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Research article

Body Condition Scores (BCS) in European zoo elephants' (*Loxodonta africana* and *Elephas maximus*) lifetimes – a longitudinal analysis

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Abstract

In further improving zoo elephant welfare, diet and feeding regimes are key factors. Together with the encouragement of physical activity, they support the management of weight and the prevention of obesity, which is considered a common concern in zoo elephants. Besides weight monitoring, visual body condition scoring (BCS) has proven a practical tool for the assessment of (zoo) elephants' physical condition. From the individual management as well as the medical perspective, documentation of an elephant´s BCS changes over time might be much more informative than a population-wide cross-sectional analysis. We present a compilation of cases where European zoo elephant BCS can be assessed against influencing factors, such as reproductive activity, physical disorders, advanced age, stressful situations and diet adaptations. The present study of the European zoo elephant population describes how various life circumstances and management adaptations are reflected in the BCS of individual elephants, and in population-wide BCS over time. An online archive to build up a reliable, individual-based data basis with minimal additional workload for elephant-keeping facilities is introduced.

Introduction

With respect to their physical size, mental capabilities, conservation status and public perception as charismatic individuals, management of captive African (*Loxodonta africana*) and Asian elephants (*Elephas maximus*) is a challenging task. Compared to dietary resources in the wild, feeding regimes for zoo elephants are presumed to often oversupply energy, leading to obesity. Although there are no established guidelines as to when an elephant is "obese" or "overweight", the terms have often been used in relation to elephants with high BCS or body mass (Clubb and Mason 2002; Harris et al. 2008; Hatt and Clauss 2006; Morfeld et al. 2014; Morfeld et al. 2016). Therefore, body condition monitoring is an important part of elephant management and preventative care. This can be done by regular weighing on a scale or by visual BCS. The latter is considered a useful method to reliably assess (zoo) elephants (reviewed in Schiffmann et al. 2017).

Several indices have recently been developed for elephants and applied in free-ranging as well as semi-captive and captive populations (Fernando et al. 2009; Morfeld et al. 2014; Morfeld et al. 2016; Treiber et al. 2012; Wemmer et al. 2006; Wijeyamohan et al. 2015). Scores have been reported to be affected by age (Chusyd et al. 2018; Somgird et al. 2016), sex (Godagama et al. 1998; Morfeld et al. 2016; Pinter-Wollman et al. 2009; Ramesh et al. 2011), living conditions (Morfeld et al. 2014; Schiffmann et al. 2018; Wijeyamohan et al. 2015), season (Albl 1971; De Klerk 2009; Foley et al. 2001; Pinter-Wollman et al. 2009; Pokharel et al. 2017; Ramesh et al. 2011; Ranjeewa et al. 2018), husbandry parameters (Harris et al. 2008; Morfeld et al. 2016), reproductive status such as lactation (De Klerk 2009), history of translocation (Pinter-Wollman et al. 2009), stress level (Pokharel et al. 2017) and duration of musth (Poole 1989; Somgird et al. 2016).

To date, only a single study has investigated BCS changes over time in (free-ranging) elephants (Pokharel et al. 2017), indicating a seasonal fluctuation of BCS with available resources. Considering the methodological advantages (reviewed in Schiffmann et al. 2017), visual BCS might represent a practical monitoring tool. Nevertheless, its usefulness in the longitudinal perspective needs further validation. This study aims to evaluate the applicability of BCS in a longitudinal approach in zoo elephants. This is performed on an individual elephant basis similar to the current work on free-ranging female Asian elephants (Pokharel et al. 2017), but emphasises the influence of specific potentially demanding periods (e.g. pregnancy, lactation, physical disorders, disturbances, transfers) in a zoo elephant's life. Given that a continuous historical photographic documentation of zoo elephant body condition is rare, our evaluation opportunistically focuses on cases where such documentation coincided with specific events or circumstances. Additionally, we investigate the change over time in BCS in a population-wide perspective for European zoo elephants. We demonstrate the method's sensitivity and propose recommendations for the application of BCS as a monitoring tool in elephant management and care.

Material and methods

Our data collection method and the criteria regarding standardisation of a pictorial document are extensively documented in a previous publication (Schiffmann et al. 2018). In addition to this photographic and life history data collection, every accessible archive or database in elephant-keeping zoos was also searched for helpful pictorial documents. There were only a few facilities conducting regular photographic body condition documentation at the time of the study; therefore, archived photographs were not consistently available. Additionally, private archives were used where access was allowed. Data collection took place between the beginning of January 2016 and the end of March 2017. To be included in the study, a pictorial document had to fulfill the following criteria: (i) datable to a month (where an accurate date was missing, the 1st day of the month was recorded); (ii) clearly identifiable individual; (iii) sufficient recognition of the relevant body regions (backbone, pelvic bone, ribs) from a lateral perspective. Moreover, (iv) the elephant had to be pictured in a standing or moderate walking body position to allow a reliable assessment. Additionally, (v) sufficient resolution of the photograph was defined if recognition of the generic wrinkles on the skin surface of the elephant was possible. If this was ensured, it is assumed that the quality of the pictorial documents allowed for an evaluation of the critical bony structures. Finally, (vi) distinct patterns of shade or masses of hay, straw and other substrates on the back of the elephant may make any assessment impossible. Likewise, bright lateral rays of sunlight can reduce the picture contrast to such a degree that the mandatory fold beside the tail head cannot be judged. Such documents were excluded from the study. Life histories of individual elephants (date of birth, required to calculate the age at the time a specific picture was taken, as well as dates of calving or transfers), were taken from the current studbooks (Schwammer and Fruehwirth 2016; van Wees and Damen 2016).

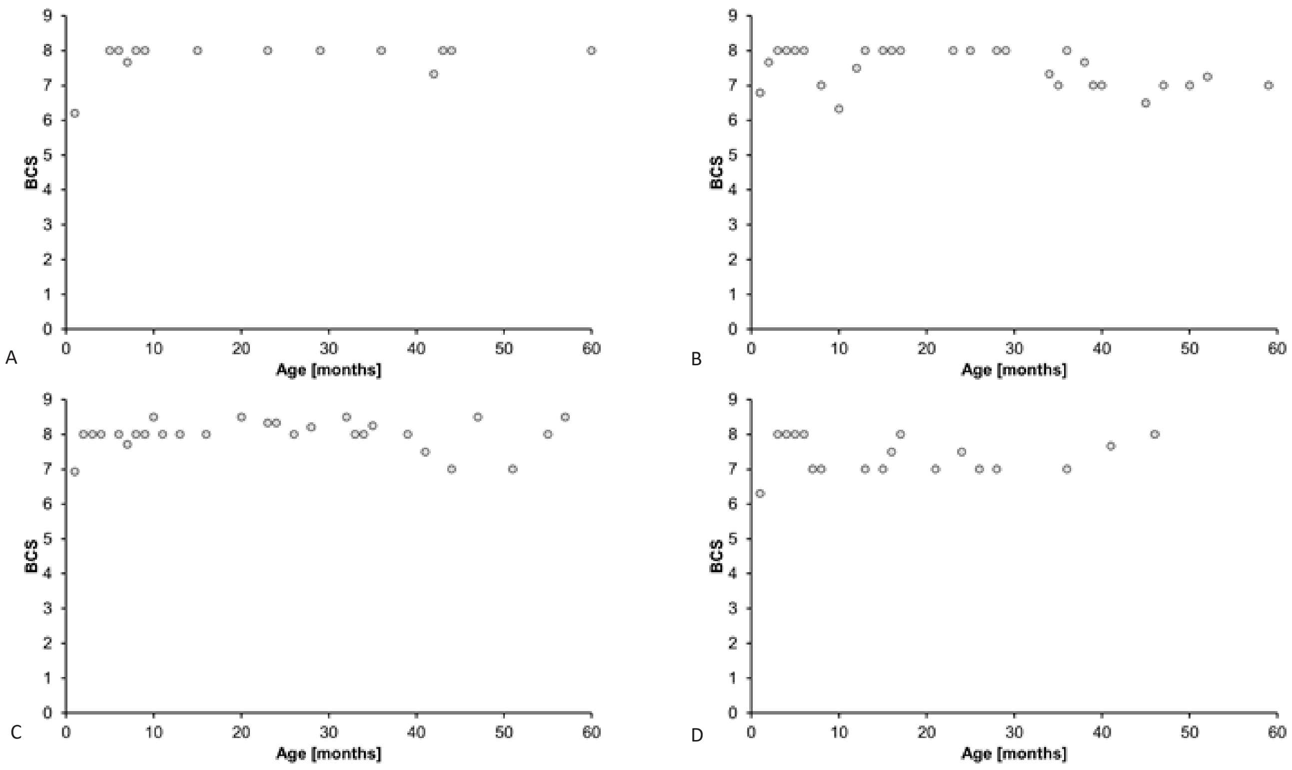


Figure 1: Change over time of body condition scores in individual zoo elephant calves during their first 5 years of life. The abbreviation 0.1 indicates female and 1.0 male individuals. A) 0.1 *L. africana*; B) 1.0 *L. africana*; C) 0.1 *E. maximus*; D) 1.0 *E. maximus*.

Body condition scoring

To assign a consistent BCS to every photograph, we used a protocol in which the species-specific indices for African elephants from Morfeld et al. (2014) and for Asian elephants from Fernando et al. (2009), Wijeyamohan et al. (2015) and Morfeld et al. (2016) were assembled in an overview approach as detailed in Schiffmann et al. (2017). According to recently published findings in dairy goats, scoring results may reach a higher reproducibility and repeatability by the use of example drawings as opposed to example pictures (Vieira et al. 2015). Therefore, we had drawings made for every score and each species, showing the elephant in side profile as well as at an angle from behind. These drawings served as the principal basis for the scoring. The score of the drawing looking most similar to the photograph under examination was assigned to each individual elephant. The focus was laid on the visibility of indicated bone structures of the lumbar region, which have been shown to correlate best with the amount of body fat in elephants (Albl 1971; Morfeld et al. 2014; Morfeld et al. 2016). In addition, the overall appearance of the elephant was taken into account and was considered more important than single characteristics (e.g. visibility of ribs or edges of the scapula). This approach is in accordance with the findings of a recent review on various scoring indices developed for elephants (Schiffmann et al. 2017). All elephants were scored by the first author. To reduce potential bias by scoring serial pictures from the same location, photographs were scored in a random order. The latter was achieved by automatically sorting them according to an independent variable (technical size of the picture). Although the scoring was performed blind, recognition of an individual elephant or the location by the examiner could not be excluded. Scoring of the photographs was done prior to further data analysis, and the method for intra-examiner agreement had been checked as previously reported (Schiffmann et al. 2018).

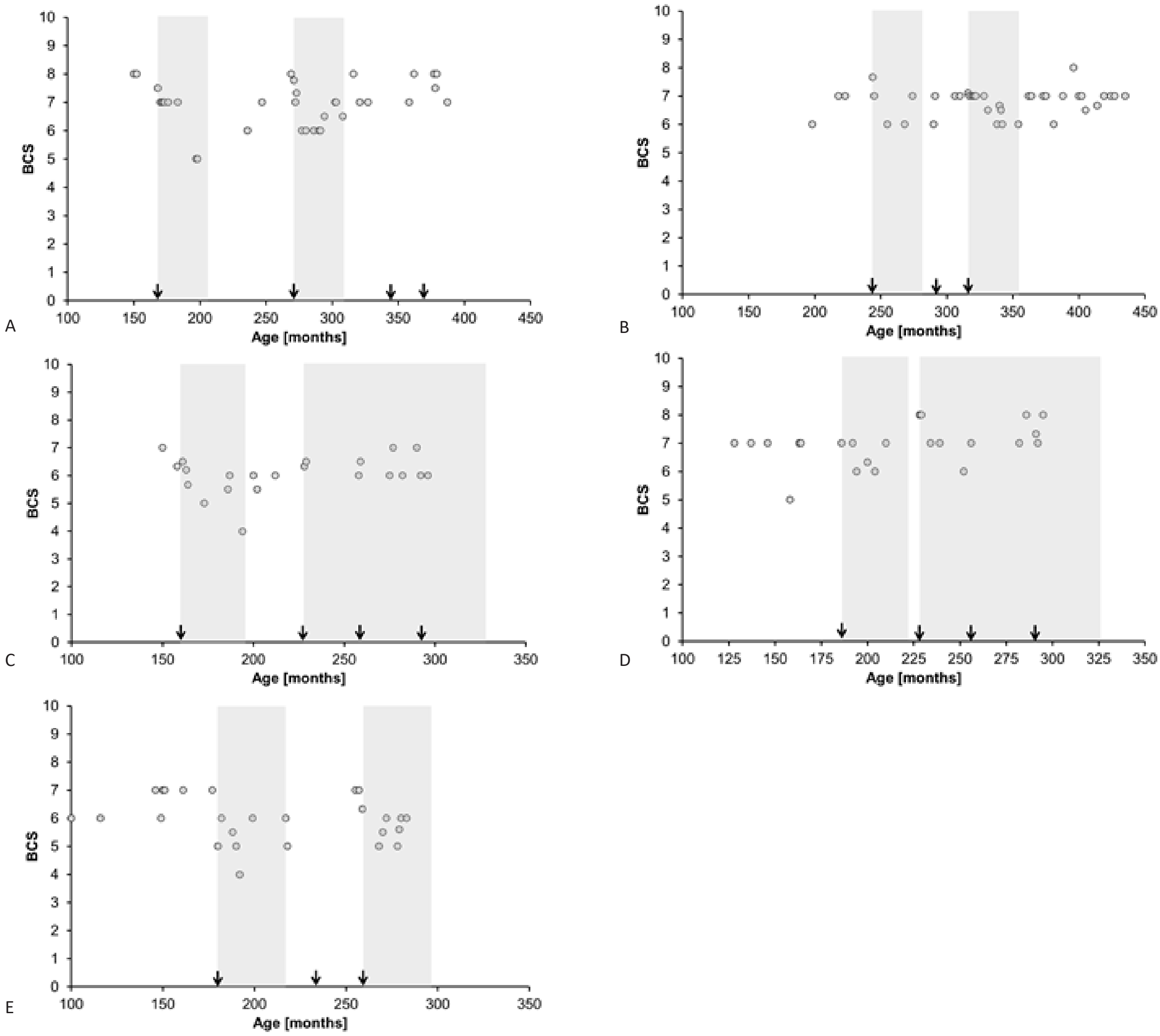


Figure 2: Change over time of body condition scores in breeding female African zoo elephants (black arrows indicate occurrence of a birth and grey shading the assumed duration of lactation (typically 36 months, but shorter in case of death of the neonate). The abbreviation 0.1 indicates female individuals. A) 0.1 *L.africana*: the 3rd and 4th calf died during the first days of life; B) 0.1 *L.africana*: the 2nd calf died on the day of birth; C) 0.1 *L.africana*; D) 0.1 *L.africana*; E) 0.1 *L.africana*: the 2nd calf was stillborn.

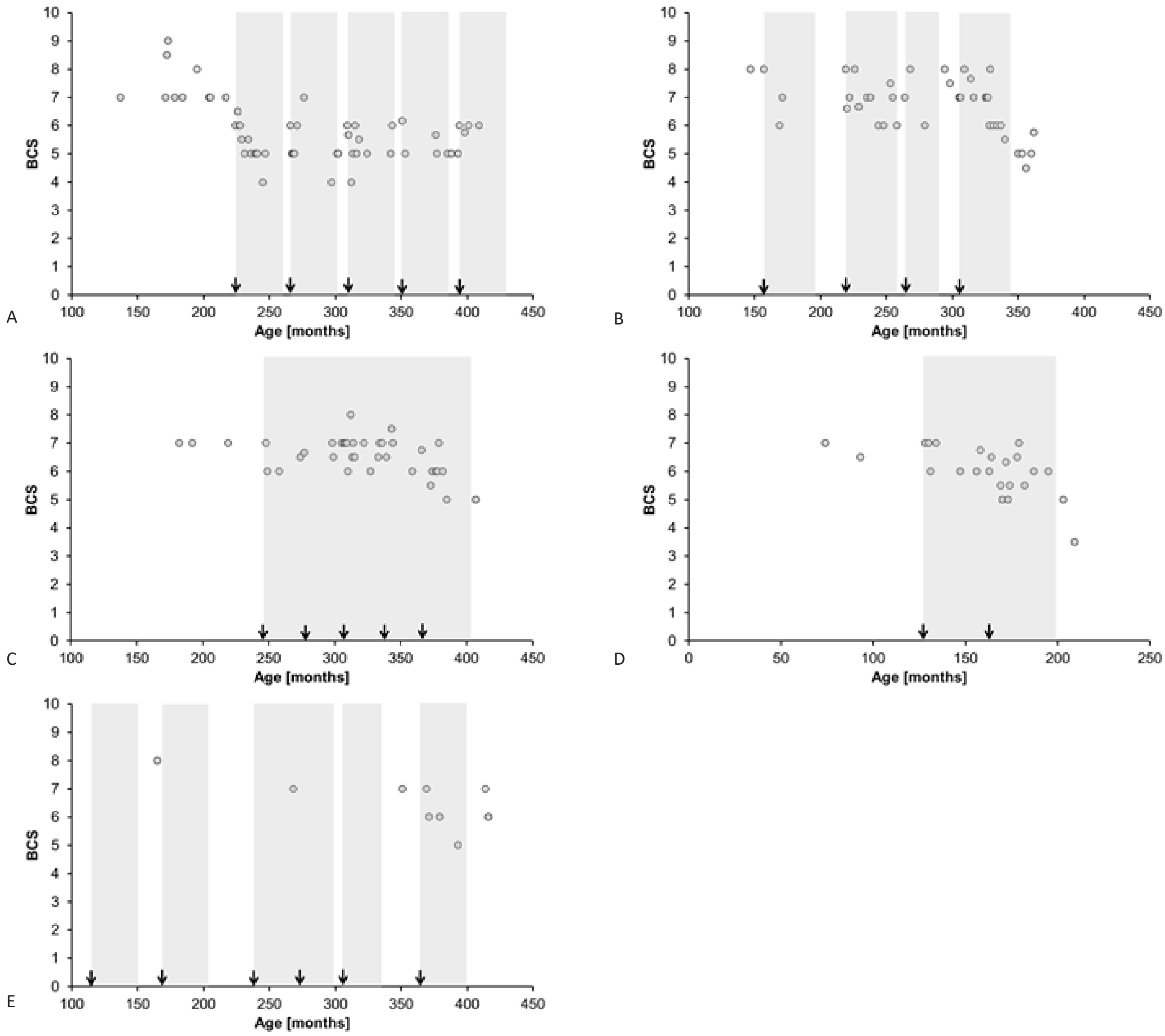


Figure 3: Change over time of body condition scores in breeding female Asian zoo elephants (black diamonds indicate occurrence of a birth and grey shading the assumed duration of lactation (typically 36 months, but shorter in case of death of the neonate). The abbreviation 0.1 indicates female individuals. A) 0.1 *E. maximus*; B) 0.1 *E. maximus*: the 1st calf was hand-reared, the 2nd and 3rd calf died around month 290; C) 0.1 *E. maximus*; D) 0.1 *E. maximus*; E) 0.1 *E.maximus:* the 4th calf died in month 298, the 5th in month 345.

Data for individual elephants

To facilitate comparison of scores between individuals, each score was linked to age in months of the assessed elephant. Where more than one score per month of life was available, the mean was calculated. Subsequently, scores were plotted against the months of life for each elephant. By checking the resulting multitude of graphs for reoccurring patterns, only individual elephants with comprehensive data (BCS photographs and life history information) available for further display and interpretation were selected. Therefore, even though a much larger number of European zoo elephants has undergone conditions such as pregnancy, birth, lactation, transfer to another facility or another enclosure, or disease, the study was limited to those cases where these conditions or events fell into a period for which, for the elephant in question, sufficient (historical) photographic documentation was available. Potentially correlating factors were not determined a priori, but recorded during data collection and investigated when the availability of data provided the opportunity to do so. According to literature data, duration of lactation was assumed to be 36 months, although individual differences may exist (Abbondanza et al. 2013; Moss et al. 2011). Sufficient data for a statistical evaluation of a specific life history event on BCS was only available for females giving birth; in 10 cases, BCS scores from the time of 3 months prior to birth, and from the time of 3 months after birth, were available. These scores were compared by Wilcoxon test for paired samples. Note that because individual BCS scores represent data that is not continuous, nonparametric statistics were applied. To preserve anonymity in displaying individuals, identifiers such as studbook numbers or names are not included in this publication.

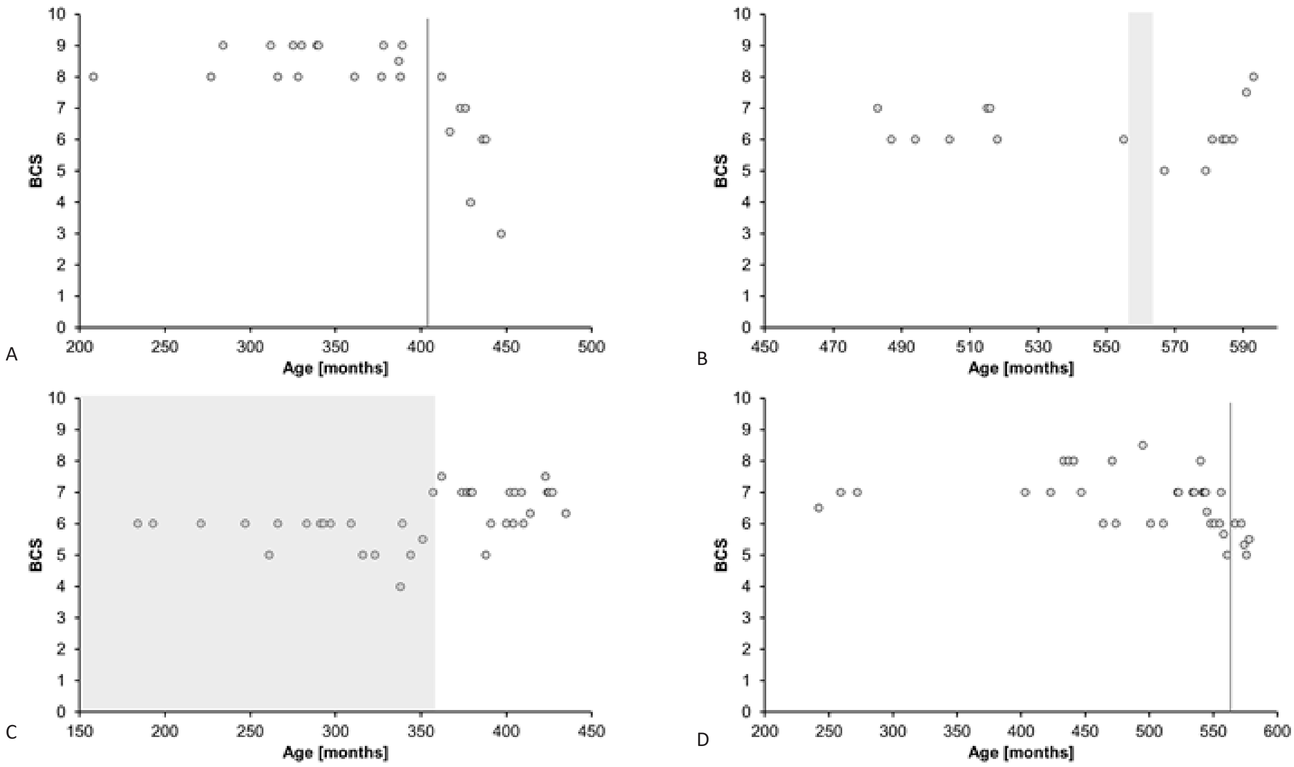


Figure 4: Change over time of body condition scores in zoo elephants during periods of disease (grey shading/vertical lines indicate the duration/beginning of the pathology, respectively). The abbreviation 0.1 indicates female and 1.0 male individuals. A) 0.1 *L. africana* – recurrent digestive disorders (colics, suspected hepatophathy) since the 405th month of life; B) 0.1 *E. maximus* – bacterial infection (*Streptococcus agalactiae*) between 556 and 562 months of life (Knauf-Witzens et al. 2015); C) 0.1 *E. maximus* – recurrent dental disease between 144 and 360 months of life (Strauss 2014); D) 1.0 *E. maximus* – suspected chronic renal failure since the 565th month of life, with consequences evident before the date of diagnosis.

Table 1: Results of General Linear Models linking the average body condition score (BCS) of a year to the year (2000–2017) and the average age, without [AR(0)] or with accounting for auto-regression with the previous [AR(1)] and with the two previous years [AR(2)].

Group	AR(0)		AR(1)			AR(2)			
	Year	Age	Year	Age	BCS_{t-1}	Year	Age	BCS_{t-1}	BCS_{t-2}
Both species & sexes	-0.054 (0.02)*	0.045 (0.03)	-0.051 (0.03)*	0.044 (0.03)	0.130 (0.25)	-0.048 (0.02)*	0.033 (0.03)	0.201 (0.24)	-0.361 (0.24)
E. max., both sexes	-0.059 (0.02)*	0.037 (0.03)	-0.059 (0.02)*	0.037 (0.03)	0.010 (0.24)	-0.068 (0.02)*	0.040 (0.03)	0.036 (0.24)	-0.324 (0.23)
E. max., females	-0.074 (0.03)*	0.048 (0.03)	-0.080 (0.03)*	0.049 (0.03)	-0.178 (0.24)	-0.081 (0.03)*	0.048 (0.03)	-0.189 (0.25)	-0.083 (0.25)
E. max., males	-0.021 (0.01)	0.005 (0.02)	-0.022 (0.01)	0.006 (0.02)	-0.048 (0.24)	-0.026 (0.02)	0.013 (0.02)	-0.081 (0.25)	-0.187 (0.26)
L. afr,, both sexes	0.018 (0.03)	-0.056 (0.07)	0.029 (0.04)	-0.071 (0.07)	0.182 (0.26)	0.035 (0.03)	-0.075 (0.05)	0.108 (0.20)	-0.436 (0.19)*
L. afr,, females	0.032 (0.03)	-0.076 (0.05)	0.038 (0.03)	-0.084 (0.05)	0.193 (0.24)	0.039 (0.02)	-0.081 (0.04)*	0.174 (0.19)	-0.530 (0.19)*
L. afr,, males	-0.066 (0.03)	0.054 (0.05)	-0.030 (0.03)	0.033 (0.04)	0.011 (0.20)	-0.028 (0.03)	0.010 (0.05)	0.001 (0.29)	-0.260 (0.22)

AR=auto-regression coefficient; parameters (slopes) are means with s.e. in parentheses; *=slope differs significantly from 0 (p<0.05)

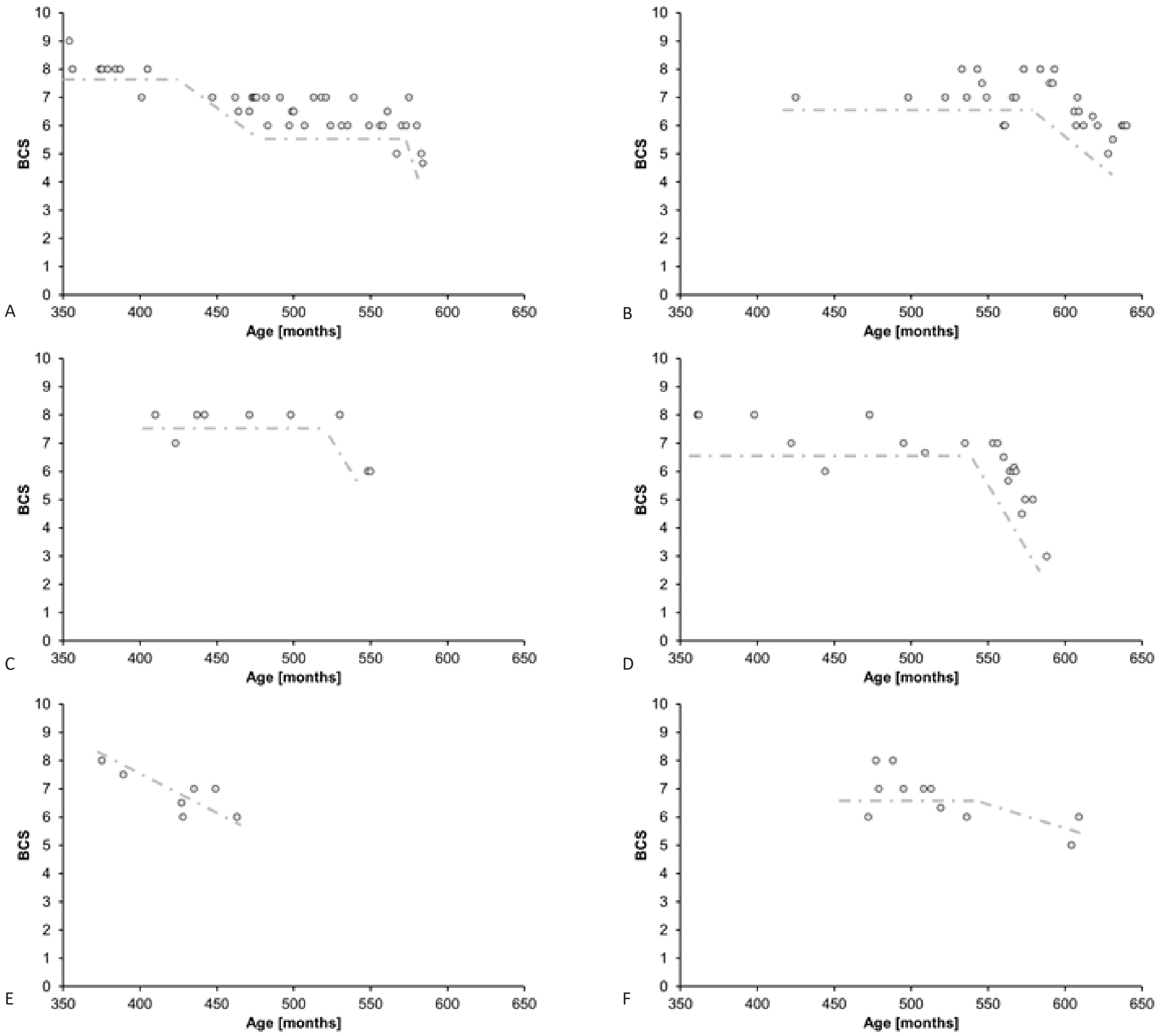


Figure 5: Change over time of body condition scores in aged zoo elephants (the dashed line visualises the BCS change over time, but does not present a statistical trend line). The abbreviation 0.1 indicates female individuals. A) 0.1 *L. africana*; B) 0.1 *E. maximus*; C) 0.1 *L. africana*; D) 0.1 *E. maximus*; E) 0.1 *L. africana*; F) 0.1 *E. maximus.*

Population-wide perspective

To check if there is a seasonal variation in BCS in the European zoo elephant population, a sample of pictures taken during spring time (between beginning and ending of March; reflecting potential changes in BCS reflective of winter) was compared to a sample originating from the beginning of winter time (between beginning and ending of October; reflecting potential changes in BCS reflective of summer). All age classes were considered in this comparison, but with respect to a potential bias by growing elephants, this analysis was restricted to adults (>15 years), comparing spring and winter data using the Mann-Whitney-U test. Because the presence of individuals in March and October data was not controlled for but instead all available data were used, regardless of whether an individual occurred in both seasons or only one season, this approach must be considered exploratory. In a second, more restricted approach, only data on individual elephants taken from spring and winter of the same year were used, accepting only one pair of values per animal, but different years across animals; these data were assessed by the Wilcoxon test for paired samples.

Additionally, the change over time of population-wide BCS was investigated, calculating the annual average of each elephant´s score. This allowed the calculation of annual mean scores for the African and Asian species. The time span between 2000 and 2017 was considered in this analysis, to test for a significant effect of time on the mean BCS. Because elephant age could influence the BCS, this variable was included as a covariate in the analysis, using General Linear Models (GLM). Because of the potential for autocorrelation within this time series, model results were compared with autoregressive (AR) models including first an AR co-efficient of 1 (i.e. BCS at t-1, where t is the year), and then both AR(1) and AR(2) as additive effects. The trend is considered

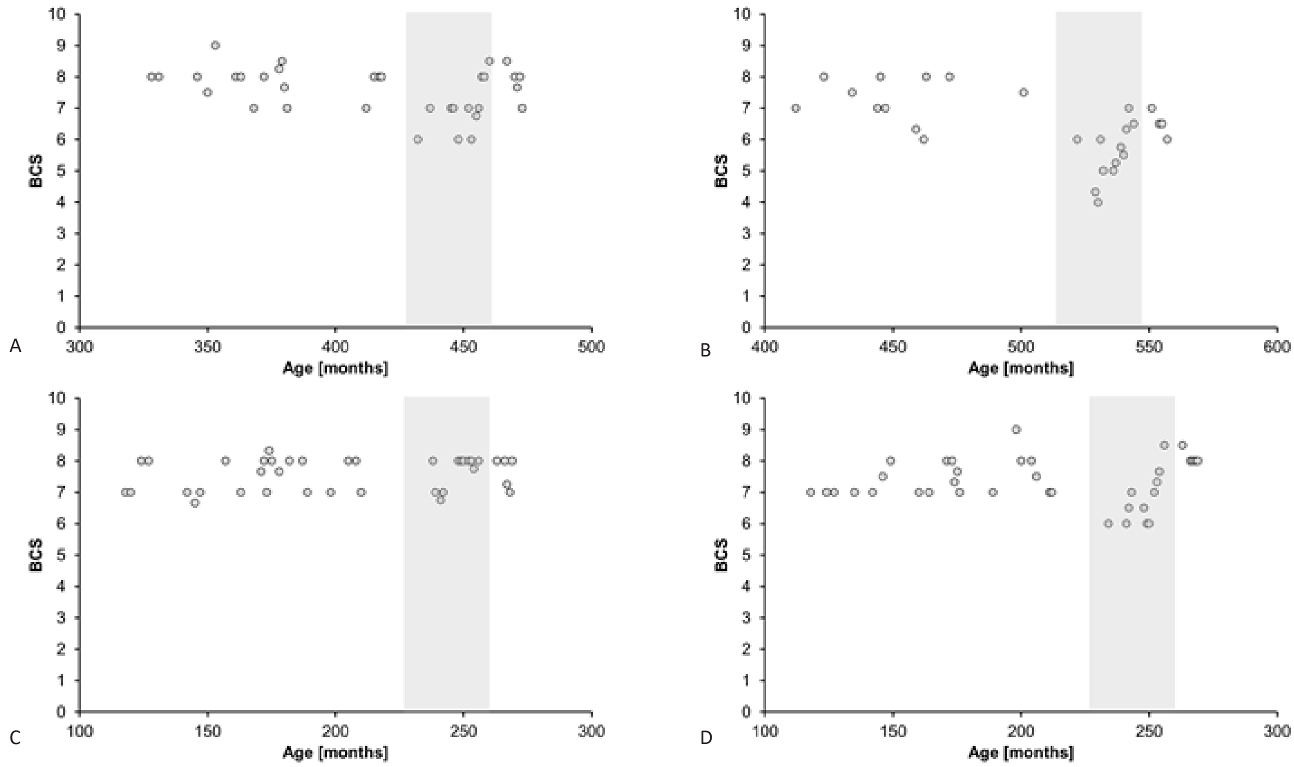


Figure 6: Change over time of body condition scores in a group of African elephants from a zoological institution during a stressful period through living on a construction site (grey shading indicates the duration of disturbances). The abbreviation 0.1 indicates female individuals. A) 0.1 *L. africana*; B) 0.1 *L. africana*; C) 0.1 *L. africana*; D) 0.1 *L. africana*.

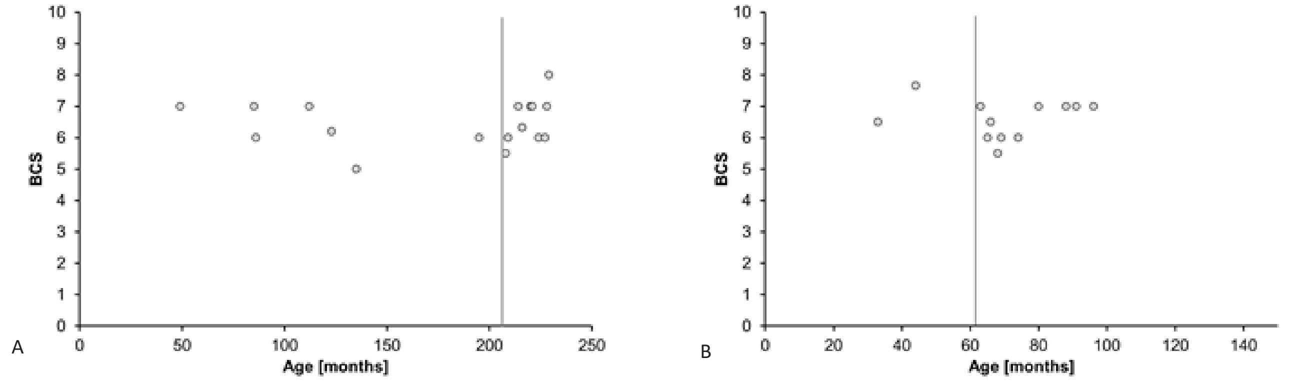


Figure 7: Change over time of body condition scores in two male Asian elephants transferred between two European facilities (vertical lines indicate the time of arrival at the new zoo). The abbreviation 1.0 indicates male individuals. A) 1.0 *E. maximus*; B) 1.0 *E. maximus.*

to deviate from the null hypothesis if H0 is rejected (α = 0.05) in AR(0), AR(1) and AR(2). Higher-order AR coefficients were not tested because of the relatively short time series and the fact that with each additional co-efficient the series becomes even shorter. GLMs were analysed using the lm function of R 3.4.2 (Team 2017). These analyses were performed, in sequence, across all individuals, for each species separately, and then for each species and sex separately, to interrogate the generality of results obtained.

Results

Collection of pictorial documents

In total, 64 different facilities maintaining 140 African and 228 Asian elephants were visited (all by the first author) on site between beginning of January 2016 and the end of March 2017. Together with photographs received by mail, 192 African and 326 Asian elephants of European zoos were included in this study. This sample consisted mainly of elephants participating in the

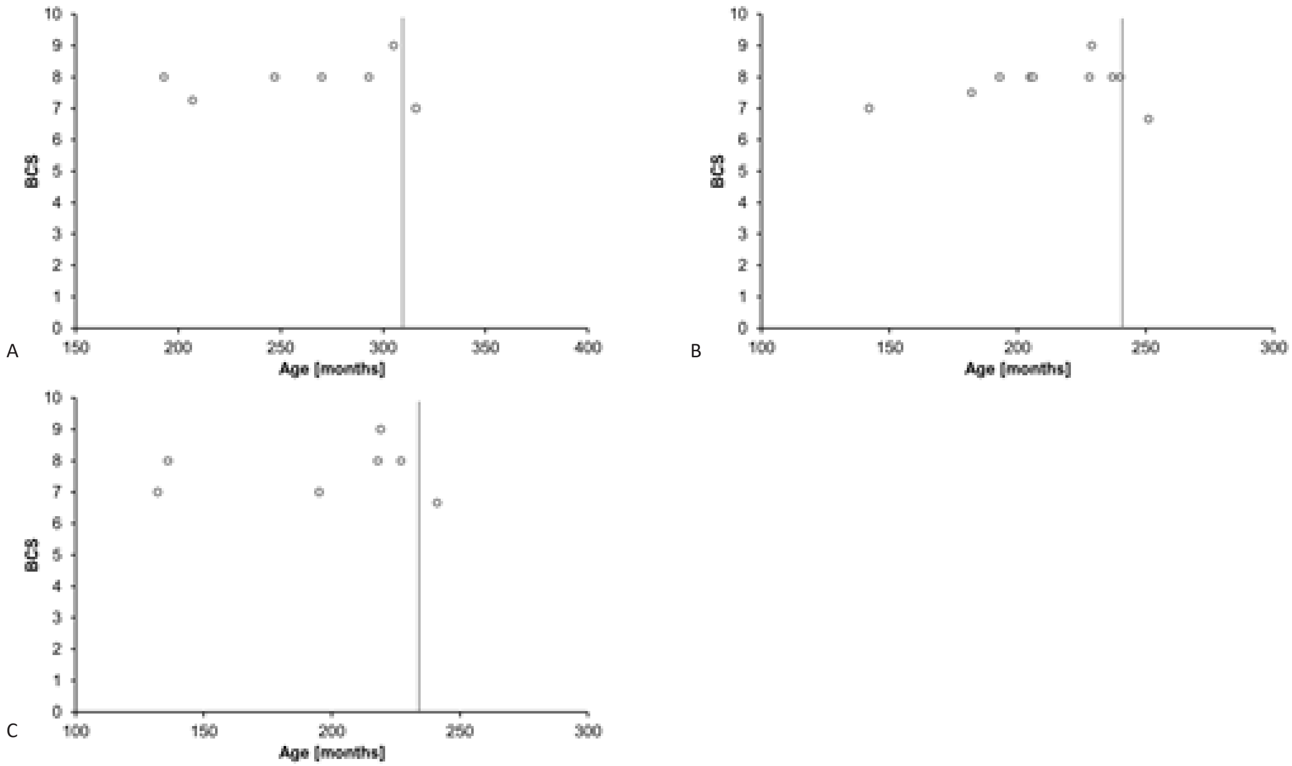


Figure 8: Change over time of body condition scores during diet adaptation in a female group of African zoo elephants (vertical lines indicate the implementation of the new feeding regime). The abbreviation 0.1 indicates female individuals. A) 0.1 *L. africana*; B) 0.1 *L. africana*; C) 0.1 *L. africana*.

European Endangered Species Programs (EEPs) (470/518=91%), but elephants of non-member facilities (48/518=9%) were also included. Altogether, a total of 8,200 pictorial documents of European zoo elephants were selected according to the aforementioned criteria. They were sampled between September 1982 and the end of March 2017. The number of pictures showing an individual elephant ranged from one to 79. The covered extent of an elephant´s period of life varied heavily between individuals (range: 1–482 months, mean: 121±75.67 months).

Life history data collection

Documentation and availability of life history and husbandry data varied considerably between institutions. As expected, comprehensive husbandry data were received only during on-site visits. Seven institutions had established BCS protocols, but only four of these zoos documented body scores with photos. Where dietary and management adaptations were documented, corresponding data were extracted from keepers' diaries. Data on physical disorders were gained from published work, from veterinarians in charge or their medical records, where access was allowed. Data on occurrences of births and inter-zoo transfers were taken from the current studbooks (Schwammer and Fruehwirth 2016; van Wees and Damen 2016).

(I) Data display for individual elephants

Distinct BCS patterns over time were detectable in (A) calves (<5 years), (B) females during pregnancy and lactation, (C) diseased elephants, (D) aged elephants (>40 years) and (E) after significant adaptations in management and/or diet.

A) Calves (<5years)

In calves, BCS appeared stable and high (around 7–8/10) during their first 60 months of life. This pattern occurred in females and males of both species and could be documented for 14 of 15 calves for which more than 10 BCS scores were available. Representative graphs are displayed in Figure 1 and further cases are provided in the supplementary material (Figure S1).

B) Females during pregnancy and lactation

No consistent BCS change during pregnancy and lactation was detectable (Fig. 2 and 3). Lowest scores regularly occurred between Months 1 and 100 after giving birth, but not consistently in all breeding females, and also not consistently within individual females. The females displayed in Figures 2 and 3 represent 10 of 25 individuals for which such data was available. The selected graphs are representative for all 25 cases as can be inspected in the supplementary material (Figure S2). In the 10 females for which BCS were available both 3 months prior to, and 3 months after birth, there was no significant difference between the time points (medians of 7.0 and 6.6, respectively, P=0.091).

C) Diseases

Several diseased elephants showed a marked decrease in BCS during the (first) occurrence of clinical signs (Figure 4). When the underlying disorder was treated and a healthy condition reestablished, BCS reached levels similar or even higher than the individual baseline before the disease (Figure 4b and c).

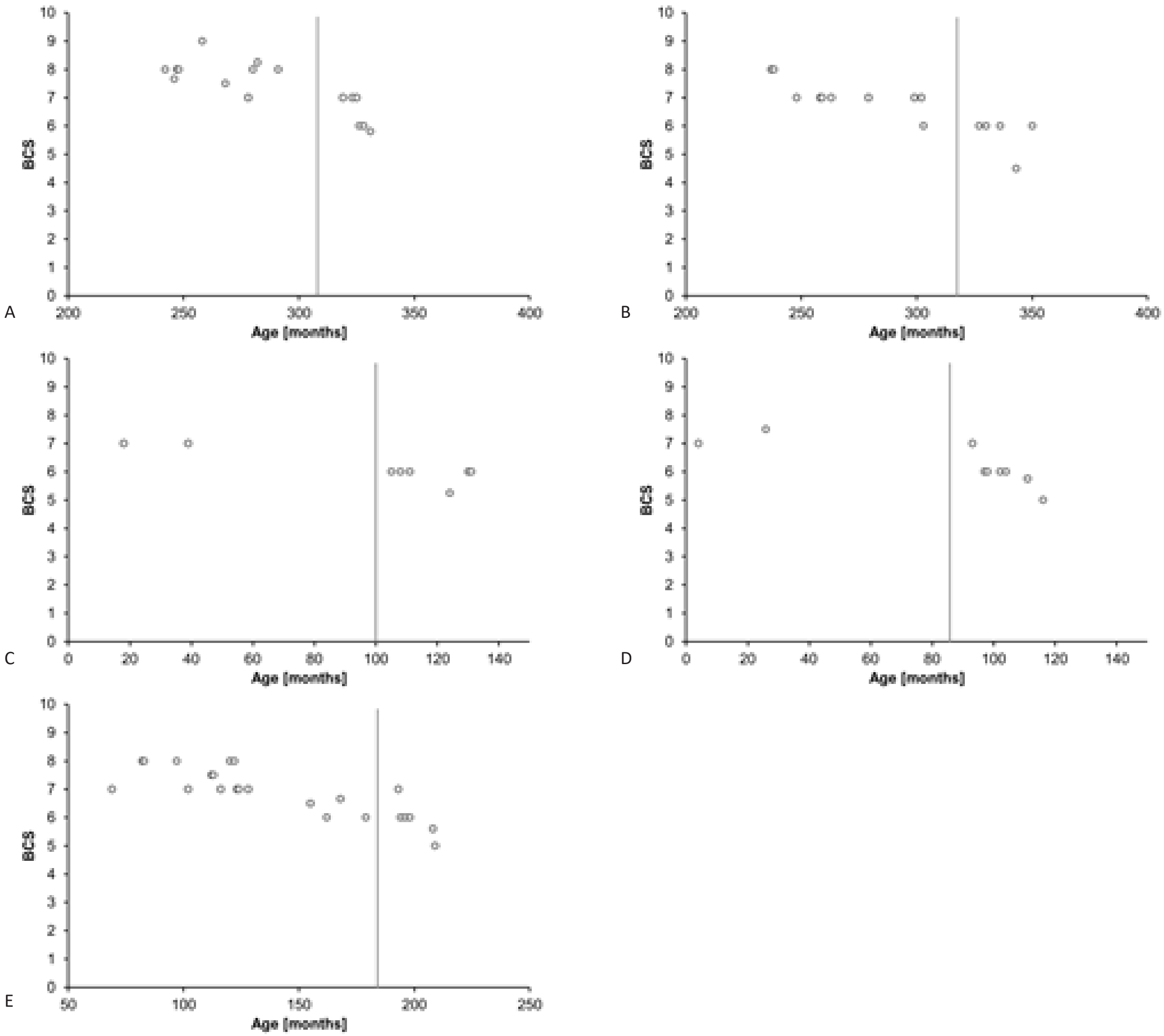


Figure 9. Change over time of body condition scores during diet adaptation in a breeding group of Asian zoo elephants (vertical lines indicate the implementation of the new feeding regimen). The abbreviation 0.1 indicates female and 1.0 male individuals. A) 0.1 *E. maximus;* B) 0.1 *E. maximus*; C) 0.1 *E. maximus*; D) 0.1 *E. maximus*; E) 1.0 *E. maximus.*

D) Advanced age (>40 years)

In elephants exceeding their 480th month of life, a continuous decrease in BCS was commonly detectable (in 24 out of 38 elephants in this age range, while 12 of the remaining 14 individuals showed a steady and two an increasing condition). This decrease varied in its pattern (time of beginning, incline) between individual elephants (Figure 5). Graphs from the cases not depicted here can be inspected in the supplementary material (Figure S3).

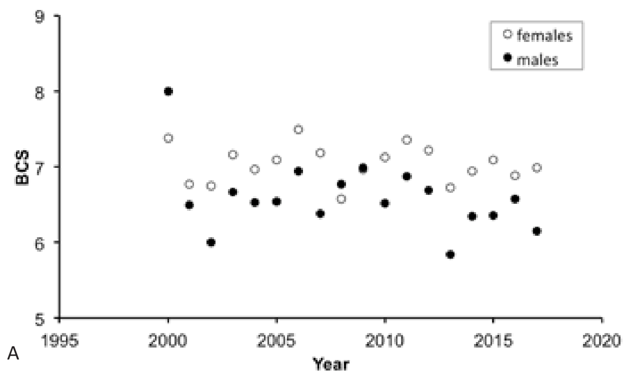
E) Stressful periods, transfers and diet adaptations

A stressful period due to the construction of a new exhibit with the elephants remaining on site (Hoby et al. 2015) led to a temporary depression in BCS in three out of four female African elephants in one facility (Figure 6). The influence of transfer on BCS was obvious in two Asian males. While an adult male continuously gained condition at his new location (Figure 7a), a young male expressed a temporary depression after his introduction into a bachelor group (Figure 7b). Diet changes with an increase in roughage and a decrease in concentrates and introduction of feeding enrichment was reported by two facilities (keeping 0.3 adult *L. africana*, respectively, 2.6 adult *E. maximus*). In both cases, the influence of the new feeding regimens was detectable by progressively decreasing BCS (Figures 8 and 9).

(II) Data analysis European zoo elephant population regarding season and change over years

No significant season-dependent variation in BCS between spring and winter was detectable, neither in the African nor the Asian species of the European zoo elephant population, regardless of whether all available data (*L. africana*: P=0.224; *E. maximus*: P=0.508) or only data from the same individuals within the same year (*L. africana*: P=0.136; *E. maximus*: P=0.930) were assessed.

During the considered years (2000–2017) the total number of available scores per year ranged from 16 to 272. Population-wide annual mean scores showed a trend towards lower values over



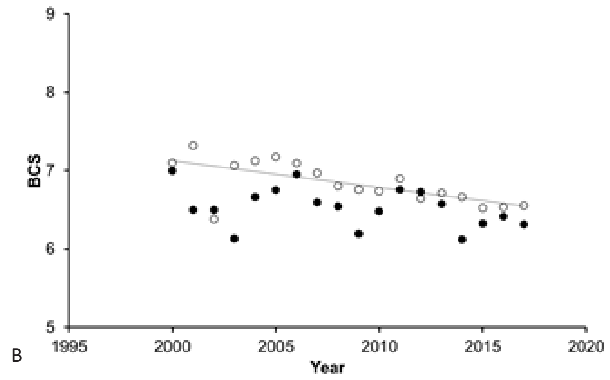


Figure 10: Population-wide change of age and body condition scores in European zoo elephants over the course of 18 years (2000–2017). In total annual scores for 470 females and 101 males of *L. africana* (A) and 917 females and 167 males of *E. maximus* (B) were considered. Only the decline in BCS over time in Asian females was significant (cf. Table 1).

time (Figure 10). While this effect was significant (P<0.05) when yearly averages for all individuals were taken together, further interrogation of the dataset revealed that significance was only evident in *E. maximus* (Table 1). Moreover, within *E. maximus,* only females actually showed a significant trend of decreasing BCS over time. These results were consistent across models with and without autoregression co-efficients (which themselves almost never produced slopes different from zero). Hence it can be confidently assumed that any temporal autocorrelation in these series is negligible. Animal age also had no significant influence on BCS once the year of data collection was accounted for.

Discussion

To minimise the effect of inherent subjectivity of visual body condition scoring, evaluation of the pictures was restricted to one single examiner, and a formalised scoring protocol was applied. Moreover, the results from our previous study support the repeatability of the applied scoring method (Schiffmann et al. 2018). The available compilation allowed the association of influencing factors and management adaptations with an individual elephant BCS as well as the population-wide change over the course of years.

The amount of available pictorial and life history data varied significantly between facilities. Reliable results are expected exclusively in cases for which additional data were available. Thus, descriptions and interpretations are biased towards elephants/ institutions with more extensive documentation. It cannot be excluded that this circumstance led to the over- or underestimation of certain aspects. Therefore, the present conclusions might not be considered invariably representative for the entire zoo population.

(I) Data display for individual elephants

(A) Calves

Between birth and Month 60 of life, a zoo elephant´s BCS remained stable on a score 7–8/10 (Fig. 1). Elephant calves significantly grow in height and weight during this period of life (Kurt and Kumarasinghe 1998; Kurt and Nettasinghe 1968; Lee and Moss 1995; Shrader et al. 2006; Weihs et al. 2001). It can be speculated whether the method of visual scoring is not sufficiently sensitive to detect variations in this stage of life. On the other hand, dietary supply and health conditions are expected to be ideal in young zoo elephants and a constant BCS may be the consequence result. In addition, reduced variance in BCS of calves and sub-adults compared to adults have been reported in free-ranging Asian elephants as well (Ramesh et al. 2011; Ranjeewa et al. 2018). By implication, a significant deviation of this BCS pattern in zoo elephant calves might indicate diet or health inadequacies. Elephant calves up to 5 years old should probably not vary significantly in BCS under zoo conditions. This hypothesis is linked to the assumption that the very high BCS observed in calves should then become lower during puberty. Although very limited in sample size, some graphs for young sub-adults (5–10 years) appear to corroborate this concept (Figure 11). Collection of more comprehensive data of calves born in European zoos during the past years might provide the basis to confirm or reject this hypothesis in the near future.

(B) Females during pregnancy and lactation

According to our knowledge, the influence of pregnancy and lactation on BCS in zoo elephants has not been investigated. Higher energy requirements during lactation lead to the expectation of lower scores in the 36 months after giving birth. This correlation has been confirmed in free-ranging African elephants (Albl 1971; De Klerk 2009). In our cross-sectional population-wide investigation we found differences in BCS between females of breeder and nonbreeder status in Asian elephants, but we did not detect differences between pregnant or lactating individuals (Schiffmann et al. 2018). In accordance with this finding, no distinct BCS pattern on the individual elephant basis occurred here. Although several females expressed higher scores pre- compared to post-partum, this pattern was not consistent, and some elephants remained on a constant level independent of pregnancy/lactation (Figures 2 and 3). Again, it is questionable whether visual scoring is not sufficiently sensitive, or whether the elephants remain in a stable condition despite the varying energetic demands. The latter might be explained by the compensation of additional costs through an energy-rich diet provided under zoo conditions (Hatt and Clauss 2006). In two Asian females with exceptionally short inter-calving intervals (3 years or even shorter), a continuous decline in BCS over the years was evident (Figure 3c and d). It can be questioned whether such short inter-calving intervals are ideal for the female´s health, and whether it would be preferable to let them breed every 4–5 years only. While limited dietary resources and/or

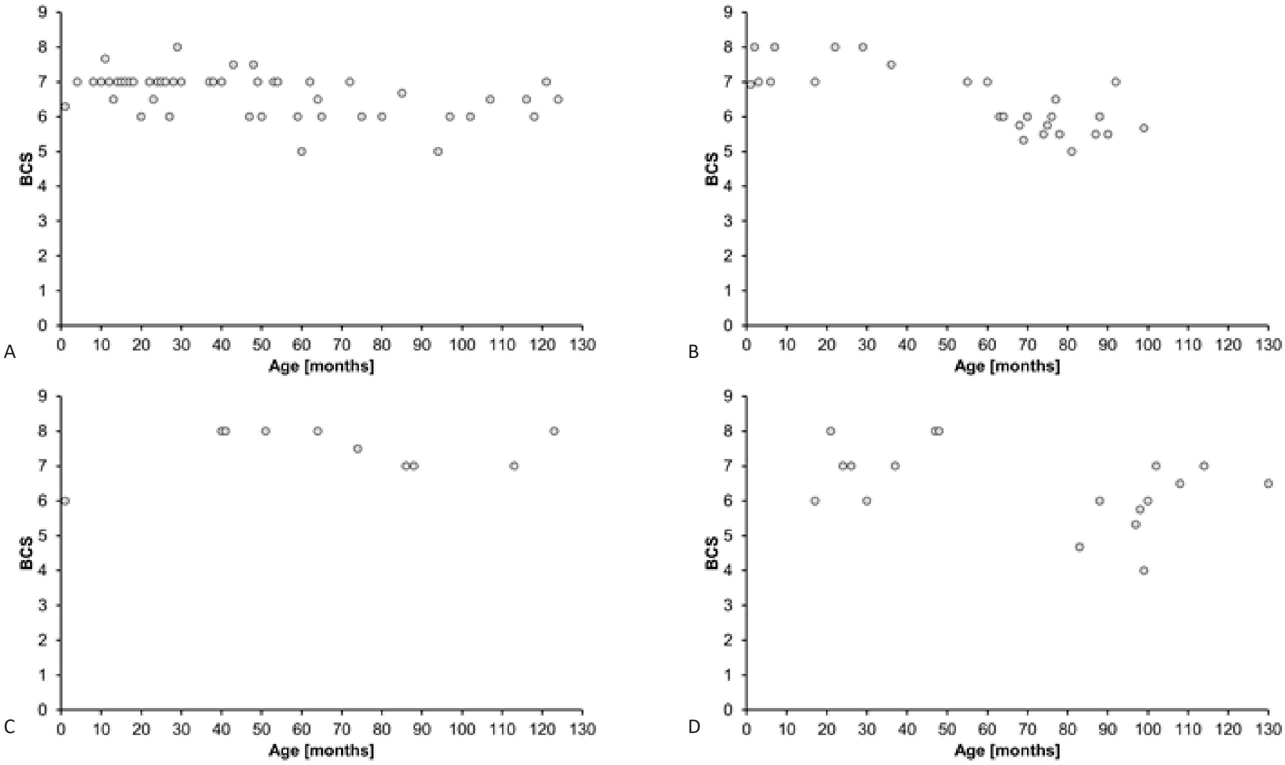


Figure 11: Change over time of body condition scores in young sub-adult zoo elephants between 5 and 10 years of age. The abbreviation 0.1 indicates female and 1.0 male individuals. A) 0.1 *L. africana;* B) 1.0 *L. africana*; C) 0.1 *E. maximus*; D) 1.0 *E. maximus*.

population density are supposed to extend inter-calving intervals in the wild (Moss et al. 2011; Slotow et al. 2005; Wittemyer et al. 2007), such constraints are lacking in captivity. Regeneration periods for female elephants might be recommendable in captive breeding management.

(C) Diseased elephants
The impact of injuries on body condition in two free-ranging male African elephants have been reported in the literature (Ganswindt et al. 2010). We demonstrate a similar pattern in four zoo elephants (one African and three Asian) affected from digestive tract disease (Figure 4). Interestingly, in two cases with ultimate resolution of the underlying disorder (molar malocclusion, acute bacterial infection), BCS subsequently reached even higher levels than prior to the incident (Figure 4b and c). On the other hand, this rebound did not occur in chronic persisting disorders (recurrent colic, hepatopathy and suspected chronic renal failure) (Figure 4a and d). Change over time of BCS in these cases indicates the capability of visual scoring as a tool for medical monitoring in elephants. To determine the sensitivity of this approach in comparison or in combination with weight monitoring or regular blood work, further research is needed. In doing so, the potential impact of age should be considered and interpretations adjusted correspondingly.

(D) Aged elephants
In elephants over 40 years of age, a continuous decrease in BCS was detected (Figure 5). This loss in condition might be caused by age-related alterations (e.g. molar abrasion) or disease. In the cases demonstrated here, no diseases were diagnosed. Literature on the correlation between BCS and age in elephants is very scarce. In nine semi-captive male Asian elephants of advanced age (45–67 years; average 58.5±8.5 years) Somgird et al. (2016) demonstrated a positive (non-significant) correlation between BCS and age, which corroborates with the findings by Chusyd et al. (2018) in a sample of 20 adult female African elephants (16–51 years; average 34.75±8.17 years) living in North American zoos. In a cross-sectional population-wide analysis of European zoo elephants we could not find any correlation between age and BCS (Schiffmann et al. 2018). We hypothesise a life-stage dependent variation of this correlation in elephants and consider further research on this subject recommendable. Especially in geriatric and potentially multi-morbid elephants, regular BCS documentation might be a valuable tool for repeated evaluation of their health state and quality of life. The latter is of increasing importance in zoo animal medicine when dealing with the management of geriatric individuals (Hatt 2017).

(E) Stressful periods, transfer and diet adaptations
A correlation between reduced physical condition and elevated stress indicators has been suggested for wildlife species including Asian elephants (Lane et al. 2014; Pokharel et al. 2017; Scheun et al. 2015). Pokharel et al. (2017) demonstrated a strong inverse correlation between fecal glucocorticoid metabolites and BCS in free-ranging Asian elephants in India. Reports on the influence of stressful situations on zoo elephant BCS is scarce. Hoby et al. (2015) documented the impact of living on a construction site on physical parameters in a group of female African elephants. Looking at the BCS graphs for these four elephants in the present study, a temporary decrease was evident in three of them (Figure 6). It can be speculated whether the fourth female is a less fearful character and thus less vulnerable to disturbances than her.

Another explanation might be her low social rank, which may make her feel less responsible for the safety of the group and thus less stressed. The negative impact on these elephants' physiology is confirmed by a similar pattern detected in further parameters (body weight, hormonal cycles, serum protein levels) (Hoby et al. 2015). As discussed by Hoby et al. (2015), it might not be ideal to keep elephants on a construction site if their level of stress leads to alterations in physical parameters. Visual BCS may be used as one of several parameters to evaluate chronic stress levels in elephants.

Transfers between facilities present another stressful situation for zoo elephants. However, these stressful periods are temporarily restricted and inevitable for the breeding management of a zoo population. The present study found visible alterations in BCS graphs after transfer in two male Asian elephants (Figure 6). While the adult male seemed to overcome the arrival in a breeding group quickly and gained condition continuously, the five-year-old male expressed a temporary decrease in BCS after being introduced into a bachelor group. Introduction of a young elephant into a new social environment can be considered very challenging for the individual and a temporary loss in condition is to be expected. The influence of various factors (e.g. age at time of transfer, diet, social environment, management) may be responsible for these BCS changes.

Overweight and obesity have been recently reported in North American as well as European zoo elephants (Morfeld et al. 2014; Morfeld et al. 2016; Schiffmann et al. 2018). An inappropriately energy-rich diet is considered one of the main causing factors (Hatt and Clauss 2006). Nevertheless, only one study has confirmed the effect of diet adaptations on zoo elephant BCS (Carneiro et al. 2015). The latter report documented a significant decrease in body condition of two female Asian elephants three months after reducing dietary energy provision by >50% in a Brazilian zoo. Similar effects of diet adaptations on BCS have been reported in domestic mammals (ponies: Bruynsteen et al. (2015), dogs: Kealy et al. (2002) and rabbits: Prebble et al. (2015)) as well as zoo-kept baboons (Cabana et al. 2018). The present study presents graphs for one zoo collection of African (Figure 8) and another of Asian elephants (Figure 9), demonstrating a decrease in BCS after a change in diet regimens. Although not quantified, the latter consisted of an increase in roughage while decreasing concentrates, and at the same time extending feeding enrichment. Being aware of the intense efforts of modern zoos to further improve their elephant husbandry and welfare, documentation of BCS approaching an ideal range might present a powerful confirmation for the actions taken.

(II) Data analysis European zoo elephant population regarding season and change over years

According to our findings European zoo elephants express no seasonal variation in BCS. This is in contrast to reports investigating free-ranging populations of both elephant species (Albl 1971; De Klerk 2009; Pokharel et al. 2017; Ramesh et al. 2011; Ranjeewa et al. 2018). In the latter, seasonal availability and quality of diet is considered the driving factor for changing physical condition in elephants. The majority of zoos across Europe provide a high-quality daily ration to their elephants independent of season, which might explain the stable condition in this population. It can be speculated whether a seasonal pattern regarding diet composition and energy content would be beneficial for zoo elephants. Although this approach might imitate the situation in the wild, this does not a priori mean an enhanced well-being for the animals (Veasey 2018). Nevertheless, seasonal variation in diet could potentially reinforce favorable environment-induced mechanisms. If coupled with suggestions to consider elephants as long day breeders (Hufenus et al. 2018), an increase in BCS in the same time period as an increasing day length might boost reproduction. Targeting self-sustaining zoo elephant populations, further research in this aspect might be of special interest.

With respect to the significant adaptations of modern zoos in their elephant husbandry and management, meaningful improvements in welfare and healthcare are expected. Evaluation of an elephant´s physical condition functions as one prominent indicator of its shape. Thus, on a population-wide basis we expect these improvements in living conditions to lead to BCS closer to an ideal range. Considering the time span between 2000 and 2017, the graph for the Asian species meets these expectations, and in the African elephant a trend towards lower scores is also detectable (Figure 10). Observations of the population-wide change over the next decades will allow deeper insights into this correlation.

Conclusion

In this longitudinal description of BCS change over time in a zoo animal species, visual body condition scoring presented a practical tool. Patterns associated with incidents, age and management actions were detectable on the individual elephant basis as well as on a population-wide perspective. A more complete dataset might be achieved by archiving standardised photographs on a regular basis (e.g. quarterly). Nowadays, available technology makes photographing as well as picture filing as easy as never before. To minimise additional workload for zoo staff, this study proposes establishing and maintaining an online database. Such a tool is available (exclusively for elephant-keeping facilities) in the form of an online BCS archive (https://www.elephants-of-europe.org/), where the first author collects and scores photographs of European zoo elephants. The archive is updated continuously and aims at an even more reliable documentation and interpretation of BCS over zoo elephant´s lifetime in the future. If proven useful in charismatic species such as elephants, similar systems might be introduced in further zoo animal species as well.

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