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Development of an image-based body condition score for giraffes *Giraffa camelopardalis* and a comparison of zoo-housed and free-ranging individuals

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Abstract

Historically, giraffes (*Giraffa* spp.) in zoos are known to have a high prevalence of deaths associated with serous fat atrophy, which has been linked to the impression that as browsers, they are more difficult to feed appropriately compared to grazing ruminants. Therefore, one could expect zoo-housed giraffes to be peculiar in that they might have, on average, a lower body condition than their free-ranging conspecifics. We collected photographs of free-ranging and zoo-housed individuals and used information on sex, age, body mass, and height for a subset of the zoo animals to develop and validate a body condition score (BCS). We developed an overview BCS for the shoulder area (4 levels) and hip area (7 levels), and validated and applied the score to 532 free-ranging and 232 zoo-housed giraffes. The rib area was not useful for BCS; skin folds in the rib area occurred across all BCS hip levels but were particularly prominent at higher BCS hip. The BCS hip was positively correlated with body mass index for adult female giraffes, suggesting it reflects body condition. The BCS hip differentiated better between age, gender, season in free-ranging animals, and habitat (zoo vs. free-ranging). The BCS shoulder was less precise, most likely because the visibility of the shoulder does not only reflect subcutaneous adipose tissue, but also muscle tissue and skin thickness, especially in males as an adaptation to the giraffe's typical mode of intraspecific combat. Using the shoulder score or the presence of skin folds on the side of the thorax/abdomen for routine BCS application is therefore not recommended. Juvenile animals had the highest BCS hip (6.04±0.69 for free-ranging, 6.00±1.07 for zoo), which decreased with age in both populations. Adult males in the wild generally had higher BCS hip (3.52±1.35) scores than the females in the wild (3.31±1.31), indicating the increased energetic strain on females due to reproduction. This was not the case in zoo animals. In contrast to our prediction, zoo-housed animals had higher scores than the free-ranging population (4.53±1.54; 3.74±1.55; $P<0.001$), especially compared to the free-ranging population scores from the end of the dry season (3.46±1.56; $P<0.001$). This indicates that on average, zoo-housed giraffe are less constrained by dietary resources than their free-ranging counterparts, and corresponds to reports of an improvement of zoo diets in European zoos and the subjective impression of a reduced incidence of serous fat atrophy in recent years. Nevertheless, the highest score, often equated with obesity in other BCS systems, was observed in both zoos and in the wild, possibly excluding obesity as a pathological condition in this zoo-housed giraffe population. While low scores should be avoided in zoo-housed giraffes, there are no indications so far that high scores in our BCS are detrimental. The hip-based BCS is easily applicable to free-ranging animals by direct observation or based on photographs, and allows for reproducible data collection to monitor giraffes at a population level.

Introduction

An erroneous feeding regime and consequent suboptimal body condition – too high or too low – is linked to health issues in zoo animals (e.g. Clauss et al. 2002; Videan et al. 2007). Monitoring animals' body condition therefore is an important component of routine husbandry procedures. A simple and practical, non-invasive option is visual judgement using a body condition score (BCS), where usually the prominence of bone structures like the shoulder blade, ribs, backbone and pelvic bones, andhence indirectly the subcutaneous adipose tissue, is assessed. The usefulness, validity and precision of BCS for assessing energy reserves in dairy cattle is well documented (Ferguson et al. 1994; Kristensen et al. 2006), and BCS systems have been established for many wildlife species (Reuter and Adcock 1998; Ezenwa et al. 2009; Schiffmann et al. 2017).

The feeding management of browsers, such as the giraffe *Giraffa camelopardalis*, is particularly challenging (Clauss and Dierenfeld 2008; Valdes and Schlegel 2012). While the uptake of forage with structural fibre is crucial for the digestive physiology of ruminants in general (Clauss and Dierenfeld 2008), the provision of sufficient browse is logistically demanding and not feasible in sufficient amounts in many facilities (Höllerl et al. 2006). Additionally, a reluctance to ingest grass hay (which should not be fed to giraffe), and to a certain extent even lucerne hay, has been reported in ruminant browsers such as giraffe, moose *Alces alces* and roe deer *Capreolus capreolus* (Clauss et al. 2003; Hatt et al. 2005; Clauss et al. 2013). The resulting higher proportional intake of concentrate feed, leading to an oversupply of easily digestible and fermentable substrates, is postulated as one of the underlying causes of increased digestive problems in browsers (Clauss and Dierenfeld 2008; Schilcher et al. 2013; Ritz et al. 2014).

While obesity is a major concern in several species kept in zoos, such as in elephants *Loxodonta africana, Elephas maximus* (Morfeld and Brown 2016; Schiffmann et al. 2018), greater one-horned rhinoceros *Rhinoceros unicornis* (Heidegger et al. 2016), or ruffed lemurs *Varecia variegata* (Schwitzer and Kaumanns 2001), some browsers might therefore be facing the opposite situation. Browsing ruminants, such as giraffe or moose, have a history of poor body condition in captivity (Shochat et al. 1997; Clauss et al. 2002). In an evaluation of 83 necropsy reports from zoo-housed giraffes, 40 animals (48%) had been diagnosed with a poor to emaciated body condition (Clauss et al. 2006), which also supports the hypothesis that some giraffe in captivity may have inappropriate diets resulting in poor body condition. In giraffes, a syndrome first named 'peracute mortality syndrome' (PMS) has

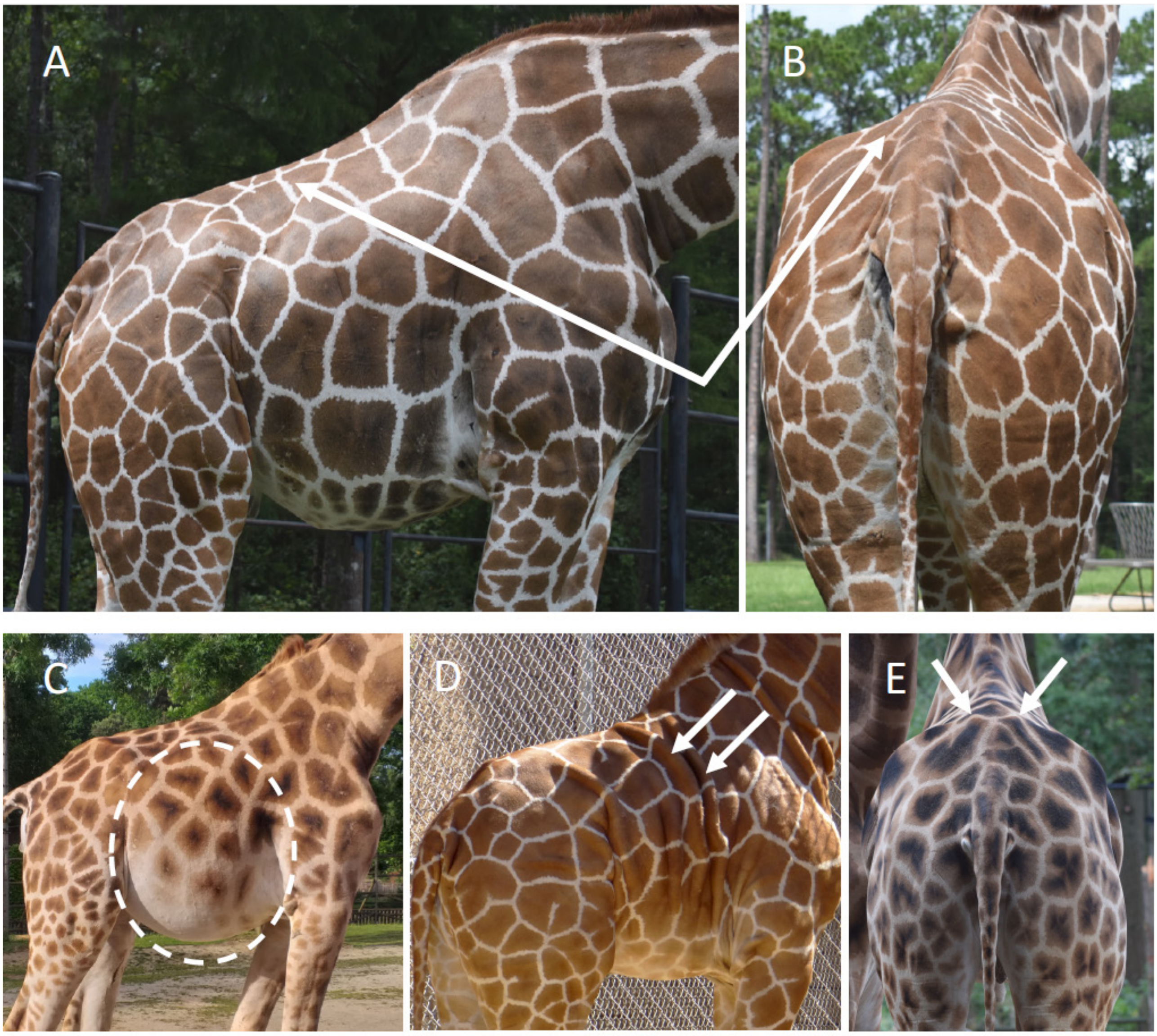

Figure 1. (A,B) Example of two photographs of the same animal with differing lighting conditions at different angles. (C) Pregnant female. (D) Excessive skin folds. (E) Coat pattern mimicking the shape of the hip bones. Photographs provided by zoological institutions participating in this study.

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been frequently reported (Fowler 1978; Junge and Bradley 1993; Ball 2002; Enqvist et al. 2003; Potter and Clauss 2005; Colvile et al. 2009; Yong 2010b; a). All cases have in common animals with seemingly adequate food intake that died unexpectedly, often related to an acute stressor (e.g., cold temperatures, parturition). At necropsy, serous atrophy of body fat depots has been detected but typically no other findings explain the peracute mortality. Serous atrophy of fat indicates a chronic energy deficit, which is thought to represent the underlying cause of PMS. Therefore, it has been suggested to change the name of the syndrome from 'peracute mortality' to 'serous fat atrophy' or 'chronic energy deficit' (Hummel and Clauss 2006).

The high incidence of serous fat atrophy might make giraffes peculiar among zoo animal species, insofar as it might be hypothesised that they are among the rare species that actually show a lower body condition in zoos as compared to their natural habitat. In order to test this hypothesis, the study aimed to first develop a species-specific BCS system, ideally reflecting body mass indices based on data from zoo-housed giraffes. The second aim was to use photographs to score and compare body condition among zoo-housed and wild, free-ranging Masai giraffes *G. c. tippelskirchi* in northern Tanzania (Lee et al. 2016; Lee et al. 2018; Knüsel et al. 2019; Bond et al. 2021a; b). To the authors' knowledge, only one BCS has been published for zoo giraffes so far (Kearney and Ball 2001), with a range from 1–8; but the corresponding drawings illustrating five of these scores do not allow a transfer to photographic evaluation. That score had been applied to free-ranging giraffes (Wolf et al. 2018). For free-ranging giraffes, a 1–5 BCS has been used (van der Jeugd and Prins 2000), for which, however, neither visual examples nor a description of the individual stages were provided. In that system, the presence of skin folds ('loose skin') in the rib area was considered an indication of poor body condition.

Material and methods

Photograph collection

Every giraffe has a unique and unchanging coat pattern that allows individuals to be identified (Foster 1966). Tens of thousands of photographs of free-ranging Masai giraffe were collected during a long-term demographic study in the Tarangire Ecosystem, Tanzania (3°50'S 36°0'E), between 2012 and 2019. The Tarangire Ecosystem is a savanna biome with heterogeneous vegetation types ranging from open grasslands to dense deciduous bushlands and thickets (Lamprey 1963). Active encounter photographic capture-mark-recapture surveys were conducted for giraffes in a 1,500 km^2 area along dirt road transects in four administrative areas: Tarangire National Park, Lake Manyara National Park, Manyara Ranch Conservancy, and Mto wa Mbu and Lolkisale Game Controlled Areas. The sampling framework comprised three sampling occasions per year near the end of each precipitation season (short wet=Jan/Feb, long wet=May/June, dry=Sept/Oct), where each sampling occasion is composed of two consecutive sampling events during which all road transects in the study area were surveyed.

During photographic sampling, each giraffe's right side was slowly approached and photographed from within a distance of approximately 100 m (mean=90±39 m) at an angle as close to perpendicular (90°) as possible. For every photograph, sex (male, female) and age class were recorded. Giraffes were categorised into three age classes: juvenile (<1 year old), subadult (1–3 years old), or adult (≥4 years) using a suite of physical characteristics (Strauss 2015). Photographs were taken by various persons.

For simple coat pattern recognition for demographic research, requirements concerning the quality of the photographs were far less extensive than for BCS. The majority of the free-ranging giraffe pictures were not suitable for body condition scoring for several reasons, including bad lighting, the animal was moving, parts of the animal were concealed behind vegetation or other individuals, or the animal was too far away from the camera to discern contours beyond the outer body shape. The final dataset for free-ranging giraffes included a subsample of 532 photographs that met the inclusion criteria.

From 2019 to 2020, photographs of zoo-housed giraffes were also collected to develop the BCS and to compare with free-ranging giraffes. Giraffe-holding facilities were approached, irrespective of the (sub)species they kept. Detailed instructions for photographs were sent to all zoos in Europe and North America with giraffes in their collection (see supplementary material). Zoos were asked to take five standardised photographs per individual giraffes, one straight from the front, one at a 90° angle from the side, one straight from the back and two additional photographs at 45° angles from the front and back, respectively. These angles were requested in order to maximise the discernability of all focus structures. For good quality and comparability of the pictures, detailed instructions were provided regarding framing, posture, position of the photographer and light conditions as follows. The desired posture has the animal standing still and putting weight on all four legs. The head must be held up in one line with the body, because pilot studies showed that a perpendicular or downward-pointing neck changes the impression of the shoulder region. The photographer needs to be positioned on the same level as the giraffe (not on a visitor's platform, for example). A certain distance from the animal, with a minimum of about 5 m, is critical in order to avoid distorted pictures. Figure 1 demonstrates the importance of the correct light conditions. Even though in Figure 1A, the important structures are captured in full light, body contours, like the dent along the spine, cannot be clearly judged. A possible contributing factor to the difficulty of visualising body contours on giraffe photographs lies in the fur pattern that tends to visually overlay body contour patterns. Apart from light exposure and angle of the photographs, in certain animals with normal anatomical features, other conditions that complicate BCS were identified, such as pregnancy, excessive skin folds or an overlay of the coat pattern with underlying bone structures (Figure 1E–G).

Development and repeatability of BCS system

All photographs from free-ranging and zoo-housed giraffes underwent a selection process, and those not meeting the above-mentioned criteria were excluded from the data set. Photographs from the front and 45° from the front also were excluded after it became evident that from these perspectives, differences in body condition were not reliably recognisable. The remaining photographs served as the basis for the development of the scoring protocol.

For several body regions, the study tested whether different appearances from the photographs could be used as scoring criteria, by sorting them visually into categories that corresponded to a gradient from a very low to a very high body condition. As a subsequent step, it was evaluated to what degree these categories of one region corresponded to those of another region. Based on existing BCSs for other ungulates (reviewed in Schiffmann et al. 2017), the following body structures or regions were considered: ribs, skin folds in the rib area, the shoulder area and the back/hip area. The shoulder area and the presence of skin folds could not be consistently scored in all photographs that allowed scoring the hip area; therefore, the number of animals for which these areas are scored do not always correspond to the total number of animals.

Although a published score for free-ranging giraffes gives a score from 1–5, one for zoo giraffes gives a range from 1–8, and the Zoological Information Management System (ZIMS) asks for a giraffe BCS from 1–10; therefore, no initial number of grades was set. Rather, the number of grades that appeared feasible for a reliable differentiation of the different visual states was recorded. While this is a subjective step, which could have only been validated by letting independent teams determine their number of categories into which they would have sorted the material, this approach is not considered any less objective than setting a certain number of scores from the outset. The scoring system was developed, and then a single observer (IC) subsequently scored all photographs meeting the above-mentioned criteria.

To test the repeatability of the BCS, side and back photographs of a subsample of 73 giraffes were randomised and scored separately in order to check for systematic over- or underscoring of one of these picture angles. In doing so, care was made to ensure animal identity was not known to the scorer between the two photographs. Additionally, 141 giraffes were scored twice (based on the same photo) by the same observer at an interval of 2 weeks and results were compared to verify consistency of the scoring.

Information on body mass, height, sex, age and season

To validate whether the BCS reflects giraffe body condition, information on body mass and height was collected for the zoo giraffes, with the aim of determining the body mass index (BMI) and testing the correlation between BMI and BCS for as many animals as possible. Therefore, in addition to the provision of the photographs, participating zoos were asked to complete a survey containing questions about sex, age, body mass and height at withers and/or head of the respective individuals. Following Strauss (2015), age categories were classified as juveniles, subadults, adults as described above, with the addition of old animals (>20 years). Body mass measurements were included if the day of weighing and the day when the photo of the respective animal was taken were less than 100 days apart. This threshold was chosen assuming that feeding regimes in zoos remain fairly constant and was inspired by Carneiro et al. (2015), who showed that, in elephants, effects on body condition can be observed 3 months after dietary reduction. Body mass divided by height was used as a simple quantitative BMI, calculated separately for head height and withers height; it is acknowledged that the use of a BMI has not been evaluated in giraffes.

For a comparison of changes in body condition depending on season for free-ranging giraffes, photographs were sorted by the precipitation seasons of northern Tanzania (rainy seasons from November to May, dry season from June to October). Photographs from May/June were included to represent condition after the long wet season (n=213) and photographs from September/October to reflect condition after the dry season (n=223). Additionally, 96 pictures from January/February were included that represent the condition after the short wet season. Because of reports of a seasonal body mass fluctuation in a group of giraffes kept in one zoo (Gloneková et al. 2016) that indicated a better body condition during months with restricted exercise, the zoo-housed animals were also compared with those whose scored photographs were from the summer (May–October) or from the winter (November–April) season.

Statistics

Since BCS does not represent continuous data, all statistical evaluations were performed using nonparametric tests. Tabulated data are nevertheless given as means ± standard deviations for ease of reading. Comparisons between different groups were performed using the Wilcoxon signed-rank test in the case of two, and the Kruskal-Wallis test (with Tukey's post hoc test) in the case of more than two groups. With respect to the taxonomic status of the zoo-housed animals, the two subspecies which were

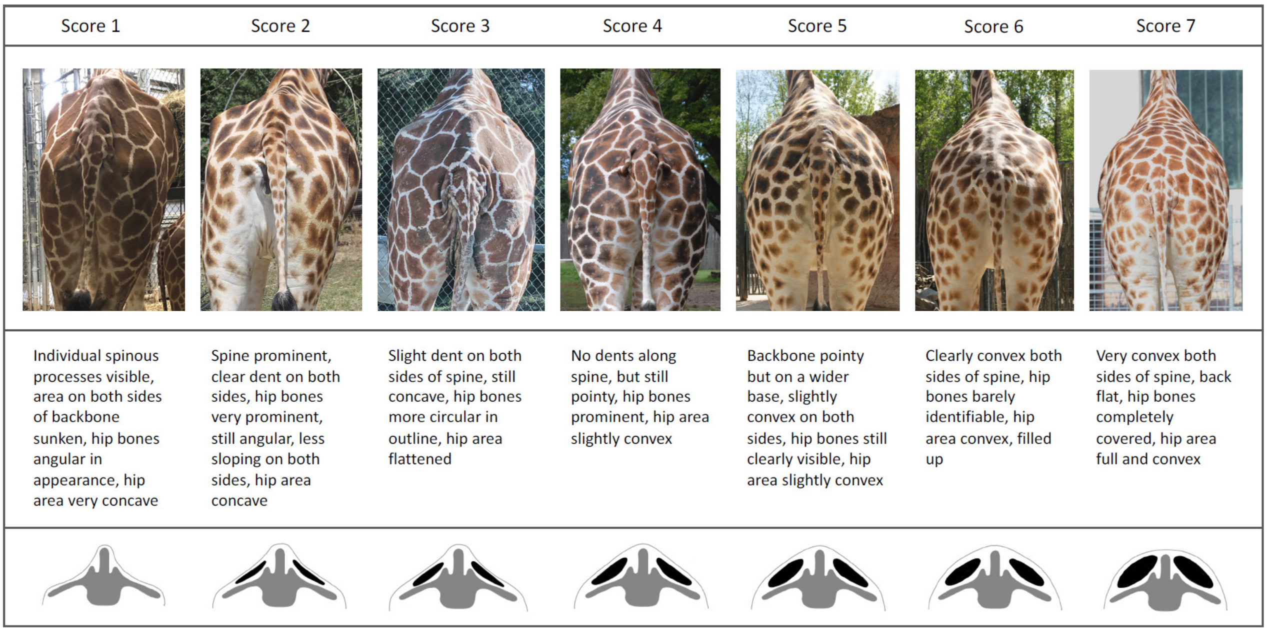

Figure 2. BCS for the hip area for giraffes. Photographs provided by zoological institutions participating in this study. (Extended score in supplement, Figure S3.)

Journal of Zoo and Aquarium Research 9(3) 2021
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represented the most (reticulated giraffe *G. c. reticulata* and Rothschild's giraffe *G. c. rothschildi*) were compared, using a chi-square test for the presence or absence of skin folds. Correlations were tested using Spearman's correlation coefficient. Whenever test statistics are given in the tables, they are not repeated in the results text. Statistical analysis was carried out with R (R Core Team 2017) using additional packages tidyverse (Wickham et al. 2019) and PMCMR (Pohlert 2014) with significance set to $P<0.05$. Some tests with a result of $0.05>P<0.10$ are mentioned as trends. Statistical analyses are considered exploratory, with the dataset not of a sufficient size to assess all possible influence factors (age, sex, taxonomy, season) in a single model.

Results

Development of a BCS system

Rib area and skin folds

The ribs were only visible unambiguously in two single photographs out of more than 30,000 pictures (free ranging and zoo housed); therefore, ribs were not considered a practical feature for the body condition scoring of giraffes. Skin folds in the rib area were recorded as present or absent but did not provide additional differentiation. Of 58 adult *G. c. reticulata* and 69 adult *G. c. rothschildi* for which skin fold presence could be judged, 69% and 38% showed the skin folds, respectively. This difference between the subspecies was significant (x^2=11.134, $P<0.001$).

Hip area

When sorting pictures of the hip area and the shoulder area, it became evident that it was not possible to distinguish the same number of different steps for both.

For the hip area (BCS hip), seven different stages could be distinguished (Figure 2, for more detailed photographic hip score see Figure S3). In an animal with score 1, the vertebrae are prominent along the spine and individual spinous processes are visible. The area on both sides of the backbone is sunken and the hip bones are sharply defined and angular in appearance. The whole hip area is very concave. With increasing body condition, the spine becomes less and less prominent and the dent on both sides less pronounced, until the dent disappears in score 4. In this score, the spine is still pointy with a flat descent on either side. In higher scores, the area along the spine becomes more and more convex up to a point where this area is very round in score 7. The hip bones get a more rounded outline with higher scores and are completely covered without visible edges or contours in score 7.

To validate the robustness of the BCS hip, results were compared from both the back view and the side view in 73 individuals. Over 64% were scored identically from both angles, 15% received a higher score when scored from the back, and 21% received a higher score when scored from the side. The difference in score was one scoring level in 92.3% and two scoring levels in 7.7% of the cases. Thus, there was no tendency to systematically over- or underestimate body condition from photographs in lateral view. Repeated scoring of 141 giraffes resulted in 87.2% identical scores and 12.8% varying by one scoring level. There were no animals differing by more than one scoring level. Mean BCS hip for the first scoring was 3.62 (±1.43) and for the second scoring 3.67 (±1.45).

Shoulder area

The shoulder area was only scored from lateral views. For the shoulder area (BCS shoulder), only four different stages could be distinguished reliably. The shoulder area appears from a very bony and prominent shoulder blade to a smooth shoulder, where no bone structures are visible at all (Figure 3).

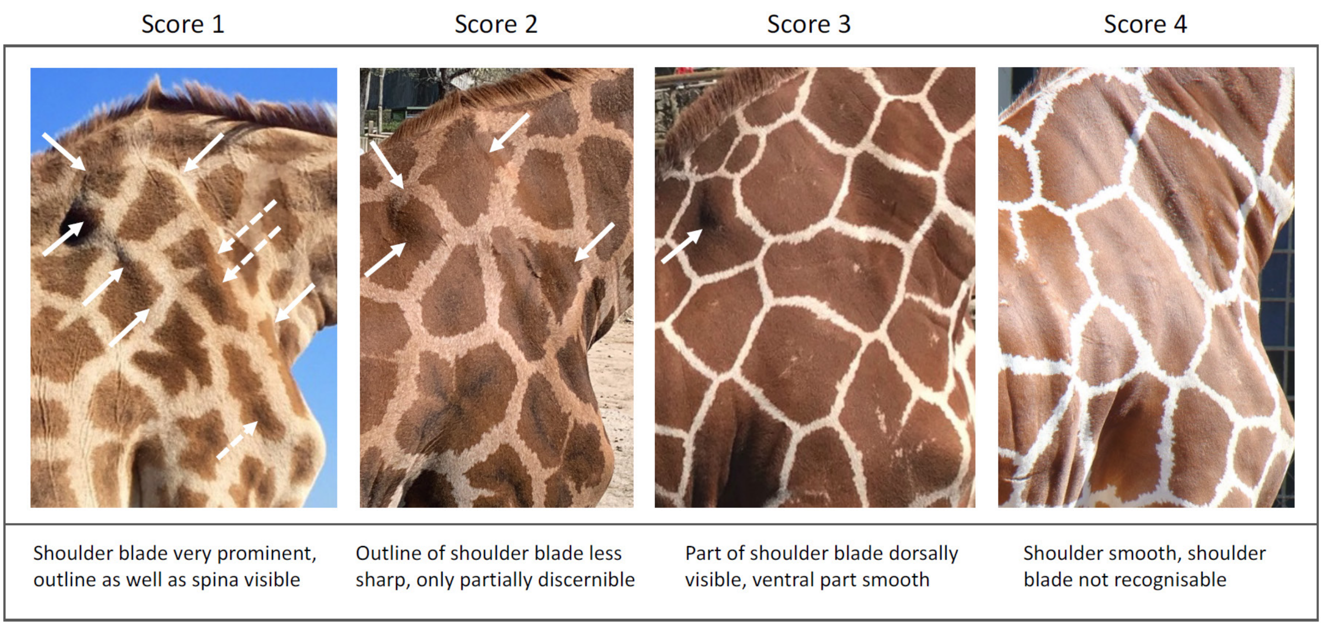

Figure 3. BCS for the shoulder area. Photographs provided by zoological institutions participating in this study.

Figure 4. Example of two animals with diverging scores for the shoulder and hip area. (A) Hip score 3, shoulder score 4, in a zoo giraffe; (B) hip score 5, shoulder score 1, in a free-ranging giraffe. For explanation of the scores, see Figure 2 for hip score and Figure 3 for shoulder score. (A) provided by a zoological institution participating in this study.

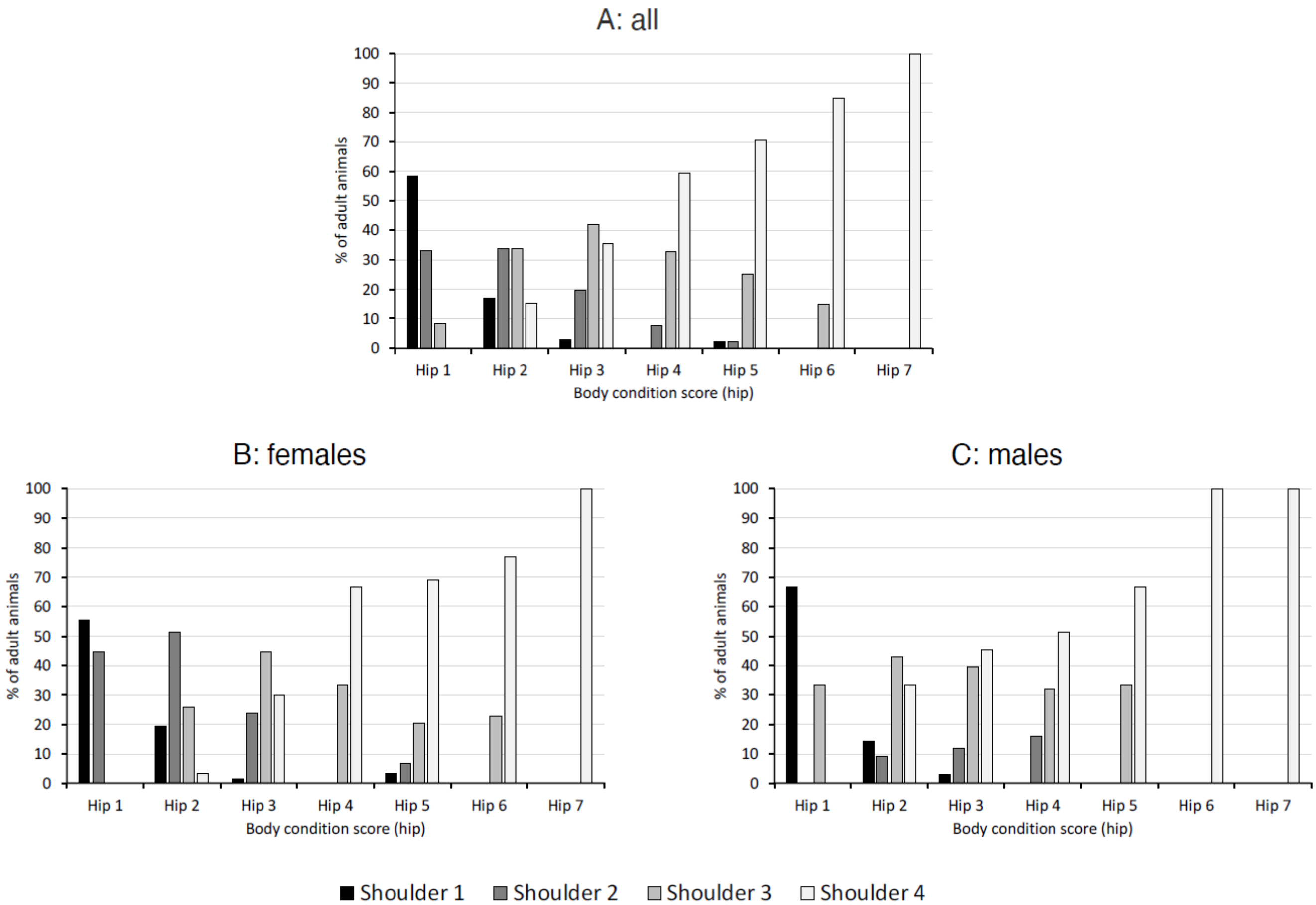

Figure 5. Distribution of the BCS shoulder (1–4) across different BCS hip (1–7) in (A) all adult free-ranging and zoo giraffes (n=299) of the present study, (B) in all adult females (n=183), (C) in all adult males (n=111). Note that while showing the same trend, the BCS shoulder overlaps with several BCS hip stages. The difference in n between all animals and the individual sexes is due to some free-ranging animals whose gender could not be determined from the photograph with certainty.

Table 1. Spearman's correlation for the body condition scores (BCS) for the hip and the shoulder in zoo giraffes with body mass, head height, withers height, the body mass index (mass/height) for the respective height measure and age. Note that information was available for varying numbers of animals.

Correlate	BCS	All animals			Adults			Adult females			Adult males		
		n	rho	P	n	rho	P	n	rho	P	n	rho	P
Body mass	Hip	-	-	-	47	0.14	0.389	41	0.46	0.016	20	-0.05	0.859
Head height	Hip	47	-0.26	0.083	37	-0.03	0.870	24	-0.28	0.186	13	0.00	1.000
	Shoulder	14	0.00	1.000	9	0.21	0.593	8	0.17	0.693	1	-	-
BMI head	Hip	41	-0.12	0.462	32	0.25	0.162	21	0.38	0.091	11	-0.16	0.647
	Shoulder	12	0.13	0.685	8	0.41	0.310	7	0.41	0.363	1	-	-
Withers height	Hip	28	-0.21	0.276	24	-0.09	0.681	16	-0.24	0.363	8	0.76	0.027
BMI withers	Hip	21	0.38	0.069	21	0.45	0.040	14	0.64	0.014	7	0.07	0.873
Age	Hip	223	-0.48	<0.001	185	-0.29	<0.001	116	-0.39	<0.001	69	-0.13	0.281
	Shoulder	86	-0.32	0.003	67	-0.24	0.055	42	-0.29	0.064	25	-0.19	0.353

Correlations between different areas

Although the correlation between BCS shoulder and BCS hip was significant for all adult animals (n=647, rho=0.56, P<0.001) as well as for the individual populations (zoo: n=223, rho=0.59, P<0.001; free-ranging: n=532, rho=0.54, P<0.001), subjective assessment of the shoulder area did not correlate consistently with the appearance of the hip area on an individual basis (Figure 4), with a large overlap of shoulder scores with hip scores (Figure 5). Therefore, it was considered unreasonable to attempt to combine the two scores. Due to the lower differentiation of the shoulder score, focus remained on the hip score and only photographs in which the hip could be scored were accepted, regardless of whether visibility of the shoulder was adequate or not.

Animals with skin folds were more represented by high hip scores; the difference in BCS hip between animals without and with skin folds was significant for all adult animals combined (no folds: n=419, 3.4±1.4, with folds: n=200, 4.0±1.5; W=31580, P<0.001) as well as for the different populations (zoo-housed giraffes: no folds: n=89, 3.9±1.4, with folds: n=85, 4.5±1.4; W=2895, P=0.006; free-ranging giraffes: no folds: n=330, 3.3±1.3, with folds: n=115, 3.7±1.4; W=15598, P<0.003). Nevertheless, there was a wide overlap with different hip scores, with skin folds occurring at each individual hip score (Figure 6).

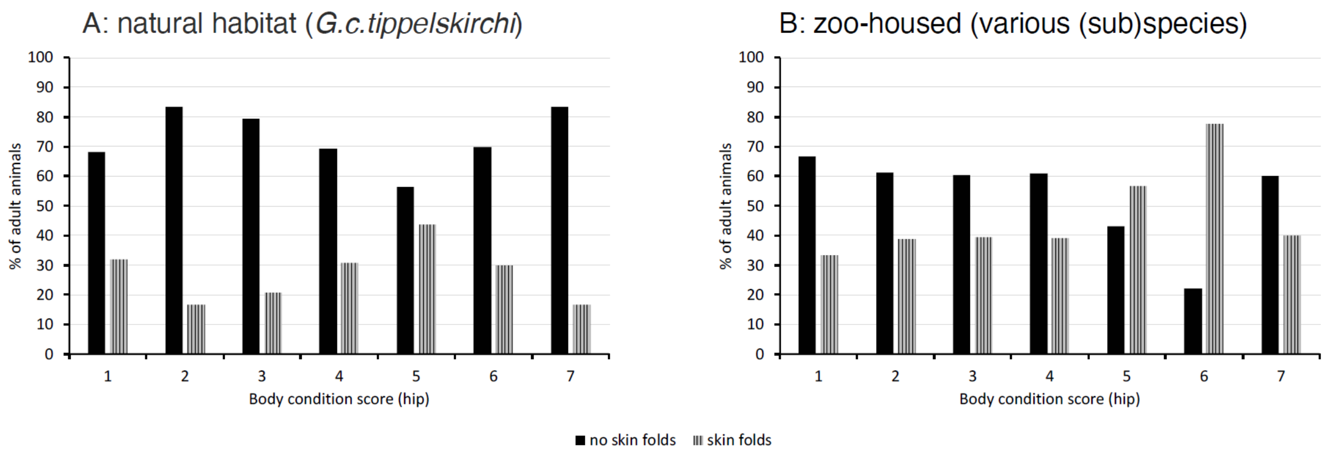

Figure 6. Presence or absence of skin folds in the rib area across different BCS hip in adult (A) free-ranging (n=445) and (B) zoo-housed giraffes (n=174) of the present study. Note that skin folds are more represented at higher BCS hip but occur across all BCS hip scores.

Table 2. Comparison of the body conditions scores (BCS) for the hip and the shoulder between adult male and female giraffes, and between the different age groups (see methods for definition) in the free-ranging and the zoo populations.

Gender comparison (male versus female)								
	n	Wilcox	W	P				
Wild adults	462	Hip	21295	0.130				
	232	Shoulder	4946	0.009				
Zoo adults	185	Hip	4208	0.552				
	67	Shoulder	554	0.677				
Age comparison (adult versus juvenile, other)								
	n	Wilcox	W	P				
All wild	532	Hip	1845	<0.001				
	268	Shoulder	2350	<0.001				
	n	Kruskal	x2	P	Tukey	adult	juvenile	old
All zoo	223	Hip	54.39	<0.001	juvenile	<0.001	-	-
					old	0.032	<0.001	-
					subadult	<0.001	0.210	<0.001
	86	Shoulder	11.7	0.008	juvenile	0.494	-	-
					old	0.130	0.031	-
					subadult	0.839	0.978	0.098

Table 3. Comparison of the body condition scores (BCS) for the hip and the shoulder in free-ranging giraffe in Northern Tanzania between seasons. Photographs were taken in Jan/Feb at the end of the short wet season, as well as in May/June at the end of the long wet season[1] and Sept/Oct at the end of the dry season[2].

	Seasonality						
Kruskal		n	x2	P	Tukey	Jan/Feb	May/June[1]
All wild	Hip	532	15.637	<0.001	May/June[1]	0.177	-
					Sept/Oct[2]	0.428	<0.001
	Shoulder	268	21.819	<0.001	May/June[1]	0.915	-
					Sept/Oct[2]	0.004	<0.001
Adult	Hip	462	11.126	0.004	May/June[1]	0.860	-
					Sept/Oct[2]	0.112	0.005
	Shoulder	232	23.809	<0.001	May/June[1]	0.973	-
					Sept/Oct[2]	<0.001	<0.001
Female	Hip	300	18.47	<0.001	May/June[1]	0.813	-
					Sept/Oct[2]	0.001	0.002
	Shoulder	141	15.656	<0.001	May/June[1]	0.956	
					Sept/Oct[2]	0.003	0.011
Male	Hip	155	3.574	0.167	May/June[1]	0.180	-
					Sept/Oct[2]	0.250	0.970
	Shoulder	87	8.454	0.015	May/June[1]	0.845	-
						0.047	0.106

Correlations with body measurements

For a limited number of zoo-housed animals, the BCS could be compared to body mass and height data. This was done in adult animals to test whether the BCS corresponded to these measurements, with the clear expectation that due to the variation in individual giraffe size, correlations with mass or height alone would not be as informative as the correlation with the body mass index. The more limited dataset for BCS shoulder did not show any correlations with body mass, height or the body mass indices (Table 1). The BCS hip showed a positive correlation with body mass in females, a positive correlation with withers height in males, a positive correlation with the withers height-based body mass index in all adults and in the females (Figure 7), and a trend for a positive correlation with the head height-based body mass index in females (Table 1).

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Table 4. Comparison of the body condition scores (BCS) for the hip and the shoulder between giraffes in the natural habitat and in zoos.

	Score	Zoo		Wild		Wild - Zoo Wilcox test	
		n	mean± SD	n	mean±SD	W	P
All animals	Hip	532	3.74± 1.55	223	4.53± 1.54	42469	<0.001
	Shoulder	268	3.20± 0.92	86	3.47± 0.84	9589	0.010
All adults	Hip	462	3.39± 1.34	185	4.23± 1.44	28737	<0.001
	Shoulder	232	3.11± 0.93	67	3.36± 0.90	6508	0.030
Adult females	Hip	300	3.31± 1.31	116	4.27± 1.52	11113	<0.001
	Shoulder	141	2.97± 0.97	42	3.40± 0.86	2192	0.007
Adult males	Hip	155	3.52± 1.35	69	4.16± 1.30	3888	<0.001
	Shoulder	87	3.31± 0.83	25	3.28± 1.00	1062	0.848
Juveniles	Hip	70	6.04± 0.69	38	6.00± 1.07	1245	0.546
	Shoulder	36	3.78± 0.64	19	3.84± 0.37	346	0.931

Table 5. Comparison of the body condition scores (BCS) for the hip and the shoulder for free-fanging giraffes in Northern Tanzania at the end of either the dry or the wet season and giraffes in zoos. Photographs of the free-fanging animals were taken in May/June at the end of the long wet season and Sept/Oct at the end of the dry season.

	Score	Wild dry		Wild dry - zoo Wilcox test		Wild wet		Wild wet - zoo Wilcox test	
		n	mean ± SD	W	P	n	mean ± SD	W	P
All animals	Hip	223	3.46 ± 1.56	15602	<0.001	213	4.06 ± 1.57	19624	0.001
	Shoulder	117	2.90 ± 1.00	3359	<0.001	85	3.48 ± 0.70	3546.5	0.670
All adults	Hip	198	3.16 ± 1.36	12117	<0.001	175	3.61 ± 1.32	10894	<0.001
	Shoulder	104	2.78 ± 0.98	2284.5	<0.001	68	3.38 ± 0.74	2204.5	0.7201
Adult females	Hip	131	2.97 ±1.34	4002	<0.001	107	3.54 ± 1.26	7122.5	0.007
	Shoulder	65	2.62 ± 1.01	762.5	<0.001	36	3.25 ± 0.81	1105.5	0.571
Adult males	Hip	63	3.56 ± 1.32	1623.5	0.010	65	3.65 ± 1.39	2649	0.020
	Shoulder	37	3.03 ± 0.90	372.5	0.169	30	3.50 ± 0.63	604.5	0.923
Juveniles	Hip	25	5.84 ± 0.75	386	0.176	38	6.16 ± 0.59	721	0.995
	Shoulder	13	3.85 ± 0.55	132	0.593	17	3.88 ± 0.33	168	0.751

Application

Free-ranging animals

The BCS hip was applied to a total of 532, and the BCS shoulder to 268, free-ranging giraffes in the wet and dry seasons. For both scores, juveniles had significantly higher values than adults (Table 2, Figure 8). Females and males did not differ in BCS hip, but in BCS shoulder, the free-ranging males had a significantly higher score than the females (Table 2; cf. Figure 5B and C). After the wet season, both hip and shoulder BCS scores were generally higher than after the dry season; only in the adult males there was little difference between the seasons (Table 3).

Zoo-housed animals

The BCS hip was applied to a total of 223, and the BCS shoulder to 86 giraffes from 65 European (n=161 giraffes) and 25 North American zoos (n=62 giraffes), representing eight different taxonomic groups (2 *G. c. angolensis*, 9 *G. c. antiquorum*, 13

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G. c. camelopardalis, 3 *G. c. giraffa*, 77 *G. c. reticulata*, 82 *G. c. rothschildi*, 15 *G. c. tippelskirchi*, 19 hybrids and 3 of unknown taxonomic status). The majority of these photographs represented late spring and summer of 2019. The BCS hip differed significantly between all age groups (except between juveniles and subadults) (Table 2), with a decrease with age (Figure 9). Correspondingly, there was a negative correlation between the BCS hip and age across all zoo animals (Table 1). This negative correlation also existed in adult females but not adult males (Table 1). Similarly, the BCS shoulder negatively correlated with age across all zoo animals, and there was a corresponding trend in the adult females (Table 1), but the only significant difference between groups was between juveniles and old animals in this case (Table 2). There were no significant differences between females and males (Table 2).

Adult animals scored from photographs representing the summer half of the year (May–October) tended to have higher BCS hip (4.3±1.5; n=140) than animals photographed in the winter

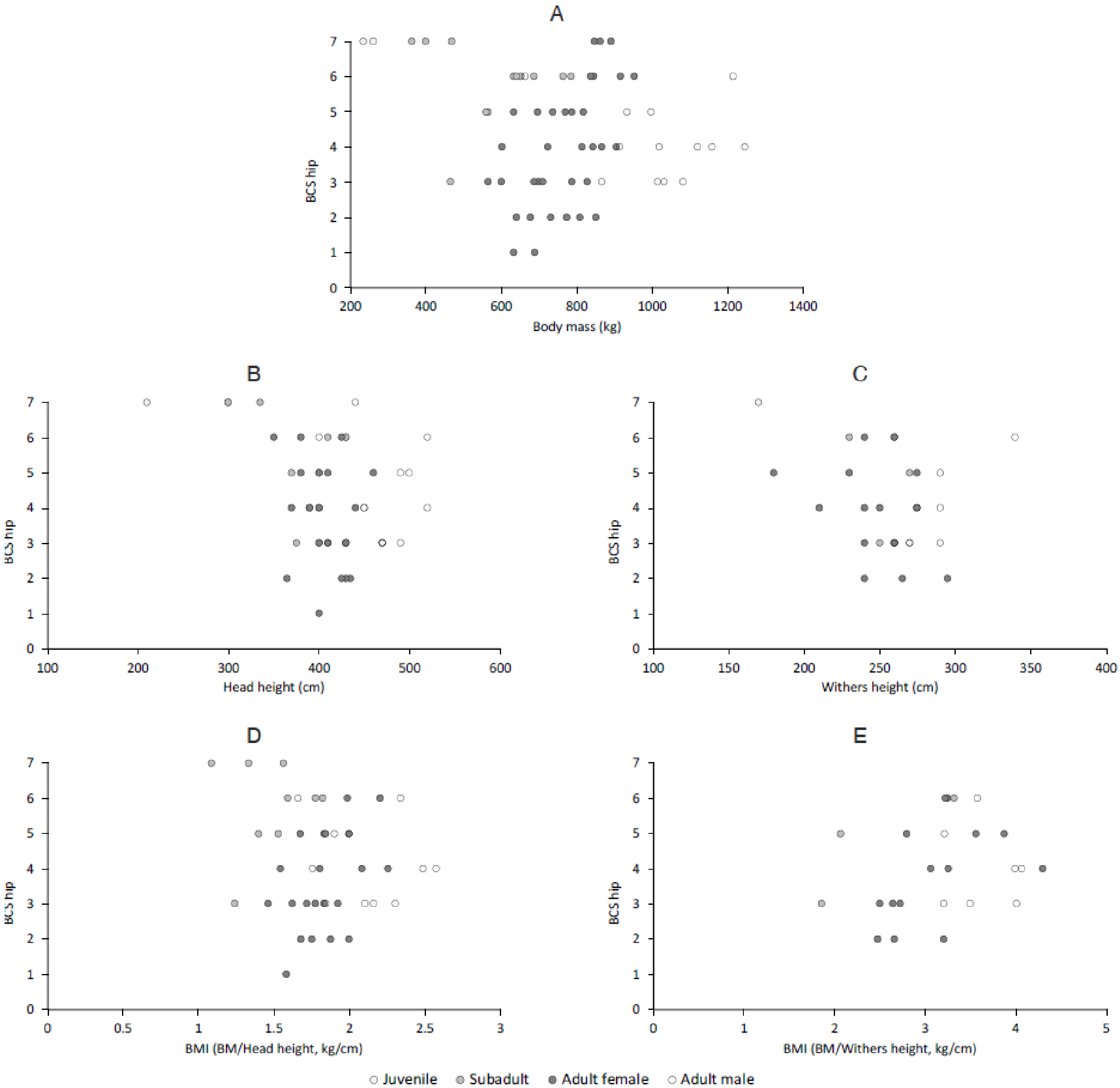

Figure 7. Correlation of the BCS hip with (A) body mass, (B) head and (C) withers height and (D,E) the respective body mass index (BMI, body mass divided by the respective height). For statistics, see Table 1.

Journal of Zoo and Aquarium Research 9(3) 2021
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half (November–April, 3.9±1.3, n=45; W=2624, P=0.086).

When comparing adult animals of the two (sub)species with the largest sample size, reticulated giraffes did not differ significantly in BCS hip (4.0±1.3, n=61) from Rothschild's giraffes (4.3±1.5, n=72; W=1952, P=0.262).

Comparison between natural habitat and zoo

Both BCS hip and BCS shoulder differed significantly between the populations, with zoo animals having higher scores (Table 4; Figure 10). This difference also remained significant for adults only, and for adult females and males (Table 4). Only for juvenile animals, there was no significant difference – in both populations, they had comparatively high BCS (Table 4).

When performing the comparison separately for free-ranging individuals from the end of the wet or the end of the dry season, the general trend of zoo animals having higher BCS remained, but differences were more pronounced when compared with the end of the dry season (Table 5). At the end of the wet season, the BCS

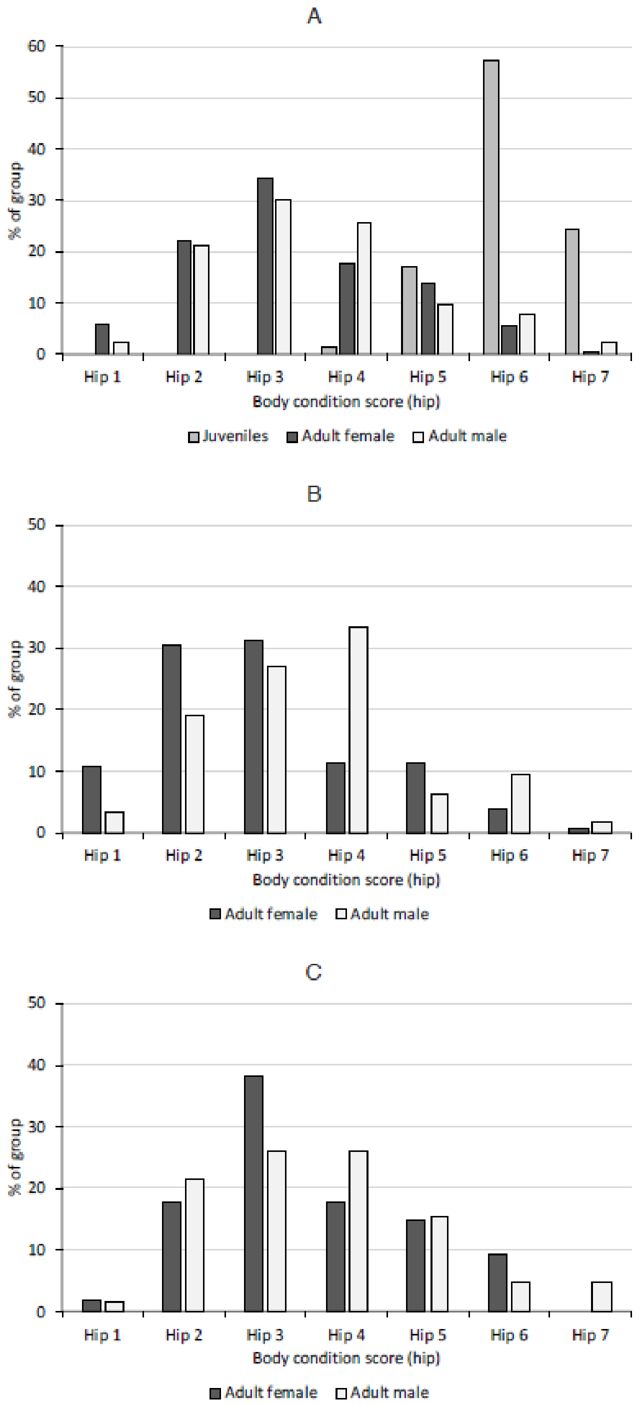

Figure 8. Body condition score (BCS hip) in free-ranging giraffes (A) according to age group, (B) in adults at the end of the dry season, (C) in adults at the end of the wet season.

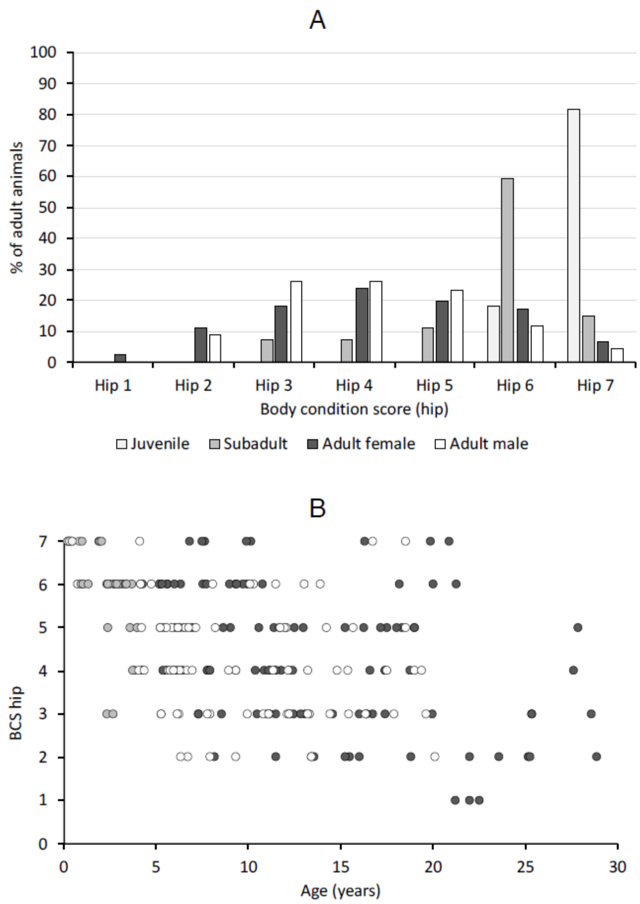

Figure 9. Distribution of body condition score (BCS hip) in zoo giraffes (A) in age categories, (B) in relationship to age.

shoulder did not yield differences between zoo-housed and free-ranging animals, while the BCS hip still did (Table 5).

Discussion

This study provides a detailed and illustrated system for body condition scoring of giraffes based on hip/back area photographs from zoo-housed and free-ranging animals. While several limitations apply to the present study, some BCS-relevant peculiarities of giraffes were detected, in particular with the shoulder and rib region, that require a different approach than in species where the whole body is used for scoring. The final BCS results show differences between the two populations, between seasons for free-ranging giraffes, as well as between sex and age categories. The system presented can be used for scoring by eye and noting the BCS in a data log; additionally, the instructions for photographs outline the requirements should photographic documentation be intended.

Development of BCS: study limitations

To establish the BCS, it was necessary to set some qualitative criteria for the photographs. As previously stated, the interplay of the light and angle with the fur patterns of the giraffe prevented an increase in the sample size in the study (see also Figure 1). Standardisation regarding posture of the animal, angle of the camera and light conditions can be granted only to a certain extent. Ideally, all zoos would have been visited and photographs would have been taken by the same person, which was not feasible due to financial and temporal restrictions.

Beyond the within-scorer consistency reported here, it remains to be seen how well the BCS can be applied at various facilities by various people. In particular, it will be interesting to note whether intermediate stages between those provided here will be identified, or whether the differentiation provided by this score is sufficient.

A limitation of the present study of unknown relevance is the differentiation between different giraffe species and subspecies (see e.g. Petzold et al. 2020 for a recent review); with respect to the number of (sub)species represented, only two subspecies could be compared. This comparison shows that zoo-housed Rothschild's giraffes did not differ systematically in the BCS hip from reticulated giraffes. Given the low sample sizes, and the fact that members of the two subspecies were kept at different facilities (i.e., most likely under different husbandry conditions), more investigations are needed to reliably conclude that the BCS does not differ systematically between giraffe (sub)species. In particular, observations concerning pathologies and mortalities that so far lumped all giraffe (sub)species (Fowler 1978; Junge

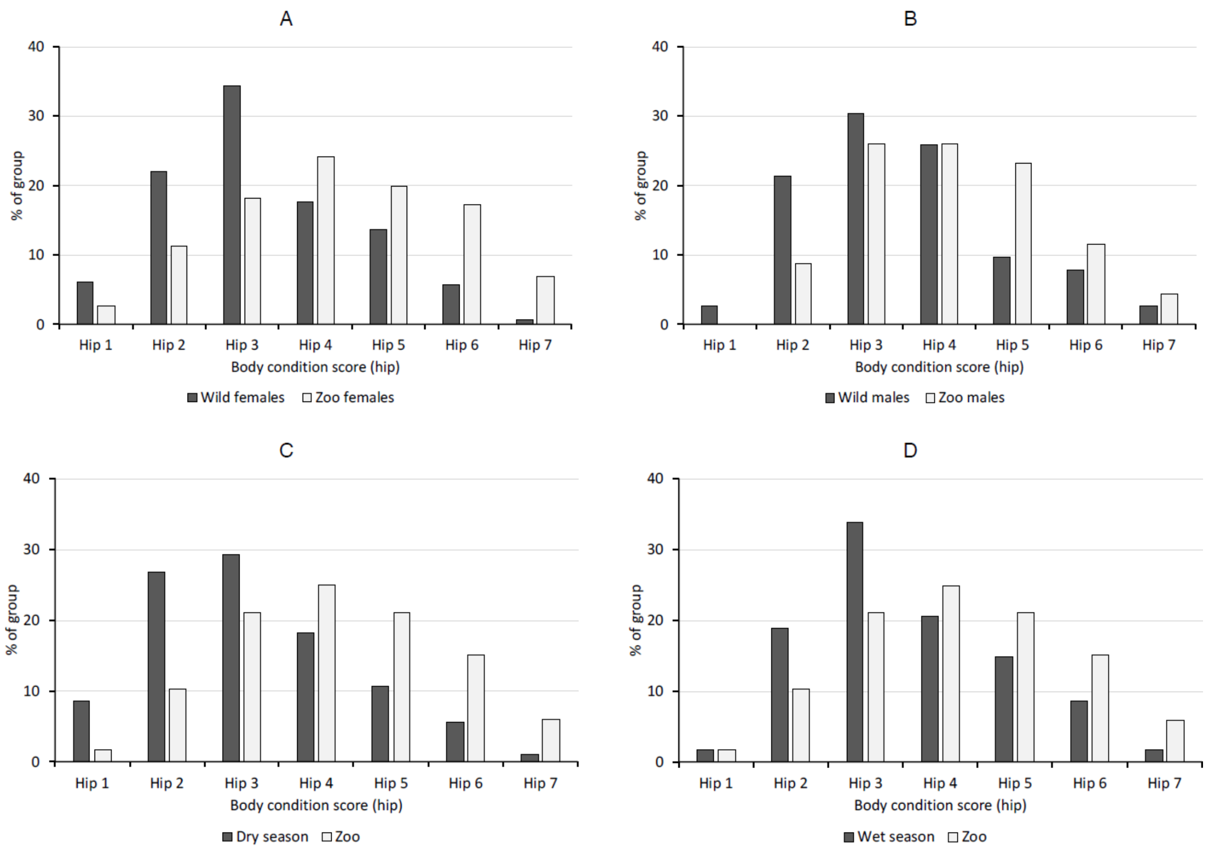

Figure 10. Distribution of body condition scores (BCS hip) in adult free-ranging and zoo (A) female and (B) male giraffes, and comparing adults from zoos to free-ranging animals at the end of the (C) dry and (D) the wet season.

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and Bradley 1993; Clauss et al. 2006) would also have to be made considering the taxonomic level. *G. c. rothschildi* has been reported to be larger, based on both skeletal and body mass measurements, than the other (sub)species (Groves and Grubb 2011; Gloneková et al. 2016). While it is unlikely that differences in size alone will affect the BCS, this remains to be tested. In dairy cattle, breed-related differences in BCS are significant between breeds depending on the intensity of selection for milk production, albeit by less than one BCS step in a score of 1–10 (Dillon et al. 2003; Walsh et al. 2008).

Development of BCS: giraffe peculiarities

Even though there was no systematic over- or underestimation of body condition when evaluating the photographs from the side, it was found that in these photographs, body contours were less well recognisable, especially when light conditions were suboptimal. The discernibility of certain structures improves in the 45° back or straight back view, where the back bone and hip bones form the outline of the animal and contrast with the background. The back view allows the assessment of a 'cross-section' of the back, which best facilitates the scoring. For the creation of a BCS database for individual giraffes, for example as in an online repertoire for elephants (Schiffmann 2020), the back and 45° side views are recommended.

As reviewed in Schiffmann et al. (2017), there are different approaches to BCS: a composite score adds scores from individual body regions; algorithmic BCS scoring increases the importance of specific body regions by using a flowchart system; whereas an overview BCS score looks more generally at an animal or larger body regions. This overview approach led to the highest differentiation of individual condition in elephants. In dairy cattle, a 'general impression' BCS correlated stronger with ultrasonographic fat measurements than a composite score (Isensee et al. 2014). For the giraffe, this study chose to look at an overview of either the shoulder area or the back area, without scoring, for example, the outline of the hip bones, the tail base and the backbone separately. The different scoring levels aim to clearly separate different body conditions. The scoring levels for many ruminant BCS schemes (3 domestic species, 13 nondomestic species including giraffe) range from 1 (low body condition or emaciated) to 5 (high body condition or obese) with level 3 being 'ideal, good or normal body condition'; for cattle and scimitar-horned oryx *Oryx dammah,* additional levels aim to refine the BCS system (www.nagonline.net, 09 Mar 2021). For the hip area in giraffes, it was possible to sort the photographs into seven levels, and the shoulder area into four levels. The decision to not stay with five, or to not extend to 10 levels, was only based on judgement of the feasibility of differentiation with the material at hand.

The combinations of scores observed (Figure 5) suggest that a giraffe shoulder may well appear 'well-nourished' before a similar effect is visible at the hip, and vice versa. Given this differential distribution of the hip and shoulder scores (Figure 5), combining both scores in an 'overview' approach did not appear reasonable. Alternatively, it would have been possible to expand the BCS system to a theoretical 7×4=28 levels, where each hip score is subdivided by the four possible shoulder scores. On the one hand, such a high number of levels would be impractical. On the other hand, these theoretical 28 levels would not represent a continuous spectrum, because an animal with a hip score of 2 and a shoulder score of 4 would not drop in shoulder score back to 1 when increasing its hip score to 3. Rather, each individual animal probably has its own hip score threshold that links to changes in its shoulder score. While the shoulder score therefore does not lend itself to a differentiated look at a whole population, it may be sometimes useful in tracking the development in individual animals of a low body condition score in a detailed manner. For example, it is speculated that some (but not all) giraffes with a hip score of 2 may first show a change in their shoulder score before changing their hip score.

The four-level shoulder score might be less representative for fat deposits in the whole body as seen in Figure 4B, where a shoulder score of 1 does not necessarily equal an overall emaciated animal. In elephants, it has been shown that scores of the shoulder area do not correlate strongly with subcutaneous fat measurements (Morfeld et al. 2014). The data suggest that the appearance of the shoulder area may be rather dependent on muscle mass and possible skin thickness than subcutaneous fat deposits. Free-ranging male giraffes had a significantly higher shoulder score than females, and the shoulder score did not respond to changes in season as the hip score. A possible explanation might lie in the fighting habits of male giraffes. The powerful head swings are mainly aimed at the counterpart's shoulder region, where thick muscles safeguard against severe injuries of the underlying structures (Coe 1967; Hall-Martin et al. 1977). Corresponding to a thicker skin at this location in males, the shoulder score was higher in males, in particular at lower hip scores (Figure 5B and C). Additionally, the skin of the anterior neck and trunk is thicker compared to the back area of giraffe (Sathar et al. 2010), which is thought to increase protection during fighting and when rushing through thickets.

This skin thickness could also be a potential reason why rib visibility is not a useful scoring tool in giraffes. The function of the skin folds (cf. Figure 1D) or 'loose skin' (van der Jeugd and Prins 2000) in the rib region has, to the authors' knowledge, not been described. One of the reviewers of the present manuscript suggested to us that these skin folds occur more frequently in reticulated giraffe – an observation corroborated in the sample population. The reason for this propensity is, to the authors' knowledge, unknown. However, in contrast to van der Jeugd and Prins (2000), who considered a skin with many folds as an indication of poor body condition, these folds did not only occur at all BCS hip levels in the present study, but were also particularly present at higher BCS hip, leading to a significantly higher average BCS in animals with compared to those without such skin folds. This was the case both in the zoo-housed as well as the free-ranging giraffe population. In the absence of detailed assessments of these skin folds, it is recommended not to include their absence or presence in a BCS for giraffes. Possibly, time series that monitor the development and persistence of these skin folds in individual giraffe over time will lead to a better understanding of what information they can provide on the individual animal.

To differentiate between thick skin, muscle mass and fat deposits, ultrasound guided measurements (e.g. Alapati et al. 2010 in buffaloes) would be needed. Such methods require close contact with the animals, and in giraffes probably warrant extensive training beforehand. The BCS system proposed here aims to provide a tool that can be easily applied remotely by any person.

Application of BCS

Juvenile giraffes (zoo housed and free ranging) have higher BCS in general. Giraffe calves are usually not completely weaned until at least one year of age (Dagg and Foster 1976). The body condition of less than 1 year old animals either does not vary notably or is not distinguishable with this method. Most likely, this is an indication that mothers compensate a potential lack of resources for milk production by their own body stores rather than by limiting the amount of milk for their offspring, leading to the differences in BCS between females and males mentioned above. A similarly high BCS in juveniles was also observed in other megaherbivores like greater-one horned rhinos (Heidegger et al. 2016) and elephants (Schiffmann et al. 2019), and might represent a common feature of large mammal ontogeny.

Apart from the above-mentioned difference in shoulder score between sexes in the wild, the hip scores between age groups were different, as well as hip scores of females and males, especially after the dry season. These results show the ability of the BCS hip to differentiate between different body conditions, providing a useful tool in free-ranging animals to deduce habitat quality and suitability, as well as investigate factors (e.g., parasitic load) that might influence body condition and affect survival. The percentage of fat in the buttock of giraffes is significantly reduced during the dry season (Hall-Martin et al. 1977), which highlights a dependence of that body region on environmental changes. Female animals might show the seasonal pattern more distinctly due to changes in reproductive status, similar to findings in free-ranging elephants (De Klerk 2009; Ramesh et al. 2011).

The BCS hip differed significantly between the different age groups in zoo-housed giraffes. During their lifetime, the BCS hip decreased significantly in female zoo giraffes, probably due to dental deterioration (Enqvist et al. 2003; Clauss et al. 2007; Yong 2010a) and other health concerns. The clinical relevance of recording the BCS therefore lies in obtaining initial information about health concerns in animals that cannot be easily checked routinely in another way. In geriatric elephants, the BCS also dropped while body mass remained stable or even increased (Schiffmann et al. 2019). In male giraffes, the impact of age on the hip score was not significant, probably due to a very limited number of old male giraffes housed in zoos (i.e., only 1 animal >20 years old in this dataset).

When comparing the zoo-housed giraffes with their free-ranging counterparts, the BCS hip and shoulder are significantly different, except for the juvenile population where BCS hip are characteristically high in either environment. Thus, the prediction that zoo-housed giraffes have a lower body condition due to the difficulty of providing them with an adequate diet, and to the high incidence of serous fat atrophy (see Introduction), was not supported. This finding possibly reflects the subjective observation of Bertelsen (2015) that cases of serous fat atrophy have recently become rarer in zoo-housed giraffes, presumably due to increased attention to the giraffes' nutritional needs, and increased attention to their susceptibility to cold (Clauss et al. 1999; Gage 2019). Actually, dietary improvement since the introduction of EAZA Ex-situ Programme (EEP) feeding guidelines (Hummel and Clauss 2006) was documented for the preceding decade by Gussek et al. (2017). Thus, the present BCS findings support the hope that husbandry progress is actually being made, leading to a majority of zoo-housed giraffes being in better body condition than their free-ranging counterparts.

This was even more pronounced when comparing the BCS of zoo-housed giraffes with that of free-ranging animals at the end of the dry season. Zoo diets, in terms of volume and nutritional quality, are usually not as seasonally dependent as in the wild (e.g. Pellew 1984), although one might expect a higher provision with fresh forage during spring and summer in zoos from the temperate zone (Gloneková et al. 2016). Actually, diets used in zoos are more energy-rich compared to natural food (Gussek et al. 2016; Gussek et al. 2018). Thus, zoo-housed giraffe body condition compares better to that of the free-ranging giraffes at the end of the wet season. Distinct physiological adaptations to seasonal fluctuations in body mass, food intake, metabolism and reproduction are well known in temperate ruminants like moose (Schwartz et al. 1984; Regelin et al. 1985; Schwartz et al. 1987a; b), with an increase of body mass from the spring postpartum minimum to the midwinter maximum of 25% in females (Schwartz et al. 1987a). However no similar photoperiod-induced physiological changes have been documented in giraffes. Given the limited body mass changes between the seasons at 5–9% in free-ranging female giraffes (Hall-Martin et al. 1977) and their non-seasonal breeding pattern (Zerbe et al. 2012), seasonal body mass and body condition fluctuations cannot be a similar target for zoo giraffes as it might be for temperate ruminant species (Lechner-Doll et al. 2000). Nevertheless, seasonal shifts in body mass (and hence, most likely, body condition) have been documented in at least one zoo giraffe population, with higher body masses of both a male and several non-pregnant females during winter (Gloneková et al. 2016); for the females, the difference amounted to 6%, similar to that of free-ranging females mentioned above. This fluctuation was explained by less movement of the animals in winter (and a potential effect of a higher incidence of female oestrus during spring and summer in this particular group, and hence more activity on the part of the male; Gloneková et al. 2016). In the present study, with just one observation per individual giraffe, there was no clear indication for such a seasonal effect. Rather, the overall BCS hip of the zoo-housed population tended to be higher in summer, which might be caused by the better availability of feeds appropriate for giraffe during this part of the year. It will be interesting to test whether corresponding seasonal fluctuations in BCS can be documented within different groups of zoo-housed giraffes that are monitored continuously for several years.

So far, in contrast to the reported issues with fat atrophy in giraffes, problems due to overconditioning have not been reported to the authors' knowledge, even though individual necropsy reports exist that indicate that some zoo giraffes may build up body fat stores that appear relevant to substantial (Cobbold 1854; Clauss 1998; Potter and Clauss 2005). Given the absence of negative reports of a high body condition for giraffe health, as well as the finding that the highest BCS hip score of 7 was also observed in the free-ranging population (where it is generally thought that no health-threatening obesity exists), it is not recommended to limit the BCS hip of zoo giraffes to the average of their free-ranging counterparts, but rather to allow BCS hip that are higher than those observed in the wild. At the same time, diets and feeding regimes should be used that maximise the amount of time spent feeding, and limit especially the occurrence of oral stereotypies (Hummel and Clauss 2006; Hummel et al. 2006; Valdes and Schlegel 2012; Duggan et al. 2016; Schüßler et al. 2017; Gussek et al. 2018; Monson et al. 2018). In the score presented by Kearney and Ball (2001), the two highest levels were called 'overweight' and 'obese', respectively, and were characterised as displaying a crease along the backbone – that is, a bilateral bulging of the area left and right of the abdominal and pelvic vertebral column. Such an appearance could also be considered a score of 8 in the present system (Figure 2); however, this level was not observed, neither in the free-ranging nor the zoo-housed population.

Outlook

It is hoped that the hip-based BCS suggested here will be applied to live animals, possibly including an assessment of inter-individual differences in scoring between different institutions. Future studies should address how the BCS correlates with various individual, environmental and husbandry-related factors. This could include the (sub)species, seasonal effects within zoos, husbandry and feeding practices, and in particular whether animals that succumb to the serous fat atrophy syndrome have a low BCS prior to death, either evaluated prospectively or retrospectively by the use of photographs. Additionally, individual BCS trajectories, especially with respect to the occurrence of skin folds in the rib area, would be interesting. Taking and storing photographic documentation has become easy today. The collection of giraffe BCS photographs in a database, either within an institution or across institutions, similar to one provided for zoo elephants (Schiffmann 2020), could serve to prospectively assess the predictive use of BCS in the future.

Conclusions

This study provides a practicable BCS protocol with illustrations to evaluate the body condition of giraffes, based on their hip area. It is specifically indicated that the visual appearance of ribs or the shoulder area have a very limited value for general body condition monitoring. Zoo-housed giraffes have generally higher BCS than their free-ranging conspecifics, which is interpreted as due to resource limitation in the wild rather than overconditioning in zoos. It is recommended that regular body condition scoring (e.g. every 3 months) is performed for zoo-housed giraffes. Ideally, a historical database of each individual is created with photographs from the back and a 45° angle.

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