Body condition assessment

– as a welfare and management assessment tool for radiated tortoises *(Astrochelys radiata)*

Hullbedömning - som ett verktyg för utvärdering av välfärd och skötsel av strålsköldpadda (Astrochelys radiata)

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Swedish University of Agricultural Sciences, SLU
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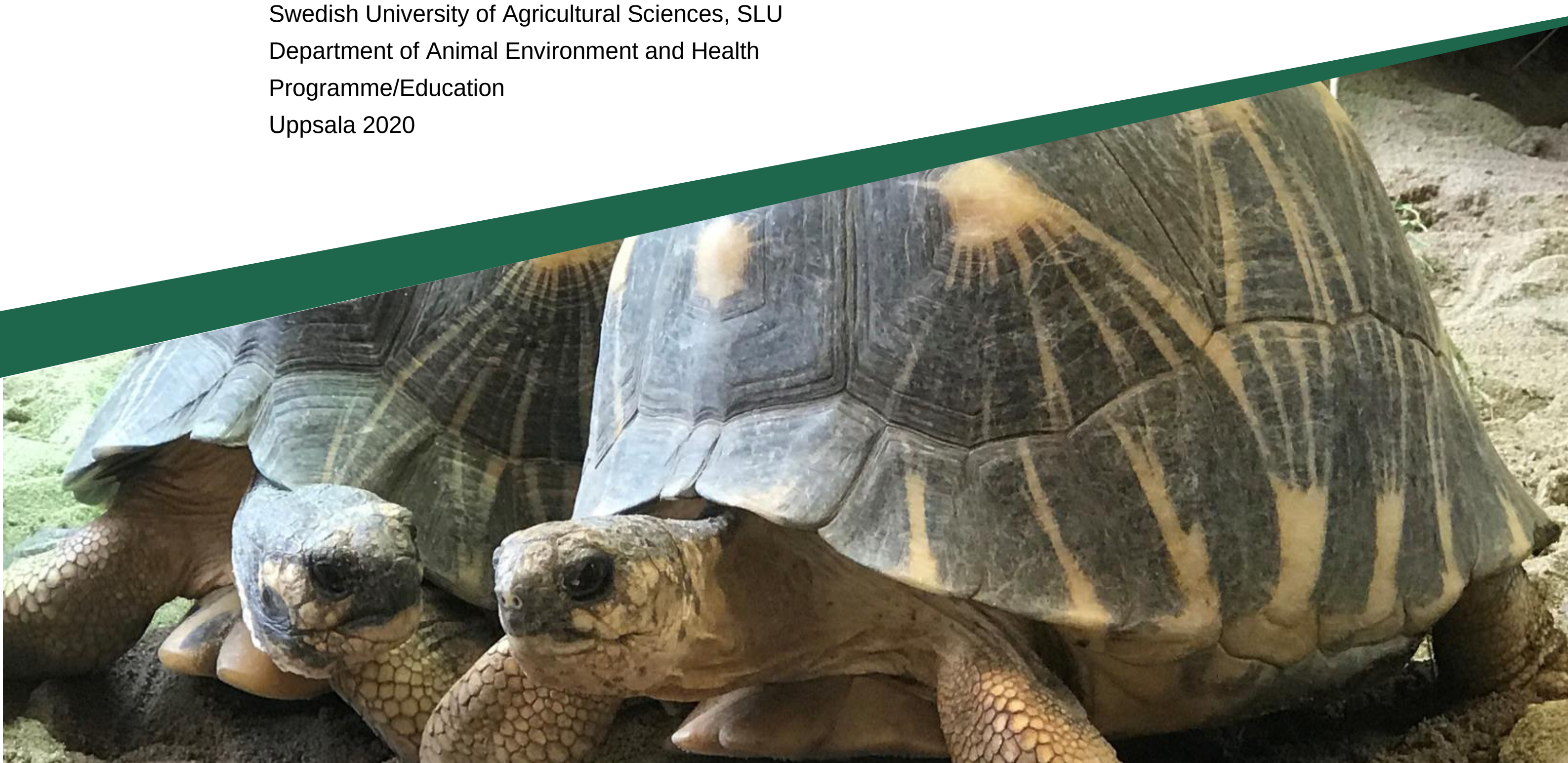

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Abstract

Body condition score (BCS) is frequently used to evaluate animal management practises for a variety of animal species in zoological collections and for production animals. The aim of this study was to apply different body condition indices and evaluate if they can be used as a welfare assessment and management tool for captive and wild critically endangered radiated tortoises *(Astrochelys radiata)*.

Measurements of body mass and shell dimensions of 203 zoo kept radiated tortoises were collected for evaluation of three body condition indices (BCI) previously published for other tortoise species. Males, females and juvenile/unsexed animals were analysed separately and additional measurements from 90 confiscated radiated tortoises in Madagascar where collected and used as a comparison to the zoo kept animals in the formula using weight/straight carapace length for the calculations for predicted weight. A body condition score (BCS) chart previously published for the desert tortoise *(Gopherus agassizii)* was also applied to some of the animals and compared with the results of BCI to evaluate if this could be helpful in assessing the radiated tortoise body condition.

Two of the formulas have potential to be a part of an assessment but with some precautions and consideration, to the sex of the animal, the age of the animal and other factors that may differ depending on the situation. Suggestions on how to use the formulas and how to maximize the benefit of the formulas are also made, from a management and husbandry improvement perspective. Further validation of the BCS chart is suggested in conjunction with training of the animals and the assessors.

Keywords: Tortoise, turtle, radiated tortoise, *Astrochelys radiata*, *Geochelone radiata*, Body Condition Indices, Body Condition Score, morphometrics

Sammanfattning

Olika typer a hullbedömningar används för att utvärdera djurhållningen på en rad olika djurarter som hålls i djurpark och även på produktionsdjur. Denna studie undersöker tre olika publicerade indexskalor för kroppskondition/hullbedömning som testas och utvärderas om de kan användas i välfärdsbedömning och skötsel av den akut hotade strålsköldpaddan *(Astrochelys radiata)*. Data från 203 strålsköldpaddor i djurpark gällande mått på skal och vikt samlades in för analyser av tre tidigare publicerade formler som testats på andra sköldpaddsarter. Honor och hanar analyserades separat, dessutom analyserades ungdjur och icke könsbestämda individer som en grupp.

Utöver det har Turtle survival alliance (TSA) Madagaskar bidragit med mått och vikter på 90 unga beslagtagna strålsköldpaddor för att kunna jämföra dessa med de individer som hålls i djurpark. Till denna jämförelse användes endast en av formlerna.

Även en hullbedömningstabell framtagen för kontroll av ökensköldpaddan *(Gopherus agassizii)* testas av 20 av djurparkerna. Dels för att se om den går att använda till strålsköldpadda som en del av hullbedömningen och dels om den går att jämföra med de andra formlerna.

Resultaten från två av de tre olika formlerna för att beräkna konditions index och den visuella bedömningsskalan har potential att användas, dock beror lämpligheten på omständigheter som djurets ålder, kön och på djurets personlighet. Rätt använt kan formlerna användas som ett komplement till hälsokontroller och även för att justera skötselrutiner, fodertillgång och andra skötselförbättringar för att optimera djurindividens fitness. Hullbedömningstabellen kan underlätta tidig upptäckt av problem som behöver justeras, dock behöver den ytterligare validering och de som ska använda den bör tränas för att säkerställa en konsekvent bedömning.

Nyckelord: Sköldpadda, strålsköldpadda, *Astrochelys radiata*, *Geochelone radiata* kroppskonditionsindex, hullbedömning.

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1. Introduction

Body condition score (BCS) is frequently used to evaluate animal health and welfare in production animals and zoo animals (Lamberski *et al.*, 2012; Schiffman *et al.*, 2017). Depending on the composition of the species in question, different criteria are used to evaluate which body condition scores the animals have. One popular way is to use a numeric scale from 1-9, where one is emaciated and nine is obese or morbidly obese (Gibbons, 2009). This system is for example used in the Zoological Information Management System (ZIMS) which is a programme used by over 11.000 zoos and aquaria worldwide for animal documentation (Species 360, 2019).

If an animal is within the normal/optimal range on the scale that does not necessarily mean that the animal is healthy, but on the other hand if the animal deviates too much from the normal/optimal range it is necessary to investigate why and the risk of health and welfare problems are greater (Jackson, 1980; Hailey, 2000; Gibbons, 2009; Rawski & Józefiak, 2014). Pros and cons have been lifted and discussed regarding different body condition measurement methods with different outcomes (Spatt, 1990; Schulte-Hostedde *et al.*, 2005; Schiffmann *et al.*, 2017). What many of the researchers on this subject emphasise is that it is important to evaluate the model used specifically for the intended species (Loehr *et al.*, 2007; Lickel & Edwards, 2009).

When handling tortoises some individuals are less stressed than others (Currylow *et al.*, 2017b), and if stressed they can excrete large amounts which will affect the body mass, and so will the hydration status and amount of food intake (Loehr *et al.*, 2004). In addition, it can be hard to find published data for ideal weight and growth for many reptile species (Donoghue, 2006).

Tortoises are ectotherms and their characteristic shell develops in different shapes depending on the species. For some tortoise species pyramiding of the shell occurs naturally but in other species this is classified as a deformity (Donoghue, 2006). The development of the shell is affected by the surrounding temperature and humidity and the availability and composition of the food among several other factors (Ritz *et al.*, 2010). If juvenile tortoises have a too rapid growth curve because of an excess amount of food, it is suspected that it might lead to nutrition related metabolic bone disease, deformities of their shell, obesity, high mortality and renal disease (Donoghue & McKeown, 1999; Donoghue, 2006; Ritz *et al.*, 2010).

To ensure that tortoises grow in a healthy way and have a healthy weight in comparison to their size there have been several ways to monitor and calculate this. For some of the European tortoise species, such as *Testudo graeca* and *Testudo hermanni*, that have quite a compact and flat carapace the straight carapace length has been used in several ways to calculate the expected weight and give an indication if they are fit enough to hibernate or are growing in a healthy way, when kept in captive conditions (Jackson, 1980; Hailey, 2000; Mahmoud, 2015).

Another way to calculate body condition was used by Nagy *et al.* (2002) with an equation based on volume used for the desert tortoise (*Gopherus agassizii)*. For the smallest tortoise species, the compact and flat speckled padloper (*Chersobius signatus)*, both a ratio of body mass to carapace length and shell volume have been tested and evaluated (Loehr et al., 2007). The same methods used on the speckled padloper have been tested on the large giant Aldabra tortoise *(Aldabrachelys gigantea)* which can reach the impressive weight over 300 kg and a carapace length of more than 130 cm (Spatt, 1990, Hatt, 2008, Harrold *et al.*, 2018). These methods have also been evaluated by Lickel and Edwards (2009) for leopard tortoises (*Stigmochelys pardalis)*, which is particularly interesting for this study that will focus on the radiated tortoise *(Astrochelys radiata)* since these two species have a similar domed shape of their carapace.

The radiated tortoise *(Astrochelys radiata)* is endemic to Madagascar and inhabits the dry spiny forest in the south and southeast of the island (Leuteritz & Rioux Paquette, 2008). They are estimated to have generation time of 42 years (Leuteritz & Rioux Paquette, 2008) and they are believed to be able to reach an age of up to 100 years (Randriamahazo *et al*., 2007). This is a medium size tortoise species, they can reach a carapace length of up to 40 cm and they can weigh up to 12 kg (Pritchard, 1979). Adult animals are sexually dimorphic, but younger animals are not and this can lead to incorrectly sexed animals (Leuteritz & Gantz, 2013). The species is critically endangered and one of the largest threats is harvesting of animals for consumption or international trade (Leuteritz & Paquette 2008). This has led to a rapid decline of wild radiated tortoises (Rhodin *et al.*, 2018). The illegal harvesting has also resulted in large confiscations of radiated tortoises that also needs to be managed after confiscation. A system of body condition score regarding the confiscated tortoises could have the same approach as the tortoises managed in zoos.

1.1. Aims and objectives

This study aims to evaluate several different body condition indices that have been used in other tortoise species to see if they can be used to calculate body condition indices for radiated tortoises and which morphological index that can work best for this species.

It will also investigate if the cubed carapace length (SCL) formula is suitable to calculate and predict an expected optimal weight for a certain size that can be helpful in the management and welfare assessment in captive radiated tortoises. In some other tortoise species, an equation called the “Jackson´s ratio” has been used to calculate this. This equation will also be tested for the specific species in question.

A body condition score chart with a system of reference points on a 1-9 scale that is used for desert tortoises, Gopherus agassizii, (Lamberski, 2013) will also be evaluated.

Questions:

1. Can Body Condition Indices (BCI) and Body Condition Score (BCS), be used as a welfare assessment and management tool for captive and wild radiated tortoises *(Astrochelys radiata)*? If so, which model is most suitable?
2. Can an easy, user friendly table be helpful when assessing health status in radiated tortoises? Does it compare with Body Condition Indices, BCI, as a tool?

2. Material and methods

2.1. Data collection

This study compared three different ways to calculate Body condition indices (BCI) for the critically endangered radiated tortoise *(Astrochelys radiata)* that are kept in zoos in Europe.

The methods chosen for evaluation have previously been tested on several other species of tortoises. Two equations which have been tested on leopard tortoises *(Stigmochelys pardalis)* using volume were investigated, (Lickel & Edwards, 2009), and two of the equations have been tested on the Namaqualand Speckled Padloper, (*Chersobius signatus)* (Loehr *et al.*, 2007). The so-called Jackson´s ratio (Jackson, 1980; Donoghue 1996; Wallis *et al.*, 1999; Calvert 2004) equation was also investigated to see if it was a suitable measurement and tool for estimating optimal weight for the radiated tortoise.

A body condition score chart system with six reference points on a 1-9 scale used for desert tortoises, (*Gopherus agassizii)*, (Lamberski, 2013) was tested to evaluate if it can be used without modifications for radiated tortoises and how it correlated to the calculated body condition indices.

Morphometric data was collected through a questionnaire, including visual body condition score (BCS) for sexed animals. The questionnaire was sent to 60 holders of radiated tortoises in the European studbook within the European Association of Zoos and Aquaria, EAZA.

The responder included pictures of the tortoise from above, below and from the left side (Fig.1).

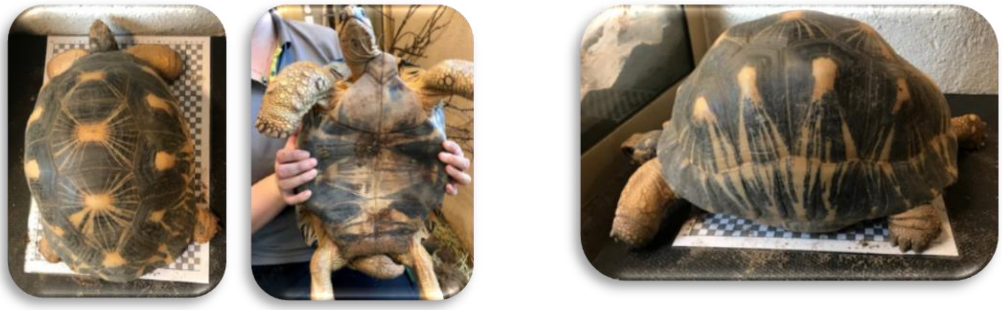

Figure 1. Example of pictures provided by the responders in the questionnaire of the radiated tortoise from above, below and the left side. This helped to evaluate if there are any abnormalities that should be considered in the results of the calculations. (Photo: Linn Lagerström, SLU)

They recorded tortoise weight in grams and provided the measurements with one centimetre's decimal of straight carapace length (SCL), curved carapace length (CCL), carapace height (CH) to get the highest point (Fig.2).

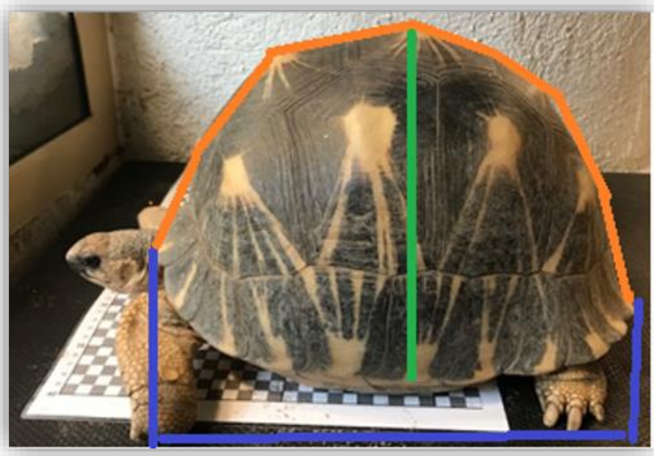

Figure 2. Radiated tortoise with marked measurement points for Straight carapace line (SCL) demonstrated with the blue line, carapace height (CH) demonstrated with the green line and curved carapace line (CCL) demonstrated with the orange line (Photo: Linn Lagerström, SLU).

The carapace width (CW) was recorded at the widest point to get maximum width of the animal, straight plastron length (PL) and finally anal fork width (AF) (Fig.3).

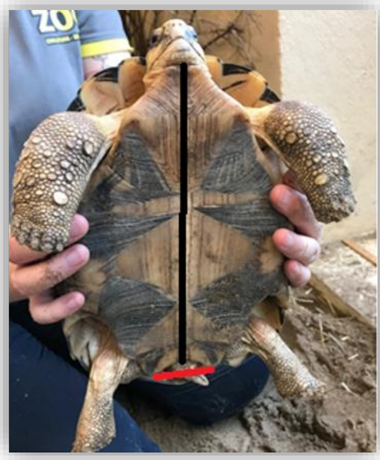

Figure 3. Radiated tortoise with straight plastron length (PL) marked with a black line and the red line is the measure for anal fork width (AF). (Photo: Linn Lagerström, SLU)

Additionally, there was a commentary field in the questionnaire for special notes from the responders where they could inform if they had any special background information or if there were other possible factors to consider.

Information regarding straight carapace length (SCL) and weight was also provided from the Turtle Survival Alliance in Madagascar regarding data for 90 confiscated unsexed animals in Madagascar, the measurements were provided from when first confiscated and after two to three months of rehabilitation when the animals were considered to be fit for transport to a long-term rehabilitation facility.

2.2. Methods

Formulas from Lickel & Edwards (2009) with volumes used for the body condition indices (BCI) calculations that were evaluated:

Formula A $\quad BCI = \dfrac{\text{Body mass, g}}{SCL \times CW \times CH}$

Formula B $\quad BCI = \dfrac{6 \times \text{body mass, g}}{\pi \times SCL \times CW \times CH,\ cm^3}$

Formula for calculation of predicted weight based on one single measurement, Straight Carapace length (Jackson, 1980; Donoghue, 1996; Calvert, 2003) was used. After calculating the predicted weight an index was calculated by dividing the observed weight with the predicted weight (Hailey, 2000; Mahmoud, 2015)

Formula C $\quad W = 0,191 \times SCL^3$

Finally, a body condition score (BCS) chart was assessed by the individual zoos according to the same criteria used for desert tortoises with a scale between 1-9 and the BCS was assigned based on an evaluation of muscle and fat deposits relative to skeletal features (tab.1). The total sum of the six reference points was divided with 6 to give an average score, with an expected optimal score close to 5.

Table 1. Reference points for assessing body condition score, BCS, evaluating muscle and fat deposits relative to skeletal features based on "Body condition scores for desert tortoises" (Lamberski, 2013).

Reference point – BCS	1	2	3	4	5	6	7	8	9
Sagittal crest visible	Extreme	yes	slight	no	no	no	no	no	no
Sagittal crest palpable	Yes	yes	yes	slight	no	no	no	no	no
Temporalis muscle developed	No	no	no	slight	yes	yes	yes	yes	yes
Muscle atrophy (limbs)	Extreme	yes	yes	slight	no	no	no	no	no
Subcutaneous fat (pre-femoral space)	No	no	no	no	no	slight	yes	extreme	extreme
Subcutaneous fat (limb and tail base)	No	no	no	no	no	slight	slight	yes	extreme

Statistical tests were performed with Excel Office 365 Analysis ToolPak and body mass was treated as the dependent variable.

3. Results

Data were compiled through the questionnaire that was sent out to 60 holders of radiated tortoises in the European studbook within, EAZA. With a response rate of 45% a total of 27 institutions responded and morphometric data was collected for a total of 203 animals in European zoos, 89 males, 73 females, 41 unsexed/juvenile animals. For the sexed animals (males and females) 20 of the institutions also did a visual body condition score (BCS) that was compared to the calculated body condition indices (BCI). The accuracy of measurements taken may vary, since the different institutions used the equipment that they normally would have used for assessing the animal.

The total distribution of SCL lengths and weight plotted together for all animals regardless of sex and age (Fig. 4).

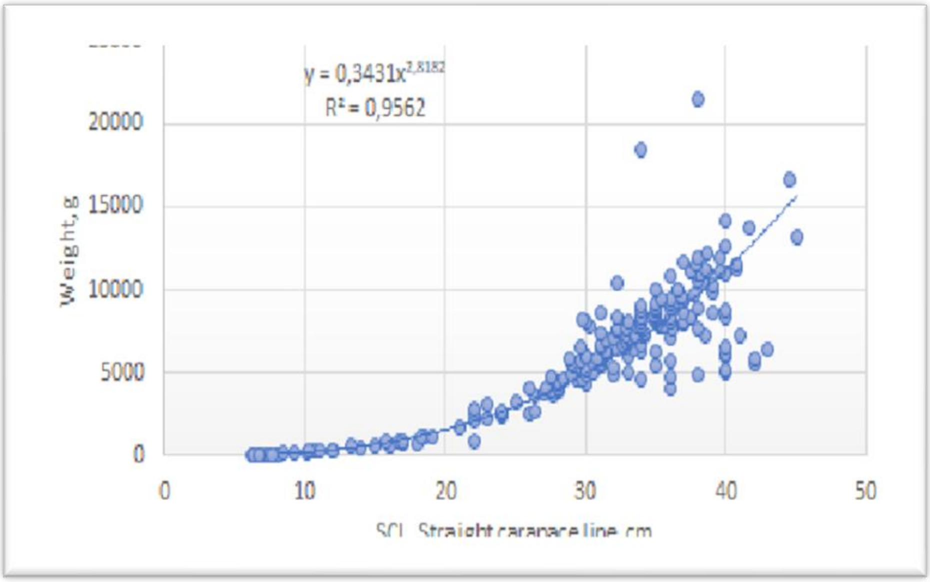

Figure 4. Distribution of SCL, straight carapace length (cm) and weight (g) for 203 zoo kept radiated tortoises *(Astrochelys radiata).*

Morphometrics from all the zoo animals were recorded (Tab. 2) and divided into three groups: males, females and unsexed/juveniles for analysis of the different equations.

Table 2. Morphometrics for all the zoo kept animals grouped by sex (weight, straight carapace length, SCL; curved carapace length, CCL; straight carapace width, CW; carapace height, CH; straight plastron length, PL; anal fork width, AF)

	Males (mean, sd, range; n = 89)	Females (mean, sd, range; n = 73)	Unsexed animals/juveniles (mean, sd, range; n = 41)
Weight (g)	8241 ± 2707 (3860-18400)	7008 ± 2885 (2500-21500)	1134 ± 1273 (47.8-4910)
SCL (cm)	35.6 ± 4.1(26-45)	32.6 ± 3.9 (22.1-40.7)	15.5± 6.8 (6.2-29)
CCL (cm)	49.9 ± 5.6 (38.4-37.5)	46.3 ± 6.8 (20-58.2)	25.0 ±17.2 (8.1-43)
CW (cm)	21.3 ± 2.9 (16-28)	20.1 ±3.6 (14-28,4)	10.0 ±4.9 (3.4-21.5)
CH (cm)	21.3 ± 4.2 (10.4-31)	20.4 ± 5.1 (11-29.8)	10.1 ±4.7 (3.1-24)
PL (cm)	29.9 ± 3.0 (23.3-37.5)	27.1 ± 3.0 (20.2-32.7)	13.4 ±5.7 (5.7-24)
AF (cm)	9.8 ± 1.8 (4.5-14)	7.0 ± 1.6 (3.5-13)	3.2 ±1.7 (1-7)

Calculations of formula A gave a result of a value in gram per cm^3. In comparison one cubic centimetre, or one ml, of water at its highest density equals approximately one gram (Stevenson & Woods, 2006). Males had an average of 0.52 g/cm^3, females had an average of 0.53 g/cm^3 and unsexed/juvenile animals had an average of 0.50 g/cm^3. This formula overestimates the volume of the tortoise since it calculated the shell as a rectangular prism which gives a result below 1.00 g/cm^3.

Calculation of formula B gave a mean result in males of 0.99g/cm^3, in females 1.00g/cm^3 in unsexed/juveniles 0.96g/cm^3.

Calculation of formula C, after dividing observed weight with expected weight, gave a mean result of 0.97 in males (n 89), 1.02 in females (n 73) and 1.08 in unsexed/juveniles (n 41).

The measurement data from the group from Madagascar was divided into three groups depending on size, all animals are juveniles or unsexed (Tab. 3). The final weight and straight carapace length for the 90 confiscated animals was compiled in a plot diagram (Figure 5).

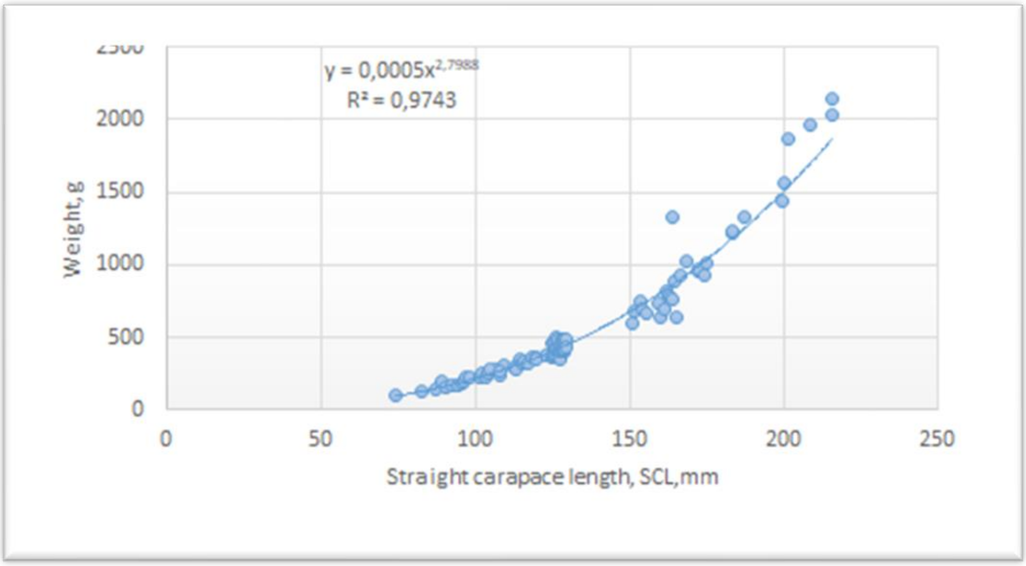

Figure 5. Final weight and straight carapace length of 90 confiscated radiated tortoises after the initial rehabilitation to make sure that they are in good enough condition to transport to long-term rehabilitation.

Table 3. Measurements from the confiscated Radiated tortoises in Madagascar divided into three groups depending on size and Straight carapace length, SCL, initial weight and final weight when the animals are estimated to be ready for transport was recorded.

	Group <125 (mean, sd, range; n = 30)	Group 126 ≤ 150 (mean, sd, range; n = 30)	Group 150 < 216 (mean, sd, range; n = 30))
SCL (mm)	104 ±12 (74-123)	128 ±1.5 (125-129)	174 ±19 (150-216)
Initial Weight (g)	206 ±64 (92-330)	365 ± 31 (295-418)	1037 ± 412 (603 -1974)
Final weight (g)	252 ± 77 (98-380)	428 ± 41 (353-503)	1069 ± 452 (597-2142)

In the group from Madagascar the 90 unsexed animals were divided into 3 groups depending on straight carapace length (SCL). Group one with a SCL <125mm (n 30) got a mean of 0.94 in the first control and in the second after two to three months of recovery a mean of 1.15. The second group with a SCL 125 ≤ 150 mm (n 30) got a mean of 0.93 in the first control and in the second control after recovery they got a mean of 1.09. In the third group they had a SCL 150 < 216 mm (n 30) they had a mean of 0.99 in the first control and in the second control they had a mean of 1.02.

Body condition score according to the system in table 1 was performed by 20 institutions on 141 tortoises. The scale ranged from 1-9, with 5 five being optimal, and resulted in a mean result of 4.97 in males (n 65), 5.19 in females (n 61) and 5.35 in unsexed/juvenile animals (n 15). The scoring chart was used in various ways of the responders. Out of the 203 radiated tortoises 73% of the males, 89 % of the females and 37 % of the unsexed animals were assessed according to this system. For the males, the lowest score was 3.8 and the highest was 7.7, for the females the lowest score was 3.5 and the highest was 7.5. For the juveniles the lowest result was 4.3 and the highest was 6.7, the younger, smaller animals were not assessed in the same extent due to shyness and the fact that young animals do not accumulate adipose tissue this early in life (N.A.T. Rakotoarisoa, DVM, Animal Health Manager, Turtle Survival Alliance, Madagascar program, personal communication 19 September 2019).

4. Discussion

With the questionnaire circulated to the holders within the European endangered species programme, and a feedback from almost half of the holders, this gave a good overview of the population within the zoo community to analyse. With the feedback from 27 out of the 60 institutions contacted and the data for 203 out of the 450 zoo kept animals, the amount of data by far exceeded the expected outcome of the request. In consideration that this was a time-consuming questionnaire and the time for responding was only 14 days the response rate was good. All animals measured were included in the results although some of the measurements from the zoo kept animals deviated from expected weight. When several animals from the same institution deviated with either very low or very high scores there might have been an issue with the assessment or a health problem with the assessed animals. This might be a source of error in the results. Therefor the comparison to the results of the confiscated tortoises from Madagascar was especially important.

The results for formula A that is based on the format of a rectangular prism gives a result considerably lower than 1.00g/cm^3, since the tortoise shape of body does not fill out the whole area, meaning the volume is overestimated. Other studies on tortoises using this formula have the same outcome, but in this study the average is consistently lower than in the other studies performed on other tortoise species. For example, by Nagy *et al.*, (2002) it is suggested that a BCI of 0.64 g/cm^3 is the average weight for a desert tortoise in prime condition, this is valid for males, females and juveniles of this species. Lickel and Edwards (2009) studies of leopard tortoises, that are similarly shaped compared to radiated tortoises, showed an average BCI of 0.60 g/cm^3. When comparing this with the result of this study in which the males had an average of 0.52 g/cm^3, females had an average of 0.53 g/cm^3 and unsexed/juvenile animals had an average of 0.50 g/cm^3, it is clear that this is even lower. With the overestimated volume with this formula it does not appear to reach a realistic density value for radiated tortoises.

Formula B is based on the relationship of a half ellipsoid and this gives a result closer to 1.00g/cm^3 in BCI for the radiated tortoises with a mean result in males of 0.99g/cm^3, in females 1.00g/cm^3 in unsexed/juveniles 0.96g/cm^3. But also, with this formula the similar shaped leopard tortoises get a higher mean BCI of 1.15g/cm^3

(Lickel & Edwards, 2009) which is more similar to the results for the radiated tortoises. One tortoise species that has small and very compact body is the wild Namaqualand speckled padloper and it gets a higher BCI with males at 1.05 g/cm3, females 1.08 g/cm^3 and juveniles 1.02 g/cm^3. The study of this species was conducted over a five-year long period and showed a seasonal variation of up to 18% for the females (Loehr *et al.*, 2007). Another aspect to consider is that the Namaqualand speckled padloper females are very small and only lay one egg and the egg has an average of 8,8 % of the total bodyweight of the female (Hofmeyr *et al.*, 2020).

When comparing the results for formula C, numbers from a study on wild radiated tortoises by Currylow *et al*. (2017) showed that there is a seasonal variation in body condition index (BCI). Where males and females get the highest score in April, with males at 1.07 and females at 1.11 when calculated with this formula. In this study the result from the calculations with formula C for the zoo kept animals the males were at 0.97 and the females at 1.02. That result is lower, but one should take into consideration that the data was collected in October, which in the wild would be the month with the lowest BCI for males and females. The juveniles in the same study from the wild showed no changes in BCI with an average weight of 674g ± 57g and140mm ± 4mm SCL, this resulted in the BCI number of 1.29 if calculated with predicted weight from formula C in this study. For the zoo kept animals this number was 1.08 for juveniles, which was considerably lower than in the study by Currylow *et al*. (2017) but that might have an explanation in that the zoo kept animals included in the study were larger with a mean SCL 155 mm ± 68mm.For the confiscated animals in Madagascar the result for group one with a SCL <125mm was initially 0.94 and after some recovery they got a mean of 1.15. The second group with a SCL 125 ≤ 150 mm initially got a mean of 0.93 and after recovery they got a mean of 1.09. In the third group they had a SCL 150 < 216 mm (n 30) they had a mean of 0.99 in the first control and in the second control they had a mean of 1.02. This indicates the same trend with the confiscated animals as the zoo kept animals that the smaller animals have a higher score.

To get a good understanding of this formula it would be beneficial to continue to take regular measurements and see if the seasonal fluctuations are the same in the zoo kept adult population as the results from the study by Currylow *et al*. (2017) showed in wild radiated tortoises.

For the BCS protocol, there was a difference in the use or interpretation of the scale that shows a very varied and subjective way of assessing the animal in question. With 20 different institutions responding and with that 20 different people using the protocol it was very clear that the responders used the scale differently, but the average total score ended up being consistent in comparison to the other formulas based on calculations. The variability of usage of the BCS protocol by the assessors illustrated the necessity for training of assessors and further research and validation of the protocol which is also highlighted in other studies done on other species (Zielke *et al.*, 2018). One thing that became very clear was that the personality or earlier experiences of the animal mattered. If the animal was shy and not used to being approached it was difficult to get access to all the reference points that needs to be assessed since they can withdraw into their shell.

Not all the reference points are relevant to assess for all age-classes, since one will not find stored adipose tissue in young animals. If further developed for this species, and particularly with consideration to which points are difficult or unnecessary to assess in the young animals, it might be more user friendly and more consistently used. Furthermore, some points are only relevant on one side of the scale, such as the sagittal crest assessment, which is only relevant if the animal is underweight. How to ensure these points do not skew total score and therefor usefulness of the BCS protocol needs to be addresses.

Moreover, the protocol also has its challenges since all the body areas that should be evaluated are not always visible or palpable on an animal that has the possibility to retreat into its shell. If the animal is not comfortable being handled this method might be more stressful than just taking the weight and some simple measurements of the shell. However, a tortoise in optimal body condition should have muscle and fat over bony protrusions (Donoghue, 2006), and this method is the only one where you physically examine the animal. Therefore, it could be very helpful when assessing animals that are used to being handled, especially if used in combination with one of the other formulas. As handling can be very stressful for some individuals, we also need to consider if it is ethically defendable to subject these individuals to it. This means that both from an ethical as well as and animal welfare point of view, for animals that are kept in zoos a training routine with positive reinforcement where the animal freely goes up on a scale would be beneficial to get accurate and regular readings of the weight with minimal stress for the animal. Since this approach also minimizes the risk of the animal urinating or excreting due to a stressful situation the result would be more reliable.

Considering that tortoises are adapted to endure long periods without water and can store a lot of water reserves as urine, up to 30 % of the bodyweight (Nagy *et al.*, 2002), this means that it can have a significant influence on the result if the animal urinates before it is weighed. The same consideration needs to be regarded for an animal that defecates, if it has eaten or not, if it has access to water or not or if it might be carrying eggs. This will influence the outcome of the weight and the ratio volume/weight. For other species examined in the wild substantial seasonal fluctuations in weight have been reported (Loehr *et al.*, 2007; Currylow *et al.*, 2017b).

Several other tortoise species have shown a growth and weight development that is much higher and faster in captive environments compared to wild tortoises of the same species (Ritz *et al.*, 2010). High growth rate might lead to problems like renal disease, “pyramiding”, obesity, gastrointestinal illness, fibrous osteodystrophy or metabolic bone disease in tortoises (McArthur, 2004; Macarthur & Barrows, 2004; Donoghue, 2006; Hatt, 2008; Ritz *et al.*, 2010).

A good tool to calculate optimal weight and growth curves will facilitate adjustment of the husbandry and management and regular control of weight and body condition scoring might be very useful in the daily management. It is difficult to find published data for ideal weight for reptiles in general, but a healthy tortoise should feel hefty for its size when lifted (Donoghue, 2006). Regular weighing and body condition evaluation is likely to be efficient and convenient to use and it may serve as an early warning system in health monitoring of zoo animals (Schiffmann *et al.*, 2017). Therefore, the results from this study can be used for recommendations on which assessments should be incorporated in management routines.

One question that needs to be investigated is what frequency or what intervals between the measurements would be most beneficial (Schiffmann *et al.*, 2017). This is very important from a management point of view, so that optimal health benefits from the assessment are gained.

Long term documentation will also be very helpful since the body condition of a tortoise will change depending on several factors like, age, reproduction, temperature, season, food availability (Lamberski, 2013). Further studies in this area should be conducted. Long term data could also be used for further studies in gaining knowledge on tortoise welfare and development.

Several studies stress the risk of using a single measurement as a single health assessment tool (Jackson, 1980; Jacobson *et al.,* 1993; McArthur, 2004). However, it can be a valuable contribution to health assessment and management if used and documented regularly and as a first approximation of condition and hydration status in the field (Nagy *et al.*, 2002; Stevenson & Woods, 2006). As pointed out by Donoghue for a seemingly “obese” individual a complete physical examination is needed first to rule out signs of diseases that may sometimes mimic obesity, such as ascites, large tumours, and, in subadult and adult females, pregnancy (Donoghue & McKeown, 1999; Donoghue, 2006). BCI formulas could be useful and fulfil the needs of both first and long-term assessments and could be combined with the BCS protocol for the physical examination.

In general, there is a growing problem with fat or obese animals reported in companion animals and zoo animals (Schiffmann *et al.*, 2017). For the radiated tortoise this does not seem to be the case because in this study several of the zoo animals were very low in weight compared to the expected weight, but they are still estimated to be in a good condition by the responders. The same was reported from another study done by Mahmound (2015) with a health assessment of a captive population of Greek tortoises, *Testudo Graeca* which showed that 40 to 50 % of the population were assessed to be under-weight. Since "condition" is often used as an imprecise expression, a good evaluation tool and a suitable growth rate table would be very beneficial for control of management parameters, such as diet, fasting days etc. Evaluating the BCI formulas and BCS protocol in this study provides important information on which tools should be used in tortoise management to more precisely and objectively assess the condition of the animal.

To ensure the survival of a threatened species like the radiated tortoise it is important to produce scientifically based best practice guidelines that ensure that all the holders keep the highest standards regarding welfare and husbandry for the species and for the individual animal. This will lead to a healthy population in the breeding programme suitable for future re-introduction. Ethically a zoo has an obligation that an animal in their care should be kept under the highest welfare standard (EAZA, 2019). This study could therefore be considered an important contribution to the species-specific knowledge that management standards should be built on. Additionally, with the issue of illegal harvesting leading to confiscation of individuals that sometimes are in bad condition, scientifically based recommendations on how to assess confiscated individuals is also of great importance.

4.1. Conclusion

Body condition indices and body condition score can be used as a welfare and management assessment tool. Two out of three formulas for calculation can be used as a part of an assessment for BCI, but none of them should be used as the only tool to assess health condition.

Formula A overestimates the volume of the animal, and this gives a ratio (BW/SV) result of 0.50 – 0.53 g/cm3 and it should not be used.

Formula B gives a result of 0.96 – 1.00g/cm3 which is closer to what would be expected when calculating volume. In studies on wild radiated tortoises it was presumed that a higher number would equal better condition. Zoo kept animals had lower numbers compared to the wild ones and it can therefore be discussed if the zoo kept animals are underweight.

Formula C, in which straight carapace length is cubed, shows a variation in the results for the different sexes and even more difference for the juvenile/unsexed animals compared with males and females. This suggests that to be able to estimate optimal weight the optimum needs to be set separately per group, with a higher number for females than males and an even higher number for juveniles. This is also supported by the comparison to the data from the confiscated animals that are all within the category of juveniles/unsexed animals.

Continued monitoring of weight and seasonal changes during the year for the zoo kept population and for future comparisons is suggested.

Regarding the assessment with the body condition score chart it requires that you can feel the animal’s limbs and if there is muscle or fat tissue. This is a very good complement to the assessment of body condition in adult animals that are used to being handled, but not all animals are used to handling or comfortable with being handled. How to deal with the issue of younger animals not storing fat tissue, normally being shy and retract into their shell and handling potentially being stressful for them needs to be addressed. Further development of the BCS chart is also needed. With this said, this model might be the best to use since it makes the assessor look and feel the individual animal and subtle changes might be detected in a very early stage and proper adjustments can be made before the welfare of the animal is affected.

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