte River, and Kearney (Fig. 1; Faanes and LeValley 1993). The remaining cranes were located between Kearney and Grand Island. By the late 1970s, channel habitat deterioration from Lexington to Kearney had resulted in most cranes moving downstream between Kearney and Grand Island, where densities of >10,000 cranes/km of river channel were recorded (Krapu et al. 1982). Changes in crane distribution and crowding caused by habitat loss raised concern that continuing habitat degradation could cause cranes to abandon this entire key staging area and prompted a decision to begin mechanically clearing central Platte River channels of woody growth starting in the early 1980s (Currier 1984), and continuing to the present.

The half-million sandhill cranes that have used the CPRV each spring for the past several decades have met their energetic requirements from foraging on plentiful corn residues (Reinecke and Krapu 1986) that became available following the invention and deployment of the mechanical corn picker during the 1930s and 1940s (Krapu et al. 1995). Harvested cornfields with plentiful corn residues in close proximity to wide braided river channels created ideal staging habitat for cranes. The CPRV was enhanced further as a crane staging area with large-scale development of cropland irrigation. After most cropland became irrigated by the late 1970s, corn dominated production agriculture for the next 20 years. Cranes in the 1970s relied almost exclusively on abundant corn residues to meet their energy requirements and for fat synthesis (Reinecke and Krapu 1986). Deposition of large fat reserves is vital for lesser sandhill cranes, which arrive on their breeding grounds with snow still covering much of the ground surface and with food scarce. The birds nest soon after arrival drawing primarily on nutrient reserves (Fox et al. 1995, Watanabe 2006) acquired on the wintering grounds or during spring migration. The ability of cranes to consistently accumulate large amounts of fat during their stay in Nebraska likely increased annual survival and reproductive rates from historical levels. Condition has been linked to survival and reproductive success in numerous species of migratory waterfowl (Johnson et al. 1992, Blums et al. 2005).

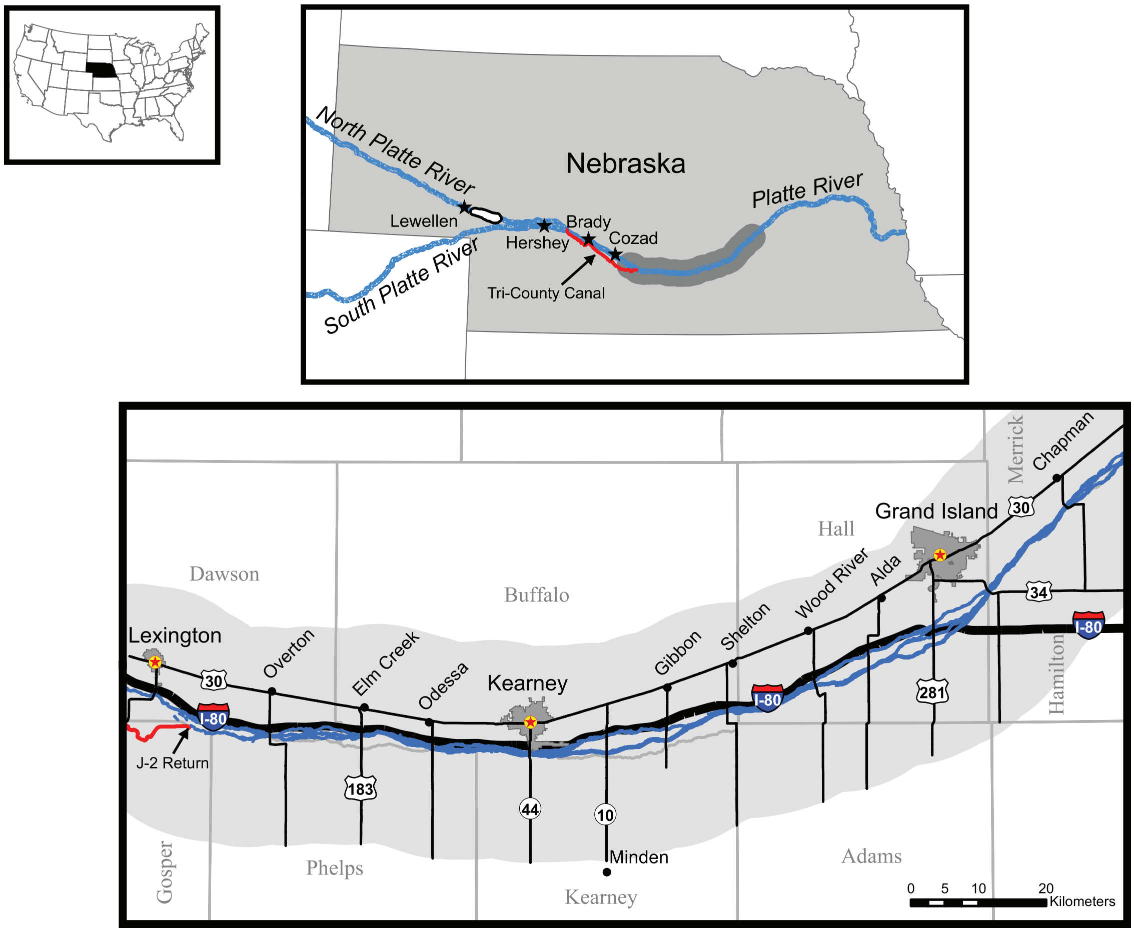

Figure 1. The principal study area for research on spring migration ecology of the Mid-Continent Population of sandhill cranes was located in the Chapman-to-Lexington reach of the Central Platte River Valley (CPRV) in south-central Nebraska (lower drawing). We trapped adult sandhill cranes and marked them with platform transmitter terminals (PPTs) in the Chapman-to-Lexington reach of the CPRV and in North Platte River Valley near Hershey, Nebraska (upper drawing) during 1998–2003, and marked additional adult sandhill cranes with very high frequency (VHF) transmitters (1998–2007) at numerous sites between Chapman and Kearney, Nebraska.

Corn residues in the CPRV declined markedly from the late 1970s to the 1990s. Development of efficient corn headers on combines led to a 79% reduction of ears in cornfields postharvest by the late 1990s, causing corn residues in fields postharvest to decline by nearly half (Krapu et al. 2004). Corn residues in cornfields also declined by about 55% and 66% from postharvest to early spring in 1998 and 1999, respectively (Pearse et al. 2010). This decline in corn residues also resulted from foraging activity of large numbers of lesser snow geese (*Chen caerulescens*; Pearse et al. 2010), which also feed mostly on corn residues during their stay in the CPRV and Rainwater Basin (Pearse et al. 2013). Snow geese were uncommon migrants in the CPRV during late winter in the 1970s (U.S. Fish and Wildlife Service 1981), but by the late 1990s had increased to several hundred thousand (Krapu et al. 2005*b*). The rapid increase in numbers of snow geese in the CPRV occurred during a period of explosive growth in the midcontinent snow goose population (Abraham and Jefferies 1997). The rapid decline in corn residues continued from crane arrival to departure. In 1978–1979, corn residues averaged 200 kg/ha at the beginning and 120 kg/ha at the end of spring staging by cranes but by 1999 had declined from 65 kg/ha at the beginning to 6 kg/ha at the end of spring staging (Pearse et al. 2010). In springs 1998 and 1999, corn residues declined 87% and 94%, respectively, during the crane staging period in contrast to 40% during 1978–1979 (Pearse et al. 2010). Also, a surge in planting of soybeans in the CPRV reduced cropland area planted to corn, posing another potential challenge to maintaining adequate high-energy food for cranes. Soybeans are not a suitable substitute for corn as a high-energy food because unprocessed soybeans contain bio-chemicals that interfere with digestive enzymes and prevent assimilation of nutrients (Reinecke et al. 1989).

Since the 1970s, fat reserves of MCP sandhill cranes in the CPRV have been synthesized mostly from corn (Reinecke and Krapu 1986) and have served a key role in meeting crane nutrient needs during spring migration and reproduction (Krapu et al. 1985). Research showing that corn residues in the CPRV have declined at the time cranes arrive and are scarce when they depart (Pearse et al. 2010) suggested cranes may no longer be able to rely exclusively on corn residues for fat synthesis. In the 1970s, lesser sandhill cranes arrived on breeding grounds in the Yukon–Kuskokwim Delta in western Alaska carrying about 500 g of fat, which represented about half of the fat accumulated by departure from the northern plains. A major portion of these

fat reserves were accumulated while the birds were in the CPRV (Krapu et al. 1985).

Measurements obtained from sandhill cranes that died during an ice storm and blizzard in the CPRV in March 1996 supported the hypothesis that fat storage may have declined since the 1970s (Krapu et al. 2005*a*). A decline in corn residues also may have led to increased foraging north of the river and I-80. In the 1970s when corn residues were abundant, 75% of diurnal locations of radio-marked cranes were in fields south of the Platte River (Sparling and Krapu 1994). A major increase in use of lands north of I-80 would be significant because <5% of habitat protected for crane use is located there.

Continued channel habitat loss, declining food resources, evidence of reduced fat accumulation, and potential changes in foraging area use provided impetus for initiation of a comprehensive study to identify the habitat base supporting the MCP in the CPRV during spring migration and determine its adequacy in providing for crane needs during migration and reproduction. Furthermore, recent research on the MCP structure has identified 4 subpopulations for management purposes with differing distributions during fall migration, winter, and summer (Krapu et al. 2011). Given the vast geographic breeding area and biomes represented in temperate, subarctic, and arctic regions, subpopulation needs can be expected to vary because of differences in migration routes, stopover use, and environmental conditions encountered in migration and at arrival on the breeding grounds. Lack of detailed knowledge of key aspects of spring migration including where MCP cranes stop, length of stay at these stopovers, and amount of fat stored at primary staging sites have prevented a thorough assessment of the current capacity of wintering grounds and spring migration stopovers to supply nutrients needed for migration and reproduction.

Research priorities for the present study were determined, in part, from scoping meetings that were held at the Ecological Services Office of the United States Fish and Wildlife Service at Grand Island, Nebraska during April 1996. These meetings were attended by stakeholders in the Central Platte Ecosystem including wildlife researchers, hydrologists, and managers representing federal and state agencies, private conservation organizations, and commercial enterprises. In addition, the signing of a cooperative agreement between the Department of Interior and states of Nebraska, Colorado, and Wyoming on 30 July 1997 to initiate a 30-year habitat restoration effort through the Platte River Recovery Implementation Program (U.S. Department of Interior 1997) served as a major impetus for the Department of Interior to initiate research to address habitat needs of key species of migratory water birds using the Central Platte River Ecosystem. The United States Geological Survey initiated the Central Platte River Priority Ecosystem Study in 1997. A multi-disciplinary research team was formed to 1) gain a comprehensive understanding of the habitat resources used by MCP sandhill cranes during spring migration and preparation for reproduction, 2) determine whether the role of the CPRV in meeting MCP needs had changed since the 1970s, and 3) increase understanding of the contribution of the CPRV relative to overall habitat needs of the MCP during spring migration.

To address study goals, we developed a research plan focusing on key information needs during spring migration of the 4 subpopulations and 2 subspecies of MCP sandhill cranes. We gathered information necessary to guide crane managers when considering how to best meet nutrient needs of the MCP during spring migration and for reproduction. We determined crane migration routes, chronology of migration, locations of stopover sites, and length of stay at each major stopover for each of the 4 subpopulations and 2 subspecies. We evaluated the potential influence of weather, food resources, stream flows, and other factors on length of stay of cranes in the CPRV. Because magnitude and timing of flows released into the Central Platte River affect roost-site use (Kinzel et al. 2009) and a concern that low river stage may cause premature departure of cranes, we investigated whether river stages influence dates of crane departure. To gain insight into crane use of nocturnal roost sites and effectiveness of mechanical vegetation control in maintaining crane roosting distribution, we determined distribution of radio-marked individuals on nocturnal roosts daily during the staging interval and surveyed the distribution of the MCP on nocturnal roosts within Platte River channels during the peak of staging in late March during 2000–2003 and 2005.

We assessed a number of questions regarding crane foraging and nutritional ecology. We compared crane diets and fat accumulation in the CPRV during springs 1998–1999 and 1978–1979 to evaluate potential effects of declining corn residues on crane nutrition. Also, because a major segment of MCP cranes in the 1970s acquired a significant part of their fat reserves after departing from the CPRV (Krapu et al. 1985), we investigated whether the amount of fat cranes accumulated before departing Saskatchewan en route to their breeding grounds had changed since the 1970s. The preference of radio-marked cranes for grasslands relative to other habitats and the disproportionate amount of time spent foraging on macro-invertebrates in grasslands during 1978–1979 (Sparling and Krapu 1994) prompted us to evaluate whether cranes continued to exhibit a preference for grassland, and if adult and juvenile sandhill cranes stored protein during their stay. Because soybeans have replaced corn on about 20% of cropland area in the CPRV, we evaluated occurrence of soybeans in the diet and the effect of expansion of soybean planting on crane daily movements and habitat use. Because post-harvest land use affected availability of corn residues, we compared crane use and evaluated selection for various post-harvest management practices used in cornfields, and compared time budgets by habitat type and year. Finally, we compared diurnal crane use north versus south of I-80 with information from 1978 and 1979 to gain insight into whether distribution of use of foraging areas north of I-80 has increased since the 1970s.

STUDY AREA

We collected locations of platform transmitter terminal (PTT)-marked MCP sandhill cranes between departure from their wintering grounds and arrival on their breeding sites. Breeding ranges, fall migration routes, fall staging areas, and wintering grounds were described previously for the MCP (Krapu et al. 2011). The wintering range was centered in Texas where an estimated 82% of the MCP spends winter. Most remaining

use occurred in Oklahoma, Kansas, eastern and west-central New Mexico, southeastern Arizona, and the Mexican states of Chihuahua, Coahuila, Durango, Tamaulipas, and Zacatecas. Breeding grounds of the MCP extended across parts of 2 continents (North America, Asia), and 3 nations (United States, Canada, and Russia) in temperate grassland, mixed coniferous–deciduous forest, parkland, boreal forest, and tundra. Most breeding sites of the MCP were located in remote northern regions with low human population density.

The exceptional use of the CPRV by sandhill cranes during spring migration is linked, in part, to the extensive high-quality roosting habitat present in the Platte River. The Platte River is a braided river formed where the North Platte River and South Platte River merge in western Nebraska. The Platte River Basin drains an area of about 230,000 km^2 with headwaters of its principal tributaries, the North Platte and South Platte rivers, being east of the Continental Divide in the Rocky Mountains in Colorado. The main channel of the Platte River is wide but generally shallow and surrounded by several narrower, more incised peripheral channels (Fig. 1). The braided channels that characterize the Platte River historically were reshaped during the period of peak discharge in spring coinciding with melting of the snowpack that had accumulated during the previous winter. Flows remained high through May because of the delayed runoff from snow melt in the upper drainages of the North Platte and South Platte rivers. Peak flows historically carried a large sediment load consisting mainly of sand, resulting in an abundance of inundated and exposed sandbars (Williams 1978). Starting in 1909 with the construction of the Pathfinder Dam on the North Platte River in Wyoming, numerous dams and diversions were built causing peak flows to decline to 10–20% of historical levels (Williams 1978).

Our principal field research site was located in the CPRV between Chapman and Lexington, Nebraska (Fig. 1). The study site consisted of 12 adjacent segments, each approximately 10 km by 32 km (16 km north and 16 km south from the main channel of the Platte River). The 12 segments under study were separated by highways leading north and south from I-80 interchanges (Fig. 1). The interstate highway parallels the Platte River on the north side from near Grand Island to Lexington. The Rainwater Basin lies adjacent to the CPRV on the south and encompasses approximately 7,000 km^2. The Rainwater Basin is a major spring staging area for millions of temperate and northern nesting waterfowl, including snow geese (Windingstad et al. 1984).

Dominant habitat types within the CPRV study site were cropland, lowland grassland (including wet meadows), upland grassland, riparian forest, and shrubland. Dominant plant species associated with lowland native grasslands were big bluestem (*Andropogon gerardii*), indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), and sedges (*Carex* spp.), and dominant plant species in the upland grasslands were big bluestem, blue grama (*Bouteloa gracilis*), buffalograss (*Buchloe dactyloides*), and little bluestem (*Schizachyrium scoparium*) (U.S. Fish and Wildlife Service 1981). The distribution of lowland grassland species was determined by depth to ground water, which was determined by topography and local land-management practices (Henszey et al. 2004). Dominant trees of the riparian forests included eastern cottonwood (*Populus deltoides*), green ash (*Fraxinus pennsylvanica*), eastern red cedar (*Juniperus virgianiana*), red mulberry (*Morus rubra*), rough-leaved dogwood (*Cornus drummondii*), and sandbar willow (*Salix exigua*). The shrubland plant community was characterized by a mixture of lowland grassland plants and woody plants such as buffalo berry (*Shepherdia argenta*), false indigo (*Amorpha fruticosa*), rough-leaved dogwood, and eastern red cedar. Detailed descriptions of migratory bird habitats in the CPRV and North Platte River Valley (NPRV) have been published (U.S. Fish and Wildlife Service 1981, Currier et al. 1985).

Land use in the study area was predominantly agricultural, with most cropland planted to corn and most grassland grazed by cattle (Table 1). In the 1990s, about 60% of the land area was irrigated agriculture (U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service 2003). Grassland (both lowland and upland) composed 18% of the CPRV in 1998. Woodlands, mostly occupying former channel, accounted for 7%, shrublands for 1%, and the current wetted channel accounted for 2%. Bridges,

Table 1. Land cover and channel area (ha) by river section of the Central Platte River Valley from 5.6 km west of Overton to Chapman, Nebraska, and extending 5.6 km north and south from the river. Land-cover measurements were based on photography taken in 1998 and percent change reflects differences from 1982 data (see U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service 2003).

River segment[a]	Lowland grasses	Percent change	Upland grasses	Percent change	Alfalfa	Percent change	Corn	Percent change	Other crops	Percent change	Channel area
12	259	−15.4	679	24.4	541	−12.2	2,154	−1.2	350	53.0	261[b]
11	960	51.2	1,319	−4.5	1,666	−25.3	6,437	0.2	1,921	28.2	339
10	629	223.1	1,563	0.3	1,142	−41.9	4,453	−2.0	1,279	127.5	261
9	186	−20.7	4,160	−4.7	1,331	−5.9	5,460	7.7	1,150	−12.0	360
8	600	7.3	958	−3.7	396	−55.2	6,611	2.7	815	39.6	316
7	844	−0.9	1,308	−4.8	629	−26.3	5,827	15.5	409	−51.3	293
6	360	49.8	1,149	11.4	358	−48.7	6,803	6.0	909	−11.8	284
5	288	−3.1	2,717	6.3	208	−35.1	9,755	−0.7	1,448	7.3	383
4	1,134	20.1	1,315	−8.7	239	−43.9	5,054	16.4	853	−41.9	291
3	2,404	32.8	1,180	−8.5	206	−75.8	6,177	7.7	917	−31.5	392
2	1,644	25.9	758	9.2	139	−80.1	6,243	1.1	1,191	14.2	343
1	2,165	62.7	1,967	−24.9	408	−63.7	10,347	9.3	2,216	−16.2	754
Total	11,473	31.7	19,073	−3.9	7,263	−39.9	75,321	5.1	13,458	−3.1	4,276

[a] 12, 5.6 km west of Overton to Overton; 11, Overton to Elm Creek; 10, Elm Creek to Odessa; 9, Odessa to Kearney; 8, Kearney to Minden; 7, Minden to Gibbon; 6, Gibbon to Shelton; 5, Shelton to Wood River; 4, Wood River to Alda; 3, Alda to US 281; 2, US 281 to Highway 34; 1, Highway 34 to Chapman.
[b] Channel area for this segment is calculated for a larger area than 5.6 km west of Overton exit.

developed commercial land, single dwellings, power lines, roads (including I-80), and railroads accounted for 10% of land area.

Land use on the study area varied from east to west. River sections 1–4 (east end) contained more lowland grassland than the other 8 sections combined (Table 1); the water table was higher in the east than in the west and has discouraged conversion of the lowland grassland to cropland. Agricultural land use remained relatively stable from 1982 to 1998 (Table 1); corn increased by 5%, other crops (wheat, soybeans, sorghum) decreased by 3%, and lowland grasses increased by about 32%. The latter increase resulted mainly from landowners putting cropland into the Conservation Reserve Program and also from grassland restoration by The Crane Trust, Nature Conservancy, and National Audubon Society. Land in alfalfa and upland grasses declined by 39% and 4%, respectively.

Habitat conservation for sandhill cranes and whooping cranes (*Grus americana*) in the CPRV has been a priority of conservation organizations for decades. Several large tracts have been purchased and are managed for cranes and other wildlife. As of 2010, The Crane Trust was the largest landholder with 3,644 ha owned in fee title or subject to perpetual conservation easement. In the early 1980s, crane managers began the practices of systematically disking the river bed during dry summers to destroy seedlings and using a Kershaw Clearway or bulldozer to clear mature trees from channels formerly used by cranes (Currier 1984). Nocturnal roosting habitat for cranes along approximately 80 km of river channel owned by conservation organizations and private landowners is improved through mechanical clearing, mowing, and disking on nearly an annual basis (Pfeiffer and Currier 2005).

METHODS

Trapping and Transmitter Deployment

We captured cranes to attach PTTs at numerous sites in the CPRV between Chapman and Lexington, in the Hershey area of the NPRV during late February–early April 1998–2003 (Krapu et al. 2011; Fig. 1) and in the Middle Rio Grande Valley of New Mexico and Sulfur Springs Valley of southeastern Arizona in 2001. The objective of trapping plans was to mark a representative sample of the MCP (see details in Krapu et al. 2011). We trapped additional cranes for marking with very high frequency (VHF) transmitters at most of the same sites between Chapman and Kearney during late February–early April 1998–2006. Trapping sites generally were located in pastures and haylands. We captured birds by using taxidermy-mounted sandhill cranes and rocket-propelled nets (Wheeler and Lewis 1972).

We removed captured cranes from nets immediately and placed them in burlap bags to restrain movement during processing. We weighed each bird to the nearest 10 g and made the following measurements (mm): post-nares culmen, exposed culmen, total tarsus length, and flattened wing chord. We selected adults for PTT attachment based upon plumage characteristics (i.e., bare and reddish forehead, lores, and crowns; Lewis 1979), and marked ≤ 2 cranes from each capture event based on social status (e.g., family groups or pairs) or location under the net (e.g., pairs at opposite ends). We established these criteria to limit the chance of sampling related birds.

Magnitude of trapping effort increased as the percentage of the MCP present increased. Trapping effort and number of cranes captured and marked with PTTs were distributed approximately proportional to the number of birds using each section of river. During 1998–2002, we captured and PTT-marked 133 sandhill cranes that formed a representative sample of the entire population that included birds staging in the NPRV near Hershey. In 2003, we captured and PTT-marked a representative sample of greater sandhill cranes ($n = 22$) to gain more insight into the life history of this less plentiful subspecies (Krapu et al. 2011).

We drew a blood sample from each crane selected to receive a transmitter from the metatarsal vein just below the tibio-tarsus joint and placed it into a storage buffer (0.1 M Tris, 0.1 M EDTA, 5% SDS, 0.01 M NaCl; Longmire et al. 1991) for later DNA extraction to determine sex and mtDNA subspecies (greater sandhill crane or lesser sandhill crane; Jones et al. 2005). Three morphological-based subspecies (Johnson and Stewart 1973) occur in the MCP, greater sandhill crane, Canadian sandhill crane (*G. c. rowani*), and lesser sandhill crane; their distributions were addressed in separate publications (Krapu and Brandt 2011, Krapu et al. 2011).

Four subpopulations were designated for management purposes based on breeding affiliations (east-central Canada–Minnesota [EC–M], western Canada–Alaska [WC–A], western Alaska-Siberia [WA–S], and northern Canada–Nunavut [NC–N]). Birds in the EC–M and WC–A subpopulations were largely greater sandhill cranes, whereas birds in the WA–S and NC–N subpopulations were mostly lesser sandhill cranes (see Krapu et al. 2011 for estimated percentage of each subspecies by subpopulation).

We attached a VHF transmitter (30–32 g, Advanced Telemetry Systems, Inc., Isanti, MN) or PTT (Microwave Telemetry, Inc., Columbia, MD; North Star Science and Technology LLC, Baltimore, MD) to the left leg of selected cranes using a 2-piece leg band. Leg bands consisted of a pair of 7.62-cm, semi-circular, flanged color-coated polyvinyl chloride (PVC; Haggie Engraving, Crumpton, MD). Together, these 2 pieces formed a band with an inside diameter approximately equivalent to United States Geological Survey Bird Banding Laboratory band sizes 8 and 9. Band halves were lined with 1-mm-thick closed-cell neoprene to prevent abrasion and to provide insulation. We secured VHF and PTT leg bands above the tibio-tarsus with the antenna pointing down. Preliminary results indicated this configuration resulted in acceptable levels of signal reception and less stress to birds than backpack harnesses (Ellis et al. 2001).

We released most birds simultaneously within 30 minutes (range: 15–60 min) of capture to maintain any social bonds. We released cranes captured in the evening before sunset or with enough ambient light to enable visual navigation to river roosts. Capture and marking procedures conformed to the recommendations of The Ornithological Council (Gaunt et al. 1997) and followed the protocol in Study Plan 169.02, approved on 13 July 1998 by the Chairman of the Animal Care and Use Committee at Northern Prairie Wildlife Research Center.

Table 2. Numbers of sandhill cranes marked with platform transmitter terminals (PTTs) and very high frequency (VHF) transmitters; number of days PTT-marked sandhill cranes carried transmitters during spring migration (Mar 1998–Jun 2004); and total number of days VHF-marked sandhill cranes staged* at the Platte River, 1998–2007.

	Year of study									
	1998	1999	2000	2001[a]	2002	2003	2004	2005	2006	2007
PTTs										
Active transmitters	5	18	48	61	63	52	20			
Tag-days	267	873	2,572	2,637	3,198	2,109	569			
VHF										
Active transmitters	10	8	36	50	69	128	148	147	141	49
Days staging	207	140	701	1,243	1,613	2,379	2,513	2,603	3,051	1,005

* First 3 days following date of marking deleted for VHF-marked birds.

[a] PTTs were attached to 6 sandhill cranes on wintering grounds in the middle Rio Grande Valley of New Mexico on or near the Bosque Del Apache National Wildlife Refuge ($n = 3$), in south-eastern Arizona on the Whitewater Draw Wildlife Area ($n = 2$) near Elfrida, and adjacent to the Wilcox Playa Wildlife Area near Wilcox ($n = 1$).

Manufacturers programmed PTTs to transmit to satellites every 1, 2, or 4 days during spring migration (Table 2; also see Krapu et al. 2011). Improving technology allowed us to increase frequency of locations as the study progressed. We simultaneously activated PTTs before deployment to ensure synchronization of transmissions. The transmission schedule of PTTs provided a battery life of 16 months and enabled us to evaluate philopatry to stopovers used the previous year. Locations of PTT-marked cranes were resolved by the Argos satellite system (Service Argos 2008) and we processed all locations received through the Douglas Argos-Filter Algorithm version 6.5 combined with further subjective review (see Krapu et al. 2011 for detailed description) to improve the robustness of our final dataset. Fancy et al. (1988) and Harris et al. (1990) provide a more detailed description of the Argos system and its application in tracking wildlife.

The VHF transmitters used in this study were programmable, enabling acquisition of multiple years of data from marked cranes. During 1998–2002, transmitters were programmed to transmit for 60 days after activation, shut down for 305 days and repeat this cycle until the battery failed. During 2003–2006, transmitters were programmed to transmit for 60 days after activation, shut down for 137 days, transmit for 60 days, shut down for 106 days, and then repeat this entire cycle. The latter duty cycle allowed us to track cranes during fall staging in the northern plains as part of another study while enabling us to track them for $\geq$2 staging periods at the Platte River. We synchronized all VHF transmitters to begin transmitting in mid-February to allow us to locate any cranes arriving at the Platte River at the onset of the staging period in subsequent years.

We used standard null-peak systems and Locate II software (Pacer, Truro, Nova Scotia Canada) to estimate all VHF telemetry locations. Beginning in 2001, we used digital compasses mounted to the mast of the null-peak antennas and LOAS software (Ecological Software Solutions LLC, Hegymagas, Hungary). In all years, we used the software to inspect estimated locations and error polygons calculated via triangulation. Before arrival of cranes, we evaluated telemetry receiving systems and operators by analyzing bearing errors obtained as we tuned our vehicle setups using transmitters in known locations. Bearing errors varied among individuals and antenna systems, but the maximum mean error was $\leq 3^{\circ}$. We used a fixed bearing error of 3° in the telemetry software programs that calculated error polygons associated with telemetry locations.

We searched the Platte River corridor each night to determine arrival dates of birds marked in previous years. This monitoring of potentially active transmitters also allowed us to determine staging duration and departure from the CPRV, which we inferred by the absence of birds believed to have departed northward.

Nocturnal Roost-Site Use

We located all VHF-marked cranes (i.e., those marked in the current year or previous years) nightly from approximately 15 February to 15 April on their nocturnal roost sites between Chapman and Kearney (Fig. 1). For newly marked birds, we initiated monitoring on the fourth day following capture to allow for recovery from stress of capture and adjustment to transmitter attachment. The decision to wait 3 days before starting to track cranes was based on information we obtained in previous studies suggesting that cranes generally recover and resume their normal daily activities by the fourth day.

We collected data on distribution of crane roosts using thermal videography (Sidle et al. 1993, Kinzel et al. 2006) during peak staging periods in late March of 1989, 2000–2003, and 2005. During 2000–2003, 2005, we made flights on 3 consecutive nights to document crane distribution on their nocturnal roosts in the Platte River using thermal videography. We flew the entire length of river under study (Chapman to Lexington) each night. We analyzed these data with geographic information system (GIS) software (ArcGIS Desktop 9.3.1; Environmental Systems Research Institute, Redlands, CA) to quantify density and distribution of roosting cranes in the CPRV. We created polygons around groups of roosting cranes and calculated annual crane abundance from the total area of these polygons multiplied by the mean density of cranes on individual roosts (see Kinzel et al. 2006 for more details).

Food Habits and Carcass Nutrient Composition

We collected sandhill cranes throughout the CPRV from early March to early April 1998–1999 by shooting 1 individual per flock while birds were flying between fields or returning to roost sites in the evening. We froze and later thawed collected specimens at a field laboratory to remove food items from the esophagus, determine sex by examination of gonads, and classify

age using plumage development (Lewis 1979). We sorted and identified food samples and dried the samples for 48 hours at 55°C before weighing them to the nearest 0.01 g.

We sent frozen specimens to the University of Western Ontario for body composition analysis. Carcasses were plucked and analyzed for lipids using duplicate petroleum ether extraction with a Soxhlet apparatus and for ash-free lean dry mass (i.e., an index of protein) following standardized procedures (Horwitz 1975, Dobush et al. 1985).

Diurnal Habitat Use, Movements, and Time Budgets in CPRV

We estimated locations of cranes marked with VHF transmitters in areas adjacent to the Platte River during daylight hours using methods described above. We located individuals at least daily in 1 of 3 time periods: departure from roost site until 1000 hours, 1000–1400 hours, and 1400 hours until returning to roost sites. To obtain a representative temporal distribution of diurnal locations of individuals, we located each crane either several times throughout the daylight hours, or once daily but at different time periods in subsequent days. For each diurnal location, we determined habitat type (i.e., cornfield, soybean field, grassland, hayland, and other) and postharvest management of cornfields (i.e., stubble, grazed, disked, mulched, and other).

We monitored a sample of VHF-marked cranes at 30-minute intervals or when a change in habitat occurred (e.g., detected using GIS, or signal indicated bird flew) during 2002–2007. During this constant monitoring, we attempted to maintain visual contact of the marked bird and collect behavior data at 10-second intervals until we lost visual contact.

We established 8 belt transects (hereafter transects) in the CPRV where sandhill cranes were most concentrated (Krapu et al. 2005*a*) to estimate distances cranes foraged from the river, compare diurnal use north and south of I-80, and monitor annual changes in crop composition and land use. Each transect was 32.2 km long, and extended 16.1 km north and 16.1 km south from the main channel of the Platte River. We divided each transect into 80 quadrants that were 800 × 400 m in size on each side of maintained roads. We determined land-use and post-harvest management within quadrats before initiating crane surveys. We surveyed sandhill cranes in each quadrat by driving the survey route, starting at 0800 Central Standard Time (CST), and stopping as needed to conduct surveys. We conducted surveys each Tuesday, weather permitting, beginning in the third week of February and continuing through the second week of April 1998–2001. In 1998, we conducted only 7 surveys, and the last was during the first week of April.

We collected time-budget data in the major areas of crane use in the CPRV throughout the staging period in 1998 and 1999. We distributed our efforts among the major habitats used by cranes to ensure an adequate sample size for comparing habitats. We observed cranes through use of spotting scopes and recorded behaviors of focal birds at 10-second intervals for 5 minutes. At the end of an observation period, we summarized data and selected a new focal bird by locating a group of cranes in the field of view of the spotting scope, looking away and slightly moving the scope horizontally and vertically, and selecting the individual nearest the center of the field of view. Our criteria for determining number of focal birds to sample from 1 flock and habitat type was 10% of the number of cranes using a particular site or a maximum of 25 focal birds per flock. Time budget observations occurred from 0630 hours to 2000 hours CST (1998–1999, 2004–2007). Behavioral categories included resting (sitting or standing still), feeding, alert, walking, preening, and other.

Data Analyses

In general, summary statistics relating to spatial locations are presented as spatial medians, whereas central tendencies for univariate data are presented as means. We presented standard errors when precision of estimates (e.g., means) was of interest, otherwise estimates of standard deviations or ranges were used to convey variation observed in the population of interest.

We summarized progress of crane migration during spring by first calculating an average daily location for each crane from all locations received each day weighted by their location class (Krapu et al. 2011). We classified all daily locations by calendar week in which they occurred (1–52, beginning 1 Jan). Because coordinates averaged across large distances can often fall far outside the actual migration corridor, we represented weekly subpopulation movements using median coordinates. Transmission cycles during migration varied among birds from approximately daily to every 5 days; therefore, we first calculated median weekly locations for each crane, creating a dataset where cranes provided equal weight each week. From individual weekly locations, we calculated a median location by subpopulation. Wintering and breeding grounds were designated uniquely for each subpopulation and reported by Krapu et al. (2011).

We estimated patterns and length of stay by first calculating the daily proportion of VHF-marked cranes present in the CPRV each year (i.e., number of marked cranes present divided by the total number of marked cranes that were ultimately detected arriving in that year). We expressed crane migration chronology as estimated numbers of cranes by multiplying daily proportions by 500,000, which was the estimated number of cranes in the MCP using the CPRV during this time period (Kinzel et al. 2006).

For VHF-marked cranes detected in the CPRV during spring migrations after marking, we estimated yearly and subspecies-specific arrival dates, staging duration, and departure dates using general linear models (GENMOD procedure; SAS Institute, Inc., Cary, NC). We used pairwise *t* tests when making comparisons and report means and standard errors from linear models. We determined relationships between arrival dates and staging duration of individual cranes by calculating Pearson correlation coefficients for each subspecies. We also calculated correlation coefficients of average annual departure date and average minimum daily temperature during mid-March through mid-April (15 Mar–15 Apr) for each subspecies. Using a subset of chronology data that included only birds in which we had 2 complete years of information, we examined if individual cranes were consistent between years in arrival dates, staging durations, and departure dates compared with other cranes in the population. The dataset included 2 observations for each individual bird and the year that the bird was initially observed. Using a general linear model (PROC GLM; SAS Institute, Inc.), we compared variation in observations among individuals with

variation within individuals, wherein rejecting a null hypothesis provided evidence that individual birds showed more consistent behaviors (i.e., lower variance) when compared among other birds in the population.

Using aerial infrared video data from nocturnal flights, we quantified density and distribution of roosting cranes in the CPRV. We represented the Platte River as a single linear channel extending from Chapman to Lexington and divided the channel into 50-m segments beginning at the Chapman bridge. We assigned roosting cranes to these 50-m segments for calculations of density and distribution. We also classified roosts used by VHF-marked cranes to 3.2-km segments of the river and computed overlap indices (Fieberg and Kochanny 2005) for all birds for which we obtained multiple years of roost data. We estimated the probability of a crane using the same segment of the river in multiple years ($PHR_{i,j}$) by summing the probability of use in year *j* across river segments used in both years *i* and *j*. We then calculated summary statistics for these probabilities for each multiyear combination.

We determined diet by calculating percentage occurrence and aggregate percentage of total dry weight (Reinecke and Krapu 1986). Structural sizes of cranes exhibit wide variation across both sex and subspecies; therefore, we included the first principal component from the correlation matrix of 3 structural body measurements (flattened wing chord, post-nares culmen, and total tarsus; an index of body size; Alisauskas and Ankney 1987) as a covariate in analyses of total body mass, fat, and protein. For each analysis, we ran sample-specific principal components analyses and the first principal component explained 80–83% of variation in these 3 variables. We used general linear models (GENMOD procedure, SAS Institute, Inc.) to examine differences in total body fat in relation to date by sex and age, and used *t* tests for comparisons between years and ages. To illustrate differences among subpopulations and between sexes within subpopulations, we used PTT-marked cranes of known subpopulation to calculate an average value of the first principal component. We predicted estimates and standard errors from linear models for each subpopulation using the average relative body size for a crane from each subpopulation and sex (−1.56, WA–S female; −0.13, WA–S male; −1.83, NC–N female; −0.46, NC–N male; 0.04, WC–A female; 1.58, WC–A male; 1.29, EC–M female; 2.67, EC–M male). We used an average arrival date of 13 March and departure date of 3 April. We also estimated mean lipids of a sample of 29 adult cranes collected during 29 April–11 May 2002 in central Saskatchewan.

We estimated habitat use from multiple observations of individual birds. To account for lack of independence among multiple observations of the same individual, we constructed a dataset by averaging observations by bird and derived final estimates weighted by the number of observations collected for each bird. We expressed diurnal habitat use as percentage of observations occurring within each habitat type. For all observations in cornfields, we calculated use of different postharvest practices similar to overall habitat use. Diurnal habitat use also was expressed in 2-hour time intervals throughout the day. We derived year-specific habitat availability from National Agricultural Statistics (National Agricultural Statistics Service 2002–2007). We used a 4.5-km buffer surrounding the Platte River and calculated percentages of habitat categories within this area for springs 2003–2006. We estimated availability of postharvest practices in cornfields by year (1998–1999, 2001–2006) from ground transect survey data. We estimated resource selection ratios for habitats, where resulting ratios >1 reflect selection and values <1 reflect avoidance (Manly et al. 2003).

We conducted 2 analyses to investigate crane diurnal distribution in relation to I-80. We identified cranes observed on ground transects as occurring north or south of I-80 and calculated an overall percentage (averaged across years, 1998–1999, 2001–2006) and mean use by transect. We also explored distribution of VHF-marked cranes with a logistic regression (GLIMMIX procedure; SAS Institute, Inc.). In this analysis, location in relation to I-80 (north = 1, south = 0) was the dependent variable and day of the year (Julian day) was the independent variable. Because we used multiple locations for each bird and across multiple years, we included bird identity and year as random effects.

To explore movements of cranes throughout the day, we summarized Euclidean distances between locations of constantly monitored VHF-marked cranes. We estimated an overall movement distance between successive use locations when birds flew between sites. We also calculated mean movement distances to each habitat type of interest (i.e., river, grassland, cornfield, soybean field). We compared these movement distances with those reported by Sparling and Krapu (1994) using *t* tests to compare mean distances moved to comparable habitat types, where individual birds were considered independent observations. Additionally, we conducted a multiple linear regression to explain variation in total distance moved over an observation period (GENMOD procedure, SAS Institute, Inc.). Independent variables used in this analysis included elapsed observation time (min), time period (morning, afternoon, or evening), subspecies (greater or lesser sandhill crane), position in relation to I-80 (north or south), normalized index of roosting cranes based on infrared videography (z-score = [observed − mean density]/SD), year (2003–2007), and Julian day. Finally, we included 4 variables to describe the landscape within which cranes moved by calculating percentage of grassland, soybeans, human development, and woodlands within an 800-m buffer surrounding locations used by cranes and the movement corridor between locations. We used backwards selection to remove dependent variables ($\alpha < 0.10$) and made inferences based on the reduced model. Finally, we estimated average time of day and minutes in relation to sunrise or sunset of constantly monitored birds moving off river roost sites in the morning or back to roost sites at the end of the day.

We summarized time-budget data using 5-minute observation sessions of individual cranes as the sample unit. We summed categories of activity and divided the sum by the total activity count to obtain the proportions of time spent in each activity. We calculated yearly and habitat-specific means and standard errors and used overlap of 95% confidence intervals to make inferences.

RESULTS

We captured and marked 169 sandhill cranes with PTTs in the CPRV and NPRV during 1998–2003, and at sites on the

wintering grounds in west-central New Mexico and southeastern Arizona in 2001 (Table 2). We monitored an average of 38 marked cranes annually (Table 2). Of the representative sample of PTT-marked birds captured in the CPRV, 42% were greater sandhill cranes and 58% were lesser sandhill cranes. Over 7 years, we monitored 169 individual cranes in the CPRV and NPRV, and 159 PTT-marked cranes migrated to the breeding grounds with functioning transmitters. Seventy-four sandhill cranes with functioning PTTs migrated from their wintering grounds to the CPRV and NPRV in spring (3 returned a third year for a total of 77 migration-years). The mean number of PTT-marked cranes tracked each year while in the CPRV and NPRV, to the breeding grounds, and from the wintering grounds to the CPRV and NPRV was 34, 31, and 13 (SD = 22, 20, 10, range = 5–58, 4–53, 1–28), respectively. Overall, the median duration of tracking of PTT-marked cranes was 321 days (0.88 yr; range: 0.02–2.29 yr). We tracked 75 individuals for $\geq$1 year and cranes carried functioning PTTs for 51,468 days or 141 crane-years. Tracking of cranes yielded 24,528 Argos-determined locations with the greatest number of cranes monitored during March–June. Tracking occurred from late winter on the wintering grounds to arrival on the breeding grounds, which occurred from mid-April to early June.

We attached VHF transmitters to 456 cranes in the Chapman-to-Kearney reach during 1998–2006 and they staged a total of 15,455 days in the CPRV (Table 2). Mitochondrial DNA analysis revealed that 65% were *G. c. canadensis* and the remaining 35% were *G. c. tabida*. Sex composition of the marked sample was 51% female and 49% male. We monitored arrival and subsequent departure from the CPRV in years following initial capture for 305 (67%) marked birds. Moreover, 54 cranes contributed multiple years of migration chronology data. Tracking of 403 cranes yielded 14,258 locations suitable for diurnal habitat use and nocturnal roost analyses. The error polygons (95% confidence ellipses) of telemetry locations averaged 4.0 ha (range <0.1–91.8 ha).

Chronology and Routes of Spring Migration

Cranes in the EC–M subpopulation spent winter primarily along the upper Texas Gulf Coast (Fig. 2A) and marked cranes, on average, departed their wintering grounds in Texas by 2 March ($n = 19$). Migration routes of EC–M cranes converged into a relatively narrow corridor in north-central Texas, and continued through western Oklahoma and central Kansas (Fig. 2A) en route to their principal spring staging area in the eastern CPRV. The average arrival date of EC–M cranes in the CPRV was 12 March (Table 3). The median wintering ground location was near the Gulf Coast and they moved to north-central Texas during 26 February–4 March (week 9 [numbered week of year]). From there, the birds moved northward during 5–11 March (week 10) into west-central Oklahoma (Fig. 3). By 12–18 March (week 11), the median location of the EC–M subpopulation was in the CPRV, where most birds remained during 19 March–1 April (weeks 12, 13). Four EC–M cranes staged an average of 11 $\pm$ 2.2 (SE) days (Fig. 4) while en route to the CPRV, 3 in the vicinity of Quivira National Wildlife Refuge (NWR) in central Kansas, and 1 near Anadarko, Oklahoma (Fig. 4).

The average date of departure of EC–M cranes from the CPRV was 3 April (Table 3). During 2–8 April (week 14), EC–M crane distribution was centered 300 km north of the CPRV in southeastern South Dakota (Fig. 3). By 9–15 April (week 15), the median location of EC–M cranes had moved 283 km north into eastern North Dakota. The migration corridor widened as birds crossed through eastern South Dakota and North Dakota (Fig. 2A). Seven EC–M cranes staged an average of 10.5 + 1.7 days in North Dakota and 4 staged 14.7 $\pm$ 2.7 days in Minnesota. By 16–22 April (week 16), the median location of EC–M cranes was centered in northeastern North Dakota, or 243 km north of the previous week. By 23–29 April (week 17), the distribution of EC–M cranes had moved 247 km into southeastern Manitoba (Fig. 3), suggesting many had either reached spring stopovers or had arrived at breeding sites in Manitoba, southwestern Ontario, or northwestern Minnesota (Fig. 2A). By 30 April–6 May (week 18), the median location was in west-central Ontario, 353 km northeast of the previous week suggesting marked cranes breeding in the James Bay Lowlands were en route or had arrived at their breeding grounds distributed from northeastern Manitoba to western Quebec. Marked sandhill cranes of the EC–M subpopulation, on average, arrived on breeding grounds by 23 April, or 20 days after departure from the CPRV.

The WC–A subpopulation spent winter primarily in western and central Texas (Fig. 2B) and about 18% of the tagged cranes wintered on the Texas Gulf Coast. Spring migration began during week 9 (mean departure date = 9 Mar, $n = 20$) with most birds still on or near their wintering grounds (Fig. 3). The migration of WC–A cranes followed a corridor across the Oklahoma panhandle or another through central Oklahoma with the 2 merging in north-central Kansas (Fig. 2B). By 5–11 March (week 10), the median location of the subpopulation was in west-central Oklahoma (Fig. 3). By 12–18 March (week 11), the median location was situated in the CPRV. Three WC–A cranes staged an average of 9 $\pm$ 1.9 days in the vicinity of Quivira NWR in central Kansas (Fig. 4) before reaching the CPRV, where they settled primarily from Chapman to Shelton (Table 4). The birds remained in the CPRV during 19 March–8 April (weeks 12–14) for an average residence time of 24 days (Table 3).

The mean date of departure of WC–A cranes from Nebraska staging areas was 7 April (Table 3). By 9–15 April, the median location of WC–A cranes was located in north-central South Dakota, 489 km north from their Nebraska staging area (Fig. 3). The migration corridor encompassed a large part of central and eastern Nebraska and South Dakota. In South Dakota, the birds' flight path turned northwest as the birds crossed central and northwestern North Dakota (Fig. 2B). Four WC–A cranes staged an average of 10.5 $\pm$ 2.2 days in North Dakota. The migration corridor of WC–A cranes continued in a northwestern direction on entering Saskatchewan but increased in breadth and extended from southeastern to south-central parts of the province. The width of the migration corridor in Saskatchewan reflected the broad distribution of breeding locations, which extended from extreme western Manitoba to western Alberta (Fig. 2B). Subarctic-nesting WC–A cranes stopped in Saskatchewan an average of 12 days before continuing on a northwest course through Saskatchewan and onto breeding grounds in northern Alberta, northeastern British Columbia, eastern Yukon

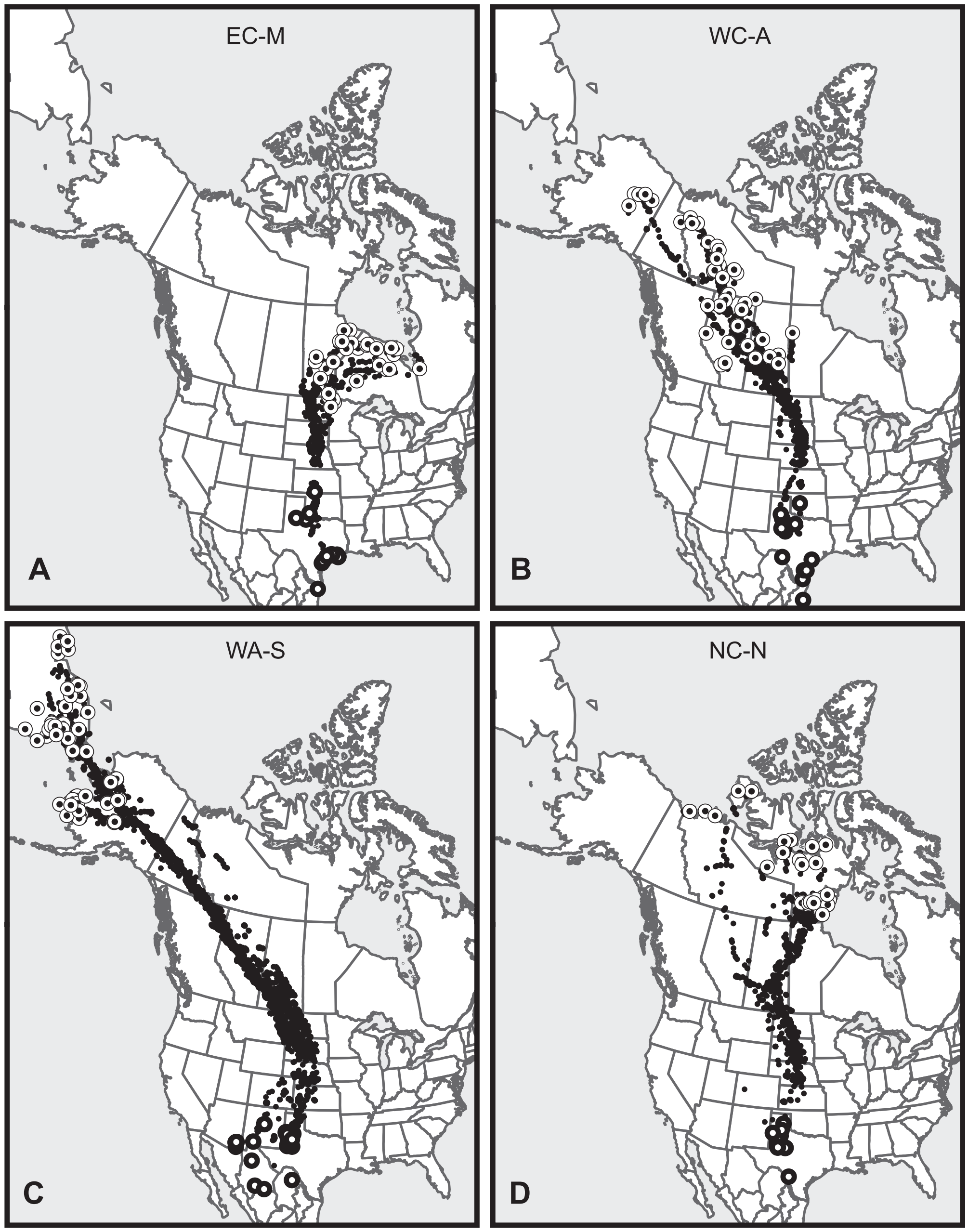

Figure 2. Spring migration routes of platform transmitter terminal (PTT)-marked sandhill cranes of the 4 subpopulations of the Mid-Continent Population: (A) east-central Canada–Minnesota (EC–M), (B) west-central Canada–Alaska (WC–A), (C) western Alaska–Siberia (WA–S), and (D) northern Canada–Nunavut (NC–N) based on distribution of their PTT locations during springs 1998–2004. Closed circles with white rings represent breeding sites of marked individuals of each subpopulation and open circles represent wintering locations.

Territory, and east-central Alaska (Fig. 2B). The mean arrival date of WC–A cranes on subarctic breeding grounds was 30 April, 23 days after departing from the CPRV.

Primary wintering grounds of the WA–S subpopulation are located in western Texas but the winter range extended across a wide area of the southwestern United States and northern Mexico (Fig. 2C). Spring migration from wintering grounds began in late February (mean departure date = 6 Mar, $n = 25$); by 26 February–4 March (week 9), the median location had moved only 161 km, indicating many cranes remained on the wintering grounds (Fig. 5). By 5–11 March (week 10), the median location for WA–S cranes moved 744 km across the Oklahoma Panhandle through southwestern and central Kansas arriving in the CPRV or NPRV (Fig. 5), where their distribution was centered through 4–10 April (week 14). Cranes in this subpopulation that wintered in southeastern Arizona and west-central New Mexico migrated northeast from their wintering grounds across south-central Colorado. Two birds staged near the Monte Vista NWR in the San Luis Valley of Colorado for 23 ± 3.3 days (Fig. 4 and Table 3) before migrating on to staging areas in the NPRV near Hershey and the upper end of Lake McConaughy near Lewellen, Nebraska. The migration of WA–S cranes from the wintering grounds to the Platte River averaged 9 days with the average arrival date being 14 March (Table 3). On average, WA–S cranes stayed in the CPRV for 28 days (13 Mar–11 Apr; Table 3).

Table 3. Migration chronology from wintering to breeding grounds of platform transmitter terminal (PTT)-marked sandhill cranes of the Mid-Continent Population by subpopulation (western Alaska–Siberia [WA–S], northern Canada–Nunavut [NC–N], west-central Canada–Alaska [WC–A], and east-central Canada–Minnesota [EC–M]), including mean dates of arrival, departure, and duration of stay at major staging areas. We captured PTT-marked sandhill cranes during springs 1998–2004 while cranes were on spring staging areas in the Central Platte River Valley (CPRV; $n = 139$) and North Platte River Valley (NPRV; $n = 24$) in Nebraska, and on winter grounds in west-central New Mexico ($n = 3$) and southeastern Arizona ($n = 3$) in 2001. We defined staging as a bird remaining in a small geographic area for ≥5 consecutive days.

Migration segment status	**Beginning date**[a]			**Ending date**[a]			**Duration (days)**		
Breeding affiliation	***n***	$\bar{x}$	**SE (days)**	***n***	$\bar{x}$	**SE (days)**	***n***	$\bar{x}$	**SE**
Winter grounds to Platte River									
Migration									
Western Alaska–Siberia	25	6 Mar	1.6	26	14 Mar	1.5	24	9	1.4
Northern Canada–Nunavut	7	9 Mar	3.1	8	20 Mar	3.8	6	11	2.4
West-central Canada–Alaska	20	9 Mar	2.1	19	13 Mar	2.1	19	7	0.7
East-central Canada–Minnesota	19	2 Mar	2.4	19	12 Mar	1.6	19	11	1.9
Staging[b]									
Western Alaska–Siberia	2	10 Mar	1.5	3	25 Mar	6.5	2	23	3.3
Northern Canada–Nunavut	1	4 Mar		1	24 Mar		1	21	
West-central Canada–Alaska	3	12 Mar	4.8	3	20 Mar	3.1	3	9	1.9
East-central Canada–Minnesota	4	3 Mar	4.1	4	13 Mar	2.3	4	11	2.2
Platte River (in CPRV unless indicated otherwise)									
Staging									
Western Alaska–Siberia	26	14 Mar	1.5	80	10 Apr	0.5	23	27	1.5
CPRV	14	13 Mar	1.4	48	11 Apr	0.6	12	28	1.6
NPRV	12	15 Mar	2.8	31	10 Apr	1.0	11	26	2.5
Northern Canada–Nunavut	8	20 Mar	3.8	38	13 Apr	0.7	8	23	3.7
CPRV	8	20 Mar	3.8	35	13 Apr	0.7	8	23	3.7
NPRV				2	17 Apr	1.8			
West-central Canada–Alaska	19	13 Mar	2.1	59	7 Apr	0.7	17	24	2.4
East-central Canada–Minnesota	19	12 Mar	1.6	48	2 Apr	0.9	17	18	2.4
Platte River to breeding grounds									
Migration									
Western Alaska–Siberia	80	11 Apr	0.5	75	16 May	0.9	72	36	1.0
Northern Canada–Nunavut	37	13 Apr	0.8	32	25 May	1.8	32	43	1.7
West-central Canada–Alaska	59	7 Apr	0.7	57	30 Apr	1.5	55	23	1.4
East-central Canada–Minnesota	48	3 Apr	0.9	47	23 Apr	1.8	46	22	1.5
Staging									
South Dakota									
Western Alaska–Siberia	1	10 Apr		1	20 Apr		1	11	
Northern Canada–Nunavut	1	14 Apr		1	18 Apr		1	5	
West-central Canada–Alaska[c]	22	3 Apr	1.1	21	12 Apr	0.9	20	10	0.9
East-central Canada–Minnesota[d]	31	2 Apr	1.0	30	11 Apr	1.2	30	11	0.9
Saskatchewan and Alberta									
Western Alaska–Siberia	79	17 Apr	0.6	78	3 May	0.5	75	17	0.6
Northern Canada–Nunavut	36	20 Apr	0.8	34	14 May	0.6	33	25	0.8
West-central Canada–Alaska	44	17 Apr	0.8	44	28 Apr	0.9	44	12	0.7
East-central Canada–Minnesota	1	16 Apr		1	26 Apr		1	11	

[a] We did not include cranes with location intervals >10 days between sequential locations.
[b] All in Kansas except 1 WA–S in Colorado, and 1 EC–M in Oklahoma.
[c] Forty percent of WC–A crane spring migrations included staging in eastern South Dakota.
[d] Seventy-four percent of EC–M crane spring migrations included staging in eastern South Dakota.

The average dates of departure of WA–S cranes from CPRV and NPRV were 11 April and 10 April, respectively (Table 3). During 9–15 April (week 15), the median location of WA–S cranes moved northwest into west-central South Dakota (Fig. 5). When departing the CPRV and NPRV, WA–S cranes migrated along a broad corridor that extended across western and central Nebraska and South Dakota, western North Dakota, the northeastern corner of Wyoming, and eastern Montana (Fig. 2C). The broad migration corridor of WA–S cranes was linked to their wide staging distribution along the Platte (Table 4) and North Platte rivers (Fig. 4) in Nebraska. By 16–22 April (week 16), the median location of WA–S cranes had moved northwest 979 km from the previous week to their second major staging area in west-central Saskatchewan (Fig. 5). The location of marked WA–S cranes remained centered on Saskatchewan and Alberta staging areas during 16–29 April (weeks 16 and 17), and only a few birds left for the breeding grounds by 30 April–6 May (week 18) as suggested by a small change in median location (Fig. 5). After departing from their Saskatchewan staging area, the birds continued on a northwestern course within a relatively narrow migration corridor, crossing diagonally from east central to northwest Alberta and northeastern British Columbia (Fig. 2C). During 7–13 May (week 19), the median location moved 1,611 km northwest into south-central Yukon Territory. This represented the longest median movement achieved by any MCP subpopulation and indicated that virtually all the birds in this subpopulation had left Saskatchewan. On 14–20 May (week 20), the median location had moved to the Seward Peninsula in western Alaska, 1,686 km northwest of the previous week. During 21–27 May (week 21) all birds in this

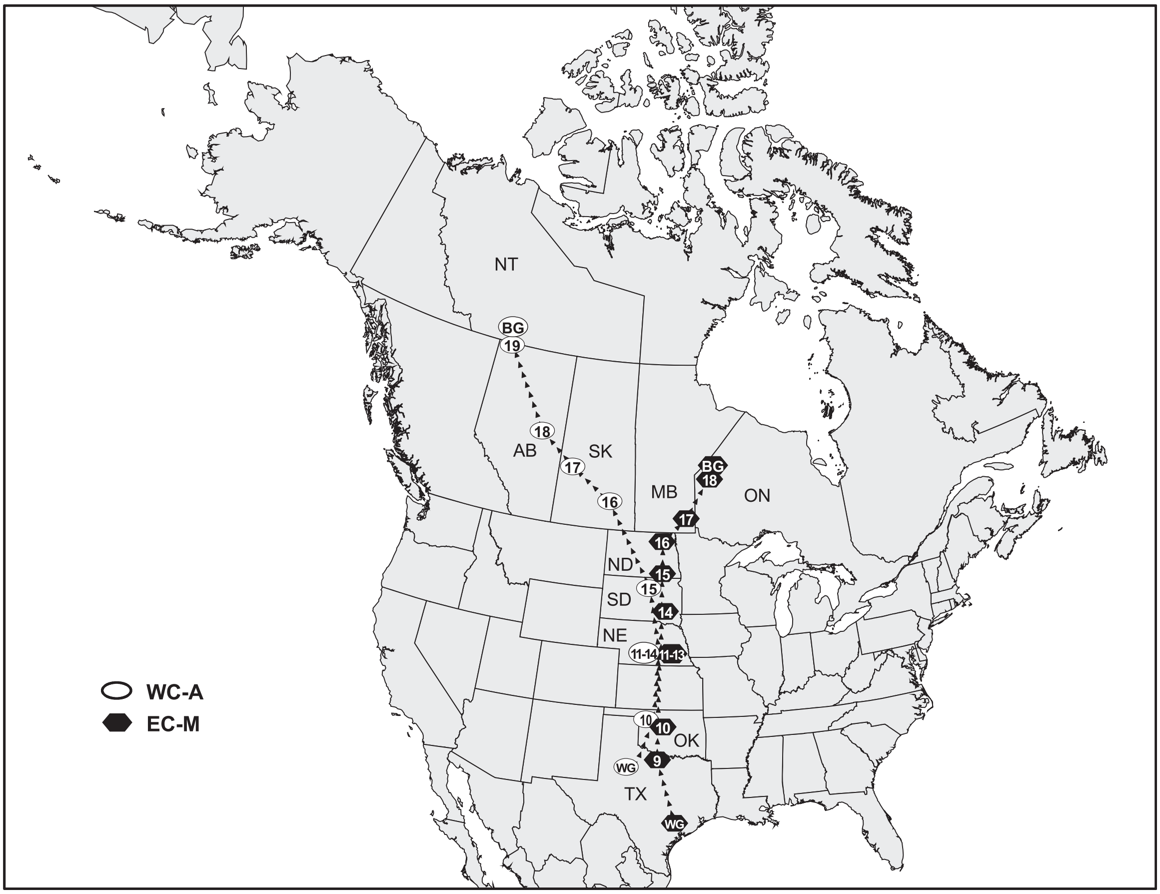

Figure 3. Median weekly locations (e.g., 1–7 Jan = week 1) of platform transmitter terminal (PTT)-marked sandhill cranes of the east-central Canada–Minnesota (EC–M) and west-central Canada–Alaska (WC–A) subpopulations during migration from their wintering grounds (WG) to breeding grounds (BG) 1998–2004.

subpopulation, including those breeding in arctic Russia, had arrived on breeding grounds 36 days after departing from Nebraska staging areas (Table 3). The median location of the distribution of WA–S cranes was in northeastern Russia along the coast of Chukotka (Fig. 5).

The wintering grounds of NC–N cranes were located principally in western Texas (Fig. 2D). The NC–N subpopulation, after departing from their primary wintering grounds (mean date = 9 Mar, $n = 7$; Table 3) moved northeast. By 26 February–4 March (week 9), the median location was along the Red River on the Oklahoma–Texas border (Fig. 5). During 5–11 March (week 10), the median location of NC–N cranes was just south of the CPRV, indicating that, like with the WA–S subpopulation, spring migration to the CPRV for NC–N cranes is relatively rapid. The migration corridor crossed the Oklahoma Panhandle into southwestern Kansas and then north-central Kansas en route to the CPRV (Fig. 2D), where NC–N cranes were widely distributed (Table 4). One NC–N crane staged for 21 days in southwestern Kansas near Garden City (Fig. 4) before continuing on to the CPRV. The NC–N cranes arrived in the CPRV, on average, on 20 March ($n = 8$), and spent 11 days migrating from the wintering grounds (Table 3). The median location of NC–N cranes remained in the CPRV during 12 March–15 April (weeks 11–15).

The average date of spring departure of NC–N cranes from the CPRV was 13 April (Table 3), and the birds' median location during 16–22 April (week 16) was 958 km northwest from Nebraska in southern Canada near their central Saskatchewan staging area, where they largely remained for 3 weeks (Fig. 5). During 14–20 May (week 20), the median location of NC–N cranes moved 596 km north near the border of northeastern Saskatchewan and the southeast corner of the Northwest Territories (Fig. 5). By the week of 21–27 May (week 21), the median location was in central Nunavut, about 628 km northeast of the previous week (Fig. 5). The latter site was near the median location of the breeding grounds of this subpopulation, which extend from along the northwest side of Hudson Bay, westward along the arctic coast of Canada into parts of the Canadian Archipelago (Fig. 2D). When departing for their Nunavut breeding grounds from staging areas in central Saskatchewan, NC–N cranes migrated across a broad corridor extending from central to eastern Saskatchewan as the birds moved northeast to enter northwestern and north-central Manitoba en route to their breeding grounds (Fig. 2D). The NC–N cranes breeding farther west in arctic Canada followed more western routes, and some crossed Alberta into the Northwest Territories before continuing on to the arctic coast. The NC–N cranes arrived on breeding grounds on 25 May, which was 43 days after departing Nebraska staging areas (Table 3).

In summary, EC–M and NC–N cranes took the longest to reach the CPRV, averaging 2–4 days more than the other subpopulations. Mean arrival dates of the 4 subpopulations in the CPRV varied by 8 days (Table 3). Overall, WA–S, NC–N, WC–

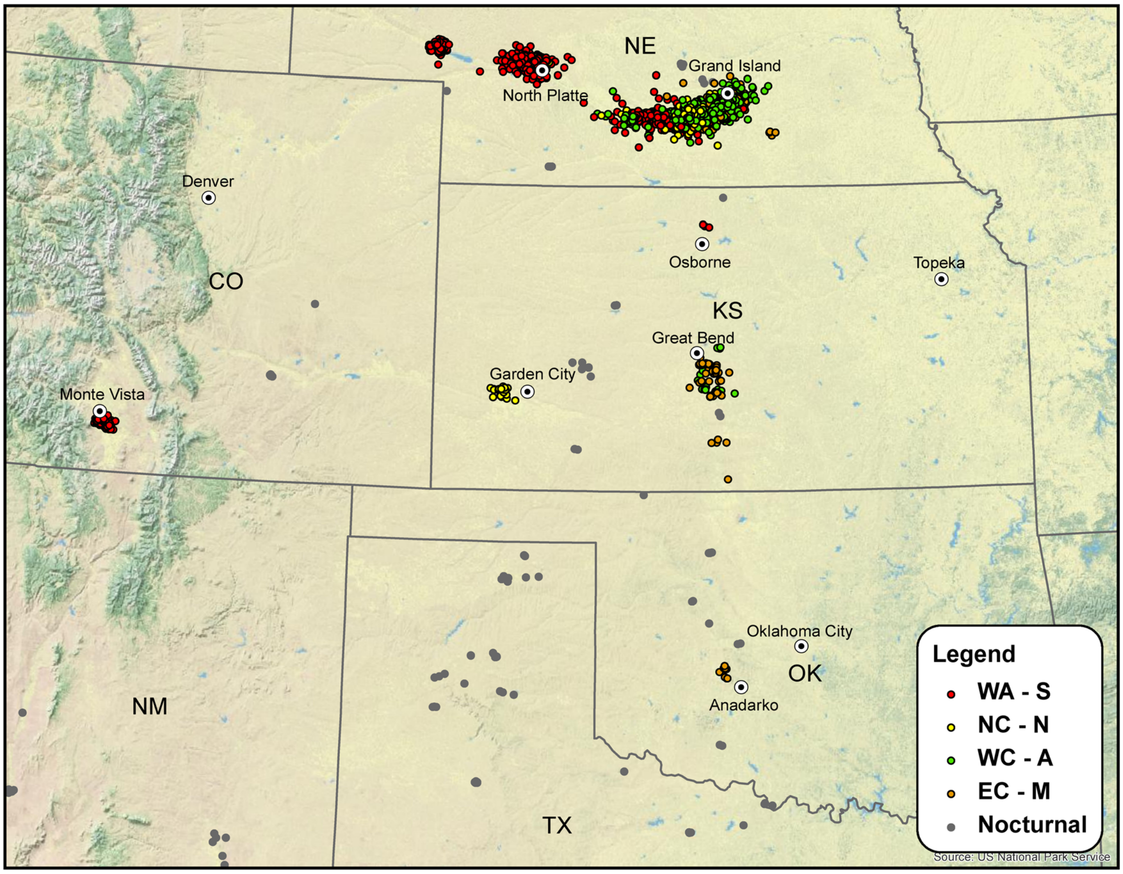

Figure 4. Distribution of locations of platform transmitter terminal (PTT)-marked sandhill cranes of the east-central Canada–Minnesota (EC–M), west-central Canada–Alaska (WC–A), western Alaska–Siberia (WA–S), and northern Canada–Nunavut (NC–N) subpopulations during stopovers in Oklahoma, Kansas, and along the Central Platte River and North Platte River in south-central Nebraska, March–April 1998–2004. Locations where PTT-marked individuals stopped for ≥5 days are represented by larger color-coded symbols that identify subpopulation status of each marked crane. The gray dots identify sites used by marked individuals from the Mid-Continent Population for 1–4 nights between 2200 and 0500 hours.

A, and EC–M subpopulations spent an average of 9, 11, 7, and 11 days migrating from wintering sites to Nebraska staging areas, and as a subpopulation, moved 907, 939, 945, and 1,289 km, respectively. Fifty-seven percent of WA–S and NC–N (mostly lesser sandhill cranes), arrived in the CPRV by 15 March, whereas only 37% of WC–A and EC–M (mostly greater sandhill cranes) were present by that date. Sandhill cranes from the NC–N subpopulation accounted for 60% of MCP cranes arriving in the CPRV after 1 April. Nine of 97 PTT-marked sandhill cranes (9.2%) used both the CPRV and NPRV within or between years (Appendix B).

Cranes in the EC–M subpopulation were the first to depart from the CPRV, averaging 8 and 10 days before WA–S and NC–N sandhill cranes and 4 days earlier than the WC–A subpopulation (Table 3), based on PTT-marked individuals. The earlier departure of EC–M cranes from the CPRV was associated with a residence time that was 5–10 days shorter than other subpopulations (Table 3). The PTT-marked WA–S, NC–N, WC–A, and EC–M cranes spent an average of 72, 77, 52, and 53 days in spring migration of which 28 (39%), 23 (30%), 24 (46%), and 18 (34%) days, respectively, were spent staging in the CPRV. The EC–M subpopulation spent 26%, 42%, and 37% less time in the CPRV than did the WC–M, WA–S, and NC–N subpopulations, respectively, because of an earlier departure (Table 3). Based on 133 PTT-marked cranes forming a random sample of sandhill cranes that were trapped in the CPRV and NPRV in springs 1998–2002, we estimated that 14%, 23%, 21%, and 42% of the MCP were from the EC–M, WC–A, NC–N, and

Table 4. Percentage of platform transmitter terminal-marked crane locations of Mid-Continent Population sandhill cranes by subpopulation (western Alaska–Siberia [WA–S], northern Canada–Nunavut [NC–N], west-central Canada–Alaska [WC–A], and east-central Canada–Minnesota [EC–M]) in 3 sections of the Central Platte River Valley, Nebraska and in the Hershey area of the North Platte River Valley, Nebraska during spring staging, 1998–2004.

	Percentage of use[a]			
Section of river	**WA–S ($n = 64$)**	**NC–N ($n = 29$)**	**WC–A ($n = 41$)**	**EC–M ($n = 30$)**
Chapman to Shelton	24.4	32.6	76.8	97.8
Shelton to Kearney	31.1	43.7	21.0	1.2
Kearney to Lexington	10.6	15.4	1.3	0.0
Hershey to Lewellen (North Platte)	33.5	8.0	0.0	0.0

[a] Column totals do not sum to 100% because all locations were not in river sections listed.

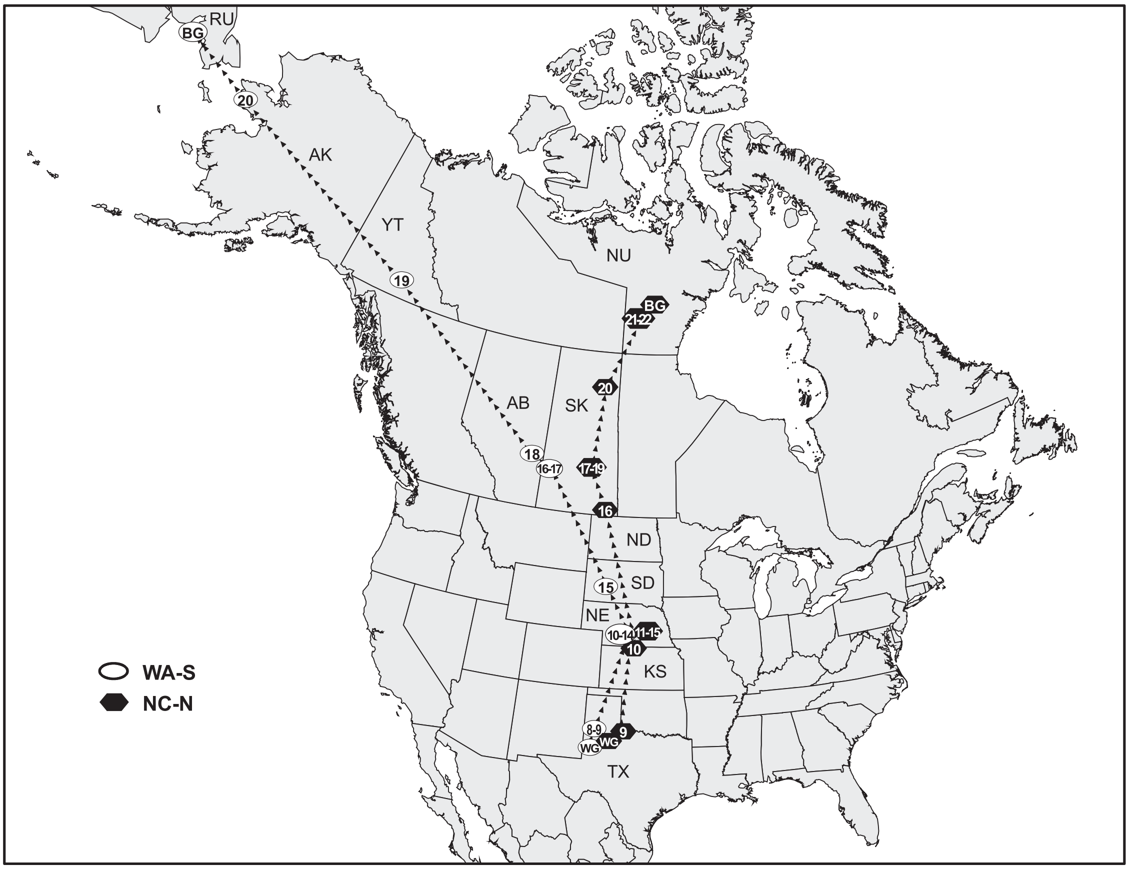

Figure 5. Median weekly locations (e.g., 1–7 Jan = week 1) of platform transmitter terminal (PTT)-marked sandhill cranes of the western Alaska–Siberia (WA–S) and northern Canada–Nunavut (NC–N) subpopulations during migration from their wintering grounds (WG) to breeding grounds (BG) 1998–2004.

WA–S subpopulations, respectively (Krapu et al. 2011). Distribution of the 4 subpopulations varied among the 3 reaches of the CPRV (Table 4); 98% of marked EC–M cranes and 77% of marked WC–A cranes occurred within the Chapman-to-Shelton reach (Table 4). Only about 1% of WC–A sandhill cranes occurred in the Kearney-to-Lexington reach. Three-quarters of the NC–N subpopulation and 56% of the marked WA–S cranes were located in the Chapman-to-Kearney reach. The remaining 44% of WA–S cranes occurred in the Kearney-to-Lexington reach and in the NPRV upstream from North Platte near Hershey.

Fidelity to staging areas was high for all 4 subpopulations. All 74 PTT-marked cranes that migrated north from the wintering grounds in the year after tagging returned to either the CPRV or NPRV. Seventy-seven percent ($n = 13$) of WA–S, 100% ($n = 9$) of NC–N, 100% ($n = 20$) of WC–A, and 100% ($n = 19$) of EC–M cranes that migrated to Nebraska in the year after tagging in the CPRV returned to stage in the CPRV in spring. The 3 WA–S cranes that returned to Nebraska but did not return to the CPRV staged in the NPRV. Eighty-three percent ($n = 6$) of WA–S marked in the NPRV returned there in their second year; 2 cranes marked in the NPRV (1 each of WA–S and NC–N cranes) moved to the CPRV in the second year (Appendix B). Two WA–S and 1 NC–N crane switched from the CPRV to NPRV within the same spring.

Among MCP-marked cranes that staged in eastern South Dakota and were monitored in multiple years, 50% ($n = 8$) and 67% ($n = 12$) from the WC–A and EC–M subpopulations, respectively, used this area both years. Sixty percent ($n = 5$) of EC–M cranes monitored for multiple springs returned to southwestern Manitoba stopovers used in the year of tagging. Among marked cranes monitored at staging areas in east-central Saskatchewan for multiple years, 66% ($n = 3$), 100% ($n = 8$), and 89% ($n = 9$) of WA–S, NC–N, and WC–A cranes returned in the year following tagging. One hundred percent ($n = 12$), 100% ($n = 1$), and 67% ($n = 3$) of marked WA–S, NC–N, and WC–A cranes, respectively, monitored during multiple years returned to western Saskatchewan or eastern Alberta staging areas used during the first migration to the breeding grounds.

Pattern and Length of Stay in CPRV

The length of the staging interval in the CPRV (arrival of first marked crane to departure of last marked crane) averaged 44 (SE = 2.5) and 43 (SE = 2.2) days for lesser and greater sandhill cranes, respectively, during 2001–2007, based on data from VHF-marked cranes. During the same years, initial arrivals ranged from 22 February to 10 March for lesser sandhill cranes (average = 27 February) and 22 February to 10 March for greater sandhill cranes (average = 26 February). Greater sandhill cranes reached peak abundance more slowly and stayed for a shorter period than did lesser sandhill cranes (Fig. 6), primarily because EC–M cranes (93% of which were greater sandhill cranes [Krapu et al. 2011]) made more frequent stops along their migration route to the CPRV and departed earlier. On average, lesser and

greater sandhill cranes took 12 and 15 days, respectively, from first arrival to reach 50% of peak abundance and 17 and 13 days, respectively, to increase from 50% to the peak. Among lesser and greater sandhill cranes, 64% and 58% arrived by 15 March, and 3% and 0% arrived after 1 April. At peak numbers, we estimated that about 85% of the population stopping in the CPRV were present during late March (Fig. 6) with numbers decreasing starting at the end of March for both subspecies.

Average arrival dates of sandhill cranes in the CPRV varied by 10 days during 2001–2007, but we did not find consistent differences between subspecies (Table 5 and Fig. 7A). During 2001–2007, cranes began arriving in late February and a significant buildup occurred in the first week of March in most years (Fig. 8). The latest arrival of marked birds was in the second week of March 2003, a year when temperatures were exceptionally cold in late February and early March (Fig. 8). Residency times varied by year and subspecies (Table 5) and averaged 20 and 25 days for greater and lesser sandhill cranes, respectively. Of the radioed sample, 8% (5% of lesser sandhill cranes, 10% of greater sandhill cranes) spent $\leq$7 days in the CPRV during spring migration. Length of stay in the CPRV was negatively correlated with arrival date for lesser sandhill crane ($r = -0.87$, $P < 0.001$; Fig. 9A) and greater sandhill crane ($r = -0.74$, $P < 0.001$; Fig. 9B). The year with the shortest staging interval (17 days) was 2004; crane numbers were slow to reach peak abundance and cranes departed early when an extended warm period occurred in the fourth week of March (Fig. 8). In 2001, when the average stopover was the longest recorded during the 7-year period (Fig. 8), virtually the entire population of cranes was estimated to be present in the CPRV at the peak.

Yearly mean departure dates varied by an interaction of year and subspecies (Table 5). During 2001 and 2002, average departure dates of subspecies were similar (2 days, $P \geq 0.200$); whereas during 2003–2007, average departure date for greater sandhill cranes was 3–12 days earlier than for lesser sandhill cranes ($P \leq 0.013$; Fig. 7B). Generally, the majority of cranes departed from the CPRV in $\leq$7 days during late March or early April (Fig. 8). However, crane departures extended over several weeks when weather fronts unfavorable for migration occurred during the departure period. In 2007, for example, an estimated 150,000 birds stayed in the CPRV until mid-April after a rapidly moving cold front accompanied by overcast skies and low temperatures arrived on 1 April at the peak of crane departures and persisted for 2 weeks (Fig. 8). Departure dates were correlated with minimum daily ambient temperatures (averaged over late Mar and early Apr) for greater sandhill cranes ($r = -0.79$, $P = 0.019$) but not for lesser

Table 5. Results of a general linear model describing variation in arrival dates, staging duration, and departure dates of sandhill cranes ($n = 305$) in the Central Platte River Valley, Nebraska during 2001–2007. Each model included year of observation (6 levels; 2001–2007), subspecies (2 levels; lesser sandhill crane or greater sandhill crane), and the interaction of independent variables.

	Year		Subspecies		Year × subspecies	
Response	$F_{6,291}$	P	$F_{1,291}$	P	$F_{6,291}$	P
Arrival	6.6	<0.001	0.1	0.787	1.5	0.180
Staging duration	7.4	<0.001	18.9	<0.001	0.4	0.907
Departure	12.7	<0.001	56.7	<0.001	5.2	<0.001

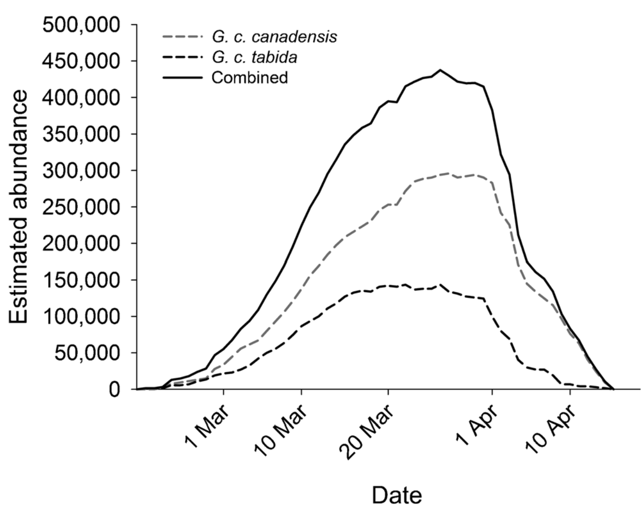

Figure 6. Temporal use of the Central Platte River Valley, Nebraska, by greater sandhill cranes (*G. c. tabida*; $n = 133$), lesser sandhill cranes (*G. c. canadensis*; $n = 172$), and subspecies combined ($n = 305$) from mid-February to mid-April averaged across 2001–2007. Estimates assume the sample of sandhill cranes marked with very high frequency transmitters was random and 500,000 sandhill cranes stopped in the Central Platte River Valley during spring migration (Kinzel et al. 2006).

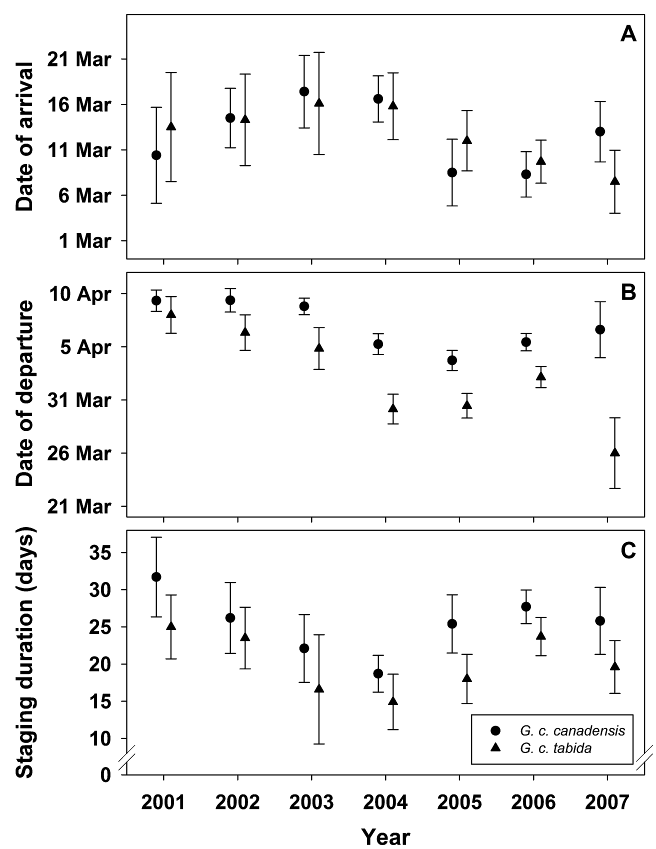

Figure 7. (A) Average arrival dates (error bars represent 95% CI) by year for very high frequency (VHF)-marked greater sandhill cranes (*G. c. tabida*) and lesser sandhill cranes (*G. c. canadensis*) in the Central Platte River Valley (CPRV), Nebraska. (B) Average departure dates by year for VHF-marked greater sandhill cranes and lesser sandhill cranes from the CPRV, 2000–2007. (C) Average staging duration for VHF-marked greater sandhill cranes and lesser sandhill cranes in the CPRV, 2000–2007. We obtained estimates by monitoring a random sample of sandhill cranes from the Mid-Continent Population marked with VHF transmitters from arrival to departure in years following marking.

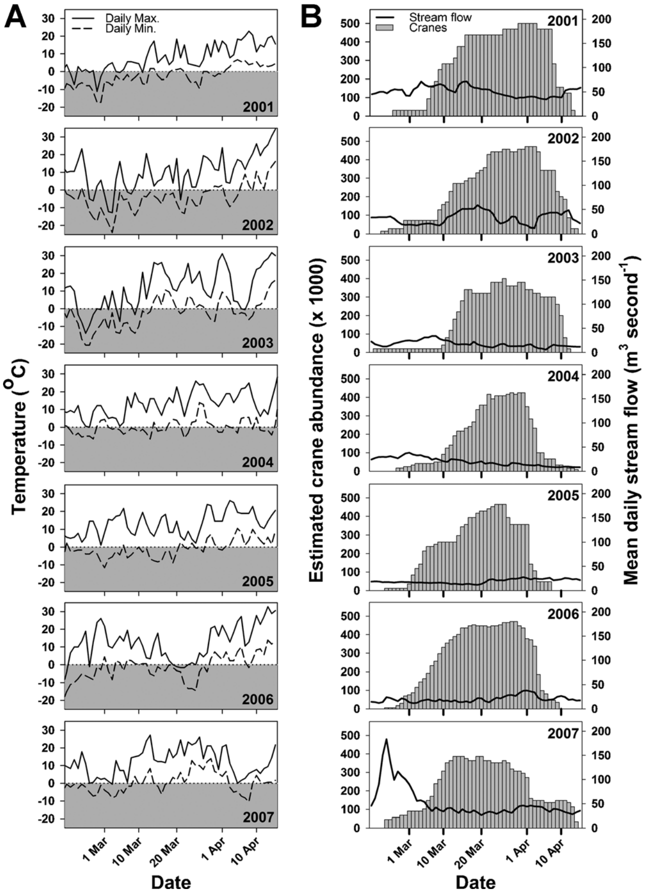

Figure 8. (A) Daily maximum and minimum temperatures in the Central Platte River Valley (CPRV), Nebraska, 19 February–15 April 2001–2007. Time intervals when ambient temperatures fell below 0°C are depicted as shaded. Ambient temperatures were measured at the Grand Island Weather Station (National Oceanic and Atmospheric Administration 20012007). (B) Estimated numbers of sandhill cranes of the Mid-Continent Population in the CPRV, Nebraska, by date, year, and mean March stream flow (m^3/s) in the main channel of the Platte River (2001–2007). Estimates were based on monitoring of a sample of very high frequency radio-marked sandhill cranes from arrival to departure from the CPRV and assumed 500,000 sandhill cranes stop in the CPRV each spring (Kinzel et al. 2006).

sandhill crane ($r = -0.25$, $P = 0.547$; Fig. 10). Cranes usually began migration from the CPRV in mid-morning based on 9 triangulation attempts that ended prematurely when the monitored birds departed northward. These departures were observed between 1–13 April and times of departure (i.e., when the birds left the ground surface) occurred between 0925 and 1116 hours and averaged 1016 hours ($n = 9$). Departure dates of cranes from the CPRV during spring migration did not occur earlier in years of low stream flow in the main channel (Fig. 8).

Using a dataset of 54 (24 lesser sandhill cranes, 30 greater sandhill cranes) birds tracked for successive migration years, we compared variation within and among individuals to determine if individual cranes were consistent in migratory behaviors compared to others in the population. We found evidence of variation among individual lesser sandhill cranes for arrival dates ($F_{20,24} = 2.7$, $P = 0.011$), staging duration ($F_{20,24} = 2.4$, $P = 0.022$), and departure dates ($F_{20,24} = 6.4$, $P \leq 0.001$) from the CPRV. For greater sandhill cranes, we did not find evidence of consistency for arrival dates ($F_{26,30} = 0.6$, $P = 0.894$) and staging duration ($F_{26,30} = 1.1$, $P = 0.399$) but found evidence for individual variation in departure date ($F_{26,30} = 3.0$, $P = 0.002$).

Sandhill cranes seldom reversed course during spring migration to return to stopover sites they had used earlier. Of 159 cranes monitored during spring migration, 6 made reverse migrations (3%, $n = 217$ migration years). In 2 cases, marked cranes returned to Nebraska after having migrated to South Dakota (1%, $n = 217$ migration years; Appendix C). No cranes ($n = 77$ migration years) reversed course and returned to Kansas or Oklahoma after arriving in Nebraska.

Nocturnal Roost-Site Use in CPRV

Crane densities on nocturnal roosts in the Platte channel varied widely among river segments between the J2 power plant near Lexington and the U.S. Highway 34 Bridge, which marked the western and eastern limits of MCP crane use, respectively (Fig. 11). In the Lexington-to-Kearney reach, cranes were most abundant from Elm Creek to Odessa. East of Kearney, high concentrations of birds occurred from Nebraska State Highway 10 to Gibbon, except in gaps occurring 2.5 km east from the Gibbon bridge, for 6.0 km east from Shelton bridge, for 1.5 km east from the U.S. 281 bridge, and for 2 km farther east between U.S. 281 and where I-80 intersects the river (Fig. 11). Crane roost-site use decreased to varying degrees adjacent to all highway bridges (Highway 10, Gibbon, Shelton, Wood River, Alda, US 281, I-80, and US 34; Fig. 11).

Over a 5-year period (2000–2003, 2005) at the peak of staging, cranes roosted on 70.9 of 152 km (47%) of the linear extent of the Central Platte River between Lexington and Chapman at mean densities ranging from 260 cranes/km (Overton to Lexington) to 10,976 cranes/km (Gibbon to Minden); densities ≥4,989 cranes/km occurred in 6 of 7 sections between U.S. Highway 281 and Kearney (Table 6). Ninety percent of cranes occurred between Chapman and Kearney and the remaining 10% occurred between Kearney and Lexington (Table 4). Mean numbers of cranes in river sections separated by bridges was highest in the Gibbon-to-Minden section during 2000–2002 and the Wood River-to-Shelton section in 2003 and 2005. Crane numbers were lowest in the Overton-to-Lexington section in 2000 and 2002, and the Elm Creek-to-Overton section in 2001 and 2003 (Table 6). Cranes occupied 16–28% (mean = 22.6%) of the river between Chapman and Lexington (152 km) during the peak staging interval in late March in any year. Distribution patterns of nocturnal roosts generally were consistent from 1 year to the next, except that the number of cranes using the Gibbon-to-Minden section decreased to 41% of average during 2005, when cranes from this section moved farther east. Total linear extent of the river used by roosting cranes did not decline from 1989 to 2000–2003, and 2005 (Table 6). Among cranes roosting in the Kearney-to-Lexington reach, about 25% and 56% occurred in the Kearney-to-Odessa and Odessa-to-Elm Creek sections, respectively. The remaining 19% occurred between the remaining 2 westerly bridge segments.

We summarized roost use from 1,723 bird/roosts for 471 bird-years. Ninety-one percent of VHF-marked crane roost locations were in the main channel ($n = 393$ cranes), but some birds also used smaller peripheral channels north of the main channel exclusively or intermittently ($n = 170$ cranes). Channel sites used

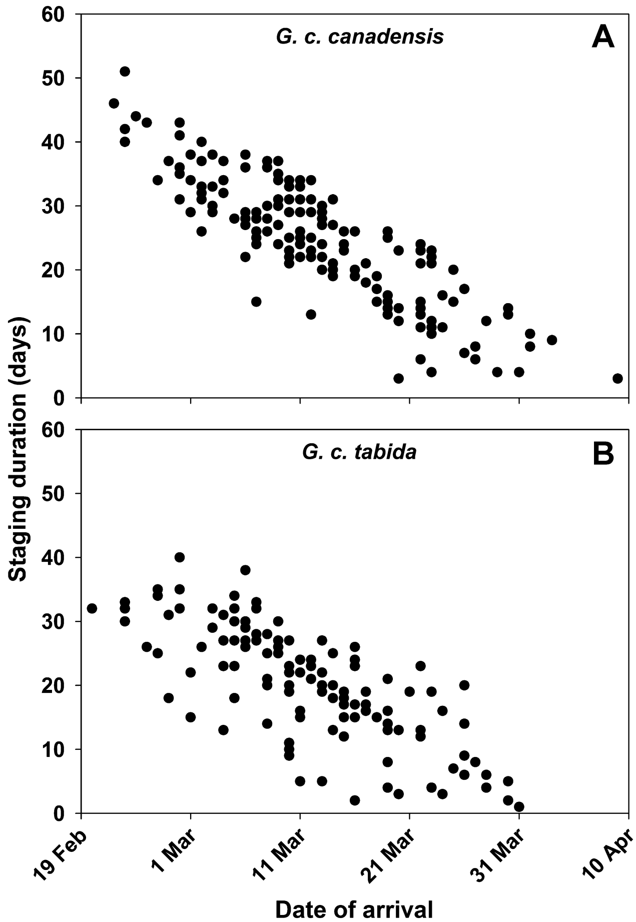

Figure 9. Relationships between staging durations (days) of a sample of very high frequency radio-marked (A) lesser sandhill cranes ($r = -0.87$, $P < 0.001$), and (B) greater sandhill cranes ($r = -0.74$, $P < 0.001$) and arrival date in the Central Platte River Valley, Nebraska, 2001–2007. We obtained estimates by monitoring marked individuals daily from arrival to departure in years following the spring of capture.

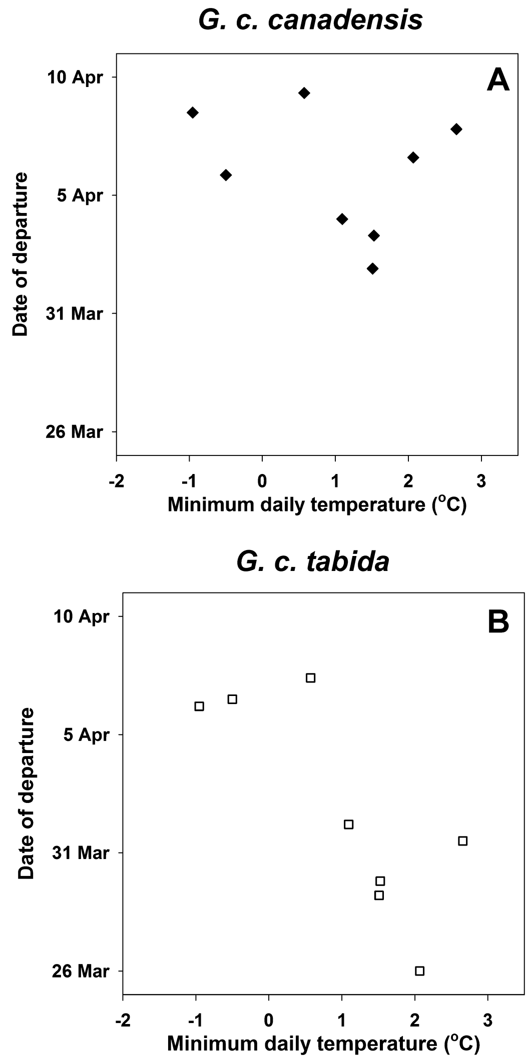

Figure 10. Relationships between annual average departure dates from the Central Platte River Valley, Nebraska and minimum daily temperatures (averaged 15 Mar–15 Apr 2000–2007) for (A) lesser sandhill cranes ($r = -0.25$, $P = 0.547$) and (B) greater sandhill cranes ($r = -0.79$, $P = 0.019$). We obtained timing of departure by monitoring a sample of Mid-Continent Population sandhill cranes marked with very high frequency transmitters from arrival to departure in years following marking.

north of the main channel were located from east of US-281 to west of the Gibbon Bridge, with most use concentrated between US-281 and Alda. Based on roost data from years subsequent to marking ($n = 336$ crane-use years), only 2 crane-use years occurred exclusively in the north channels. In contrast, 223 crane-use years occurred only in the main south channel and just 34% of all roosting individuals used the peripheral north channels. The probability that sandhill cranes would return to roost in years 2 through 4 in the same area (3.2-km river segment) that was used in the year of capture was 71% (Table 7).

Sandhill cranes marked with VHF transmitters used an average of 3.7 roosts (range 1–13, $n = 471$) during each spring stay in the CPRV. Most (88.3%) of marked cranes used >1 roost during their stay and 94% used ≤5 roosts; cranes using 2, 3, or 4 roosts accounted for 59% of roost locations. Most locations of individuals occurred at 1 roost (65%). Mean length of a roost was 360 m. The spatial extent of roosts used by 83% and 99% of cranes were ≤1.6 km and ≤2.6 km, respectively. Eighty-four percent of cranes using multiple roosts made multiple movements between these roosts and traveled an average of 5.0 km between roosts, whereas 15.6% of cranes using multiple roosts moved only to subsequent roosts (i.e., no redundant use) and traveled an average of 9.3 km between roosts (range: 1.3–61.8 km). Among 416 marked cranes using >1 roost, inter-roost movements accounted for, on average, 38.3% of their locations (range 3.7–100%, $n = 416$).

Food Habits and Nutrient Storage in CPRV

Corn dominated the diet of sandhill cranes during their stay in the CPRV in 1998 and 1999 and accounted for 93–98% of esophageal contents on an aggregate dry-weight basis (Table 8). Corn was the only high-energy food consumed. Soybean residues did not occur as esophageal contents during 1998–1999 (173 sampled cranes). Lack of soybeans in the diet, in part, was consistent with limited use of soybean fields by cranes (Table 9). Transect surveys conducted from mid-February through mid-April showed that cornfields accounted for >50% of habitat use by sandhill cranes, greater white-fronted geese (*Anser albifrons*), white geese (lesser snow geese and Ross geese [*Chen rossii*]), and

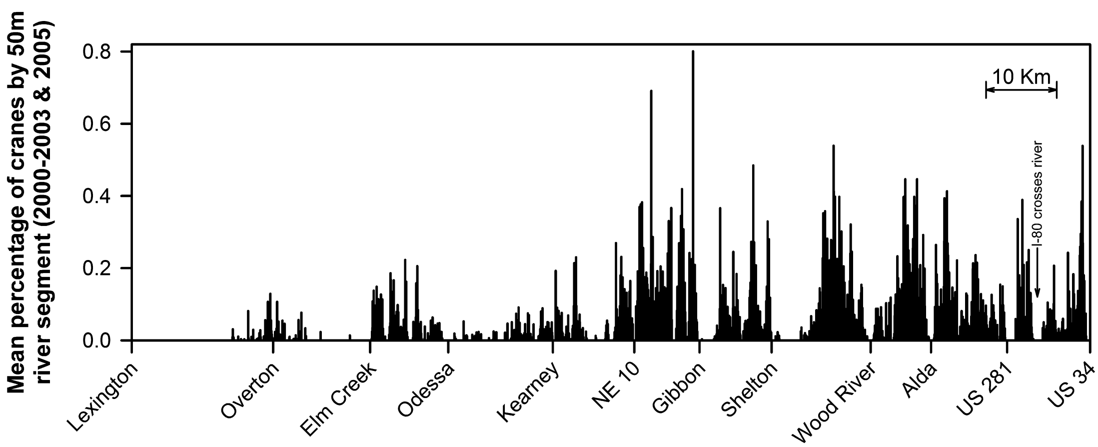

Figure 11. Average percentage of sandhill cranes of the Mid-Continent Population by 50-m intervals in the main channel of the Platte River during their spring stopover in the Central Platte River Valley, Nebraska, 2000–2003, 2005. We determined nocturnal roost distribution from aerial infra-red videography at night between 1200 and 0300 hours while cranes were on their nocturnal roosts during the last week of March at the peak of spring staging. Each tick mark shown on the *x*-axis above the location of a town, city, or highway identifies location of a bridge over the main channel of the Platte River.

Table 6. Linear coverage (km), percent river coverage, and estimated (est.) number and densities (individuals/km) of Mid-Continent Population sandhill cranes using nocturnal roosts in each of 12 segments of the Central Platte River separated by bridges between Chapman to Lexington, Nebraska (see Fig. 1 for a more detailed description). Estimates are from aerial infrared videography collected to document crane distribution by river section at night during the last week of March 1998, 2000–2003, and 2005.

	Section of river (bridge segment)[a]												
	1	2	3	4	5	6	7	8	9	10	11	12	Combined
Length of channel	17.1	11.6	10.7	8.5	13.9	10.1	9.1	11.4	14.7	11.0	13.6	19.8	151.5
Year													
1989[b]													
Linear coverage	0.0	4.2	5.3	3.4	4.4	3.6	6.2	1.9	0.5	2.0		1.5	33.1
% river covered	0.0	36.2	49.3	39.9	31.8	35.7	68.2	17.0	3.7	18.3		7.6	24.0
Estimated number	0	47,705[c]	72,881	54,324	87,893	48,018	110,046	24,048	1,821	36,397	2,850	16,963	502,946
Estimated density	0	4,102[c]	6,824	6,429	6,341	4,745	12,040	2,106	124	3,321	210	856	3,320
2000													
Linear coverage	0.0	2.9	4.6	3.2	4.7	3.5	6.8	2.6	1.0	2.0	0.4	0.1	32.1
% river covered	0.0	25.2	43.3	38.2	33.6	34.9	74.8	23.1	7.0	18.3	3.2	0.6	21.2
Estimated number	0	34,712	87,542	76,059	71,838	49,394	154,993	33,885	7,976	31,380	3,353	1,551	552,681
Estimated density	0	2,985	8,197	9,001	5,183	4,881	16,958	2,967	544	2,863	247	78	3,649
2001													
Linear coverage	0.0	3.5	3.3	2.5	3.0	1.8	4.2	1.7	1.1	1.9	0.3	1.1	24.4
% river covered	0.00	30.1	30.4	30.1	21.9	17.9	45.6	15.0	7.7	17.5	2.1	5.6	16.1
Estimated number	0	60,946	62,202	69,946	63,936	32,148	119,746	20,233	12,432	25,711	3,834	15,525	486,660
Estimated density	0	5,240	5,824	8,278	4,613	3,177	13,101	1,772	849	2,346	282	783	3,213
2002													
Linear coverage	0.0	4.1	4.5	3.8	3.2	2.9	6.0	3.1	1.5	1.5	0.8	<0.1	31.7
% river covered	0.0	35.3	42.3	45.4	23.2	29.1	65.7	27.5	10.5	14.0	5.8	0.2	20.9
Estimated number	0	71,603	58,448	68,593	65,880	48,632	106,183	32,447	12,356	16,706	5,955	155	486,957
Estimated density	0	6,157	5,473	8,118	4,753	4,806	11,617	2,841	843	1,524	438	8	3,215
2003													
Linear coverage	0.0	4.6	5.5	5.1	5.2	4.8	6.2	3.6	1.8	3.8	0.9	1.3	42.8
% river covered	0.0	39.2	51.5	60.8	37.4	47.6	68.1	31.4	12.0	34.9	6.4	6.8	28.2
Estimated number	0	54,800	56,463	69,960	105,003	58,720	79,593	34,894	12,676	35,900	3,960	7,037	519,006
Estimated density	0	4,712	5,287	8,279	7,576	5,802	8,708	3,056	865	3,276	291	355	3,426
2005													
Linear coverage	0.0	4.5	6.3	5.0	4.6	4.5	4.0	3.6	2.3	2.4	0.6	0.1	37.8
% river covered	0.0	38.9	58.8	58.6	33.1	44.1	43.5	31.5	15.4	22.1	4.2	0.7	24.9
Estimated number	0	68,029	92,156	89,606	73,915	64,200	41,077	36,440	18,671	30,796	5,342	1,511	521,744
Estimated density	0	5,849	8,629	10,604	5,333	6,344	4,494	3,191	1,274	2,810	393	76	3,445
2000–2005													
Linear coverage	0.0	7.9	9.2	7.0	8.5	7.2	7.9	6.6	5.8	6.5	2.1	2.2	70.9
% river covered	0.0	68.2	86.5	82.3	61.4	71.3	85.9	57.4	39.6	59.4	15.7	11.0	46.8
Mean est. number	0	58,018	71,362	74,833	76,114	50,619	100,318	31,580	12,822	28,099	4,489	5,156	513,410
Mean est. density	0	4,989	6,682	8,856	5,492	5,002	10,976	2,765	875	2,564	330	260	3,390

[a] 1, Chapman to Highway 34; 2, Highway34 to US 281; 3, US 281 to Alda; 4, Alda to Wood River; 5, Wood River to Shelton; 6, Shelton to Gibbon; 7, Gibbon to Minden; 8, Minden to Kearney; 9, Kearney to Odessa; 10, Odessa to Elm Creek; 11, Elm Creek to Overton; 12, Overton to Lexington.

[b] Data for 1989 were collected during a flight on 5 April 1989 to survey nocturnal crane use of roosting habitat in the Central Platte River Valley, Nebraska. The methods and selected results from the survey were presented in Sidle et al. (1993). Estimates not presented in their paper were calculated from digitized imagery of their original data.

[c] Unpublished video data for this segment. Sidle et al. (1993) flight on 5 April 1989 was used for calculation of crane density.

Table 7. Numbers of very high frequency (VHF) radio-marked lesser sandhill cranes (*G. c. canadensis*) and greater sandhill cranes (*G. c. tabida*) providing multiple years of data on roost locations and probability (*P*) of a marked crane using the same roosting area (3.2-km section) of the Platte River in years subsequent to the year of marking.

	Year monitored					
Subspecies	**2**	**3**	**4**	**Mean P^a**	**Median P^a**	**SE**
G. c. canadensis	68	11	0	0.73	0.92	0.04
G. c. tabida	56	12	1	0.70	0.86	0.04
Combined	125[b]	23	1	0.71	0.90	0.03

[a] Calculated from all individual crane's probability of using same sections in subsequent years. We obtained probabilities ($PHR_{i,j}$) using Fieberg and Kochanny (2005).
[b] Includes 1 crane for which subspecies was not determined.

Table 9. Distribution (%) of Canada geese, white-fronted geese, white geese, and sandhill cranes in relation to land use within 8 belt transects centered on roads located in the Central Platte River Valley between Overton and the Highway 34 Bridge near Grand Island, Nebraska, 1998–2002.

Land use	**All quadrants**	**Canada geese**	**White-fronted geese**	**White geese[a]**	**Sandhill cranes**
Corn	55.2	53.5	71.5	67.5	61.9
Soybeans	11.7	6.0	7.5	5.3	7.8
Other habitats[b]	33.1	40.5	21.0	27.2	30.3

[a] White geese = lesser snow geese and Ross' geese combined because these species are not readily distinguishable when in large flocks.
[b] Other habitats included native grassland (mostly in pastures), restored grassland, ponds, and riparian lands.

Canada geese (*Branta canadensis*), whereas soybeans accounted for <8% of use by geese and cranes (Table 9).

Animal foods represented a small component of the diet, with earthworms being the primary animal food taken. Snails (mostly shells) and immature stages of insects also occurred in crane diets (Table 8). Three families of Coleoptera (Carabidae, Scarabaeidae, Elateridae), 2 families of Orthoptera (Acrididae, Gryllidae), unknown dipteran larvae, larvae and pupae of the lepidopteran family Noctuidae, and arachnids were present but each accounted for <0.03% aggregate weight. Some calcium intake came from lime nodules excavated from soils in the CPRV and adjacent areas.

Female sandhill cranes in the CPRV gained an average of 322 g and 320 g in body mass from 13 March to 3 April during 1978–1979 and 1998–2006, respectively. We did not find evidence that body mass gains differed between periods ($P = 0.98$; Table 10). Males averaged 155 g heavier early in the staging period at the CPRV in 1998–2006 than in 1978–1979 but averaged 182 g lighter closer to departure. These differences indicated a 337-g lower gain in body mass during the staging interval in 1998–2006 compared to 1978–1979 ($P < 0.001$; Table 10). Males in all years had larger body masses than females at arrival and departure as expected because of their larger body sizes (Appendix D). Rates and magnitude of body mass gain varied widely among years ranging from 1.1 g/day to 35.3 g/day (gaining 23–742 g over the entire staging period) for males, and 9.2–19.7 g/day (gaining 193–414 g over the entire staging period) for females (Appendix E).

Adult male sandhill cranes at the CPRV had less stored fat in 1978–1979 on 1 March (143 g, 95% CI: 58–228) than in 1998 (349 g, 95% CI: 293–404; 1978–1979 vs. 1998: $P \leq 0.001$) or 1999 (300 g, 95% CI: 238–363; 1978–1979 vs. 1999: $P = 0.004$). Adult male cranes maintained a higher rate of fat storage in 1978–1979 (15.0 g/day, 95% CI: 11.8–18.2) than 1998 (8.6 g/day, 95% CI: 5.7–11.5; 1978–1979 vs. 1998: $P = 0.004$) and 1999 (10.9 g/day, 95% CI: 7.8–14.1; 1978–1979 vs. 1999: $P = 0.079$). However, adult male fat reserves were comparable around departure (10 Apr mean = 708.4 g, 95% CI: 662–754.4; Fig. 12A). Adult females maintained similar rates of fat storage while staging at the CPRV in 1978–1979 (10.2 g/day, 95% CI: 6.8–13.7), 1998 (10.7 g/day, 95% CI: 6.6–14.8), and 1999 (10.5 g/day, 95% CI: 5.8–15.2) for an estimated overall rate of 10.5 g/day (95% CI: 8.1–12.8; Fig. 12B). Average rate of fat accumulation was generally less for juveniles compared with adults during spring staging periods of 1998 (juvenile: 6.1 g/day, 95% CI: 2.5–9.6; adult: 9.0 g/day, 95%: CI 6.8–11.2) and 1999 (juvenile: 6.9 g/day, 95% CI: 4.2–9.6; adult: 10.4 g/day, 95% CI: 8.0–12.8; Fig. 12C). Because of uncertainty in estimation of accumulation rates, we could not detect statistical differences between ages in 1998 ($P = 0.175$) or 1999 ($P = 0.059$).

Approximately 450 g of fat were stored by adult female and male WA–S, NC–N, and WC–A cranes between departure from the CPRV and departure from Saskatchewan (Table 11). For WA–S and NC–N cranes, which moved quickly from Nebraska to Saskatchewan and spent an average of 17 and 25 days in Saskatchewan and Alberta (Table 3), respectively, most of the fat likely was acquired in Saskatchewan.

Protein content of adult males increased in all years while staging at the CPRV with rates differing little among years (1978–1979: 2.3 g/day, 95% CI: 1.0–3.6; 1998: 1.8 g/day, 95% CI: 0.6–2.9; 1999: 1.4 g/day, 95% CI: 0.1–2.6) for an estimated overall rate of 1.8 g/day (95% CI: 1.1–2.5). Protein content of adult female cranes varied among years. Females on 1 March had similar protein content in 1978–1979 (624 g, 95% CI: 591–658), 1998 (596 g, 95% CI: 560–632), and 1999 (631 g, 95% CI: 601–662). Females' protein content increased during the staging interval in the CPRV in 1998 (2.1 g/day, 95% CI: 0.4–3.7) but not in 1978–1979 (1.3 g/day, 95% CI: −0.1–2.7) and 1999 (−0.1 g/day, 95% CI: −2.0–1.8). Protein storage for juveniles was not different from 0 in 1998 (−0.1 g/day, 95% CI: −1.5–1.2) and 1999 (0.6 g/day, 95% CI: −0.4–1.6). Rates of protein increase in juveniles and adults differed in 1998 (1.7 g/day difference, SE = 0.8, $P = 0.039$) but not in 1999 (0.6 g/day difference, SE = 0.7, $P = 0.406$).

Table 8. Percentage of occurrence and percentage of aggregate dry weight of esophageal contents of sandhill cranes collected in the Central Platte River Valley, Nebraska, during late winter and early spring 1998 ($n = 81$) and 1999 ($n = 92$).

	% occurrence		% aggregate dry weight	
Esophageal contents	**1998**	**1999**	**1998**	**1999**
Corn	96.3	98.9	93.4	98.1
Other plant matter	11.1	17.4	4.5	<0.1
Earthworms	29.6	25.0	0.3	0.5
Snails	9.9	14.1	0.1	<0.1
Other animal matter	24.7	22.8	1.3	1.2
Calcium concretions	11.1	14.1	0.4	0.2

Table 10. Average change in body mass (g) of female and male sandhill cranes (after adjusting for body size) during spring staging in the Central Platte River Valley, Nebraska, during 1978–1979 and 1998–2006. We adjusted body mass values of individuals separately for average body sizes of females and males.

	1978–1979		1998–2006			
	Body mass (g)	SE	Body mass (g)	SE	Difference[a]	*P*
Females						
n	42		374			
13 March	3,422	55.4	3,351	16.6	−70.7	0.222
3 April	3,744	60.2	3,671	23.2	−72.9	0.258
Difference[b]	322	77.0	320	26.1	−2.2	0.978
Males						
n	58		392			
13 March	3,869	52.1	4,023	17.2	154.6	0.005
3 April	4,503	51.1	4,321	26.3	−182.0	0.002
Difference[b]	634	72.1	297	30.2	−336.6	<0.001

[a] Differences between 1978–1979 and 1998–2006 within sexes and dates were tested using the student's *t* statistic.
[b] Differences between 13 March and 3 April within sexes and time periods were tested using the student's *t* statistic.

Diurnal Habitat Use, Movements, and Time Budgets in CPRV

Across all years (1998–1999, 2001–2006), cornfields accounted for 66% of diurnal habitat use followed by grasslands; together these habitats accounted for 89% of diurnal use. Soybeans and hayland accounted for most of the remainder (Table 12). Crane use of cornfields peaked early in the day as cranes left roosts to forage. Use of grassland generally increased from morning into afternoon and early evening (Table 13), when many cranes moved from cornfields to grazed pastures to forage on soil invertebrates or rest at mid-day and join large flocks before returning to nocturnal roosts. Cornfield use remained high throughout the day (Table 13) consistent with the time spent feeding in cornfields and importance of corn in the diet. Cranes selected cornfields disproportionate to availability and used grasslands and soybean fields less than expected given their availability (Table 12). Cranes showed little consistent selection among postharvest land use practices in cornfields (Table 12).

Transect surveys indicated an estimated 40% of crane use in the CPRV during 1998–2001 occurred on lands north of I-80, although use varied widely among transects. Only 3% and 8% of crane use occurred north of I-80 on transects 1 and 8, which lie at the western and eastern ends of the study area (Fig. 13A). The probability of a radio-marked crane using lands north of I-80 diurnally increased by Julian day ($\beta = 0.074$, $SE = 0.009$, $F_{1,1702} = 64.4$, $P < 0.001$). Averaged across 2001–2007, probability of crane use of lands north of the highway increased 1.07 times per day between 1 March and 15 April (Fig. 13B). Seventy-four percent of greater sandhill cranes were detected only south of I-80, whereas 50% of lesser sandhill cranes were detected exclusively south of the highway. Birds found using only lands north of I-80 diurnally ($n = 23$) arrived in the CPRV 5 days later (95% CI: 1–8 days) than cranes using lands exclusively south of the highway ($n = 130$).

The mean distance between diurnal sites used by continuously monitored cranes was 1,850 m ($SE = 91$, $n = 511$ movements) and the mean number of flights per hour was 0.6. The highest rate of movement (0.7 flights per hour) occurred in the morning; birds were more sedentary during the afternoon (0.5 flights per hour) and evening (0.5 flights per hour). Mean distances cranes moved to reach habitats used indicated cranes flew relatively long distances to cornfields despite corn being the dominant crop (Table 14). Cranes traveled the longest distance to reach soybean fields and the shortest distance to reach grasslands, although all 95% confidence intervals overlapped (Table 14). Distances flown to cornfields were greater in 2001–2007 compared with 1978 and

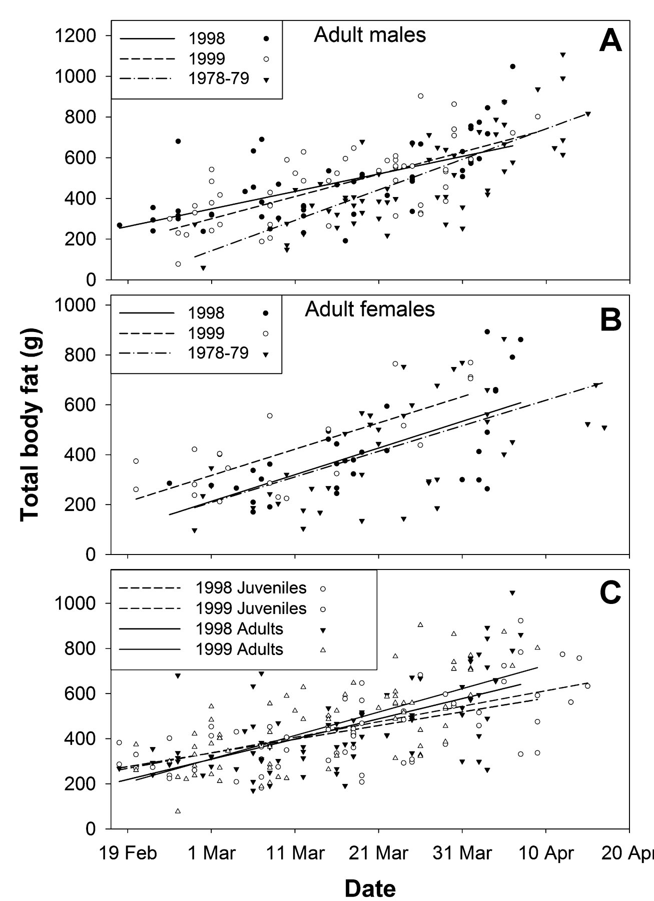

Figure 12. Total body fat (g) of (A) individual adult male sandhill cranes and predicted rates of increase in fat content while in the Central Platte River Valley (CPRV), Nebraska, from arrival to departure during late winter and early spring of 1998, 1999, and 1978–1979; (B) individual adult female sandhill cranes and predicted rates of increase in fat content while in the CPRV, Nebraska, from arrival to departure during late winter and early spring of 1998, 1999, and 1978–1979; and (C) individual juvenile and adult sandhill cranes and predicted rates of increase in fat content while in the CPRV, Nebraska, by date from arrival to departure during late winter and early spring of 1998 and 1999.

Table 11. Predicted body fat (g) of adult sandhill cranes for each of 4 subpopulations (western Alaska–Siberia [WA–S], northern Canada–Nunavut [NC–N], west-central Canada–Alaska [WC–A], and east-central Canada–Minnesota [EC–M]) collected at the beginning (13 Mar) and end (3 Apr) of the staging period in the Central Platte River Valley, Nebraska, 1998–1999 and for 3 subpopulations at the end (5 May) of staging in Saskatchewan, 2002. We used mean body size of marked birds 1998–2003 for each subpopulation and sex combination prediction.

		Predicted total body fat (g)						
		13 March		3 April		5 May		
Subpopulation	Sex	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	Difference[a]
WA–S	F	377	20	573	33	1,024	40	451
	M	432	15	635	24	1,110	33	475
NC–N	F	370	21	567	33	1,017	45	450
	M	424	16	627	25	1,101	30	474
WC–A	F	416	21	613	34	1,065	45	452
	M	474	16	677	25	1,154	73	477
EC–M	F	447	27	643	38			
	M	501	23	704	29			

[a] Difference between end of staging in the Central Platte River Valley and end of staging in Saskatchewan.

Table 12. Diurnal habitat use by very high frequency radio-marked sandhill cranes ($n = 280$) of the Mid-Continent Population in the Central Platte River Valley, Nebraska, 1998–2006, and selection ratios for habitats (2003–2006) and post-harvest treatments of cornfields, 1998–1999, 2001–2006.

			Habitat selection	
Habitat	% use	SE	Selection ratio[a]	95% CI
Corn	66.0	1.3	1.57	1.47, 1.67
Stubble	35.9	1.7	1.13	0.96, 1.30
Grazed	23.9	1.6	0.85	0.66, 1.03
Tilled	18.2	1.6	0.99	0.67, 1.31
Mulched	21.4	1.7	1.05	0.79, 1.32
Other	0.6	0.2	0.43	0.02, 0.83
Soybeans	5.0	0.6	0.45	0.31, 0.59
Grassland	22.6	1.1	0.66	0.54, 0.79
Hayland	3.8	0.5	0.81	0.48, 1.14
Other	2.6	0.4	0.17	0.03, 0.59

[a] Percent use divided by percent available. Values >1 indicate selection for, and <1 indicate avoidance.

Table 13. Percentage of diurnal locations for very high frequency (VHF) radio-marked sandhill cranes ($n = 280$) of the Mid-Continent Population for major habitat types by time of day in the Central Platte River Valley, Nebraska, during 1998–2006.

	Time of day (hours)					
Habitat	<0900	0900–1100	1100–1300	1300–1500	1500–1700	>1700
Corn	75.0	76.7	69.7	64.0	63.1	68.1
Soybeans	12.5	3.3	6.1	9.6	6.0	3.5
Grassland	12.5	13.3	18.2	19.2	25.3	21.4
Hayland	0.0	6.7	3.0	4.8	4.2	3.4
Other	0.0	0.0	3.0	2.4	1.4	3.6

all other distances flown to habitats used were comparable between past and contemporary time periods.

Factors influencing variation in distances that cranes moved included period of day ($X_2 = 22.7$, $P < 0.001$), crane density on nocturnal roosts ($X_1 = 13.7$, $P < 0.001$), year ($X_4 = 15.1$, $P = 0.005$), and percentage of landscape in soybeans ($X_1 = 12.2$, $P < 0.001$). A model including these variables explained 30% of variation in movement distance. Movements by cranes were longest in the morning (6.0 km, SE = 0.3, 95% CI: 5.4–6.6) and shorter at mid-day (3.2 km, SE = 0.5, 95% CI: 2.2–4.2) and in the evening (4.7 km, SE = 0.3, 95% CI: 4.1–5.3). The average distance a crane moved increased with the percentage of cropland in soybeans on the landscape; for every 1% increase in soybeans planted, the mean length of crane movements increased 77 m (SE = 22, 95% CI: 35–120). Distance moved was shortest and similar during 2004 ($\bar{x} = 3.7$ km, SE = 0.5, 95% CI: 2.7–4.7), 2007 ($\bar{x} = 3.8$ km, SE = 0.4, 95% CI: 3.0–4.6), and 2005 ($\bar{x} = 4.3$ km, SE = 0.4, 95% CI: 3.5–5.1). Movement distances were moderate during 2003 ($\bar{x} = 5.3$ km, SE = 0.5, 95% CI: 4.3–6.3). Cranes moved farthest during 2006 ($\bar{x} = 6.0$ km, SE = 0.5, 95% CI: 5.0–7.0) and significantly more than in 2004 ($P = 0.001$), 2007 ($P = 0.001$), and 2005 ($P = 0.015$). Distances cranes moved during the day were positively related to crane density on nocturnal roosts. Developed lands (e.g., sites used for housing and commercial development) apparently did not occupy a sufficient percentage of the area where marked cranes were monitored to affect distances traveled.

Mean departure time from roosts of cranes that were continuously monitored was 0741 hours ($n = 60$), and birds were re-located at their first foraging sites, on average, at 0755 hours ($n = 86$). Comparing time of roost departure to sunrise, the earliest departure was 27 minutes before sunrise and, on average,

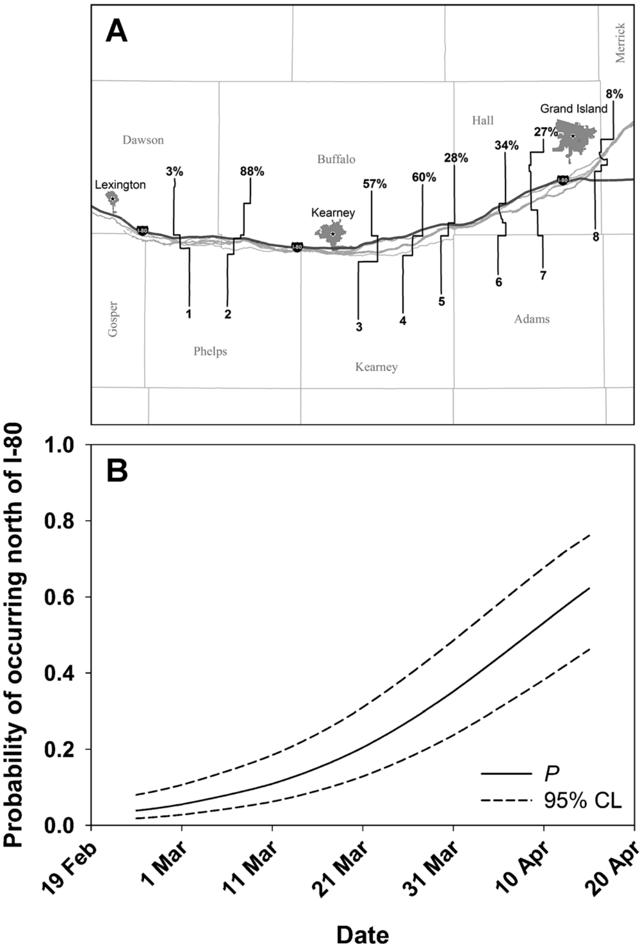

Figure 13. (A) Average percentages of sandhill cranes occurring north of Interstate 80 (I-80) in the Central Platte River Valley (CPRV), Nebraska, by belt transect route based on weekly surveys (20 Feb–10 Apr) of cranes on 8 transects each 800 m wide and 32 km in length (16 km north and 16 km south of the Central Platte River, 1998–2001). (B) Probability of a sandhill crane occurring north of I-80 in the CPRV, Nebraska, by date during 2001–2007 based on monitoring of very high frequency radio-marked adult sandhill cranes ($n = 287$). We used logistic regression analyses to estimate the probability of cranes being located north of I-80 (P) by $P = e^{-7.304 + 0.074(jday)}/1 + e^{-7.304 + 0.074(jday)}$, where *jday* is Julian day of the year.

birds departed roosts 83 minutes after sunrise. Time of departure from fields back to roost in the evening averaged 1859 hours ($n = 38$) and cranes arrived back at the roost at 1916 hours ($n = 60$). Comparing time of roost flights to sunset, birds arrived at roosts, on average, 8 minutes after sunset ($n = 60$; range = 84 min prior to sunset to 102 min after sunset).

Time budgets of all cranes (adults, juveniles, and age unknown) while in cornfields generally covaried with density of corn residues. Cranes walked in cornfields 21% (95% CI: 6–36%) more when corn densities were lower in 1999 compared with 1998. Cranes also spent more time alert during years of low compared with high corn density (1999 vs. 1998, 56% increase [CI: 25–86%]; 1999 vs. 2007, 133% increase [CI: 60–206%]; and 2006 vs. 2007, 83% increase [CI: 10–156%]). Cranes using cornfields rested less in most years of low compared with high corn density (1999 vs. 1998, 35% decrease [CI: 10–61%]; 2006 vs. 1998, 71% decrease [CI: 38–100%]; and 2006 vs. 2007, 69% decrease [CI: 25–100%]). In soybean fields, cranes resting decreased 48% [CI: 4–92%] in 1998 than during 1999. In grasslands, crane foraging increased 140% (CI: 118–162%), walking increased 100% (CI: 72–128%), and resting decreased 64% (CI: 49–79%) in 1998 as in 1999 (Table 15). Across all habitats, adult sandhill cranes fed approximately the same amount of time in 1978 and 1998 (45% vs. 43%), but feeding increased 21% (CI: 9–32%) in 1999. Time spent resting averaged 12%, 17%, and 21% in 1978, 1998, and 1999, respectively. Over all habitats and years, adult feeding rate was 30% less (CI: 23–38%) than juveniles, and resting was 111% greater (CI: 80–142%; Fig. 14).

Use of Staging Areas in South Dakota, Saskatchewan, and Alberta

Following departure from the CPRV in March, 40% of marked WC–A and 74% of EC–M cranes stopped in eastern South Dakota. The birds were widely dispersed with their distribution centered near U.S. Highway 281 from about the Nebraska border northward to near Aberdeen (Fig. 15). The WC–A and EC–M cranes that stopped in South Dakota spent an average of 10 and 11 days in the state (Table 3), respectively. The EC–M cranes also staged at several locations in eastern and central North Dakota, and in southwestern, south-central, and southeastern Manitoba (Fig. 15). One marked EC–M crane staged in Saskatchewan near the border with Manitoba and several EC–M cranes also staged in west-central and northwestern Minnesota, mostly near the eastern edge of the Red River Valley. Four marked WC–A cranes staged in central and northwestern North Dakota (Fig. 15). No marked NC–N cranes staged in South Dakota, Manitoba, or Minnesota and only 1 NC–N and 1 WA–S crane staged in North Dakota.

The WC–A cranes stopped to rest and store fat over a wide area of southeastern, eastern, central, and western Saskatchewan, with the largest numbers staging east and southeast of Saskatoon (Fig. 16). Major staging areas of NC–N cranes were located in

Table 14. Mean flight distances (km) of very high frequency (VHF) radio-marked sandhill cranes to different habitats during spring staging in the Central Platte River Valley, Nebraska, 2001–2007. Data from 1978 and 1979 adapted from Sparling and Krapu (1994).

	2001–2007				1978					1979				
Habitat	n[a]	Mean	SE	95% CI	n[a]	Mean	SE	95% CI	P[b]	n[a]	Mean	SE	95% CI	P[b]
River	75	2.1	0.2	1.7, 2.5	6	1.8	0.5	0.9, 2.7	0.617	13	2.1	0.4	1.3, 2.9	0.932
Grassland	44	1.5	0.3	1.0, 2.0	6	1.1	0.4	0.4, 1.9	0.476	13	1.6	0.4	0.9, 2.4	0.723
Cornfield	177	1.9	0.1	1.6, 2.1	6	0.9	0.3	0.3, 1.6	0.006	13	1.6	0.3	0.9, 2.3	0.438
Soybean[c]	20	2.2	0.5	1.3, 3.1										

[a] Number of birds monitored.
[b] P-value associated with t-test comparing mean flight distances with those observed in 2001–2007.
[c] Soybeans were planted on <1% of cropland in 1978 and 1979.

Table 15. Time-activity budgets of sandhill cranes estimating the percentage of time engaged in each activity by habitat in the Central Platte River Valley, Nebraska, 1978, 1998, 1999, 2004–2007. Sample size (*n*) refers to number of bird observations in each habitat. For 2004–2007, percentages of time spent in each activity are only presented for cornfields because of small sample sizes in other habitats.

			Activity											
			Feeding		Walking		Resting		Preening		Alert		Other	
Habitat (year)	Estimated waste corn (kg/ha)[a]	*n*	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE
Corn														
1978		71	35	3	21	2	23	3	10	2	11	1	<1	<1
1998	165	330	43	2	19	1	17	2	10	1	9	1	2	<1
1999	65	647	43	1	23	1	11	1	8	1	14	1	1	<1
2004		87	48	4	18	2	11	3	8	2	14	2	<1	<1
2005	97	67	49	4	19	2	8	2	7	2	14	2	2	2
2006	54	58	60	4	21	3	5	2	2	1	11	1	1	<1
2007	176	35	50	5	18	3	16	3	9	2	6	2	1	<1
Grassland/hayland														
1978		181	46	2	13	1	11	1	11	1	17	1	1	<1
1998		217	48	2	20	1	13	2	8	1	8	1	3	<1
1999		304	31	2	10	1	36	2	12	1	9	1	1	<1
Soybeans														
1998		41	53	5	20	3	13	4	6	3	6	1	2	1
1999		74	45	4	13	2	25	4	10	3	8	1	<1	<1

[a] Corn density for 2005–2007 from Sherfy et al. (2011).

central Saskatchewan, primarily east and southeast of Saskatoon with some birds staging northward to east of Prince Albert (Fig. 16). Cranes in this subpopulation stayed an average of 25 days (Table 3). The NC–N cranes breeding in the western arctic of Canada staged in the same areas as WA–S cranes in western Saskatchewan and eastern Alberta (Fig. 16). The WA–S cranes stayed at their Saskatchewan and Alberta staging areas for an average of 17 days (Table 3). Staging sites of WA–S cranes were highly concentrated in western Saskatchewan with small but significant numbers staging in eastern Alberta primarily southeast of Strome (Fig. 16). Use of staging sites in Alberta was greatest during 2002 when severe drought caused most wetlands used by cranes in western Saskatchewan to dry. The WA–S cranes also staged widely across central and southeastern Saskatchewan but in much reduced numbers (Fig. 16). On Saskatchewan staging areas, corn was not grown. Therefore, birds foraged primarily in harvested fields of wheat and barley, and roosted in saline lakes and freshwater wetlands. During their stay in the northern Great Plains, all 4 subpopulations roosted

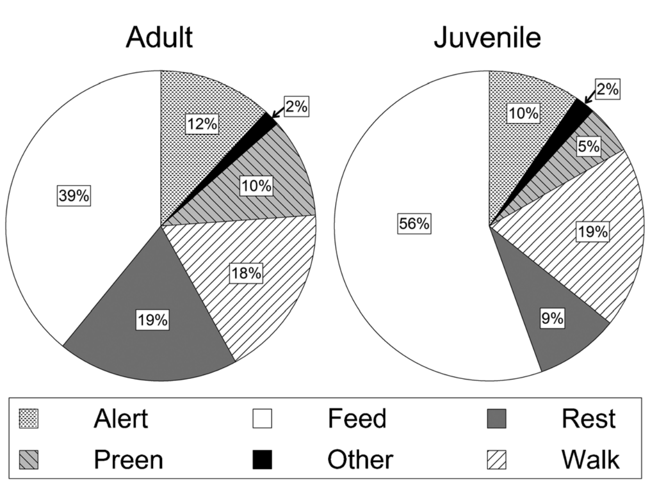

Figure 14. Time-activity budgets of adult and juvenile sandhill cranes in the Central Platte River Valley, Nebraska, during springs 1978, 1998–1999.

principally in basin wetlands (prairie potholes) at night and foraged primarily in harvested cropland. Overall, WA–S and NC–N cranes spent 36 and 43 days in migration between Nebraska staging areas and the breeding grounds (Table 3).

DISCUSSION

Factors Influencing Chronology of Spring Migration

Weather was a major factor influencing speed of spring migration by sandhill cranes, including length and pattern of stay in the CPRV. Sandhill cranes generally did not attempt to migrate during inclement weather but rather waited until weather conditions improved. When unfavorable weather conditions existed during the normal departure period, for example, 2007 (Fig. 8; also see U.S. Fish and Wildlife Service 1981:21), cranes would wait weeks if necessary before continuing on their migration. Likewise, cranes did not retreat from the CPRV before or after the onset of extreme weather. We suspect that the reluctance of cranes to reverse course when confronted with cold fronts and subsequent harsh weather occurs because in the absence of warm thermal updrafts suitable for sustained soaring flight, the birds must rely on flapping flight, which is expensive energetically. Cranes encountering inclement weather after arrival in Nebraska generally stayed. This behavioral response presumably has been adaptive, in part, because of energetic savings. However, a strategy of waiting out severe early spring weather events is not without risk, for example, on 23 March 1996, at least 2,000 cranes died during an ice storm in the CPRV (Krapu et al. 2005*a*; also see Wheeler 1966).

Individually marked lesser sandhill cranes were more consistent between years in their arrival dates, staging intervals, and departure dates from the CPRV than were greater sandhill cranes. Increased annual variation in migration schedules of greater sandhill cranes suggests their movements are more sensitive to weather conditions and availability of high-energy food that influence their ability to store fat. An earlier departure by greater sandhill cranes may have been influenced by corn residue scarcity in late March that made it

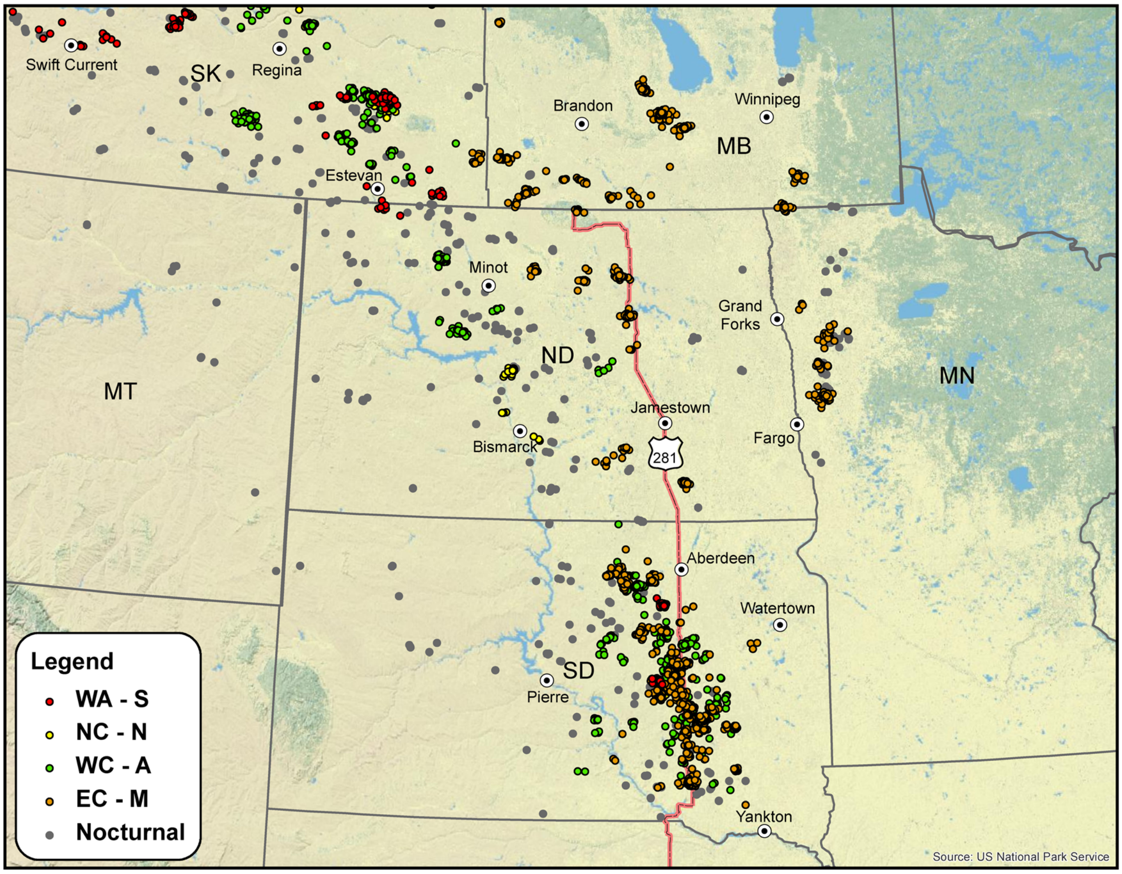

Figure 15. Distribution of locations of platform transmitter terminal (PTT)-marked sandhill cranes of the east-central Canada–Minnesota (EC–M), west-central Canada–Alaska (WC–A), western Alaska–Siberia (WA–S),and northern Canada–Nunavut (NC–N) subpopulations during stopovers in South Dakota, North Dakota, Minnesota, and Manitoba during March–April 1998–2004. Locations where PTT-marked individuals stopped for $\geq$5 days are represented by the larger color-coded symbols that identify subpopulation status of each marked crane. The gray dots identify sites used by marked individuals during 1–4 nights between 2200 and 0500 hours.

difficult for this larger subspecies to meet energetic and fat storage needs. Birds are more likely to stay longer at sites where food is plentiful than where food is scarce (Newton 2006). Lesser sandhill cranes required less corn intake to meet needs because of their smaller body sizes so their dates of departure may have been less influenced by declining corn residues. Our assessment that availability of corn residues may have influenced migration schedules is supported by greater sandhill cranes having migrated a relatively short distance to eastern South Dakota before undertaking another lengthy stopover.

Differences in timing of onset of breeding also affected migration chronology. Sandhill cranes on staging areas in Saskatchewan probably cannot sense when conditions are suitable for their return to their arctic breeding grounds but differential fitness can select for behaviors like departure dates if cranes respond to cues such as length or rate of change in photoperiod. Cranes from NC–N, despite being much closer to their breeding grounds than WA–S cranes while staging in Saskatchewan, departed 11 days later, on average, and arrived on their breeding grounds 8 days after WA–S cranes. Later arrival of NC–N cranes on breeding grounds in the central Canadian arctic is adaptive because snow cover remains into late May or early June (Fox et al. 1995), 2–4 weeks longer than on the Yukon Delta in western Alaska, a major breeding ground of WA–S cranes (Krapu et al. 2011).

Condition of cranes influenced length of stay at stopovers and speed of migration. The PTT-marked lesser sandhill cranes that left wintering grounds late, migrated rapidly to the CPRV, and stayed only a brief period were suggestive of birds in good condition from the onset of migration. Birds with high fat levels migrate more rapidly and stay for shorter periods at stopovers (Serie and Sharp 1989, Newton 2006). An inverse correlation existed between arrival date and length of stay by sandhill cranes in the CPRV (Fig. 9). A late start from the wintering grounds followed by rapid migration and a short stop in the CPRV implies later arrivals wintered where high-energy food remained sufficient to allow the birds to store significant fat before spring migration. Availability of suitable foods and roosting habitat within the migration corridor has a major influence on where cranes stop for extended periods as indicated by the exceptionally high crane use and length of stay of the CPRV. We estimated that 14% of the MCP stopped >5 days south of Nebraska for an average of 13.5 days, indicating cranes will stop for extended periods to store fat where suitable habitat conditions exist, but most cranes apparently do not encounter such sites in most years.

The average date of arrival of sandhill cranes in the CPRV probably advanced after corn residues became abundant. Plentiful corn residues lowered the risk of cranes encountering food shortages when the ground surface remained frozen and

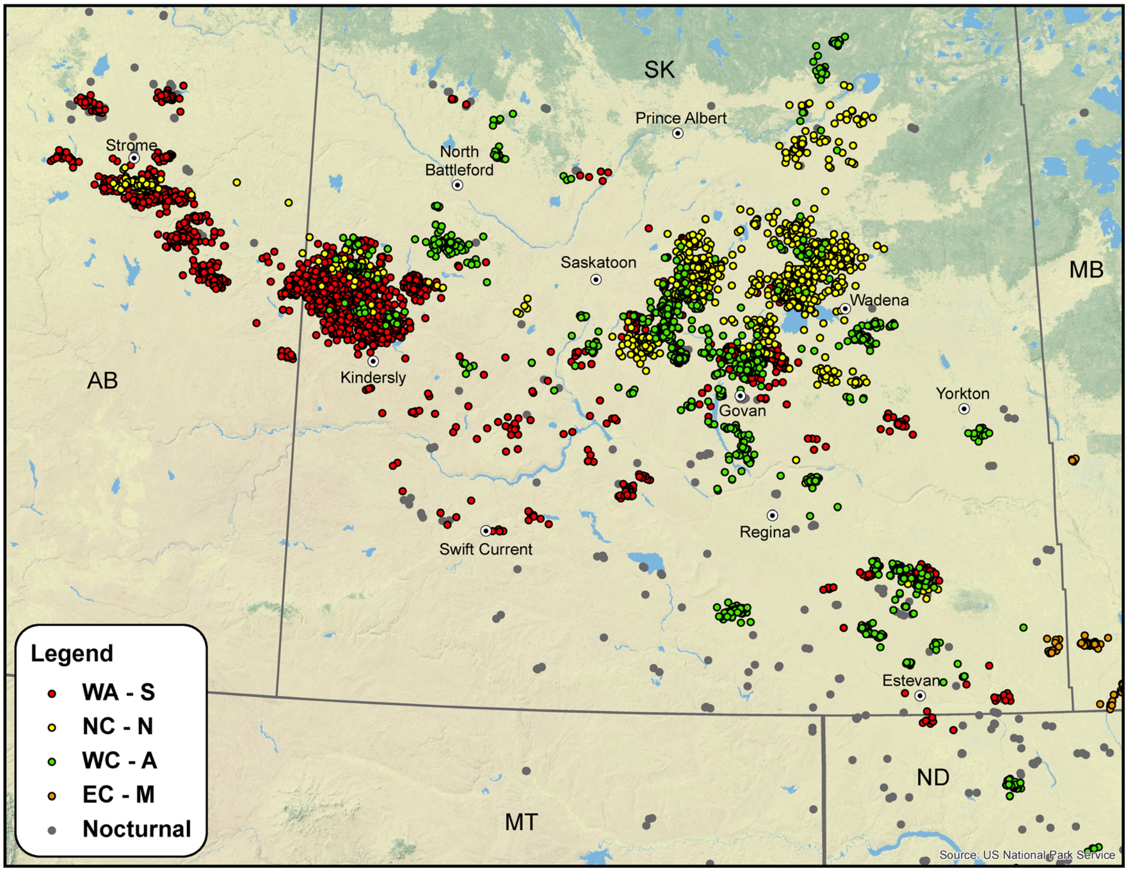

Figure 16. Distribution of locations of platform transmitter terminal (PTT)-marked sandhill cranes of the east-central Canada–Minnesota (EC–M), west-central Canada–Alaska (WC–A), western Alaska–Siberia (WA–S), and northern Canada–Nunavut (NC–N) subpopulations on spring staging areas in Saskatchewan and Alberta, 1998–2004. Locations where PTT-marked individuals stopped for ≥5 days are represented by large color-coded symbols that identify subpopulation status of each marked crane. The gray dots identify sites used by marked individuals from the Mid-Continent Population during 1–4 nights between 2200 and 0500 hours.

conditions were unsuitable for probing below the soil surface for tubers and other subterranean foods. An abundance of corn residues also allowed cranes to extend their stay for several weeks and fatten. The accumulation of large fat reserves before leaving Nebraska allowed WA–S and NC–N cranes to migrate rapidly to their next major staging areas in Saskatchewan.

Nocturnal Roost-Site Use in CPRV

Density of sandhill cranes on nocturnal roost sites in the Platte River varied widely among river sections (Table 6 and Fig. 11). Channels that had become narrow and colonized by woody vegetation supported few roosting cranes as noted in previous studies (Krapu et al. 1984, Norling et al. 1992, Davis 2001, Parrish et al. 2001). Sandhill cranes similarly abandoned narrow channels at the Goodwin-Young roosts on the Salt Fork of the Red River in Oklahoma after salt cedar (*Tamirex gallica*) encroached on roosts (Lewis 1976). Sandhill cranes roosting in the North Platte River and in wetlands on the Jasper-Pulaski Fish and Wildlife Area in northwestern Indiana (Eastern Population) roosted closer to woody vegetation than did cranes in the CPRV (Lovvorn and Kirkpatrick 1981, Folk and Tacha 1990). Greater tolerance to roosting near trees and other obstructions at some sites may, in part, reflect less exposure to predator activity or other forms of disturbance in these areas. Cranes used sites close to stands of trees during extreme weather in the CPRV, when the birds sought protection from rain, sleet, or snow, particularly when accompanied by high winds (G. Krapu, U.S. Geological Survey, unpublished data).

Most cranes use the same roosting areas in the CPRV year after year. Fidelity to sites occupied in previous years presumably is adaptive because sites cranes successfully used in previous years are more likely to be secure from human and other sources of disturbance. Also, prior use provides cranes with information on potential feeding sites, enhances foraging opportunities, reduces energy costs, and provides knowledge on distribution of power lines. Numerous crane mortalities occur annually in the CPRV from striking power lines (Morkill and Anderson 1991, Ward and Anderson 1992, Wright et al. 2009). These losses probably are exacerbated when disturbance causes large numbers of cranes to change roost sites at night.

Most lands in the CPRV are managed primarily for agriculture (Table 1) including part of the lands managed for wildlife conservation. As a result, land use adjacent to the river channels, except where woody growth, bridges, roads, or buildings and associated human activity exclude use, is mostly compatible with crane roost-site use. Restricted public access on most land bordering the river also limits human disturbance of cranes.

Food Habits and Nutrient Storage

The MCP sandhill cranes have switched from native plant foods to forage primarily on grain residues during a major part of their spring migration (Tacha et al. 1987). Corn residues accounted for >95% of food consumed by cranes (on a dry weight basis) in the CPRV and dominated the diet in 1998 and 1999 as in 1978 and 1979 (Reinecke and Krapu 1986) despite fewer corn residues being available to the birds. The lack of other high-energy foods in the diet reflects none were present in significant quantities. Soybeans were the only other crop widely grown in the CPRV and did not occur in the diet of collected birds presumably because of being inadequate for meeting crane nutrient needs. Fat is synthesized mostly from cereal grains consumed on temperate staging areas.

In the 1970s, cranes acquired most of their protein and calcium requirements in the CPRV by foraging on soil macro-invertebrates in grazed grasslands and hayland (Reinecke and Krapu 1986). Most soil invertebrates taken during the current study came from grasslands (i.e., grazed pastures), where earthworms were the principal animal food as in 1978–1979. The primary earthworm species found in the CPRV is *Aporrectodea trapezoides*, a widely occurring species introduced to North America from the Palearctic (Edwards and Lofty 1977). This species was the only earthworm found in soil blocks sampled at crane foraging areas in low grassland during the 1978–1979 study (Reinecke and Krapu 1986). In 1999 and 2000, it accounted for 91% of earthworm biomass and 61% and 51% of total macro-invertebrate biomass at 12 sites (Davis et al. 2006). Some cranes excavated and consumed lime nodules as in 1978–1979, suggesting a diet dominated by corn is deficient in calcium without ingesting invertebrates (e.g., snails) or lime nodules.

Gain in adjusted body mass of sandhill cranes from arrival in the CPRV to departure remained similar from the 1970s to the 1990s for females, but not for males. Comparable rates of fat gain by female sandhill cranes during the 2 time intervals (Fig. 12B) indicated that corn residues were sufficient during the late 1990s to allow similar levels of fat to be accumulated despite a major reduction in corn residues. Males had a lower rate of fat gain in 1998 and 1999 than during 1978 and 1979 (Fig. 12), which reflected a reduced capacity to store fat. This difference between the sexes probably reflects the differing roles of the sexes in reproduction. Because paired females contribute more to parental investment during nesting than their mates, males may invest in the quality or condition of females preparing to nest by increased vigilance. This hypothesis is supported by evidence that paired MCP males remain alert 8.5× more than paired females during winter and spring migration (Tacha 1988). Increased male vigilance reduces their foraging time but allows their mates more time for active foraging and subsequent fat deposition. Under conditions of low density of corn residues, males may have difficulty securing enough corn to deposit adequate fat.

Annual differences in foraging conditions on the principal wintering grounds of the MCP in western Texas probably were a major cause of annual variation in body masses of adult males and females at arrival in the CPRV (Appendix E). Low adjusted body masses of adult males at arrival during spring 1979 (Table 10) followed the droughty winter of 1978–1979 in western Texas when milo (*Sorghum bicolor*) residues were scarce but still accounted for 97% of the crane diet by aggregate volume (Iverson et al. 1982). Cranes lost an average of 3.8 g of fat daily during January and February 1979 while in western Texas (Tacha et al. 1987).

Annual variation in foraging conditions on the wintering grounds and in Nebraska did not appear to affect the capacity of cranes to acquire large fat reserves before departing for their breeding grounds. In 2002, female cranes arrived and left the CPRV with the lowest body masses observed during the 1998–2006 period (Appendix E), but fat levels at departure from Saskatchewan in spring 2002 were comparable to 1978–1979 (Table 10; Krapu et al. 1985). This relationship suggests high-energy food remained adequate to meet needs of northern-nesting cranes in Saskatchewan over a wide range of foraging conditions on wintering grounds and CPRV. While staging in Saskatchewan during spring, cranes forage primarily on wheat (*Triticum aestivum*), which occurred in the esophagi of 30 of 40 (75%) cranes collected in Saskatchewan during April 2002 (G. Krapu, unpublished data). In April 1980, >90% of diurnal habitat use by cranes in Saskatchewan was in wheat stubble (Iverson et al. 1987).

If corn residues were to continue to decline in the CPRV to where fat accumulation was severely limited, lesser sandhill cranes, despite their smaller size and reduced dietary needs, could not likely make up for this loss within the time available at their stopovers in the northern Great Plains. This assessment is supported by the effect of reduction in corn residues on midcontinent greater white-fronted geese, which also stage in the CPRV and in the Rainwater Basin during late winter and early spring. When corn residues became less available in the late 1990s, geese departed from the CPRV and Rainwater Basin 1–2 weeks earlier than in the 1970s (Krapu et al. 2005*b*) and with less fat (Krapu et al. 1995). They spent more time in Saskatchewan but did not fully compensate for the deficit in fat storage that had developed in Nebraska (Pearse et al. 2011). Moreover, after departing for their breeding grounds with less fat than in the 1970s, they fledged fewer goslings (U.S. Fish and Wildlife Service 2008), suggesting potential sensitivity of recruitment rates to declines in high-energy foods in temperate staging areas.

Diurnal Habitat Use, Movements, and Time Budgets in CPRV

Individual crane preference for harvested cornfields over other habitats reflected the pivotal role of corn in supplying energetic needs for maintenance and fat synthesis during an era of growing scarcity of corn residues. With fewer corn residues available, cranes spent a disproportionate amount of their time in cornfields in contrast to the late 1970s, when corn residues were plentiful (Reinecke and Krapu 1986) and a larger percentage of cropland was planted to corn (Pearse et al. 2010). Cranes spent the most time walking and least time resting in some years when corn densities were low, increasing energetic costs and reducing fat storage. Higher crane use of idle than grazed or mulched cornfields (Table 12) likely resulted from corn residues being 42% and 48% more plentiful in idle than in grazed or mulched fields, respectively, at the onset of the staging period (Sherfy et al. 2011). Shelled kernels accounted for most corn residues available to cranes, in contrast to the 1970s when kernels attached

to cobs dominated corn residues (Krapu et al. 2004). As a result, non-grazed corn stubble in the 1970s had higher standing crops of corn than grazed stubble, where most of the corn on ears was consumed by cattle and other livestock. In contrast to corn, cranes avoided soybean fields in the CPRV (Table 12) as previously documented in Indiana (Lovvorn and Kirkpatrick 1982). As the percentage of cropland in soybeans increased in Nebraska, cranes flew farther from the river and expended more energy to satisfy nutrient needs.

Forty percent of crane diurnal use of the CPRV during 1998–2001 occurred north of I-80. Early-arriving cranes preferred traditionally used sites south of the river first but increasing numbers shifted to north of I-80 later (Fig. 13B), presumably because disproportionate crane use of lands south of the river early in the staging period had depleted corn residues. More lesser sandhill cranes than greater sandhill cranes shifted from foraging south of the river to north of I-80 over the staging interval. This difference likely was linked to the longer stay of lesser sandhill cranes, which exposed them to a greater scarcity of corn residues south of the river. Marked cranes that occupied lands north of I-80 generally arrived later than birds that foraged on lands south of I-80 and also departed later. This pattern of use also likely was linked to corn residues declining more slowly north of I-80 because of limited use of this area by cranes early in the staging period (Fig. 13B). Traffic disturbance on I-80, which caused many flocks of cranes attempting to cross the highway to flare and increase their elevation, may have contributed to disproportionate crane use of fields south of the river until late in the staging interval when corn residues were becoming scarce.

Variable use of those parts of transects lying north of I-80 by cranes resulted from differences in land use and channel conditions among sections of the CPRV. Crane use was highest on transects where cropland, grazed grassland, and channels suitable for roosting formed a higher percentage of the habitat. Transect 1, where only 3% of birds occurred north of I-80, was adjacent to a degraded section of river channel where few cranes roosted. Birds that did roost there could meet most of their dietary needs on agricultural lands south of the main channel. Transect 8 had the second lowest crane use north of I-80, but supported large numbers of cranes south of I-80 (Fig. 13A). The section of this transect north of the highway contained tracts of residential and commercial development at the southern edge of the city of Grand Island, and crane avoidance can be attributed to human disturbance and limited suitable habitat.

Role of Staging Areas to MCP

The CPRV continues to be the principal spring staging area for MCP sandhill cranes based on the high percentage and length of MCP stopping, and importance of this area for fat storage by all 4 subpopulations. Staging areas in Saskatchewan also serve a critical role in preparing WA–S, NC–N, and subarctic nesting WC–A cranes for reproduction, as approximately similar amounts of fat were stored by cranes in Saskatchewan as in Nebraska. Considering that some fat is used during migration from Nebraska to Saskatchewan, we estimate that a maximum of about 40% of the fat reserves of cranes departing from Saskatchewan were acquired before leaving the CPRV. The predicted amount of fat stored by departure from Saskatchewan in 1998 and 1999 (Table 11) was similar in magnitude to the late 1970s, when MCP lesser sandhill cranes arrived on breeding grounds on the Yukon Delta in Alaska carrying approximately 500 g of fat (Krapu et al. 1985). These findings suggest that for subarctic and arctic-nesting cranes, the decline in corn residues to date (Pearse et al. 2010) has not been sufficient to adversely affect amount of fat carried to the breeding grounds nor recruitment rates. High use of stopover sites over a wide area of South Dakota by EC–M and WC–A cranes likely allow these birds to continue to prepare nutritionally for reproduction and to partially compensate for the decline in high-energy food resources in the CPRV.

Arctic-nesting sandhill cranes and arctic-nesting geese accumulate large fat reserves before departing from their last spring staging areas in temperate North America, which are used in reproduction. Cranes allocate fewer nutrients to clutch formation than do northern-nesting geese, which gives cranes an advantage in successfully coping with highly variable and often extreme weather conditions encountered on arctic-breeding grounds (Krapu et al. 1985:Table 2). Cranes allocate more nutrients than geese toward helping young survive; both crane parents feed their offspring starting at hatch (Walkinshaw 1973) and continue sporadically until independence the following spring. Crane parents allow juveniles to remain with them until early April when they depart Nebraska (Tacha 1988), helping to ensure their offspring from the previous year have become adept at foraging and predator avoidance, traits that are likely to enhance their survival after becoming independent from their parents.

Changes in survey techniques probably account for some of the apparent increase in size of the MCP over the past 60 years, but long-term population growth likely accounted for most of the change. Remarkably, all 271 cranes marked with VHF transmitters and monitored during years following tagging survived during 7,190 crane-use days while staging in the CPRV. Increased recreational harvest of cranes during recent decades has slowed population growth, for example, an estimated average of 33,427 MCP cranes (included birds not retrieved) were legally harvested annually during 2000–2006 (Kruse et al. 2008:Table 7). Mid-Continent Population cranes are hunted in 12 states (Minnesota added in 2010) in the United States, 2 provinces in Canada, and 3 states in Mexico (Sharp et al. 2007).

Migration Adjustments to Habitat Change

Sandhill cranes have exhibited exceptionally high fidelity to the CPRV over the past half century in response to habitat conditions being consistently favorable, causing a strong staging tradition to develop. However, cranes adjust their use of the CPRV and NPRV and other stopover sites as landscape conditions change within their migration corridors. Infrequently, highly favorable habitat conditions develop temporarily along the spring migration route of the MCP south of Nebraska, and when such events occur, large numbers of cranes stop to rest and feed for an extended period. For example, in March 1999, an estimated 100,000 cranes stopped in the Playa Lakes Region of southwestern Kansas and stayed into the fourth week of March (Solberg 1999). High use of this non-traditional stopover followed a hailstorm and extensive flooding the previous fall, resulting in plentiful waste grain and inundated fields that provided suitable nocturnal roosts across an extensive area the

following spring. In March 1999, after stopping in Kansas for an extended period, female cranes arrived in the CPRV with the highest average body masses of 1998–2006 (Appendix E). Large-scale use of non-traditional stopovers south of Nebraska appears to be infrequent based on findings of the Annual March Crane Survey conducted in Texas, Oklahoma, and Kansas over the past 20 years (1988–2008) by the United States Fish and Wildlife Service and states of the Central Flyway (Solberg 2008). Their findings are consistent with our results from PTT-marked cranes, which suggest that most MCP cranes stop only briefly along their migration route until reaching the CPRV and NPRV.

We expected most WA–S cranes would stage in the NPRV because this subpopulation breeds in western Alaska and Russia at the western edge of the MCP breeding range. Our expectation was supported by the staging distributions of the other 3 subpopulations, which were aligned to the directions of their breeding grounds. We estimated that >90% of cranes staging in the NPRV were from the WA–S subpopulation, but >50% of this subpopulation stage downstream in the CPRV. High use of the CPRV by WA–S cranes suggests that crane habitat is inadequate in the NPRV to support a higher proportion of this subpopulation. Numbers of cranes using the NPRV decreased during a period of declining corn residues (Folk and Tacha 1991) and growth in size of the WA–S subpopulation, particularly in Russia (G. Krapu, unpublished data). Declining food and possibly other factors probably caused large numbers of WA–S cranes to move to the CPRV over time. Movements of PTT-marked cranes between the CPRV and NPRV within and between years (Appendix B) indicate some adjustments in distribution between these sites still occur on an ongoing basis. Studies of the common crane (*Grus grus*) in Europe indicated crane numbers on staging areas ultimately decline when they exceed expected carrying capacity, that is, the number of birds that could be expected to be supported for the entire season (Alonso et al. 1994).

The reduction in high-energy corn residues over the past 2 decades (Pearse et al. 2010, Sherfy et al. 2011) likely will prevent major new traditional stopover sites from becoming established. Neither high-energy food nor roosting habitat is likely to be available consistently and in sufficient quantity over time to support new large concentrations of cranes. The more likely trend is for increasing numbers of cranes to depart earlier from the CPRV than in the past and use more stopovers as we observed in eastern South Dakota, where birds stay for shorter periods of time and in smaller numbers than occurs in the CPRV. The growing scarcity of corn residues in the CPRV by late March has elevated the significance of our finding that 74% and 40% of EC–M and WC–A subpopulations stopped for an average of 11 and 10 days at sites distributed across a wide area of eastern South Dakota. Use of stopover sites in South Dakota appears to be increasing and has allowed greater sandhill cranes to adjust to the growing scarcity of corn in the CPRV and continue to prepare nutritionally for reproduction.

A shortage of fresh water at traditional staging sites can also cause staging patterns to change during spring migration. The northern plains of midcontinent North America is subject to occasional severe and prolonged droughts (Clark et al. 2002), causing most wetlands, including lakes, to dry and leave cranes with few sources of fresh water for drinking. Sandhill cranes abandon nocturnal roosts when freshwater springs or other sources of fresh water for drinking are no longer available (see Iverson et al. 1985). In western Saskatchewan, severe drought during spring migration, particularly during 2001–2003, caused many WA–S cranes to shift from traditional staging sites north of Kindersley, to sites located about 150 km northwest near Strome, Alberta (Fig. 16), where conditions remained better suited for staging. The percentages of our PTT-marked sample of WA–S cranes that moved to sites in eastern Alberta were: 0% ($n=2$), 0% ($n=6$), 0% ($n=18$), 19% ($n=21$), 38% ($n=24$), and 20% ($n=10$) in 1998, 1999, 2000, 2001, 2002, and 2003, respectively. Ten of fifteen (67%) PTT-marked cranes monitored during 1998–2003 that stopped in Alberta first used sites in western Saskatchewan.

MANAGEMENT IMPLICATIONS

Food Resources and Nutrient Storage

A major challenge for the future is to maintain sufficient high-energy food resources in the CPRV and NPRV to enable MCP sandhill cranes to continue accumulating large fat reserves while staging there. Marked declines in corn residues combined with evidence that rate of body mass gain is declining among male cranes in the CPRV reflects a growing scarcity of high-energy food, and if this downward trend continues, could adversely affect MCP use of the CPRV and lower reproductive success and survival in the future.

Several factors are likely to influence the amount of cropland planted to corn in the CPRV in coming decades. These factors include renewable fuel targets established by Congress under the Energy Independence and Security Act (EISA) of 2007 (Mehaffey et al. 2012), climate change, commodity prices, and water resources available for irrigation of cropland. Corn is likely to remain a major crop, but the percentage of cropland planted to corn will be influenced by amount of surface and ground water available for irrigation as competition for this finite resource increases. Corn requires higher inputs of water and fertilizer than soybeans to produce high yields, potentially making soybeans more attractive economically as costs of production increase.

Ongoing improvements in corn harvest efficiency and changes in post-harvest land use of cornfields likely will cause some additional reduction in corn residues. Incentives could be provided to landowners in the CPRV and NPRV to encourage them to apply harvesting and postharvest practices that will ensure adequate corn residues on the ground surface in late winter and early spring when cranes are present. Discouraging of fall tillage of corn fields could be beneficial because cultivation reduces availability of corn residues and increases use by geese (Anteau et al. 2011). If the decline in corn residues should become severe in the future and alternate high-energy foods are not produced by existing farming operations, growing of corn or another high-energy crop on food plots for cranes may need to be considered.

Snow goose use of the CPRV has continued to increase through the first decade of the 21st century and recent estimates suggest >20 million birds may exist in the midcontinent population (Alisauskas et al. 2011). Snow goose use of the CPRV increases under dry conditions when fewer wetlands exist in the Rainwater Basin (Vrtiska and Sullivan 2009). Also, spring hunting of white

geese in the Rainwater Basin increases flight time and distances traveled by snow geese as they search for safe foraging sites (Pearse et al. 2013; R. R. Cox, Jr., U. S. Geological Survey, unpublished data). This disturbance probably has the unintended consequence of increasing snow goose use of the CPRV. Hunting of white geese is prohibited within 0.8 km of the outer channel of the Platte River between U.S. Highway 281 and Nebraska Highway 14 between 6 February and 10 March and within 5 km of the outer channel of the Platte River from U.S. Highway 281 west to U.S. Highway 283 during 11 March–15 April to protect whooping cranes. (http://www.outdoornebraska.ne.gov/hunting/guides/waterfowl/WFlightgooseconservation.asp).

Disturbance caused by hunting of white geese in the CPRV probably has not had a significant effect on fat storage by cranes thus far because most snow geese leave before the peak of crane use (Krapu et al. 2005*a*). However, fat reserves declined in white-fronted geese within the area of the Rainwater Basin open to hunting of white geese in 1998 and 1999 (Pearse et al. 2012). If hunting of geese intensified in areas used jointly by cranes and geese in the CPRV, cranes may experience reduced fat deposition. The most disturbance of cranes to date from goose hunting likely has occurred from late February to 10 March, when hunting of white geese is allowed to within 0.8 km of the outer channel of the Platte River. Large numbers of white geese are present within the area during this time interval (Krapu et al. 2005*b*) along with significant numbers of sandhill cranes (Fig. 8).

Steps that potentially could be taken to reduce snow goose use of the CPRV include increasing the number of sites where spring hunting of white geese is prohibited in the Rainwater Basin, thus encouraging more geese to stay there during February and March. The number of wetland basins available for roosting by geese is limited in the Rainwater Basin because nearly 90% of the wetland habitat has been destroyed by agricultural drainage (Tiner 1984). Ducks Unlimited, the United States Fish and Wildlife Service, and the State of Nebraska have been actively restoring wetland habitat in the Rainwater Basin for several decades. Continuing these efforts could help reduce numbers of geese moving into the CPRV and limit pressure on corn residues sought by MCP cranes, while also improving habitat for migrant populations of several species of midcontinent waterfowl.

Cranes rely primarily on managed grassland (grazed or burned) for macro-invertebrates that supply protein and calcium needs. Efforts to conserve and restore grassland could help meet these needs by focusing on protecting high-quality unprotected grassland tracts in areas of high crane use and making restoration of grassland tracts a priority in sections where least available to the birds. Sandhill crane habitat needs are best met where grassland tracts are widely interspersed with cropland within 3.6 km of river channels suitable for roosting. The probability of cornfield use by cranes increased with amount of wet grassland habitat within 4.8 km of field (Anteau et al. 2011). Maintaining grassland, cropland, and roosting habitat in relatively close proximity reduces crane energetic costs, creating conditions conducive for fat accumulation, and meeting dietary protein and calcium requirements. Restored grassland tracts that contain ponds or remnant channels with standing water can provide birds' access to drinking water during mid-day roosting. Within the floodplain grasslands of the CPRV, water table depth and soil moisture are the most important variables affecting earthworm distribution, with earthworm biomass declining from wet to dry conditions (Davis and Vohs 1993). This relationship underscores the need for a hydrologic regime that will maintain moisture-tolerant taxa, and high biomass of earthworms to meet crane protein requirements. In parts of the CPRV, major sandhill crane roosts occur close to strategically located grassland sites that are not protected by conservation easements or in fee title. These areas are likely to benefit from continued efforts to use available tools and explore new programs to ensure current land use is maintained to meet sandhill crane and whooping crane habitat needs in the future.

Another challenge is to improve habitats on the wintering grounds and stopovers south of Nebraska to ensure cranes have alternative sites where fat accumulation can occur. Sandhill cranes that arrived late in the CPRV because of longer stays on stopovers south of Nebraska or on their wintering grounds stayed fewer days in Nebraska. Enhancement or restoration of wetland habitat suitable for crane use within the migration corridor south of Nebraska could lead to increased crane use of these dispersed stopovers and reduce average length of crane stay in the CPRV. A later arrival date in Nebraska by more cranes would lead to less competition among cranes for food, potentially increasing average fat content of staging cranes by departure.

Nocturnal Roosting Habitat in CPRV

Intensive management of woody vegetation in the main channel of the Platte River has been important in maintaining crane use of the CPRV for the past 3 decades. In 1998 and 1999, an estimated 59% and 66% of cranes roosted at sites where woody vegetation had been mechanically cleared (Davis 2001). Without annual mechanical removal of seedlings during summer when the riverbed is dry, most of the roosting area available to cranes could have been lost to encroachment by woody vegetation in recent decades. Mechanical clearing of seedlings through annual disking and removal of mature trees and brush using appropriate equipment will need to continue, wherever feasible, focusing first on those parts of the river with an adjacent mix of cropland and pastureland for foraging. Clearing of abandoned channels would have the greatest potential benefit when focused on sites where high-quality habitat complexes will exist after roosting habitat is restored. Ideally, managers should restore sufficient roosting habitat appropriately spaced across the CPRV so that virtually all cropland and grassland under suitable management in the Chapman-to-Overton reach (i.e., most of the study area) would remain available for use by the MCP.

Another benefit of maintaining adequate habitat to meet needs of MCP cranes in the CPRV (along with the NPRV) is that virtually the entire population gathers at these sites in late March, making possible surveys to obtain reliable estimates of population size (Kinzel et al. 2006). Sandhill cranes that form the MCP nest at low densities across vast and mostly remote areas of the United States, Canada, and Russia. Annual population surveys on the breeding grounds are not feasible within constraints of manpower and funds available. The MCP also is widely dispersed during the remainder of spring migration, during fall migration, and on their wintering grounds (Krapu et al. 2011), further limiting potential for obtaining reliable estimates of size of the MCP outside of

Nebraska. Sandhill cranes have the lowest annual recruitment rate of any hunted avian species in North America (Drewien et al. 1995) so greater precision is required for estimates of population size before making decisions affecting size of annual MCP harvest than is necessary for other game birds.

Major restoration of crane roosting habitat in the lightly used Kearney-to-Lexington reach (Fig. 11) and potentially upstream to the confluence of the North Platte and South Platte rivers would encourage more WA–S cranes to use sites within their historical distribution that currently are receiving limited or no use. Habitat improvements upstream from Kearney offer the potential for reducing competition for food and space among cranes across a major part of the CPRV, particularly for EC–M and WC–A subpopulations that were most affected by declining corn residues late in the staging interval.

The long-term habitat management and restoration plan being implemented in the CPRV for whooping cranes and several other endangered and threatened species through the Platte River Recovery Implementation Program (Platte River Recovery Implementation Program 2010) will complement future efforts to maintain and restore channel habitat for MCP sandhill cranes. Controlling woody vegetation and other invasive species to manage roosting habitat for sandhill cranes and other species is expensive and time consuming. A methodology has been developed using geographic information system simulations to identify tracts for vegetation removal that would provide the most economically efficient allocation of resources when seeking to restore sandhill crane roosting habitat in the CPRV (Kessler et al. 2013).

In the CPRV, conservation efforts have been underway for several decades and have made significant progress in protecting crane habitat through purchase in fee title or through acquiring conservation easements. Efforts to date have focused primarily on protecting the riverbed of the main channel and adjacent lands mostly lying south of I-80 where most crane use traditionally occurred. Because ≤5% of lands protected for sandhill cranes and whooping cranes are located north of I-80, where an estimated 40% of sandhill crane diurnal use now occurs, a greater focus on protecting lands north of I-80 is justified. Specifically, conservation easements could serve as an important tool for maintaining existing land use on key tracts north of the highway, mostly within 3.6 km of I-80 and centered in sections where crane use is most concentrated (Table 5). Landscapes north of I-80 most in need of protection contain a mixture of cropland, pasture, and hayland. The shallow remnant North Channel meanders through the area north of I-80 and is partly bordered by pastures, attracting large numbers of cranes, particularly during mid-day when these lands are used as roosts. Maintaining current land use on these tracts through conservation easements should help to ensure the birds will have daytime roosts close to their foraging areas.

Habitat Protection at Crane Stopovers in Northern Great Plains

The distribution of stopovers used by PTT-marked cranes after departing from Nebraska indicates the MCP relies on a widely distributed (i.e., thousands of km^2) habitat base to meet its needs for migration and for reproduction. Most of the habitat base supporting the MCP at all major stopovers is in private ownership. A majority of the wetlands and adjacent lands are not protected from changes that could adversely affect the value of these sites to cranes. Therefore, conservation efforts must rely on tools that can be applied over large areas where most land is in private ownership. In South Dakota, Saskatchewan, and Alberta, many key sites remain in private ownership with wetlands having limited protection. In most cases, protecting key roosts or other important habitats can be accomplished most effectively through use of conservation easements. Because sandhill crane needs typically are compatible with agricultural land use in regions of the Great Plains where major staging areas are located, maintaining existing land-use patterns (along with suitable roost sites) offers the best long-term solution for protecting key habitats.

Stopover use varied among years and most locations lie outside the scope of potential protection either through ownership in fee title or conservation easement. Wetlands used by PTT-marked MCP cranes <5 days during spring migration represent a small part of the thousands of widely distributed, isolated wetlands that MCP cranes use across midcontinent North America. The most effective means of ensuring the long-term presence of these wetlands on the landscape would be through enacting federal laws and corresponding policies that provide protection for isolated wetlands used by sandhill crane, whooping crane, numerous species of waterfowl, and many other migratory water bird species. Migrant waterbird populations need to be able to adjust their distributions because drought leads to a temporary loss of suitable wetland habitat over vast areas. Failure to maintain widely distributed wetlands suitable for crane use will aggravate the increased and possibly excessive demands of cranes for food resources in the CPRV and NPRV. Because the habitat supporting the MCP in spring migration is mostly located in the United States and Canada, close cooperation will be required among natural resource agencies and private conservation organizations in the 2 nations to ensure protection of sufficient wetland habitat to meet habitat needs of the MCP during spring migration.

Risk to the MCP From Extreme Weather and Low Stream Flows in CPRV

The potential for a severe late winter or early spring storm causing a catastrophic loss of MCP cranes has increased over the past 60 years as the area suitable for crane use in the Platte River Valley has decreased, and numbers and length of stay by cranes have increased. Over the 7-year period we monitored temporal patterns of crane use of the CPRV, an average of about 85% of the 500,000 cranes were present at the peak between mid-March and early April (Fig. 6). The presence of this unparalleled concentration of MCP cranes in a relatively small geographic area during a period when severe blizzards and ice storms can occur poses a risk of potential catastrophic losses. This risk provides another incentive to manage in a way that ensures suitable habitat is as widely dispersed as possible, for example, restoring crane habitat in the Upper Platte River Valley and NPRV. Crane exposure to extreme weather (blizzards, ice storms) in the CPRV can be reduced by maintaining mature stands of trees on the north bank of the main channel in areas of high crane use.

The Central Platte River, if allowed to enter into a non-flowing state during early spring, may pose a high risk of major outbreaks of avian cholera and possibly increase exposure to other diseases, creating a potential major threat to MCP cranes and Central

Flyway waterfowl. The risk of disease outbreaks is heightened by avian cholera being endemic to the nearby Rainwater Basin, where thousands of waterfowl have died in past years when wetland conditions suitable for the spread of avian cholera existed (Windingstad et al. 1984). Regular movements by waterfowl between wetlands in the Rainwater Basin and the Platte River increase the potential for outbreaks of avian cholera in the CPRV should conditions conducive to outbreaks of avian cholera (e.g., low- or no-flow conditions in the Central Platte during drought coupled with high waterfowl use) exist there. Reluctance of cranes to depart early despite poor roosting conditions suggests that a majority of the MCP may continue to use the river if flows cease in March or early April, leaving only pools of standing water in channels. To reduce risk of disease outbreaks and improve foraging opportunities, cranes need to be dispersed as widely as feasible across suitable roosting habitat in the CPRV. One potential way to achieve adequate crane dispersal is to hold sufficient water upstream to ensure a minimum flow of 28 m^3/s, which is a flow rate that would leave 25% of the active channel exposed (Currier 1997) from 1 March to 15 April during spring staging.

Long-Term Habitat Monitoring Program in CPRV

The strategic importance of the CPRV to the MCP, declining corn residues, and the precarious status of nocturnal roosting habitat in Platte River channels emphasize the need for a long-term effort to monitor habitat conditions and crane health during their annual spring stopover. Collecting detailed information on crane habitat and body condition will enable policy makers and crane managers to make informed judgments on when and where actions are needed to ensure habitat is adequate to meet needs of the MCP. Knowledge of annual changes in crop composition, particularly the area planted to corn and soybeans, can provide important insight into changes that could affect crane condition. Agricultural statistics compiled annually by the National Agriculture Statistics Service and made available by the United States Department of Agriculture through the internet (http://www.nass.usda.gov/research/Cropland/SARS1a.htm) provide annual summaries of crops raised and harvested by county. Early detection of major changes in crop composition will provide crane managers with increased lead time for taking management actions to compensate for changes that would adversely affect the MCP.

Monitoring of several key parameters linked to habitat suitability for sandhill cranes every 5–7 years would allow researchers and managers to assess habitat change and capacity of the CPRV in meeting crane needs. Surveys can take advantage of benchmark data available from our established transects (Fig. 13A) to evaluate potential changes in crane habitat use, magnitude of use by waterfowl, postharvest land use, and distances cranes travel from the river to forage. Further, information from research documenting density of corn residues (Krapu et al. 2004, Pearse et al. 2010, Sherfy et al. 2011) will allow comparisons between future corn density and benchmark levels. Another beneficial program would be periodic analysis of the distribution of cranes on nocturnal roosts in Platte River channels at the peak of staging in late March following methods described by Kinzel et al. (2006). Documentation with aerial videography will enable detection of major changes in crane distribution on roost sites. It also would provide an ongoing assessment of the effectiveness of clearing of woody vegetation and management of flows on maintaining or increasing crane distribution. Channel habitat conditions will be systematically monitored as part of efforts to improve habitat for whooping cranes and other endangered species (Platte River Recovery Implementation Program 2010); and these results will be available to sandhill crane managers.

Periodic determination of crane body condition in late March would facilitate detection of declines in adjusted body mass among female lesser sandhill cranes. If such declines occur, measuring body fat content at Saskatchewan stopovers for comparison with 1979–1980 and 2002 (Table 11) would help determine if cranes can recoup fat losses in Nebraska through increased fat gain during stopovers in the northern Great Plains. The long-term management goal of keeping the MCP at approximately its current size to provide a wide range of recreational and aesthetic benefits to the public (Central Flyway Webless Migratory Game Bird Technical Committee 2006) is predicated on the CPRV remaining a major fat storage site for sandhill cranes.

SUMMARY

1. Of approximately 500,000 sandhill cranes using the CPRV during spring, we estimated 42% were greater sandhill cranes and 58% were lesser sandhill cranes, and they spent an average of 20 and 25 days in the CPRV (2000–2007), respectively. Cranes in WA–S, NC–N, WC–A, and EC–M subpopulations spent an estimated 39%, 30%, 46%, and 34%, respectively, of their spring migration in the CPRV, indicating that the CPRV continues to serve as a vital spring staging site for all 4 subpopulations.
2. Fourteen percent of PTT-marked cranes (10 of 74) in spring migration spent $\geq$5 days (mean $=$ 13.8 days) at stopovers south of Nebraska, suggesting most MCP cranes do not stay long enough to acquire large fat reserves in these areas. Enhancement of existing crane habitat and restoration of habitat at other sites within the migration corridors may protract spring migration, and reduce forage demand from the CPRV.
3. An estimated 64% (36 of 56) of WA–S cranes staged in the CPRV although >90% of cranes staging in the NPRV were from the WA–S subpopulation. Absence of most WA–S cranes from the NPRV suggests inadequate crane habitat exists in the NPRV to support more WA–S cranes. Habitat restoration from Kearney to the confluence of the North Platte River and South Platte River and in the Hershey area of the NPRV would likely encourage WA–S cranes to use these areas, and reduce demand for food resources in the CPRV.
4. Most cranes returned to the same nocturnal roost sites in the CPRV used in previous years, and presumably benefited from familiarity with surrounding foraging areas. The program of mechanical removal of mature stands of woody vegetation and seedlings to encourage nocturnal roosting by sandhill cranes and whooping cranes has stabilized the roosting distribution of cranes over the past 2 decades and can be expected to remain beneficial in the future.
5. We did not observe a relationship between river stage and sandhill crane departure dates. If no-flow conditions develop, large numbers of cranes may continue to roost in shallow

pools in the riverbed. Crane use of river channels in a non-flowing state increases the potential for major outbreaks of avian cholera. The risk of cholera can be minimized by establishing minimum flows in the river during 1 March–15 April when most crane use occurs in the CPRV.

6. Corn dominated the diet of sandhill cranes in the CPRV during this study, as in the 1970s, despite a marked decline in density (kg/ha) of available corn residues. The recent downward trend in corn residues is expected to continue. Effective strategies are needed to mitigate effects of declining corn residues, assuming managers adhere to the long-term goal of maintaining the CPRV as a key spring staging area for the MCP.
7. Body masses of sandhill cranes (after adjusting for body size) varied widely across years (1998–2007) at arrival in the CPRV, and indicated habitat conditions on the wintering grounds play a key role in determining amount of fat that MCP cranes carried at arrival in the CPRV. Males and females stored an average of 262 and 271 g fat in the CPRV (assuming arrival and departure dates of 13 Mar and 10 Apr), respectively. These patterns emphasize the importance of maintaining high-quality foraging habitat on the wintering grounds and CPRV to ensure cranes accumulate adequate fat to satisfy needs for migration and reproduction.
8. We found distances cranes traveled to reach foraging areas lengthened as the percentage of cropland planted to soybeans and crane density on nocturnal roosts increased. Habitat conservation efforts have the greatest potential for benefits if they focus on providing habitat complexes where all habitat needs are available in close proximity to each other whenever feasible (Pfeiffer and Currier 2005), expanding distribution of nocturnal roosting habitat for cranes in Platte River channels through mechanical clearing of woody vegetation, and maintaining minimum stream flows.
9. Sandhill cranes spent 40% of their diurnal time north of I-80, where $\leq$5% of lands dedicated to crane conservation are located. Crane managers should consider focusing greater attention on protecting crane habitat north of I-80, a strategic part of the habitat base supporting the MCP in the CPRV.
10. Seventy-four and 40% of PTT-marked EC–M and WC–A cranes stopped in eastern South Dakota for 11 and 10 days, respectively, suggesting stopovers in this region may be of major importance in conditioning the birds for the remaining migration and reproduction. The primary sites used by cranes in South Dakota would be good candidates for perpetual easements to protect existing land use.
11. Cranes from the NC–N, WA–S, and WC–A subpopulations staged, on average, 25, 17, and 12 days in central and western Saskatchewan and Alberta. Magnitude of fat storage indicates these stopovers served a vital role in preparing subarctic and arctic-nesting sandhill cranes for reproduction. A conservation strategy to ensure the long-term suitability of landscapes in Saskatchewan and Alberta for meeting MCP needs would be beneficial.
12. Subarctic and arctic-nesting sandhill cranes departing from stopovers in the northern Great Plains had comparable fat reserves to the 1970s despite a major decrease in corn residues in the CPRV. However, a decline in body mass and rate of fat gain among males during their spring stay in the CPRV from the 1970s suggests that if corn residues continue to decline, females also may store less fat, potentially leading to lower reproductive success and reduced recreational opportunities.
13. Marked cranes of all MCP subpopulations roosted in isolated basin wetlands when migrating across the Great Plains in spring. Crane use of basin wetlands in the northern Great Plains is likely to increase in the future as crane carrying capacity on the CPRV and NPRV staging areas decreases because of declining high-energy food. Unfortunately, most isolated basin wetlands in the Great Plains have limited protection. We emphasize the need for laws and policies that provide adequate protection of remaining isolated basin wetlands in midcontinent North America.

ACKNOWLEDGMENTS

This research was conducted by the Central Platte River Priority Ecosystem Study, Biological Resources Discipline, United States Geological Survey. We thank D. Douglas for providing technical and Argos program support during this study. We thank D. Sharp, J. Dubovsky, J. Roberson, M. O'Meilia, T. Mitchusson, J. Hansen, M. Szymanski, M. Johnson, J. Gammonley, H. Hands, S. Kohn, D. Nieman, M. Vrtiska, S. Taylor, S. Vaa, V. Bevill, R. George, L. Roberts, J. Solberg, D. Dolton, the late J. Gabig, D. Benning, R. Parker, S. Anschutz, J. Cornely, M. Forsberg, and P. Tebbel for their help in facilitating various aspects of the study. We are grateful for comments by K. Reinecke and J. Lovvorn who improved earlier drafts of this manuscript and thank I. Barcelo, A. Desmarteaux-Houle, and I. Bysykatova for translating the abstract into Spanish, French, and Russian. We thank the late P. Currier and F. Chavez-Ramirez, Directors of the Whooping Crane Habitat Maintenance Trust (The Crane Trust), for allowing use of their facilities near Wood River, Nebraska, when trapping and tagging sandhill cranes in the Platte River Valley and North Platte River Valley. We thank R. Kirby, J. Hestbeck, J. Powell, R. Gleason, Directors, and D. Jorde, M. Sherfy, Deputy Directors at the Northern Prairie Wildlife Research Center for their support during this study and R. Swanson, Director, USGS Nebraska Water Science Center. We thank D. Fronczak, A. Olson, A. Stonsifer, J. Drahota, W. Jones, T. Buhl, F. Sargeant, J. Feist, L. Wood, S. Hawks, D. Grandmaison, M. Westbrock, K. Seginak, B. Hanson, C. Mettenbrink, R. Knopik, C. Graue, V. Carter, B. Geaumont, J. McCabe, D. Smith, L. Potter, J. Thibault, B. Toay, M. Stoley, M. Heiser, and M. Pieron for field assistance. We thank K. Jones for determining sex and mtDNA lineage of marked birds (see Krapu et al. 2011 for details). We thank the many private landowners in Nebraska that allowed access to their lands to trap and tag cranes and landowners in Nebraska and Saskatchewan that allowed cranes to be collected to determine fat and protein levels and food habits. Any mention of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the United States Government.

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Appendix A. List of acronyms and abbreviations.

Acronym	Definition
CPRV	Central Platte River Valley
EC–M	East-central Canada–Minnesota
MCP	Mid-Continent Population
NC–N	Northern Canada–Nunavut
NPRV	North Platte River Valley
NWR	National Wildlife Refuge
PTT	Platform transmitter terminal
PPR	Prairie Pothole Region
VHF	Very high frequency
WA–S	Western Alaska–Siberia
WC–A	West-central Canada–Alaska
WMA	Wildlife Management Area

Appendix B. Monitored exchanges of platform transmitter terminal (PTT)-marked sandhill cranes between the Central Platte River Valley (CPRV), Nebraska, and North Platte River Valley (NPRV), Nebraska, within and across years, 1998–2003.

Bird No.	Subpopulation	Chronology of events
Within year		
01_G7	WA–S[a]	Marked in CPRV 2/26/01, in CPRV through 3/15, at NPRV 3/19–4/8, departed by 4/20
01_N9	NC–N	Marked in CPRV 4/12/01, in CPRV through 4/18, at NPRV 4/22, departed by 4/26
02_W4	WA–S	Marked in CPRV 3/12/02, in CPRV through 3/12, at NPRV 3/17, departed by 4/9
Across years		
01_J8	WA–S	Marked in NM 12/7/01, NPRV (near Lewellen) 12 days in 2002, CPRV 10 days in 2003
02_Q0	WA–S	Marked at NPRV 3/28/02, NPRV 17 days in 2002, CPRV 14 days in 2003
02_W4	WA–S	Marked in CPRV 3/12/02, NPRV 24 days in 2002, NPRV 17 days in 2003
02_W9	WA–S	Marked in CPRV 3/23/02, CPRV 20 days in 2002, NPRV 27 days in 2003, last 23 days near Lewellen
02_X4	NC–N	Marked in NPRV 3/30/02, NPRV 16 days in 2002, CPRV 29 days in 2003
99_48	WA–S	Marked in CPRV 4/1/99, CPRV 9 days in 1999, NPRV 32 days in 2000

[a] Subpopulation acronyms are as follows: WA–S, western Alaska–Siberia; NC–N, northern Canada–Nunavut; WC–A, western Canada–Alaska; EC–M, east-central Canada–Minnesota.

Appendix C. Platform transmitter terminal (PTT)-marked sandhill cranes making major reversals in their northward spring migrations during 1998–2007 between Nebraska (NE), South Dakota (SD), Texas (TX), Kansas (KS), Oklahoma (OK), and Minnesota (MN).

			Approximate distance (km)	
Year	**Crane no.**	**Spatial chronology**	**North**	**South**
2000	00_51	NE → SD → NE	240	230
2000	99_14	NE → SD → NE	310	320
2002	01_K4	TX → KS → OK/TX	465	415
2003	02_Q3	TX → KS → TX	320	205
2004	03_A4	NE → SD → NE	395	395
2004	03_C0	SD → MN → SD	410	275

Appendix D. Selected measurements (mm) for 4 subpopulations and 2 subspecies of Mid-Continent Population of sandhill cranes captured or collected in the Central Platte River Valley, Nebraska, 1998–2006.

Subpopulation or subspecies	Sex	*n*	Flattened wing chord			Post-nares culmen			Total tarsus		
			Mean	**Min.**	**Max.**	**Mean**	**Min.**	**Max.**	**Mean**	**Min.**	**Max.**
WA–S[a]	F	45	463	423	487	69.0	58.6	77.4	200.7	172.0	228.3
	M	21	492	461	525	75.3	66.9	81.7	215.4	198.7	237.0
NC–N	F	21	451	410	480	70.5	64.5	77.3	194.2	174.3	218.2
	M	11	477	464	498	77.6	65.6	91.0	203.9	171.1	235.5
WC–A	F	10	476	446	502	78.0	68.8	90.4	229.1	215.5	247.5
	M	31	508	460	541	85.2	75.5	95.0	245.3	219.1	261.5
EC–M	F	9	488	477	516	89.1	82.5	100.5	236.9	224.4	254.6
	M	26	519	488	552	92.6	86.5	103.0	257.5	237.8	273.1
G. c. canadensis	F	290	458	410	565	70.9	58.2	88.2	199.0	152.0	263.4
	M	253	487	421	533	76.4	61.0	91.4	213.4	171.1	275.6
G. c. tabida	F	105	479	429	525	81.6	60.7	100.5	228.9	199.2	257.3
	M	190	508	458	550	87.0	69.4	107.6	244.9	190.2	279.0

[a] Subpopulation acronyms are: WA–S, western Alaska–Siberia; NC–N, northern Canada–Nunavut; WC–A, western Canada–Alaska; EC–M, east-central Canada–Minnesota.

Appendix E. Predicted body mass adjusted for body size (g; SE) and rates of mass gain (g/day; SE) of adult female and male sandhill cranes in the Central Platte Valley, Nebraska, in relation to dates of arrival (13 Mar) and departure (3 Apr) during 1978, 1979, and 1998–2006. We estimated adjusted body mass from body mass and body size measurements obtained from a sample of individuals that were captured, measured, and marked with transmitters on trapping sites (Krapu et al. 2011: Fig. 1) or collected in the Central Platte River Valley, Nebraska.

			Arrival		Rate of gain		Departure		Gain in mass	
Sex	**Year**	*n*	$\bar{x}$	**SE**	$\bar{x}$	**SE**	$\bar{x}$	**SE**	$\bar{x}$	**SE**
Female	1978	16	3,420	91	13.8	6.1	3,711	95	291	128
	1979	26	3,424	63	16.8	4.1	3,778	74	354	86
	1998	39	3,347	48	18.5	3.9	3,735	74	388	82
	1999	42	3,474	42	11.1	2.8	3,706	70	233	60
	2000	34	3,422	48	9.2	3.2	3,616	72	193	67
	2001	47	3,290	47	17.1	3.2	3,648	57	358	67
	2002	33	3,196	61	15.8	5.0	3,527	82	331	105
	2003	56	3,258	46	14.9	3.1	3,571	52	313	66
	2004	50	3,409	45	19.7	3.8	3,822	69	414	80
	2005	46	3,478	49	12.3	3.6	3,737	61	258	75
	2006	27	3,290	58	18.6	4.3	3,681	83	391	90
Male	1978	25	3,837	75	35.3	5.6	4,579	86	742	118
	1979	33	3,900	72	25.1	4.0	4,427	55	527	83
	1998	62	4,109	35	13.6	2.6	4,394	60	285	55
	1999	65	4,086	36	13.2	2.9	4,363	57	278	60
	2000	29	4,036	52	11.4	3.2	4,276	73	239	68
	2001	27	3,947	58	13.9	4.2	4,238	81	291	88
	2002	33	3,771	55	25.1	5.5	4,299	98	527	115
	2003	64	3,841	43	19.7	3.4	4,255	56	414	71
	2004	37	4,152	57	7.3	5.8	4,306	97	154	121
	2005	46	4,124	40	22.4	4.3	4,594	95	470	90
	2006	29	4,144	74	1.1	5.6	4,167	81	23	118