SEASONAL VARIATION IN LIPID CONTENT AND CONDITION INDICES OF SANDHILL CRANES FROM MID-CONTINENTAL NORTH AMERICA

By

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CHAPTER I

INTRODUCTION

This thesis is comprised of 2 manuscripts written in formats suitable for submission to international scientific journals. Each manuscript is complete without supporting materials. The manuscript, "Seasonal variation in lipid content of sandhill cranes" (Chapter II), was written in the format of the AUK and is the principle paper of this thesis. Chapter III, "Estimating lipid content of sandhill cranes using field measurements", was written for submission to the JOURNAL OF WILDLIFE MANAGEMENT in the Short Communication format.

CHAPTER II

SEASONAL VARIATION IN LIPID CONTENT OF SANDHILL CRANES

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Abstract: Dynamics of lipid reserves of Sandhill Cranes (*Grus canadensis*) from the mid-continental United States were studied in 1979 and 1980. Samples were obtained in Oklahoma during autumn migration; in western Texas during winter; in Nebraska, Saskatchewan, and eastern Alaska during spring migration, and in western Alaska just before nest initiation. Minimum lipid levels, expressed as a percent of dry tissue weight, occurred during early winter (Nov) in western Texas ($\bar{X}$ = 31.3%, SE = 1.16). Maximum levels ($\bar{X}$ = 51.8%, SE = 2.21) in cranes occurred immediately before the northward migration from Nebraska (Apr). Maximum levels continued to be present in Saskatchewan (Apr) and eastern Alaska (May). Adults preparing to nest on the Yukon-Kuskokwim Delta in western Alaska had lipid reserves 34.0% lower than adults migrating through

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eastern Alaska. Lipid content in relation to body size did not differ between adult males and females ($\underline{P} > 0.10$). Juvenile cranes had significantly ($\underline{P} < 0.05$) greater lipid levels than adults during mid-winter (8.2%) and late staging (7.2%) periods in 1979 and during early (4.7%) and mid-winter (6.6%) periods in 1980. Juveniles had significantly ($\underline{P} < 0.05$) lower lipid levels (9.1%) than adults during the northward migration in eastern Alaska. The loss of lipid reserves among adults preparing to nest in Alaska emphasized the importance of lipid accumulation during the 5-week staging period in Nebraska and maintenance of those levels during migration to Alaska.

INTRODUCTION

The purpose of this study was to describe the lipid dynamics of Sandhill Cranes in relation to location and general phenology. Lipid levels provide a measure of physiological condition of cranes, and knowledge of the dynamics in relation to temporal and spatial aspects provide valuable insight to guide management efforts. A majority of the Sandhill Cranes, classified by managers as the mid-continental population, winter on the High Plains of western Texas from October through February (Walkinshaw 1973, Lewis 1977). Approximately 300,000 or more cranes from the mid-continental population congregate in the Platte River Valley in Nebraska for 4-6 weeks during spring migration (Lewis 1978). Cranes depart the Platte River area in early April, and those nesting on the Yukon-Kuskokwim Delta, Alaska arrive in early May (Boise 1977, Lewis 1977).

Clutch size in Ross' Goose (*Anser rossii*) may have evolved in relation to nutrient reserves accumulated by females before arrival on nesting grounds (Ryder 1970). Nesting success in the Lesser Snow Goose (*Chen caerulescens caerulescens*) may have been affected by the "nutritional state" of females arriving on nesting grounds (Harvey 1971). Quality and availability of winter food was judged important to the condition of arriving geese. Mean clutch size showed a positive relationship to mean body weights of Common Eider (*Somateria mollissima*) females the preceeding winter (Milne 1976). Indirect evidence suggests that clutch size and nesting success were influenced by amounts of stored reserves of female Canada Geese (*Branta canadensis hutchinsii*) (MacInnes et al. 1974). Female Lesser Snow Geese arriving on nesting grounds in northern Canada with larger nutrient reserves had larger potential clutches as measured by the number of large, highly vascularized ovarian follicles (Ankney and MacInnes 1978).

Fredrickson and Drobney (1977) discussed the importance of post-breeding and wintering periods to waterfowl and indicated a need for integrated research efforts in several areas of behavior, ecology, and physiology to better understand habitat requirements. Information concerning the physiological condition of Sandhill Cranes is essential to: interpret reproductive and survival patterns during the annual cycle, evaluate the importance (in an energetic context) of habitats used by cranes during winter and spring migration, model population energetics to estimate energy requirements to support desired population levels, understand refuging patterns (Hamilton and Watt 1970) on wintering areas and during spring migration, and evaluate the effects of human disturbance including hunting.

MATERIALS AND METHODS

Cranes collected for lipid analysis were placed in plastic bags and frozen within 5 hours of collection. Lipid samples were grouped by season and/or location to facilitate statistical analysis (Table 1).

Most Texas birds were collected at Rich Lake, but 8 cranes were obtained in mid-February 1980 at Muleshoe National Wildlife Refuge (NWR), 125 km northwest of Rich Lake. Cranes were collected in Nebraska along the North Platte River between Hershey and North Platte.

Juveniles (young-of-the-year) were identified by brown feathering on the occiput (Lewis 1974). Sex of all birds was determined by internal examination. Measurements of the tarsus, culmen post-nares, wing chord and total length from the bill to the longest rectrix were recorded to the nearest 1 mm. Mud and water adhering to the feathers prohibited using feathered body weights for analysis. Feathers were plucked, gizzard contents removed, thawed carcasses weighed to the nearest 1 g on a triple beam balance, and the carcass refrozen. Frozen carcasses were sliced into 3 cm sections on a band saw, the bill and scaled portions of the legs were removed to facilitate grinding, and the sections were homogenized in a meat grinder. Three (in 1979) and 2 (in 1980) subsamples of the homogenate of each crane were weighed and then dried in a vacuum oven at 105 C for 22-24 hours. Samples were cooled in a desiccator for 2 hours and reweighed to determine moisture content. All lipids were extracted from the samples with petroleum ether (B.P. 30-60 C) for 22-24 hours on a Goldfisch ether extraction apparatus and collected in a preweighed beaker. The extracted lipids were cooled for 1 hour and weighed. All weights were obtained to the nearest 0.0001 g using a Mettler analytical balance. Data are presented as g lipids/100 g dry tissue weight (lipids as a % of dry tissue weight). Wet weights were not used because birds were de-feathered before analysis and the potential for desiccation from repeated thawing and refreezing was considerable. Water content was quantified as g water/100 g thawed carcass weight (water as a % of carcass weight). The non-ether extractable residue was used to estimate protein content (Raveling 1979) and calculated by: (100 - % water) - % lipids. The product of the residue fraction and carcass weight was the non-fat dry carcass weight. The Statistical Analysis System (Barr et al. 1979) was used for Student's T-test, ANOVA, Duncan's multiple range test, and simple linear regression.

To determine the adequacy of subsampling, the lipid content of 3 subsamples from all 56 cranes collected in 1979 were inspected for variability. Variation in lipid content between cranes was larger (ANOVA, $\underline{P} < 0.0001$) than the variation among samples ($N = 3$) within a crane. Consequently, only 2 subsamples from each of 205 cranes obtained in 1979-80 were analyzed for lipid content. Sampling error was again insignificant, and the subsamples were pooled. Data used for subsequent analyses represented the mean of the 2 or 3 subsamples available per bird.

RESULTS

Body weights or absolute amounts of fat were not used as indicators of physiological condition because thawed carcass weights of cranes collected in 1980 varied from 2073 to 4585 g. Variation in carcass weight resulting from seasonal differences in lipid and water content was removed by calculating mean non-fat, dry carcass weights (Table 2). Significant differences ($\underline{P} < 0.05$) in non-fat, dry carcass weights suggest thawed carcass weights (or absolute levels of grams of fat) provide biased estimates of physiological condition (amount of lipids). The heaviest non-fat, dry carcass weights corresponded to structurally larger cranes from Oklahoma and Canada. Body weights were not reliable estimates of physiological condition due to variation in structural size among conspecifics (this study, Hanson 1962, Owen and Cook 1977, Wishart 1979) so we used the percentage of dry body weight that represented lipids for comparisons by age, sex, and season; a measure that is also useful for interspecific comparisons.

No differences were detected in lipid content between years during mid-winter ($\underline{P} = 0.95$), late winter ($\underline{P} = 0.18$), or late staging ($\underline{P} = 0.90$) (Student's T-test). Sandhill Cranes had significantly larger ($\underline{P} < 0.0001$) lipid levels during early staging 1979 than during the comparable period in 1980 (Table 3). Data from each year were considered separately in subsequent analyses.

Mean lipid content of Sandhill Cranes differed ($\underline{P} < 0.0001$) between periods of the annual cycle (Table 3). Lipid deposits in cranes increased linearly from mid-October to early January in the 1980 sample (Fig. 1). Lipid levels among cranes collected in western Texas in November 1979 represented the lowest levels during this study ($\bar{X} = 31.3\%$) (Table 3). A significant linear decline occurred in lipid levels of wintering cranes during January and February, 1979 (Fig. 2). In 1980, a linear relationship was evident from mid to late winter, except that $B_1 = 0$ suggesting that lipid levels of Sandhill Cranes remained relatively constant from early January to late February (Fig. 1). The mean lipid content of a sample of 8 cranes collected on Muleshoe NWR in mid-February was 32.9% while a sample of 10 cranes collected on Rich Lake 1 day later had a mean lipid content of 37.5%. The lipid level of cranes from Muleshoe was not statistically different ($\underline{P} = 0.14$, Student's T-test) from the level of cranes from Rich Lake. However, the Muleshoe sample may have been biologically different (lower) in lipid levels as evidenced by the observed significance level (OSL).

Sandhill Cranes migrated from western Texas to the Platte River Valley in Nebraska during late February and early March both years. A rapid increase in lipids was detected both years during the 4-6 week delay in spring migration along the Platte River Valley. Cranes accumulated lipid reserves to maximum levels, from 44.2% to 51.8% in 1979 and from 34.4% to 51.5% in 1980, (Table 3) before continuing the northward migration to Canada and Alaska. During the staging period on the Platte River lipid accumulation was linear both years (Fig.s 1, 2), and these lipid levels were maintained throughout the northward migration to Delta Junction, Alaska (Fig. 1).

The mean lipid content of adult Sandhill Cranes before nest initiation (May 5-9, 1980) at Clarence Rhode NWR in western Alaska was 36.1% (Table 4). This pre-nesting lipid level represented a significant decline ($\underline{P} < 0.05$) of 34.0% as these adults moved from eastern Alaska (mean lipid content = 54.7%) to their nesting grounds on the Yukon-Kuskokwim Delta. Lipid levels of pre-nesting cranes was similar to mid and late winter levels in Texas (Table 4).

Lipid levels of adult males and adult females did not differ ($\underline{P} > 0.10$) throughout the annual cycle. Insufficient sample size prevented comparisons of differences between sexes in juveniles. Juveniles had statistically greater lipid content than adults during mid-winter ($\underline{P} = 0.04$) and late staging ($\underline{P} = 0.03$) periods in 1979, and during early ($\underline{P} = 0.06$) and mid-winter ($\underline{P} = 0.05$) 1980. Adults had higher ($\underline{P} = 0.04$) lipid levels during spring migration at Delta Junction, Alaska (Table 4).

Mean thawed carcass weights of adult males were consistantly greater than mean carcass weights of adult females during all periods of the annual cycle, but these differences were not always significant ($P > 0.10$). Mean carcass weights of juveniles were lower (except for late staging and late winter 1980) than carcass weights of adults both years (Table 5).

The relatioship between % moisture and % lipids was inverse ($r = -0.92$, $P = 0.0001$). No significant differences ($P > 0.10$, Student's T-test) in moisture content occurred between male and female adults. During periods when lipid levels were different between age classes, moisture content was also different ($P < 0.05$) (Table 6).

DISCUSSION

The seasonal variation in lipid levels exhibited by Sandhill Cranes during winter was similar to other migratory species (Evans and Smith 1975, Owen and Cook 1977), especially Canada Geese (Hanson 1962, Raveling 1979). Lipid content decreased during mid-winter both years, but a slight "premigratory" increase in lipid reserves occurred among cranes from Rich Lake during mid-February, 1980. Premigratory increases in lipid levels have also occurred in Mallards (Owen and Cook 1977). Late winter declines in body weight have occurred in several species of waterfowl (Raveling 1968, Ryan 1972).

Cranes accumulated maximum lipid reserves during the 5-6 week staging period along the North Platte River both years. Maximum amounts of lipids attained by cranes just before departing Nebraska were present upon arrival in Delta Junction, Alaska. These data suggest that the energetic cost of migratory flight was minimal (Raveling and Lumsden 1977) or that energy reserves were replenished during migration.

Patterns of lipid storage in cranes during spring migration to Delta Junction appeared similar to those of arctic nesting geese (Ankney and MacInnes 1978, Raveling 1979). Canada Geese departed principle winter areas in southern Illinois with little or no increase in reserves but deposited large amounts of lipids during a 2-3 week staging period in Wisconsin before continuing northward (Hanson 1962). Snow Geese at staging areas at James Bay, Ontario maintained lipid reserves earlier during spring migration (Wypkema and Ankney 1979).

A 34% decline in lipid content occurred among adult Sandhill Cranes between the time of their departure from Delta Junction and our sampling on the Yukon-Kuskokwim Delta, whereas arctic nesting geese maintained lipid levels until arrival on nesting areas (Ankney and MacInnes 1978), Raveling 1979, Wypkema and Ankney 1979). An estimated 75% snow cover in early May (Tacha, pers. comm.) limited food availability. Annual variation in presence of snow has delayed initiation of nesting by arctic nesting geese (Barry 1962, Ryder 1970, Mickelson 1975, Raveling 1979). Hanson (1962) hypothesized that large lipid reserves in Canada Geese in spring functioned primarily as an adaptation to sustain geese on nesting grounds if snow cover was heavy and food was limited. Lipids stored by Canada Geese during spring migration were used as an energy reserve to initiate nesting before resources were available on the nesting areas (Raveling 1979). Additional study is needed to determine if the drop in lipid levels in cranes between Delta Junction and the Yukon-Kuskokwim Delta resulted from the energetic cost of this migratory flight or from heavy snow cover that temporarily limited food availability on nesting areas.

Relative lipid levels of adult male and female Sandhill Cranes did not differ from autumn migration to pre-nesting periods. This same pattern has been reported for Oldsquaws (Clangula hyemalis) from winter to spring migration (Peterson and Ellarson 1979) and for Canada Geese (B. c. minima) from autumn to spring migration (Raveling 1979). However, adult female geese had greater lipid concentrations than adult males upon arrival on the nesting grounds (Hanson 1962, Ankney and MacInnes 1978, Raveling 1979, Wypkema and Ankney 1979). These additional reserves in female geese may be necessary for egg production and incubation (Raveling 1979), and unlike Sandhill Cranes, only female geese incubate. Female geese feed little or not at all during incubation (Ryder 1970, Ankney 1977, Raveling 1979) and require additional endogenous reserves while operating under a negative energy balance. In cranes, incubation is accomplished by both members of the adult pair (Drewien 1973, Boise 1977) and differences in nesting behavior between geese and cranes are reflected in differences in lipid content of the males of the species and their contribution to incubation.

Juvenile Sandhill Cranes had greater relative lipid reserves than adults during mid-winter and late staging 1979 and early and mid-winter 1980. Body weights or physiological condition of juveniles are usually at or below that of adults during comparable periods of the annual cycle (Raveling 1968, Evans and Smith 1975, Ryan 1972, Peterson and Ellarson 1979, Wypkema and Ankney 1979). Nevertheless, condition indices of juvenile female mallards were higher than indices of adults in November (Owen and Cook 1977). Crane family units of the adult pair and 1 (occassionally 2) young remain intact at least until February (Walkinshaw 1973). Juvenile Sandhill Cranes in Family units may be benefiting from a "guardianship" by adults and from searching and foraging efficiencies of both parents plus their own efforts. Adults benefit only from their individual efforts, independent of additional advantages related to flocking behavior (Alexander 1974). Juveniles in family units are relatively inattentive (compared to adults) where 1 member of a pair remains on alert (Walkinshaw 1973). Higher lipid reserves among juveniles in family units may result from a higher energy intake or lower energy expenditure because less time is expended on alert behavior.

Juveniles arriving at Delta Junction during spring migration had lower lipid reserves than adults. Hypothetically, lower levels among juveniles later in the first year of life may be related to breakup of family units as adults prepare to reproduce. Juveniles must become independent and in the transition may function with lowered efficiency. However, juveniles do not breed and their biological needs to maintain lipid levels may not be as high as that of adults.

The inverse relationship between % moisture and % lipids detected in the body composition of Sandhill Cranes has been identified in several studies of other species (Bailey 1979, Peterson and Ellarson 1979, Wishart 1979). Lean, dry body weights (protein) of cranes were relatively constant except for differences related to variation in body (structural) size. Protein content of adult male and female Canada Geese remained constant from autumn migration to pre-laying (Raveling 1979).

The spring staging period along the North Platte River in Nebraska enabled Sandhill Cranes to achieve maximum levels of stored lipids before moving north to more uncertain climatic conditions. The decrease in lipids immediately before nesting underscored the importance of endogenous reserves at the time of arrival on the nesting grounds. Stored lipids may be critical for the last stage of migratory flight to nesting grounds and/or lipid reserves may be necessary for establishment and maintenance of nesting territories before food resources become available on nesting areas. Assimilation and subsequent movement of large amounts of stored lipids as cranes migrate from central United States to northern nesting areas is probably an adaptation of high survival value. The annual migratory delay or "staging" along the North Platte River in Nebraska is essential to Sandhill Cranes for building energy reserves necessary for migration and reproduction. Availability of good quality habitat to accumulate lipid reserves during winter and spring, especially along the North Platte River, is critical to Sandhill Crane reproductive strategies.

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Table 1. Sample sizes by location, period of the annual cycle, month, and year of Sandhill Cranes analyzed for lipid content. Cranes obtained from January to April, 1979 constitute the 1979 sample; cranes obtained from October 1979 to May 1980 constitute the 1980 sample.

Location	Period	Month	1979	1979-80
Oklahoma				
Washita NWR*	Fall migration	Oct		14
Texas				
Rich Lake	Early winter	Nov-Dec		17
Rich Lake	Mid-winter	Jan	17	30
Rich Lake	Late winter	Feb	11	51**
Nebraska				
North Platte	Early staging	Mar	16	30
North Platte	Late staging	Early Apr	12	18
Saskatchewan				
Last Mountain Lake	Spring migration	Late Apr		15
Alaska				
Delta Junction	Spring migration	Early May		21
Clarence Rhode NWR	Pre-nesting	Mid-May		9
Totals			56	205

* National Wildlife Refuge

** Includes 8 cranes from Muleshoe NWR

Table 2. Means of lean dry carcass weight, tarsus length, total length, and wing chord of Sandhill Cranes collected during periods of the annual cycle in 1979-80. Means underscored by the same lines are not significantly different (P > 0.05, Duncan's multiple range test).

Period	Autumn migration (AM-O)	Spring migration (SM-C)	Pre-nesting (PN-A)	Late staging (LS-N)	Mid winter (MW-T)	Spring migration (SM-A)	Early staging (ES-N)	Late winter (LW-T)	Early winter (EW-T)
Location	Oklahoma	Canada	Alaska	Nebraska	Texas	Alaska	Nebraska	Texas	Texas
Lean-dry[a] weight	832	789	706	699	695	693	692	683	677
Period-location	AM-O	SM-C	ES-N	SM-A	EW-T	MW-T	LW-T	LS-N	PN-A
Tarsus[b] length	237	220	209	208	207	207	206	205	203
Period-location	AM-O	SM-C	PN-A	MW-T	SM-A	EW-T	LW-T	LS-N	ES-N
Total length[b]	978	939	907	904	903	896	887	882	880
Period-location	SM-C	AM-O	PN-A	MW-T	ES-N	LS-N	SM-A	LW-T	EW-T
Wing chord[b]	486	478	473	466	465	465	463	462	454

[a] Weight (gms)
[b] Length (mm)

Table 3. Lipid content as a percentage of dry tissue weight of Sandhill Cranes collected during winter 1979, and fall to spring 1979-80. Means underscored by the same line are not significantly different (P > 0.05, Duncan's multiple range test). Mean, ± SE, (sample size).

1979

Period	Late winter	Mid winter	Early staging	Late staging
Location	Texas	Texas	Nebraska	Nebraska
	33.0	36.7	44.2	51.8
	2.04	1.60	1.48	2.21
	(11)	(17)	(16)	(12)

1979-80

Period	Early winter	Autumn migration	Early staging	Late winter	Pre-nesting	Mid winter	Spring migration	Spring migration	Late staging
Location	Texas	Oklahoma	Nebraska	Texas	Alaska	Texas	Alaska	Canada	Nebraska
	31.3	31.8	34.4	35.6	36.1	36.8	49.5	49.9	51.5
	1.16	2.42	1.54	0.79	3.99	1.27	2.50	0.87	1.47
	(17)	(14)	(30)	(51)	(9)	(30)	(21)	(15)	(18)

Table 4. Lipid content as a percentage of dry tissue weight of adult and juvenile Sandhill Cranes collected during winter 1979, and fall to spring 1979-80. Student's T-test was used to test for differences in lipid content between age classes within a period. Mean, ± SE, (sample size).

Period	Autumn migration	Early winter	Mid winter	Late winter	Early staging	Late staging	Spring migration	Spring migration	Pre-nesting
Month	Oct	Nov-Dec	Jan	Feb	Mar	Apr	Apr	May	May
1979									
Adults			35.3 1.61 (14)	31.2 1.02 (10)	43.8 1.53 (15)	50.1 2.72 (9)			
			[a]P=0.04			P=0.03			
Juveniles			43.5 3.09 (3)	51.2 — (1)	50.1 — (1)	57.1 0.57 (3)			
1979-80									
Adults	32.6 3.31 (10)	29.9 1.15 (12)	35.8 1.40 (25)	35.7 0.89 (43)	33.4 1.71 (24)	51.2 1.59 (16)	49.9 1.84 (13)	54.7 0.98 (9)	36.1 3.99 (9)
	P=0.58	P=0.06	P=0.05	P=0.70	P=0.19	P=0.46	P=0.86	P=0.04	
Juveniles	29.6 2.16 (4)	34.6 2.43 (5)	42.4 1.56 (5)	34.9 1.70 (8)	38.4 3.32 (6)	54.7 3.73 (2)	50.7 5.84 (2)	45.6 4.01 (12)	

[a] Probability that means in a column are significantly different (2-tailed, T -test).

Table 5. Mean carcass weights (g) of Sandhill Cranes collected during winter 1979 and during fall to spring, 1979-80. Mean, ± SE, (sample size).

Period Location	Autumn migration (Oklahoma)	Early winter (Texas)	Mid winter (Texas)	Late winter (Texas)	Early staging (Nebraska)	Late staging (Nebraska)	Spring migration (Canada)	Spring migration (Alaska)	Pre-nesting (Alaska)
Month	Oct	Nov-Dec	Jan	Feb	Mar	Apr	Apr	May	May
1979									
Adult females			2931 ±182(6)	2690 ±83(6)	3052 ±130(7)	3461 ±147(5)			
			[a]P=0.27	P=0.01	P=0.01	P=0.24			
Adult males			3141 ±85(8)	3267 ±138(4)	3662 ±133(8)	3745 ±170(4)			
Pooled adults			3051 ±92(14)	2921 ±117(10)	3378 ±121(15)	3575 ±115(10)			
			P=0.70			P=0.42			
Juveniles			2966 ±204(3)	3260 ----(1)	2980 ----(1)	3390 ±116(3)			
1979-80									
Adult females	3480 ±263(5)	2632 ±91(9)	2720 ±44(13)	2719 ±50(20)	2764 ±63(13)	3124 ±71(10)	3301 ±282(5)	3276 ±377(2)	2899 ±151(4)
	P=0.56	P=0.01	P=0.01	P=0.01	P=0.01	P=0.02	P=0.07	P=0.75	P=0.61
Adult males	3679 ±201(5)	3099 ±37(3)	3152 ±58(12)	3086 ±47(25)	3217 ±66(11)	3493 ±150(6)	3904 ±163(8)	3361 ±108(7)	3017 ±161(5)
Pooled adults	3579 ±159(10)	2749 ±91(12)	2927 ±56(25)	2923 ±43(45)	2971 ±65(24)	3262 ±83(16)	3672 ±164(13)	3342 ±104(9)	2964 ±107(9)
	P=0.21	P=0.21	P=0.02	P=0.01	P=0.42	P=0.87	P=0.94	P=0.03	
Juveniles	3198 ±226(4)	2543 ±111(5)	2619 ±58(5)	2510 ±105(9)	2860 ±72(6)	3222 ±106(2)	3704 ±99(2)	2987 ±108(12)	

[a] Probability that adjacent means in a column are significantly different (2-tailed T-test).

Table 6. Water content as a percentage of fresh carcass weight of adult and juvenile Sandhill Cranes obtained during winter 1979, and fall to spring 1979-80. Student's T-test was used to test for differences in water content between age classes within a period. Mean, ± SE, (sample size).

Period	Autumn migration	Early winter	Mid winter	Late winter	Early staging	Late staging	Spring migration	Spring migration	Pre-nesting
Month	Oct	Nov-Dec	Jan	Feb	Mar	Apr	Apr	May	May
1979									
Adults			62.3 0.61 (14)	64.8 0.40 (10)	60.1 0.80 (15)	56.1 1.50 (9)			
			[a]P=0.05			P=0.18			
Juveniles			59.1 1.77 (3)	54.7 ---- (1)	56.7 ---- (1)	52.2 0.45 (3)			
1979-80									
Adults	64.2 1.07 (10)	63.7 0.40 (12)	61.7 0.51 (25)	62.5 0.40 (43)	63.9 0.65 (24)	55.3 1.00 (16)	56.5 0.98 (13)	52.3 0.42 (9)	61.9 1.31 (9)
	P=0.78	P=0.04	P=0.36	P=0.27	P=0.79	P=0.69	P=0.75	P=0.01	
Juveniles	64.7 1.20 (4)	61.9 1.00 (5)	60.5 0.87 (5)	63.5 0.64 (8)	63.5 0.90 (6)	54.2 1.00 (2)	57.3 2.04 (2)	57.0 1.63 (12)	

[a] Probability that adjacent means in a column are significantly different (2-tailed T-test).

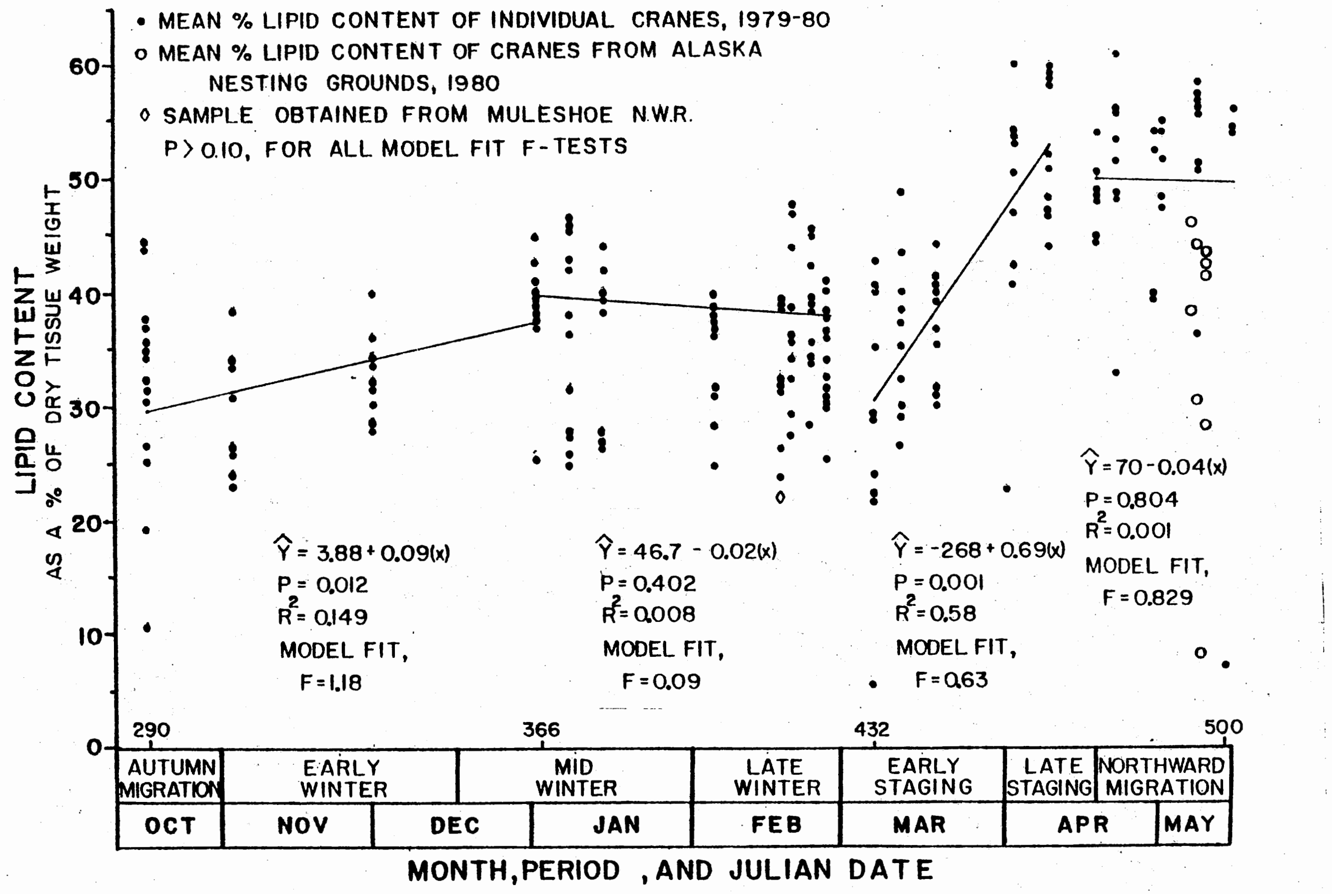

Fig. 1. Fitted regression lines of changes in lipid content, expressed as a percentage of dry tissue weight, from autumn migration to pre-nesting in Alaska. Periods of the annual cycle are shown on the X-axis. Cranes collected on the nesting grounds on the Yukon-Kuskokwim Delta, Alaska are not included in the last regression.

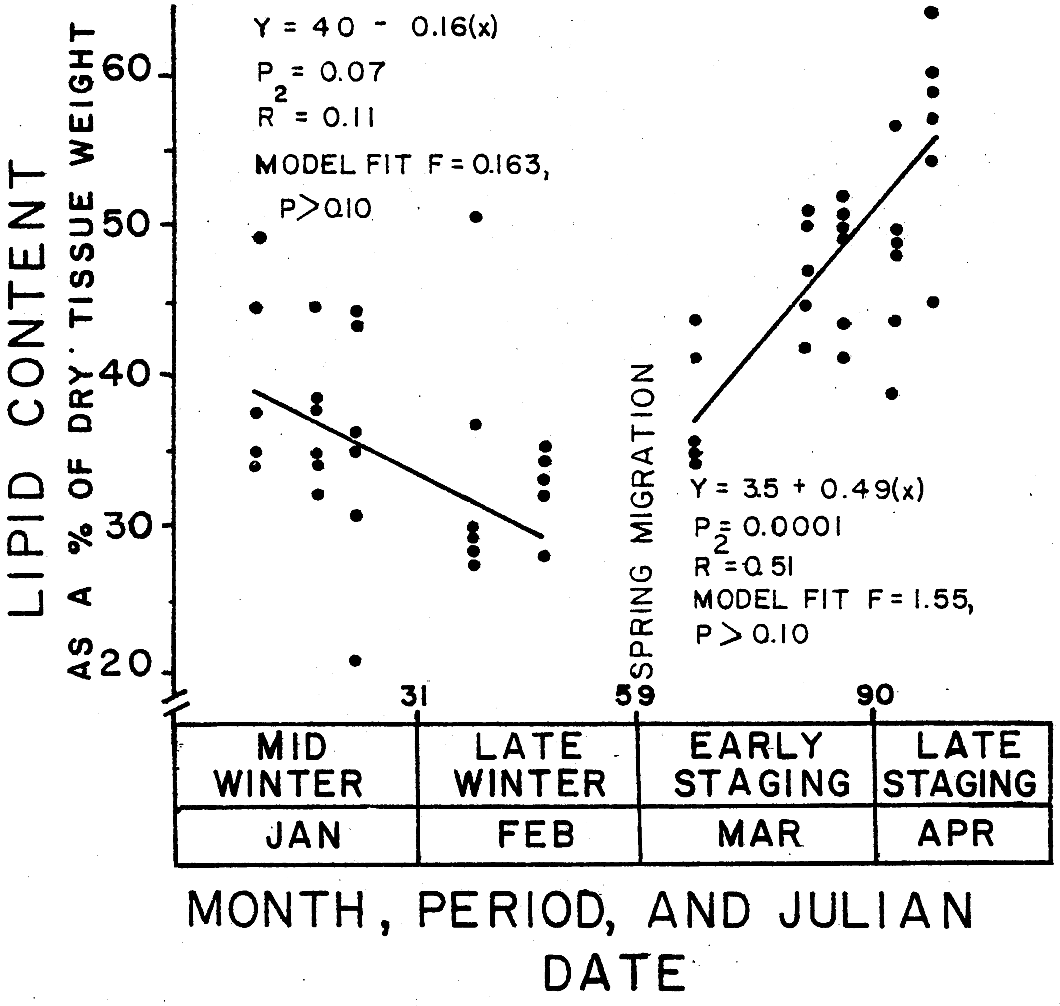

Fig. 2. Fitted regression lines illustrating the changes in lipid content of Sandhill Cranes during winter in Texas and spring in the Platte River Valley in Nebraska, 1979. Each point represents the mean lipid content of an individual crane.

CHAPTER III

ESTIMATING LIPID CONTENT OF SANDHILL CRANES FROM FIELD MEASUREMENTS

Condition, estimate, index, lipids, physiological, sandhill cranes, structural

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Our purpose is to present a reliable and efficient method to estimate total lipid reserves in sandhill cranes (Grus canadensis) from mid-continental North America. Lipid content alone (Evans and Smith 1975, Woodall 1978, Bailey 1979) and lipid content with protein reserves (Wishart 1979) have been used as indicators of physiological condition. Positive relationships have been found between physiological condition during winter (Milne 1976) and spring (MacInnes et al. 1974, Ankney and MacInnes 1978) and subsequent clutch size. Also, a positive relationship was detected between condition on mallards (Anas platyrhynchos) and wintering food supplies (Owen and Cook 1977). Lower body weights of Canada geese (Branta canadensis) during winter may be

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caused by decreased winter food supplies (Hanson 1962, Raveling 1968).

Knowledge of the physiology and condition of a species is essential to the understanding of habitat requirements (Fredrickson and Drobney 1977). The ability to assess the physiological condition of sandhill cranes provides a management technique to evaluate the physiological response of a species to dynamic environmental conditions and to quantify management activities related to refuging species. Approximately 10,000 cranes are harvested annually in mid-continental North America (Lewis 1977). Methods are needed to allow periodic evaluation of the condition of sandhill cranes, particularly because lipid levels of cranes have been shown to vary annually during comparable periods of the annual cycle (Iverson 1981).

MATERIALS AND METHODS

Methods of ether extraction to determine total body lipids were described by Iverson (1981). Body weight in this paper refers to whole, fresh, feathered sandhill cranes weighed to the nearest 5 g on a spring scale. Only cranes having dry plumage when weighed were included for statistical analyses. Fat-free body weights were calculated as: fresh body weight - (fresh body weight)(%lipids). The Statistical Analysis System (Barr et al. 1972) was used for simple and multiple linear regression analyses.

Indices of body structure were evaluated from measurements of the following structural variables recorded to the nearest 1 mm: 1) culmen (post-nares); 2) tarsus; 3) wing chord; 4) total length from the tip of the bill to the longest rectrice; and 5) keel (ventral surface of the sternum). Structural variables that explained the greatest amount of variation in fat-free body weight (an estimate of body size without seasonal variation in lipid deposits) were identified using simple linear regression. The resulting structural index was used to calculate a condition index that estimated the total grams of lipids in live sandhill cranes using body weights adjusted for variation in structural size.

Specific fat deposits were evluated for reliability as lipid indices for predicting total lipid content of dead sandhill cranes using simple linear regression. The following fat deposits of thawed cranes were measured in vivo to the nearest 1 mm: 1) greatest thickness of fat present on the gizzard; 2) length of the 'finger' of abdominal fat extending anteriorally from the cloaca on the right side of the gizzard; 3) the greatest thickness of the abdominal deposit; and 4) the thickness of the subcutaneous fat deposit immediately ventral to the junction of the neck and body. Both condition and lipid indices were then used to identify the best prediction equation to estimate total lipid content of dead cranes using multiple linear regression.

RESULTS

Mean lipid content of 144 adult and juvenile sandhill cranes used in this analysis ranged from 1.9% (percentage of fresh body weight) during the early wintering period in western Texas to 30.4% on spring migration staging areas along the North Platte River, Nebraska. Periods of the annual cycle from early wintering (Nov) in Texas to pre-nesting (May) in Alaska are represented in this sample.

Differences in structural size of sandhill cranes precluded the use of body weights as a reliable indicator of physiological condition

(Iverson 1981). Body weight explained only 59% of the variation in total lipid deposits of cranes (Table 1). The sum of total body length and wing chord was the most reliable (highest R^2) structural index of sandhill cranes, explaining 62% of the variation in fat-free body weight (Table 2). Regression of total grams of ether extractable lipids on the resulting condition index: body weight/(total length + wing chord) (BW/TL + WC), yielded a coefficient of determination of 0.68 (Table 1) and the following 95% prediction interval:

$$\pm\ 306.78 \quad \sqrt{1.4656 - 0.3691(BW/(TL + WC)) + 0.0001(BW/(TL + WC))^2}$$

Estimates of total lipid content using the condition index (reducing variation due to differences in structural size) increased the explained variation in total lipids by 9% over estimates using only body weight.

Measurements of selected fat deposits from dead sandhill cranes were tested for reliability as estimators of total lipid reserves. The thickness of breast fat (B) just ventral to the junction of the neck and body and the greatest thickness of fat present on the gizzard (G) each explained 74% of the variation in total grams of ether extractable lipids of cranes. Summing these 2 measurements (B + G) increased the R^2 to 0.83 (Table 3). Multiple regression of total lipid reserves on the sum of breast and gizzard fat deposit measurements and the condition index (BW/(TL + WC) revealed a coefficient of determination of 0.88 and the following prediction equation for estimating total grams of lipid reserves of sandhill cranes:

$$Y = -483.58 + 26.50(B + G) + 297.42(BW/(TL + WC);$$

and the 95% prediction interval:

$$\pm\ 186.10 \sqrt{\begin{array}{l}1.7442 + 0.0188(B + G) - 0.6870(BW/(TL + WC)) + \\ 0.0003(B + G)^2 - 0.0106\ (B + G)(BW/(TL + WC)) + \\ 0.1650(BW/(TL + WC))^2\end{array}}$$

This was the best 2-variable model (having the highest R^2 among all 2-variable models) constructed with available data. Because the best 3-variable model increased the R^2 value by only 1.0%, this 2-variable model was judged to be the best overall model for use in predicting total grams of lipids present in dead sandhill cranes using measurements obtained under field conditions.

DISCUSSION

Several authors (Hanson 1962, Owen and Cook 1977, Wishart 1979) recognized that body weights may not be reliable indicators of physiological condition. Body weights are biased estimates of condition because of variation in body size among conspecifics. Variation in structural size among passerines has been corrected by analyzing groups of birds with similar wing lengths (Connell et al. 1960, Rogers and Odum 1964). Structural variables have been evaluated with regression analysis to identify structural indices that best characterize body size. Total length explained 58% of the variation in fat-free body weight of adult redheads (*Aythya americana*) (Bailey 1979). The sum of body length and wing length explained the greatest amount of variation ($R^2 = 0.71$) in body size (estimated by lipid-free skeletal weights) of American wigeon (*Anas americana*) (Wishart 1979). The structural index (total length + wing chord) also explained the greatest amount of variation in fat-free body weights of sandhill cranes.

Positive relationships between specific fat deposits and total lipid reserves were found for redbilled teal (Anas erythrorhyncha) (Woodall 1978) and hooded crows (Corvis cornix) (Houston 1977). Weight of the abdominal fat deposit in wigeon revealed a coefficient of determination of 0.83. The sum of weights of skin and abdominal fat deposits dissected from wigeon explained 92% of the variation in total lipid reserves (Wishart 1979). Bailey (1979) obtained a coefficient of determination of 0.93 for redheads using a 3-parameter, multiple regression analysis (weights of skin, abdominal, and visceral fat deposits). Total body water was used to estimate lipid content of lesser snow geese (Anser c. caerulescens) resulting in a close relationship (r = 0.95) between estimated and determined values of lipid content (Campbell and Leatherland 1980). The coefficient of determination of 0.88 we obtained (2-parameter multiple regression analysis of total grams of ether extractable lipids on the sum of measurements of breast and gizzard fat and the condition index BW/(TL + WC) is comparable statistically to previous studies. If the predicted value of total grams of body lipids is divided by body weight, the quotient yields the percentage of body weight composed of lipids that is useful for comparisons among birds, between seasons of the annual cycle, or between years.

Predictions of total lipid content discussed by Bailey (1979), Wishart (1979), and Campbell and Leatherland (1980), had the advantage of providing methods of estimating total lipid content without conducting expensive ether extractions. However, each of these methods required relatively time-consuming laboratory preparations, dissections, or weighing of discrete fat deposits to obtain reliable predictions of total lipid content. Measurements of structural variables and the thickness of specific fat deposits used in this study have the advantage that data can be collected expediently in the field using a knife, a mm ruler, and a spring scale. Tactical problems of transport and storage of carcasses are also eliminated if estimation of lipid content is the sole remaining objective.

MANAGEMENT IMPLICATION

Based on the equations presented, total lipid content of sandhill cranes can be estimated from data collected in the field on live cranes using only a condition index, or on dead birds using a condition index and measurements of specific fat deposits. Techniques provided herein are rapid, inexpensive, and especially suited for application at hunter check stations. The ability to estimate the physiological condition of sandhill cranes will allow managers to periodically monitor fitness of cranes in response to population concentrations of birds; changes in land use, especially on wintering grounds in western Texas and on spring staging areas along the Platte River in Nebraska; and response to human disturbance. Prediction equations presented in this paper can aid future ecological studies of sandhill cranes by allowing field biologists to estimate total lipid content of cranes without expensive and time-consuming laboratory extraction procedures.

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Table 1. Regression of total grams of lipid reserves on condition indices of sandhill cranes collected during winter and spring 1979-80. $\underline{N} = 144$.

Independent variable (X)	R^2	$SE(B_1)$	Fitted regression equation
Body weight (BW)	0.59*	0.03	$Y = -811 + 0.41(BW)$
Body weight/keel BW/K	0.62	4.81	$Y = -1106 + 74.4(BW/K)$
Body weight/culmen BW/C	0.64	2.11	$Y = -996 + 34.3(BW/C)$
Body weight/wing BW/W	0.65	14.8	$Y = -1193 + 243(BW/W)$
Body weight/tarsus BW/T	0.67	6.41	$Y = -1198 + 109(BW/T)$
Body weight/total length BW/TL	0.67	28.3	$Y = -1236 + 482(BW/TL)$
Body weight/TL + T BW/(TL + T)	0.68	34.2	$Y = -1280 + 608(BW/TL + T)$
Body weight/TL + WC BW/(TL + WC)	0.68	42.6	$Y = -1267 + 744(BW/TL + WC)$

* $\underline{P} < 0.0001$, for all $H_o : B_1 = 0$

Table 2. Regression of fat-free, fresh body weights on structural indices of sandhill cranes collected during 1979-80. $\underline{N} = 144$.

Independent variable (X)	Mean	Range	R^2	SE (B_1)	Fitted regression equation
Culmen (C)	73.6	61-89	0.26*	4.66	$Y = 387 + 32.7(X)$
Keel (K)	148.9	121-181	0.36	2.55	$Y = -596 + 22.8(X)$
Tarsus (T)	207.9	177-254	0.45	1.47	$Y = -532 + 16.0(X)$
Wing chord (WC)	464.2	391-570	0.49	0.93	$Y = -2228 + 10.8(X)$
Total length (TL)	895.8	801-1031	0.53	0.46	$Y = -2488 + 5.90(X)$
Total length + tarsus (TL + T)	1103.7	985-1276	0.58	0.35	$Y = -2593 + 4.89(X)$
Total length + wing chord (TL + WC)	1360.0	1196-1527	0.62	0.30	$Y = -3443 + 4.59(X)$

* $\underline{P} < 0.0001$, for all $H_o : B_1 = 0$

Table 3. Regression of total grams of lipid reserves on measurements of specific fat deposits of sandhill cranes obtained during winter and spring 1979-80. N = 144.

Independent variable (X)	Mean	Range	R^2	SE (B_1)	Fitted regression equation
Abdominal length (Al)	89.4	0-120	0.42*	1.02	$Y = -359 + 10.5(X)$
Abdominal thickness (At)	9.28	0-23	0.64	3.43	$Y = 71.6 + 55.0(X)$
Breast thickness (B)	5.91	1-18	0.74	3.33	$Y = 187 + 66.8(X)$
Gizzard thickness (G)	6.43	0-18	0.74	3.04	$Y = 183 + 61.9(X)$
Breast + gizzard (B + G)	12.3	1-31	0.83	1.35	$Y = 135 + 36.2(X)$

* $P < 0.0001$, for all $H_o : B_1 = 0$

VITA

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Thesis: SEASONAL VARIATION IN LIPID CONTENT AND CONDITION INDICES OF SANDHILL CRANES FROM MID-CONTINENTAL NORTH AMERICA

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