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SEXUAL SIZE DIMORPHISM AND SIZE INDICES OF SIX SPECIES OF CAPTIVE CRANES AT THE INTERNATIONAL CRANE FOUNDATION

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Abstract: Sexual size dimorphism and size indices in captive cranes were studied to learn dimorphism patterns and size relationships that could be used in the management of captive cranes. In 6 species of captive cranes, Siberian (*Grus leucogeranus*), eastern sarus (*G. antigone sharpii*), white-naped (*G. vipio*), common (*G. grus*), hooded (*G. monacha*), and red-crowned (*G. japonensis*), males averaged 14.5–28.5% heavier than females ($P < 0.05$) in all species. Males had longer culmens, tarsi, and wing chords in all species. Males had significantly longer culmens ($P < 0.05$) in 4 of 6 species and had significantly longer tarsi than females ($P < 0.05$) in 3 of 6 species. Culmen and tarsus lengths both averaged 7% longer in males than females when the 6 species were combined. Wing chord length was not significantly dimorphic ($P > 0.05$) in any of the 4 species measured (Siberian, white-naped, hooded, and red-crowned cranes), averaging only 1.3–3.3% longer in males than in females. Body weight correlated significantly with tarsus length, culmen + tarsus length, and culmen × tarsus length in 5 of 6 species ($P < 0.05$). Weight covaried significantly with culmen length in 4 species, and with wing length in 1 species ($P < 0.05$). Sex-specific linear regression models predicted weight from linear measurements more accurately than when both sexes were combined, suggesting differences in body scaling between sexes in some species. The best regression formulae used linear measurements to predict crane weights at the International Crane Foundation (ICF) within 1.2–4.2% of actual weight for 5 of the 6 species. Because ICF cranes weighed more than cranes from 3 other zoos sampled, these regression formulae were poor predictors of crane weights at those zoos. Body weight was the best index of overall size within a site, followed by culmen + tarsus and culmen × tarsus. Culmen + tarsus and culmen × tarsus are probably the best indices of overall size among sites. Wing chord and weight measurements vary over time, so caution should be used when comparing these among individuals. All species gained weight between September and November. Red-crowned and Siberian cranes undergo large fall weight gains and remain heavier than normal all winter. Sexual size dimorphism could be used to determine the sex of some crane species. Using normal weights of cranes may help detect potentially unhealthy weight changes (usually losses) in captive or rehabilitated cranes.

Key Words: crane, *Grus*, sexual size dimorphism, size indices

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Cranes are monomorphic in plumage, with slight sexual size dimorphism (Walkinshaw 1973, Johnsgard 1983). Several studies of wild cranes (Blackman 1971, Aldrich 1979, Tacha et al. 1985*b*) have demonstrated that males average larger than females, but that much size overlap exists. Among wild pairs of brolgas (*G. rubicunda*), males were larger than their mates in 20 of 20 cases (Blackman 1971), suggesting assortative mating by size.

Murata et al. (1988) developed a method of predicting the sex of most captive red-crowned cranes by discriminant analysis. Soviet researchers used body measurements to develop a discriminant function that can correctly assign sexes to nearly all wild common cranes they have captured (Y. Markin, Oka State Nature Reserve, pers. commun.). There are few published data on normal weights and measurements of captive cranes (e.g., Johnsgard 1983), so crane breeders and wildlife rehabilitators are often unable to determine whether their cranes are heavier or lighter than normal. Crane weights vary over time. Therefore, weights from different seasons are needed in order to assess a species' weight variation pattern.

I examined sexual size dimorphism in 6 species of cranes and generated models to predict crane weights from body measurements. I also compared different size indices in an effort to determine which measurements best describe a crane's overall size. I quantified fall weight changes in several species in order to characterize part of the annual weight cycle of captive cranes. I then compared sexual size dimorphism patterns and relationships among size measurements of cranes at the International Crane Foundation (ICF) to those of captive cranes at 3 widely disparate localities to learn whether trends I observed at ICF were general or site-specific.

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STUDY AREA

Cranes housed on ICF's 2 sites (43°29'–43°32'N, 89°45'W) were used in this study. The ICF is a non-profit foundation started in 1973 with the purpose of protecting

the world's cranes and their wetlands. During the study period ICF housed a captive breeding flock of 125 individuals of 14–15 species of cranes. Cranes at ICF have a constant supply of fresh, pelleted food. Because they live in 275-m^2 pens, the cranes are unable to exercise as much as wild cranes. I also used published and unpublished measurements of captive cranes from a variety of latitudes, including The U.S.S.R. Crane Center at the Oka Nature Reserve (Oka Center) (55°N), Japanese zoos (35°N), and the Korat Zoo, Thailand (15°N), to corroborate or test some of my results.

METHODS

I compiled tarsus, wing chord (distance from the wrist to the tip of the longest unflattened primary), and exposed culmen lengths (Pettingill 1970:446) of Siberian, common, hooded, and red-crowned cranes measured during annual physical exams at ICF in October 1980. I took the same measurements on eastern sarus cranes (of Australian origin) in August 1986 and on white-naped cranes in October 1989. Within a species, all measurements were taken by the same personnel to minimize measurement bias. I collected all weights that were recorded on these measured cranes' medical records from 1980 to 1990, but excluded weights taken when cranes were ill or injured, or when cranes were less than 16 months old (i.e., not fully adult weight). The largest sample of weights (up to 11 per individual because I collected weights from 11 calendar years) was gathered in October during the annual physical exam. Samples were only 1–2 per individual for other months, so I used October weights as baseline values. I used the mean October weight of each individual for statistical analyses. Male Siberian cranes measured in 1980 weighed less than other conspecific males at ICF, so I included weights of all adult Siberian cranes for comparing males to females. Different species of cranes differ in sizes and body shapes, so all comparisons were intraspecific.

Cranes at ICF weigh more in winter than in summer, so I examined seasonal weight variation. I compared weights taken in October to those taken in the months immediately preceding or following October. Only month pairs that included October had large enough sample sizes for statistical analyses. I also examined seasonal weight changes in 13 Siberian cranes from the Oka Center (V. Panchenko, Oka Center, unpubl. data).

I tested for correlations (multiple coefficient of correlation, R) among weight, culmen, tarsus, and wing chord measurements. The results suggested that an index combining tarsus and culmen lengths would be a good size descriptor, so I tested for correlations between culmen + tarsus length (cultars) and culmen × tarsus length (tarscul) vs. wing chord length and body weight.

To determine whether one can accurately predict crane weights from linear measurements, I calculated regression formulae and ANOVA's for tarsus length vs. weight, culmen length vs. weight, cultars vs. weight, and tarscul vs. weight for 3 groups: all cranes of a species, males of each species, and females of each species. Using these regression formulae, I calculated 8 predicted weights (4 regressions on all cranes of that species and 4 sex-specific regressions) for each crane. I calculated the deviation of predicted weight from actual weight for each crane and each formula, and determined which formulae predicted weight most accurately for all cranes of a species, males, and females.

To test whether the weight prediction models developed from ICF's cranes are applicable to captive cranes in general, I used the models to predict weights of red-crowned cranes from zoos in Kobe, Okayama, and Osaka, Japan (Murata et al. 1987), Siberian cranes from the Oka Center (V. Panchenko, unpubl. data), and eastern sarus cranes from the Korat Zoo, Thailand (J. Barzen, ICF, unpubl. data). I compared weights of cranes from all these captive centers to learn the degree of weight variation found in captive cranes at different sites. All statistical analyses were performed by the SYSTAT (SYSTAT, Inc., Evanston, Illinois) database program.

RESULTS

Sexual Size Dimorphism

Male cranes of all 6 species averaged larger than females for every measure of size (Table 1). October weight was the most dimorphic character; males were significantly heavier than females in all 6 species ($P < 0.05$, independent t-test) (Table 2). Culmen and tarsus measurements exhibited significant sexual dimorphism in 4 and 3 species, respectively ($P < 0.05$, independent t-test). Wing chord length exhibited small, non-significant differences between sexes in Siberian, white-naped, hooded, and red-crowned cranes.

The degree of weight dimorphism, ranging from 14.5% to 28.5%, was larger than the dimorphism in linear measurements in all 6 species (Table 2). Culmen and tarsus lengths each averaged 7% larger in males than females. The magnitude of linear measurement dimorphism was greatest in the species that had the most weight dimorphism.

There were interspecific differences in the magnitude of sexual size dimorphism. The most dimorphic species were the common, eastern sarus, and white-naped cranes, and the least dimorphic were hooded and red-crowned

Table 1. Linear measurements (mm) and October weights (g) of males and females of 6 species of cranes at ICF.

Species	Culmen				Tarsus				Wing chord				October weight			
	$\bar{x}$	SD	Range	*n*	$\bar{x}$	SD	Range	*n*	$\bar{x}$	SD	Range	*n*	$\bar{x}$[a]	SD	Range	*n*
Siberian																
Males	174.6	12.7	162−191	6	277.6	15.8	262−295	6	599.6	34.4	557−640	5	6,779	447	6,094−7,450	16
Females	156.3	6.1	151−165	4	261.1	13.9	244−278	4	588.8	8.6	576−595	4	5,827	456	5,491−6,970	10
Eastern sarus																
Males	159.3	4.6	154−165	4	315.5	7.0	307−323	4					7,211	147	7,020−7,333	4
Females	142.8	6.6	135−151	4	290.5	3.8	285−293	4					5,636	305	5,338−6,031	4
White-naped																
Males	144.5	7.2	138−154	6	285.8	8.2	278−297	6	585.2	17.7	566−616	6	6,643	275	6,370−7,160	6
Females	134.5	5.6	127−141	6	265.8	7.8	259−276	6	566.3	5.5	542−572	4	5,373	243	4,930−5,620	6
Common																
Males	107.3	4.2	102−113	8	249.0	17.3	226−270	8	590.4	9.3	582−605	5	5,359	647	4,420−6,433	8
Females	102.0	2.9	98−105	5	223.8	15.3	200−239	5	519.0		519	1	4,172	333	3,900−4,700	5
Hooded																
Males	104.3	3.5	102−109	5	219.9	12.2	209−237	5	504.6	30.4	455−535	5	4,100	175	3,933−4,383	5
Females	101.7	4.1	96−108	6	212.9	11.1	196−228	6	498.3	20.6	479−520	4	3,580	141	3,467−3,733	6
Red-crowned																
Males	154.9	9.1	141−167	9	282.7	12.2	262−299	9	646.3	25.7	593−669	9	8,959	843	7,800−10,550	9
Females	148.6	6.5	144−158	4	271.3	18.9	248−294	4	631.5	22.6	605−660	4	7,501	1,089	6,605−8,983	4

[a] Grand mean of mean October weights.

cranes. The Siberian crane exhibited an intermediate amount of sexual size dimorphism. In eastern sarus, white-naped, and hooded cranes there was no overlap in mean October weight of males vs. females. The lightest male averaged at least 5% heavier than the heaviest female. In the other 3 species, 1 large female weighed more than at least 2 males. Even in the 3 species where all males had higher mean October weights than all females, however, single female weights (most individuals were weighed in several different Octobers) were sometimes higher than the lowest individual male October weight.

Seasonal Weight Variation

An individual crane's weight varied as much as +10% from its mean between Octobers in consecutive years. Cranes weighed less during the warm months preceding October and continued to gain weight after October (Table 3). Between September and November, mean weights increased 15% in Siberian cranes, 9% in white-naped cranes, and 10% in red-crowned cranes. Wherever the sample size was larger than 5, October weights were significantly higher than September weights and lower than November weights ($P < 0.05$, paired *t*-test). More than 95% of individual November weights were higher than the crane's mean October weight.

Siberian and red-crowned cranes remained heavier than average into the winter. Red-crowned cranes at ICF weighed 34% more, and Siberian cranes 23% more, in December than in July. Similarly, Siberian cranes at the Oka Center (V. Panchenko, unpubl. data) averaged 23.0% heavier (range 11.5−36.0%, $n = 13$) ($P < 0.001$, paired *t*-test) in January 1983 than in August 1982.

Relationships Between Linear Measurements and Weight

Weight was significantly correlated with tarsus length in 5 of the 6 species ($P < 0.05$, Pearson's product-moment correlation matrix) (Table 4). Weight covaried strongly

Table 2. Percentage that males averaged larger than females in 6 species of cranes at ICF. Probabilities[a] are from independent *t*-tests.

Species	Culmen	Tarsus	Wing chord	October wt
Siberian	11.7*	6.3	1.9	16.3***
Eastern sarus	11.6**	8.6**		27.9***
White-naped	7.4*	7.5**	3.3	23.6***
Common	5.1*	11.1*		28.5**
Hooded	2.6	3.3	1.3	14.5***
Red-crowned	4.3	4.2	2.0	19.4*

[a] *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

with culmen length in 4 of the 6 species ($P < 0.05$, Pearson's product-moment correlation matrix). Weight was more highly correlated (multiple coefficient of correlation, R) with tarsus length than with culmen or wing chord lengths in all 6 species. Weight correlated significantly with wing chord in only 1 species and had a weak negative correlation with hooded crane wing length.

Cultars and tarscul, which combine culmen and tarsus lengths, each correlated more highly with weight than the other 3 measurements in at least 5 of the 6 species (Table 4). Cultars and tarscul were about equally correlated with weight. Since body weight appeared to be geometrically related to linear measurements, I examined the correlation between $cultars^2$, $cultars^3$, $tarscul^2$, and $tarscul^3$ and body weight. In several cases (some common and eastern sarus cranes, and male white-naped cranes) some of these 4 size indices were significantly correlated with October weight, but they were never as highly correlated with body weight as the best of the other linear measurements or their derivatives I examined.

Culmen length correlated significantly with tarsus length in 3 species and with wing chord length in 2 species (Table 4). Wing chord length covaried strongly with tarsus weight in 2 species, with cultars in 3 species, and with tarscul in 2 species (Table 4). Culmen length generally correlated more highly with tarsus and wing chord lengths than did the latter 2 measurements with each other.

Sex-specific Size Relationships

The 2 sexes of a species generally had similar scaling among measurements, but there were several sex differences. For example, in male Siberian cranes tarsus length correlated more highly with culmen and wing lengths than it did in females.

Female measurements correlating significantly with October weight were culmen ($P = 0.026$), cultars ($P = 0.030$), and tarscul ($P = 0.012$) in Siberian cranes, and tarscul ($P = 0.025$) in hooded cranes. Male common cranes showed significant relationships between October weight and tarsus, cultars, and tarscul measurements ($P = 0.014$, 0.004, and 0.001, respectively). Male Siberian cranes had significant correlations between October weight and culmen, tarsus, cultars, and tarscul ($P = 0.048$, 0.039, 0.042, and 0.043, respectively). Probabilities were derived from Pearson's product-moment correlation matrix.

Predicting Weight from Linear Measurements

Many regression models produced statistically significant estimators of weight from linear measurements, especially in Siberian, eastern sarus, white-naped, and common cranes (ANOVA, significance levels are the same as for the correlations in Table 4). Cultars and tarscul typically produced the best regression model estimators of body weight. Sex-specific models produced more accurate estimates of weight from measurements than models combining both sexes in 43 of 48 comparisons. Because of their smaller sample sizes, however, sex-specific relationships among size measurements were statistically significant less often than in all-crane models.

The best 2–4 estimators of body weight for each species and sex had mean errors from actual weight of 1.2–3.0% in Siberian cranes, 1.3–3.5% in eastern sarus cranes, 2.3–3.3% in white-naped cranes, 2.7–4.2% in common cranes, 2.3–3.0% in hooded cranes, and 5.7–9.7% in red-crowned cranes. Averaging the predicted weights from the best 3 or 4 regression models sometimes produced more robust predictors of weight from measurements. This technique reduced the mean error of weight predictions in female Siberian cranes from 1.7% to 0.7%,

Table 3. Seasonal weight variation in 6 species of cranes at ICF. October weight = 100. Probabilities[a] are from paired *t*-tests comparing October weight to weights from other months.

Species	Jul	Aug	Sep	Oct	Nov	Dec
Siberian	90.6		93.6**	100.0	108.1***	111.7
Eastern sarus		96.7	94.9	100.0		
White-naped			96.5*	100.0	104.7	
Common			89.2**	100.0		
Hooded			97.4	100.0		
Red-crowned	92.5		95.8*	100.0	105.7**	124.2*

[a] *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

Table 4. Multiple coefficients of correlation (*R*) among linear measurements and between linear measurements and mean October weight in 6 species of cranes at ICF. Probabilities[a] are derived from Pearson's product-moment correlation matrix.

	Species	Culmen	Wing chord	Tarsus	Culmen + tarsus	Culmen × tarsus
October weight	Siberian	0.893**	0.442	0.908**	0.919***	0.911**
	Eastern sarus	0.873**		0.914**	0.976***	0.968***
	White-naped	0.751**	0.759*	0.841***	0.825***	0.809**
	Common	0.776**	0.665	0.830***	0.868***	0.893***
	Hooded	0.397	−0.205	0.463	0.546	0.570
	Red-crowned	0.395	0.304	0.586*	0.612*	0.587*
Culmen	Siberian		0.583	0.881**		
	Eastern sarus			0.680		
	White-naped		0.862**	0.902***		
	Common		0.614	0.636*		
	Hooded		0.369	0.111		
	Red-crowned		0.853**	0.376		
Wing chord	Siberian			0.492	0.384	0.398
	White-naped			0.732*	0.808**	0.838**
	Common			0.842*	0.826*	0.790
	Hooded			−0.176	0.054	0.066
	Red-crowned			0.349	0.636*	0.740**

[a] *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

but did not improve weight predictions for male Siberian cranes.

Application of Results to Cranes From Other Zoos

Siberian cranes at the Oka Center exhibited the same degree of sexual size dimorphism as ICF cranes. Males ($n = 10$) had significantly larger weights and culmen lengths than females ($n = 4$) ($P = 0.020$ and $P = 0.005$, respectively, independent *t*-test). Oka males had nearly significantly longer tarsi ($P = 0.052$, independent *t*-test) than females. Unlike the ICF Siberian cranes, the Oka birds had no significant correlations between linear measurements and weight. Tarsus and culmen lengths were the only measurements of Oka cranes that covaried strongly ($P = 0.036$, Pearson's product-moment correlation matrix). Mean weight of Oka cranes was 0−5% lower than for ICF cranes of the same sex.

Weight of eastern sarus cranes in the Korat Zoo, Thailand, was significantly correlated with culmen, cultars, and tarscul ($P = 0.016$, 0.030, and 0.020, respectively), and nearly correlated with tarsus length ($P = 0.060$) (all probabilities derived from Pearson's product-moment correlation matrix). These results were similar to those of the ICF cranes. The Korat cranes exhibited larger linear measurements than ICF cranes, but the ICF cranes weighed an average of 0.8 kg (>14%) more than the Korat cranes.

Regression models developed from the ICF data were inaccurate at predicting weights of cranes at other sites from linear measurements. My weight predictions of Siberian cranes at the Oka Center had an average error of 12% from the cranes' true weights. This was in part because the regression model overestimated the weight of both sexes of Oka Siberian cranes by 3.8%. My regression model overestimated the weight of red-crowned cranes from Japanese zoos (Murata et al. 1987) by 18% for males and 24% for females. The regression model overestimated weights of eastern sarus cranes in the Korat Zoo, Thailand, by 31%. The Korat eastern sarus cranes were of Asian origin, whereas their conspecifics at ICF were of Australian stock; this difference in genetic background, however, is of unknown significance. In summary, among birds having similar linear measurements, ICF birds weighed slightly more than Oka (55°N) birds, a large amount more than Japanese zoo (35°N) birds, and an

even larger amount more than captive birds in Thailand (15°N).

DISCUSSION

Value of Different Body Measurements

October weight was the best index of size in the 6 species of cranes I examined, because it correlated more highly with linear measurements than did linear measurements with one another. Murata et al. (1988) used culmen, tarsus, tail, and wing chord lengths in their discriminant function for predicting red-crowned crane sexes. In that study, as in this one, culmen and tarsus lengths were the linear measurements exhibiting the highest correlations with other measurements. Y. Markin and V. Krever (Oka State Nature Reserve, pers. commun.) use body length, culmen, and tarsus measurements to predict wild common crane sexes. Wing chord and tail measurements can be at least 10% smaller than normal on captive cranes due to feather wear, especially in aggressive male cranes. Tail wear in captive cranes results in shorter than normal body lengths; therefore, body length data are not as useful. Culmen and tarsus lengths, which remain relatively stable, are the best size indices among linear measurements for captive cranes. Cultars and tarscul combine these 2 size measurements and are therefore better size indices than either culmen or tarsus length alone. In captive cranes having overgrown bills, culmen length is not a reliable size index.

Magnitude of Sexual Size Dimorphism

The degree of sexual size dimorphism I found in captive cranes is similar to that found in wild sandhill cranes (*G. canadensis*) by Aldrich (1979) and slightly less on average than that exhibited by wild brolgas (Blackman 1971). Compared to wild birds (Walkinshaw 1973, Johnsgard 1983), I found significantly more sexual size dimorphism in common cranes, slightly to moderately more sexual size dimorphism in Siberian, eastern sarus, and white-naped cranes, and a similar degree of size dimorphism in red-crowned and hooded cranes. Captive red-crowned cranes in Japan had an average of twice as much sexual size dimorphism in tarsus, culmen, and wing chord lengths (Murata et al. 1988) and 1.5 times as much weight dimorphism (Murata et al. 1987) as their conspecifics at ICF.

Ecological Correlates of Sexual Size Dimorphism

I could detect no taxonomic, ecological, or geographical pattern in the degree of sexual size dimorphism in these cranes. A nonmigratory tropical crane (eastern sarus) and 2 northern temperate breeding cranes (common and white-naped) had the greatest sexual size dimorphism. An arctic-nesting crane (Siberian), a northern temperate breeding crane (red-crowned), and a northern temperate to arctic breeding crane (hooded) exhibited a smaller degree of sexual size dimorphism. All but the eastern sarus crane among these species typically migrate at least 2,000 km (although 30% of wild red-crowned cranes are nonmigratory, the ICF birds are from migratory stock).

Hooded and red-crowned cranes exhibited the weakest relationships between weight and measurements, and the least sexual size dimorphism in linear measurements. These tendencies might be the result of these 2 cranes having a higher percentage of their weight packed into their relatively spheroidal bodies than the other 4 species, which are all relatively thin-bodied.

Seasonal Weight Variation

The large weight variation recorded during October might be due to sampling during a rapid weight gain that begins in August or September and prepares cranes for the autumn migration and colder winter weather. Weights of cranes taken during this period vary according to how long ago the crane began the rapid weight gain. Sandhill cranes staging in North Dakota gained 17–20% in body mass between early September and late October by putting on fat (Krapu and Johnson 1990). The lipid content (as a proportion of dry tissue weight) in sandhill cranes tripled between mid-August and late September during staging in Saskatchewan (Tacha et al. 1985*a*). Spring weights of migrant crane species can be equally volatile. Central flyway sandhill cranes increased their weight more than 30% and quadrupled their body fat between early March and late April (Krapu et al. 1985).

The red-crowned crane's massive weight gain from summer to winter (34%) could be an adaptation to the cold places (up to 44°N) where this crane winters. At ICF, captive red-crowned and other northern breeding cranes often fast during the first warm days of spring, living off their large fat reserves. Likewise, some wild lesser sandhill cranes (*G. c. canadensis*) live largely off their fat reserves when they first arrive on their frozen nesting grounds (Krapu et al. 1985). Siberian cranes nest at high latitudes (65–72°N) and migrate 5,000–6,000 km (Sauey 1985). Like arctic-nesting lesser sandhill cranes, they perhaps need large fat reserves for both the migration and survival during the first few weeks of the nesting season, when food is scarce.

Latitudinal Weight Variation

Although I believed that the tropical eastern sarus crane would exhibit less seasonal weight variation than the high latitude nesting cranes, there were not enough weight data on the eastern sarus crane to test this hypothesis. The nonmigratory Florida sandhill crane (*G. c. pratensis*), however, experiences smaller fall weight gains at ICF than the 3 species for which I had adequate data to compare September and November weights (Table 3). This crane weighed an average of only 7.7% more in November than in September (n = 8) at ICF.

Captive crane weights were positively correlated with latitude. ICF (43.5°N) and Oka (55°N) Siberian cranes weighed about the same. ICF red-crowned cranes weighed 18–24% more than their conspecifics having the same linear measurements in Japanese zoos (35°N) . The raw weights of ICF cranes were only 8–15% larger than those of the Japanese zoo cranes, however, since the Japanese cranes had larger average linear measurements than the ICF cranes. Similarly, the Korat, Thailand (15°N), eastern sarus cranes had longer measurements than ICF cranes but weighed substantially less. ICF cranes had raw weights of 14% more than the Korat cranes, but were 31% heavier when I applied my regression models to cranes having similar linear measurements. Since these weight comparisons among pairs of sites each employed a different species of crane, I urge caution in interpreting the relationship between crane weights and latitude. Different diets and husbandry among the captive sites could greatly affect crane weights. There might also be geographical differences in cranes that make size indices difficult to apply over 9 wide geographic areas. For example, condition indices of wild sandhill cranes developed in 1 study (Iverson and Vohs 1982) do not always agree with those from another study (Johnson et al. 1985), nor do they necessarily produce accurate estimates of fat content of cranes in other studies (Tacha et al. 1985*a*).

MANAGEMENT IMPLICATIONS

Robustness of Size Indices

No single measure of size correlates well with all other size indices. Therefore, one must use several measures of size when measuring sexual size dimorphism or developing models to predict weight from measurements in captive cranes. Models predicting the mass of fat reserves in wild cranes are more reliable when body weight is combined with structural size indices (e.g., tarsus, wing chord, culmen, keel, or body length) than when weight alone is used (Iverson and Vohs 1982, Johnson et al. 1985). Weight, tail, body, and wing chord lengths vary greatly over time in captive cranes. Weight was the best index of size among these 4 variables because, unlike the others, it varies on a predictable annual cycle. However, crane weights are accurate size indices only when they are taken at the same time of year. Culmen and tarsus measurements are reliable size indices at any time. I recommend that weight, cultars, and tarscul be used as size indices in captive cranes within a site. Among sites, cultars and tarscul are better indices than weight for comparing crane sizes. In wild birds, which may have less feather wear than captive birds, wing, body length, and tail measurements can be useful indicators of size.

Since captive crane weights change rapidly during the spring and fall, comparisons of their weights should consider what time of year the weights were taken. Captive cranes in temperate to high latitudes will be heaviest in winter and lightest in summer. Most cranes at ICF lose weight during March–May (pers. observ.), mirroring their fall weight gains.

Sex Determination Based On Size

There is potential for developing discriminant functions to identify sexes of several species of cranes, but this task is beyond the scope of this paper. The red-crowned crane, which has only moderate sexual size dimorphism among cranes, was dimorphic enough in Japanese zoos for Murata et al. (1988) to determine the sex of most individuals based on size. Two of 14 females, however, were classified as males by the discriminant function. Eastern sarus cranes at ICF exhibited sexual size dimorphism by the time they were 100 days old and displayed no overlap in weights of the 2 sexes (Hesch 1987) ($P < 0.001$, independent t-test done by me; sex of the largest "female" is now known to be male).

Weight Variation and Health

Ill or injured cranes are frequently underweight (Carpenter 1979). Veterinarians, crane managers, and wildlife rehabilitators could more accurately assess crane weights if there were normal published values. However, the large seasonal variation in some species can make single weights less useful clinically, until more data on seasonal weight variation can be obtained. The weight data and discussion of seasonal weight changes in this paper give some indication of the normal range of crane weights. Crane weights vary among sites due to environmental and dietary differences. As noted above, cranes in temperate zoos probably weigh more than cranes in subtropical zoos.

When a crane weighs less than usual but shows no

signs of illness or injury, one should reweigh the crane at a reasonable interval. Sometimes a second weighing confirms that the crane is abnormally light and should be examined further. Ideally, one should compare the crane's weight with its previous weight at the same time of year. Comparing its weight to that of another crane is useful and can be used if no previous weights for that individual crane are recorded. Crane weights change rapidly during spring and fall, such as a red-crowned crane that weighed less than average in October but had gained 3.1 kg (37%) and was at his highest recorded weight by the time we re-weighed him in December. The plumpness of the crane's keel indicates its nutritional status as well. Comparisons of keel condition to other cranes of the same species can indicate whether a crane is malnourished. Individual cranes of a species vary in their normal keel plumpness as well as in weight, however, and it is best to have data from the same individual. Some individual Siberian, sarus, brolga, whooping (*G. americana*), wattled (*Bugeranus carunculatus*), black crowned (*Balearica pavonina*), and gray crowned cranes (*B. regulorum*) normally have very thin keels during summer and relatively thin keels the rest of the year (pers. observ.). Conspecifics of these individuals are consistently plumper.

A poor appetite sometimes indicates that a crane is ill, but cranes sometimes fast when they have large fat reserves and the weather becomes warm. Red-crowned and Siberian cranes at ICF frequently eat little or no food for several days during warm spells from February to April (pers. observ.). Weighing a crane can indicate whether the crane is ill or simply fasting due to warm weather. If the crane is at the low end of its weight range and still fasts, it might be ill. This is another instance in which established normal weight criteria would be invaluable.

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