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Abstract: We used linear and mass measurements to construct a body mass index (BMI) for 2 subspecies of sandhill cranes (*Grus canadensis*). We found that BMI declined during the spring and early summer period. We used the BMI to show that juvenile Florida sandhill cranes (*G. c. pratensis*) reach their full mass at about 270 days of age, near the age at which they begin to leave the company of their parents. We used mensural data to predict a minimum expected mass for normal sandhill cranes which could be then used to evaluate the relative health of an individual suspected of being diseased or underweight.

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Some of the 6 currently recognized subspecies of sandhill cranes (*Grus canadensis*) are distinguished by morphometric variations (Johnson and Stewart 1973, Guthery 1975). Population management and harvest decisions based on the relative abundance of morphometric differentiation of subspecies have been proposed in the past (Stephen et al. 1966). More recently, this approach was deemed "not feasible" because "... a continuum in size…" precluded reliable differentiation among subspecies (Tacha et al. 1985). Mensural procedures have been used to distinguish between gender, subspecies, or age in some sandhill crane populations (Nesbitt et al. 1992), in other cranes (Swengel 1992), and among some other sexually dimorphic species (e.g., tundra swans [*Cygnus columbianus*] Miller et al. 1988).

Regressing mass on some linear index of body size, and using the outcome as an index of body condition, is a commonly used and accepted predictor of physical status (Schulte-Hostedde et al. 2005). External measurements have been used to predict expected mass and health in a variety of species (Brown 1996, Berry and Christopher 2001).

Florida has both a population of nonmigratory Florida sandhill cranes (*G. c. pratensis*) and a wintering population of migratory greater sandhill cranes (*G. c. tabida*). We used mensural data to develop a Body Mass Index (BMI) for both subspecies. A similar approach, based on specific linear measurements, could produce an expected mass for an individual. Furthermore, a mean BMI of sandhill cranes by month, by gender, and by subspecies would show changes in the body condition of individuals in a population throughout the year, which could be used for recognizing those that fell outside the mass as predicted based on linear measurements. The BMI could also be useful for assessing the condition and progress of newly released individual whooping cranes (*G. americana*) as they adjust to life in the wild in an attempt to establish new populations. In juvenile sandhill cranes it has been determined that the growth of long bones is completed at 10 weeks of age (Curro et al. 1994), although juvenile cranes do not reach full mass until sometime between 10 and 12 months later (Walkinshaw 1949, Tacha et al. 1985). We will utilize a BMI of developing juveniles to clarify the age at which juvenile sandhill cranes in Florida reach their mature body mass.

METHODS

We used alpha-chloralose (an oral tranquilizer; Bishop 1991) to capture cranes on Paynes and Kanapaha Prairies in Alachua County Florida. We weighed each bird to 0.01 kg and measured the lengths, to the nearest mm, of exposed culmen (culmen posterior nares to tip), tarsus, and the unfeathered tibia (see Stephen et al. 1966). We did not consistently record additional measurements (e.g. wing cord, mid toe, tail, and bill depth at base) that others have reported (Du Mont 1933, Johnson and Stewart 1973). We did not measure wing cords because both migratory and nonmigratory sandhill cranes studied in Florida replace their wing feathers sequentially over a period of years (Nesbitt and Schwikert 2005); therefore, an individual's wing cord measurement would decrease as wear reduced wing feather length. We evaluated the relationship between tarsus length and mass in healthy cranes to predict an expected range of body mass, based on leg length. We also

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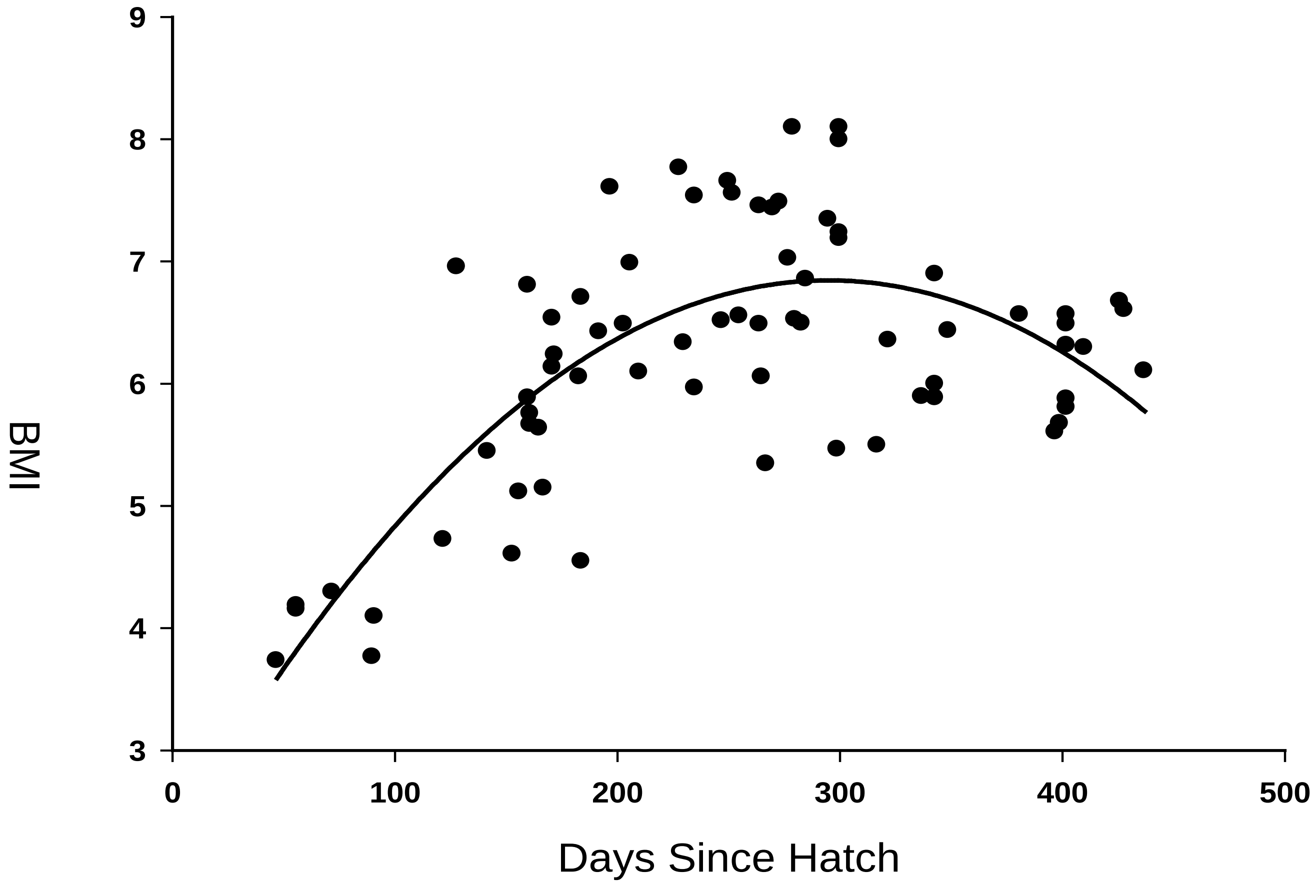

Figure 1. Body mass index (based on tarsus) of developing Florida sandhill cranes captured in Florida, 1974 to 1999 (n = 108).

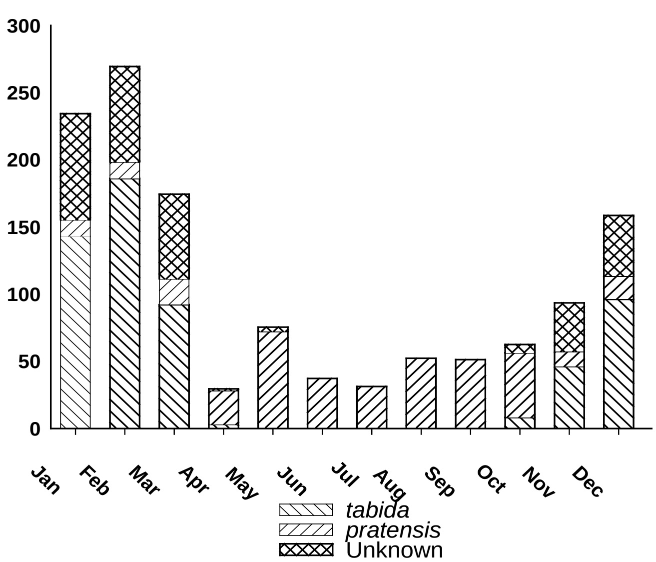

Figure 2. Handlings by month and subspecies of 1,265 adult sandhill cranes captured in Florida, 1974 to 1999.

used culmen length because it is often easier to measure more precisely than tarsus length with a struggling crane.

Juvenile cranes (< 1 year of age) were distinguished from older birds based on plumage (Lewis 1979). Linear measurements were taken each time a juvenile crane was recaptured during its first year. Linear measurements in adult plumage birds were taken only during the initial capture because we assumed their bones had stopped growing. Mass was measured for every bird each time it was handled, irrespective of age. To standardize days-since-hatch for body mass measurements of juveniles through their first year, uniform hatch dates were chosen based on the average laying dates of each population (Tacha et al. 1992) Florida sandhill cranes were all given the date of 1 April and greater sandhill cranes were given the date of 1 May. These dates were chosen based on the average laying/hatch date of the 2 subspecies we studied (Tacha et al. 1992).

In this analysis we did not include data for any cranes that appeared sick or were unable to fly when captured, nor did we include birds that had obvious physical abnormalities (leg or bill deformities; Nesbitt et al. 2005). We suspected illness, injuries, or abnormalities could have affected foraging and, therefore, a bird's mass. Sex, subspecies, and social status (breeding/nonbreeding) was determined based on observations of the crane's behavior (calls, social interactions, nesting, and migration) in the natural setting post capture (Nesbitt et al. 1992).

We looked for relationships between body mass of male and female adult plumage cranes, of both subspecies, and length measurements of the culmen, tarsus, and exposed tibia for males and females of both subspecies. We used linear regression analysis to look for relationships between increase in mass and days-since-hatch for juveniles, and to correlate mass with bill length and leg length. All analyses were performed with the use of programs available in JMP, Version 5 (SAS Institute Inc., Cary, North Carolina, 2002).

RESULTS

We examined data from 1,265 handlings of 745 individual sandhill cranes captured in Florida between 1974 and 1999; of these, we determined the subspecies for 452 (217 were Florida, 235 were greater sandhill cranes). As was reported in a prior study (Nesbitt et al. 1992), tarsus appeared to be a stronger predictor of mass for all combinations of subspecies and sex than exposed culmen, but we report the results for both. We used the relationship of tarsus length (or exposed culmen) to mass to calculate a body-mass index (BMI) using the following formula: BMI = (mass [g]/tarsus length [mm]^2) x 10^5.

The mean BMIs for all the adult plumage Florida sandhill cranes were 6.65 (based on tarsus length) and 25.77 (based on exposed culmen). The mean BMIs for all the adult plumage greater sandhill cranes were 7.42 (based on tarsus length) and 24.25 (based on exposed culmen). The differences in BMI for the 2 subspecies are similar to the differences found in measurements in a prior study (Nesbitt et al. 1992).

Fifty-one cranes captured and banded as juveniles were handled 108 times at ages that ranged from 46 to 447 days post-hatching. Thirty-three of the recapture were cranes < 12 month old (24 twice, 3 three times). The mean recapture interval was 72.4 days and ranged from 7 to 253 days. To more exactly determine when juvenile sandhill cranes reached their approximate adult mass, we plotted BMI (based on tarsus length) against days-since-hatching. The BMI slope appears to become asymptotic at about 270 days post hatching (Fig. 1).

We used handlings by month and by subspecies (Fig. 2) and BMI to investigate changes in mass of all adult plumage sandhill cranes during the year. We plotted the mean BMI by month and by subspecies (Fig. 3). We did not observe any normal greater sandhill cranes outside of the wintering period; consequently, we have no information on variations in mass for them between April and late October. However, what information we had (over fall, winter and early spring)

Table 1. Body measurements and predicted minimum mass (lower 95% predicted confidence interval) based on regression of tarsus and culmen length against mass for 277 Florida and 476 greater sandhill cranes with adult plumage handled in Florida, 1974 to 1999.

Tarsus length (mm) and predicted minimum normal mass (kg)		
Tarsus	*G. c. pratensis* (adjusted r^2 = 0.352)	*G. c. tabida* (adjusted r^2 = 0.356)
209	2.59	3.03
212	2.65	3.09
215	2.71	3.16
218	2.77	3.22
221	2.83	3.28
224	2.89	3.34
227	2.95	3.40
230	3.01	3.46
233	3.07	3.52
236	3.92	3.59
239	3.18	3.65
242	3.24	3.71
245	3.30	3.77
248	3.36	3.83
251	3.42	3.89
254	3.48	3.95
257	3.53	4.01
260	3.59	4.07
263	3.65	4.13
266	3.71	4.19
269	3.76	4.25
272	3.82	4.31
275	3.88	4.37
278	3.94	4.43
281	3.99	4.49
284	4.05	4.55
287	4.11	4.61
290	4.16	4.67
293	4.22	4.73
296	4.28	4.79
Exposed culmen length (mm) and predicted minimum normal mass (kg)		
Culmen	*G. c. pratensis* (adjusted r^2 = 0.131)	*G. c. tabida* (adjusted r^2 = 0.229)
97	2.60	2.58
100	2.67	2.67
103	2.74	2.76
107	2.81	2.85
110	2.89	2.94
113	2.96	3.03
116	3.03	3.12
119	3.11	3.22
122	3.18	3.31
125	3.25	3.40
128	3.32	3.49
131	3.39	3.58
134	3.46	3.67
137	3.53	3.76
140	3.60	3.85
143	3.67	3.94
146	3.73	4.03
149	3.80	4.12
152	3.87	4.21
155	3.93	4.30
158	4.00	4.39
161	4.07	4.48
165	4.14	4.57

seemed to indicate that annual mass changes in the greater and Florida subspecies are dissimilar. Average BMI for Florida cranes began to decline in February; which coincides with the onset of the nesting season of adults. The nadir in seasonal mass occurred in June. When we compared the mean BMI for Florida cranes in June, July, and August (*n* = 110), there was a 5.5% decrease from November, December, and January (n = 32). The decline in BMI in January compared to December and February was likely an artifact of a smaller sample size for the winter months (January had fewer recaptures [10] than any month). This same pattern was apparent in both the breeding and nonbreeding-age segments of the Florida subspecies. In the greater subspecies, there was a decline in mass subsequent to their fall arrival in Florida (October-November) and again as spring migration began in late January-mid February. Though slight the decline in relative mass in the spring could have been the result of breeding adults (those that would likely have a greater proportional increase in body mass) leaving early in the migration period and non-breeding birds leaving later in the season.

Using the 95% confidence interval for the relationship of mass to tarsus length or exposed culmen length we have constructed a table (Table 1) of expected masses for a given tarsus or culmen length. An individual crane's mass and tarsus or exposed culmen length can be compared with this table to make a relative health assessment for sandhill cranes under field conditions. An individual with a body mass that approaches, and particularly one that is below, the predicted lower confidence mass value should be considered an abnormally light individual.

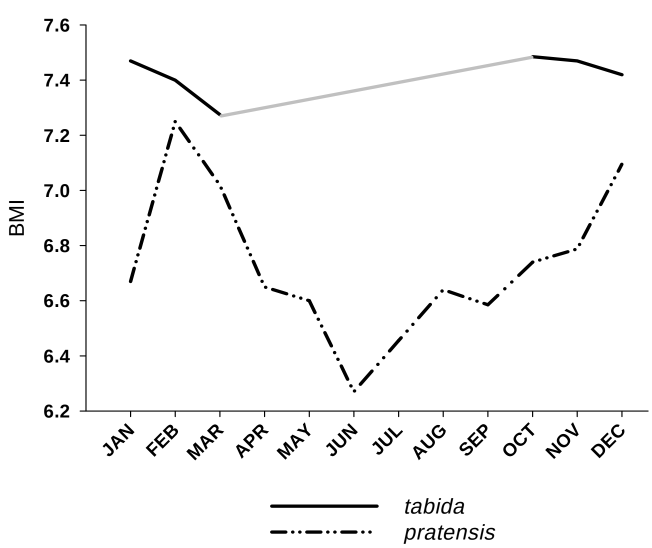

Figure 3. Change in body mass index by month of 81 adult sandhill cranes (55 *G. c. pratensis*, 26 *G. c. tabida*) handled 186 times in Florida, 1974 to 1999.

DISCUSSION

The age at which the juvenile Florida sandhill cranes we studied reached their adult BMI (270 days) was similar to the age (256 days) when they would begin leaving the company of their parents (Nesbitt et al. 2002); this was more than 6 months after the long bone growth was completed (about 10 weeks Curro et al. 1994). The acquisition of adult mass may be a more critical feature of fitness for independence than physical stature (as measured by bone length) alone.

The decline in body mass we noticed in the Florida subspecies took place during the season when nesting adults would be occupied with egg laying, incubation, and chick rearing (if nesting efforts were successful). However, we noticed the same spring-summer decline occurred in the nonbreeding segment of the population. Mass loss during the summer may occur throughout the population and not be due only to breeding birds devoting more of their energy to nesting and chick rearing than to foraging. Because we avoided attempting to capture families until after the young were fledged, the seasonal mass loss among breeding adults could have been even more dramatic than we were able to detect. Body mass loss during summer may also be a consequence of annual molt. Molting in Florida sandhill cranes begins around the mean hatching date, 1 April, and continues through early fall (Nesbitt and Schwikert 2005, Nesbitt and Schwikert 2008). The migratory subspecies may also experience a decline in mass during the summer. Other causes of summer weight loss could be a physiologic response to the change in temperature and changes in food abundance or food quality.

MANAGEMENT IMPLICATIONS

We report the predicted minimum mass for sandhill cranes, given its general body size (as indicated by tarsus length), as a tool to assess a crane's relative physical condition under field conditions. We believe such an assessment would help in deciding the disposition of a crane with unusually low body mass; decisions such as whether an individual should be taken into captivity for treatment or allowed to remain in the field could be informed with this assessment process.

In our efforts to reestablish a population of whooping cranes in Florida, we have released juvenile cranes transported to Florida from captive rearing sites to the north (Nesbitt et al. 2001). Most cranes lost weight during the 2 weeks of pre-release conditioning following their arrival in Florida (Florida Fish and Wildlife Conservation Commission, unpublished data) and it would be useful to know with confidence whether this weight loss was within the normal range for the species. If losses were below the expected minimum then additional diagnostic testing and investigation into probable causes of weight loss would be warranted.

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