RESEARCH ARTICLE

Creation and Validation of a Novel Body Condition Scoring Method for the Magellanic Penguin (*Spheniscus Magellanicus*) in the Zoo Setting

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This research aims to validate a novel, visual body scoring system created for the Magellanic penguin (*Spheniscus magellanicus*) suitable for the zoo practitioner. Magellanics go through marked seasonal fluctuations in body mass gains and losses. A standardized multi-variable visual body condition guide may provide a more sensitive and objective assessment tool compared to the previously used single variable method. Accurate body condition scores paired with seasonal weight variation measurements give veterinary and keeper staff a clearer understanding of an individual's nutritional status. San Francisco Zoo staff previously used a nine-point body condition scale based on the classic bird standard of a single point of keel palpation with the bird restrained in hand, with no standard measure of reference assigned to each scoring category. We created a novel, visual body condition scoring system that does not require restraint to assesses subcutaneous fat and muscle at seven body landmarks using illustrations and descriptive terms. The scores range from one, the least robust or under-conditioned, to five, the most robust, or over-conditioned. The ratio of body weight to wing length was used as a "gold standard" index of body condition and compared to both the novel multi-variable and previously used single-variable body condition scores. The novel multi-variable scale showed improved agreement with weight:wing ratio compared to the single-variable scale, demonstrating greater accuracy, and reliability when a trained assessor uses the multi-variable body condition scoring system. Zoo staff may use this tool to manage both the colony and the individual to assist in seasonally appropriate Magellanic penguin nutrition assessment. Zoo Biol. XX:1–9, 2015.

Keywords: Magellanic penguin; body condition score; *Spheniscus Magellanicus*; avian veterinary practitioner; seasonal weight fluctuation

INTRODUCTION

Body condition assessment in the zoo and wildlife setting is a critical tool used to inform many health and management decisions at the individual and population level [Burkholder, 2000; Olsen et al., 2000; Stringer et al., 2010]. Body condition is described as the "energy capital accumulated in the body as a result of feeding" [Peig et al., 2009]. Maintaining an optimal body condition in many species, including humans, decreases adverse health outcomes associated with over, and undernourishment [Khan et al., 2009]. Health consequences secondary to suboptimal body condition are documented in a range of zoo species, including chimpanzees [Videan et al., 2007], elephants [Morfeld et al., 2014], and parrots [Bavelaar et al., 2011].

In many avian species, capture, and manual restraint is necessary to make an adequate body condition assessment because plumage may mask their true condition [Gregory and Robins, 1998]. Species such as flamingos, parrots, and cranes hide weight fluctuations with their plumage. The penguin is unique among avian species because of its extraordinarily dense, flat coat of feathers [Dawson et al., 1999; Miller et al., 2015] that makes a visual evaluation of body condition possible. The Magellanic penguin (*Spheniscus magellanicus*) is a charismatic species found in both wild and zoo managed populations. This species undergoes dramatic and distinctly visible morphological body changes related to fluctuating subcutaneous fat stores during seasonal nutritional gains and losses [Davis et al., 1990]. These two

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factors, distinct morphological changes and a dense, flat feather coat, facilitate visual body condition evaluation. Visual assessment does not require an animal to be captured and restrained, making this method efficient, easy, and less stressful for the animals being evaluated.

An important component of animal health and welfare management is an accurate and objective assessment of body condition. In the zoo setting, finding an over- or under-conditioned animal motivates management action and potential medical intervention. Therefore, it is important for body condition to be clearly and objectively understood by all staff evaluating animals in the collection. Individual chronically obese penguins may be managed with dietary changes. Hand feeding is a common feeding strategy for captive penguins but it may lead to reduced foraging behaviors and obesity. Under-conditioned animals may require a medical assessment to rule out disease processes. Suboptimal conditioning also typically warrants an investigation into natural history, nutrition, and behavior. A quantitative, descriptive categorization, such as a low body condition score, is useful for communicating effectively amongst a care team in the zoo setting. The degree to which an animal is over- or under-conditioned cannot be directly conveyed using just body weight for a team member who is not intimately familiar with Magellanic penguin body condition.

Magellanic penguins in the wild are "near threatened" and rapidly declining, primarily due to human imposed environmental stressors [IUCN, 2015]. The global wild population has been estimated at 1.3 million breeding pairs [IUCN, 2015] and is distributed on both the Atlantic and Pacific coasts of South America, primarily in Argentina, Chile, and the Falkland Islands. Intensive long-term studies are ongoing in wild Magellanic colonies, including many related to body condition [Gandini et al., 1996; Hood et al., 1998]. Wild Magellanic penguins show decreased reproductive success in lean years when foraging sources are less abundant [Boersma et al., 1990; Yorio and Boersma, 1994; Yorio et al., 2001]. Over-conditioned wild Magellanics restricted to Patagonian desert climates during molt may suffer from overheating [Borboroglu and Boersma, 2013]. Magellanic colony health in the zoo setting is yet to be studied so intensely; however, ad libitum feeding is associated with obesity in select groups of captive penguins [Tully et al., 2009], potentially leading to sequelae such as pododermatitis and likely aggravated lameness related to musculoskeletal disease [Erlacher-Reid et al., 2011].

Magellanic penguins in the wild and in captivity undergo several different seasonal positive and negative energetic phases throughout the year, resulting in a seasonal loss of up to 45% of maximum mass [Fowler et al., 2001]. Ample protein and lipid stores [Davis et al., 1990] are needed to thrive while fasting during molt [Cooper, 1978] and during the demands of reproduction [Fowler et al., 1994; Vleck et al., 1999; Moreno et al., 2002]. In the wild, Magellanic penguins spend the austral winter (May to August) feeding far offshore where prey such as small pelagic schooling fish, squid, and crustaceans are abundant [Boersma, and Yorio, 1994; Scolaro et al., 1999; Miller et al., 2015]. Magellanics return to land around September to begin mating and nesting. While on land for courting, nesting, and chick rearing, the parents fast intermittently and will naturally lose body mass over the course of the reproductive season (October to February) [Boersma and Yorio, 1994; Fowler et al., 1994]. After the breeding and chick rearing season has concluded, Magellanic penguins go through a significant condition increase just prior to molt, [Fowler and Cubas, 2001] physiologically preparing themselves for a long period of fasting. Determining a single ideal body condition for the Magellanic penguin is challenging because of seasonal weight dynamism.

The San Francisco Zoo maintains a large breeding colony of over fifty Magellanic penguins that has been in situ for almost forty years. This penguin colony goes through a similar activity and physiological pattern as its wild counterparts, but reproduction appears to have less impact on body condition due to hand feeding by keepers while in the nest. The penguins choose mates and settle into burrows in the early spring (February–March), then nest and raise chicks through the summer (April–July). In late summer (July) molt starts with the last individuals completing molt by October. During the winter months (November–February), when its wild counterparts would be migrating looking for food, the zoo colony is very active and returns to an adequate to over-conditioned state. These seasonal changes in behavior result in natural mass fluctuations similar to wild populations. To effectively evaluate the health of a captive Magellanic penguin the assessor needs the ability to differentiate between healthy seasonal condition changes and those associated with illness. The assessment system for any institution must include information accounting for seasonal adjustments.

We studied the Magellanic penguin body condition in the zoo setting to create a standardized evaluation tool that could be used at any time of the year. A standardized body condition guide for the Magellanic penguin may provide a sensitive and objective health assessment tool [Kaiser, 1992, Hickman and Swan, 2010], optimizing management of the colony and the individual for their health and well-being.

MATERIALS AND METHODS

At the San Francisco Zoo, each Magellanic penguin annually receives a standard avian physical examination and is evaluated for bumblefoot, lameness, weight measurement, body condition score, fecal parasite screening, vaccination against West Nile virus, and coping of bills as needed. We initiated this study by developing and illustrating a visual body condition guide for Magellanic penguins to be used during their individual annual health examination. We assigned pertinent morphometrics to a given body condition score category of one through five, with one being the most under-conditioned and five being the most over-conditioned. A one-to-five body condition system removes as much statistical variability as possible, as nine-point systems give observers too much choice and increase "inter-observational variability" [Hickman and Swan, 2010]. Each category was illustrated, providing a visual representation of the conditioning, and differences in the appearance of external anatomy between categories were described. We tested this assessment tool using morphometric data sets, weights, and body condition scores collected during the annual physical exam for the entire colony. These objective data sets standardized the more subjective body condition numerical score assigned by an assessor.

As in other bird species, the keel in Magellanic penguins is one point of palpation reliable for evaluation of body condition [Gregory and Robins, 1998, Olson and Orosz, 2000]. San Francisco Zoo staff previously used a "single-variable" nine-point scale based solely on keel palpation while the penguin was being restrained in hand, with no standards assigned to each scoring category. We chose the morphometric points in our novel "multi-variable" body condition scale based on the American Zoological Associations Penguin Taxon Advisory Group husbandry manual [Wallace and Walsh, 2005] and the observational experience of long-term penguin keepers and medical staff at the San Francisco Zoo. The points of visual evaluation noted in this study are the keel, legs, spine, furcula, shoulders, hips, and caudal ventrum [Wallace and Walsh, 2005]. The presence or absence of subcutaneous fat and muscle overlying these areas can be readily seen. The scale consists of five body condition categories scored from one to five. Each body condition score (BCS) is assigned to specific morphometric visual markers (Fig. 1). For this study we palpated each individual's keel while the bird was in hand and then watched as the bird walked approximately 15 feet to the enclosure. During this walk the observer noted each variable and assigned a score of one to five.

The categories were defined verbally and with a corresponding illustration. Individuals in the BCS category 5 are birds considered obese or considerably over-conditioned with rounded pectoral tissue resulting in the keel being difficult to palpate, rounded shoulders, and the absence of discernable hips, spine, or furcula. The fat deposits in the caudal ventrum in category 5 diminish the visibility of the stifle joint leaving only the most distal metatarsal region visible. In BCS category 4, the keel is not visible nor easily palpated. The keel muscle is rounded but not mounded above the keel. The angle between the tail and the base of the back is greater and the shoulder area is more angular. The dorsal ventral fat deposits are reduced and more of the metatarsal is visible. In BCS category 3, progressive reduction in pectoral mass is noted with a keel that is easily palpated but not visible. The bulging fat deposits of the caudal ventrum are not present and the metatarsal is readily visible. The shoulders and base of back are moderately angular. In BCS category 2 the stifle joints, keel, furcula, and scapulae become readily apparent visually. In the very lean or under-conditioned BCS category of 1, all of the abovementioned factors for category 2 are evident plus the dorsal spinous processes, and dorsal pelvic bones become evident. The pectoral muscles are concave at this point and the keel appears sharp.

Quantitative morphometric data collected from each animal included weight (kg), girth at the level of the axillae (cm), foot length (cm), bill length (mm), bill depth at rostral margin of nares (mm), bill width at the rostral margin of nares (mm), and antebrachium ("wing") length from caudal process of olecranon to distal wing tip (cm). Morphometric data collection also included keel palpation and BCS assessment. These data points were chosen based on previous studies of body condition in penguin studies for the Magellanic [Hood et al., 1998] and king penguin (*Aptenodytes patagonicus*) [Viblanc et al., 2012]. After statistical analysis of each morphometric point we determined that body mass to wing length ratio was the most effective data point for a 1–5 BCS categorization. Measuring precise wing lengths on active penguins during manual restraint is challenging. Magellanic penguins are capable of delivering significant blows with their wings and their bites can lead to laceration and bruising of the animal handler.

Prior to the data collection event, we weighed and measured five penguins to define landmarks that could be feasibly reproduced. It was also confirmed that visually assessing morphometric points of walking or standing penguins was necessary to observe fat stores accurately. When penguins are physically restrained they tend to contract their bodies and appear larger than they actually are. Also, when the penguins are on their hocks their true condition may be masked. The morphometric points generated in this research are illustrated below (Fig. 2). The points were derived from king penguin measurement schematics [Fahlman et al., 2006] and those determined by our hands-on work prior to the study. Visual BCS assessment was performed by the same observers throughout the study. These observers were not aware of the results of the morphometric data before making their assessments.

In February 2013, 48 penguins (21 females and 27 males, 42 adults, and 6 juveniles) were manually restrained for annual heath examinations, collection of morphometric measurements, and body condition scoring. The visual assessment occurred while the penguins walked back across a fifteen-foot bridge back to their colony. All penguins were assigned a BCS according to the prior single-variable and novel multi-variable scales. This process was repeated for the same colony in February 2014 for 42 of the initial 48 penguins (18 females, 24 males, 42 adults), except the penguins were only given a BCS using the multi-variable scaling system. Penguins were weighed in 2014 but morphometrics were not measured; therefore, only penguins that were sexually mature and considered to be adults (females: 2 years 10 months, males: 1 year 10 months) when initially measured in 2013 were included in the 2014 data set.

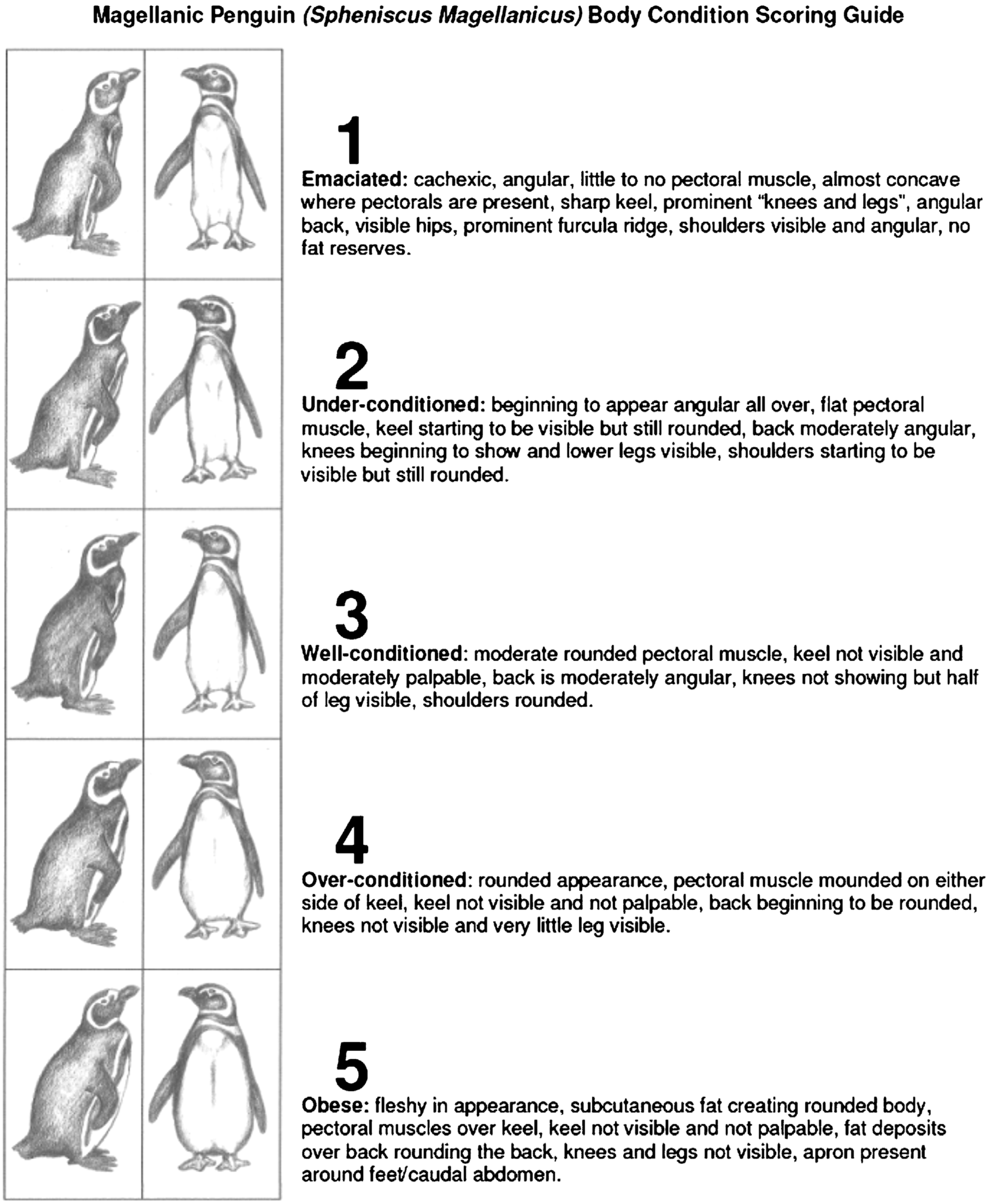

Fig. 1. Body condition chart created for the Magellanic penguin (*Spheniscus Magellanicus*). Illustrations and descriptors for categories 1, the most under-conditioned, through 5, the most over conditioned.

The 6 penguins (3 females, 3 males) that were juveniles in 2013 were not included in 2014 analyses. Data from each year were analyzed alone to avoid pseudo-replication due to resampling the same individuals in both years and to demonstrate the reproducibility of the new scoring system. The ratio of weight (kg) to wing length (cm; Fig. 3) was used as the index of true body condition and used as the "gold standard" for comparison to BCS [Hood et al., 1998]. Body weight and weight:wing ratio were tested for normality using a Shapiro–Wilk test to ensure there were no initial biases in the dataset and a range of body weights were represented. Ninety-five percent confidence intervals (95%CI) of this weight:wing ratio were calculated for each subset of sex, age class ("juvenile" and "adult"), and BCS (1–5). The weight:wing ratio was compared among sexes, age classes, and BCS categories using an ANOVA. A Cohen's kappa

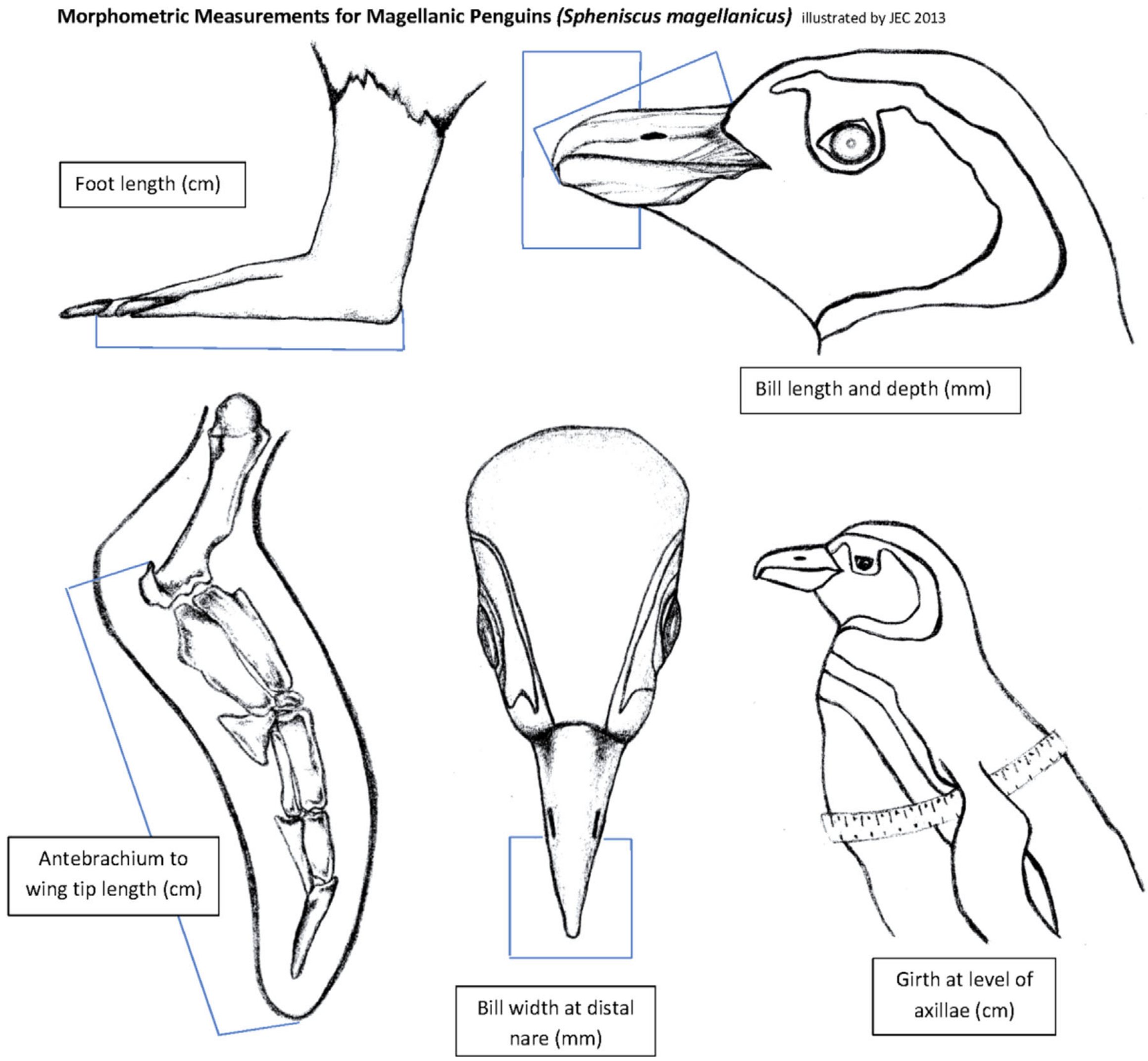

Fig. 2. Morphopmetric measurement points taken during this study for the Magellanic Penguin (*Spheniscus Magellanicus*).

coefficient was used to compare the agreement between the novel multi-variable BCS and the prior single-variable BCS method. The upper and lower standard deviations of weight:wing ratio within each BCS category (as determined by the multi-variable scale) were used to retrospectively assign cutoff values for each BCS class and each penguin was assigned to a "predicted BCS" based on its weight:wing ratio. This allowed comparison of the "predicted BCS" to both the multi-variable and single-variable scales using a Cohen's kappa coefficient. All 2013 analyses were repeated with juveniles excluded to account for any physiological differences that might confound the scoring system, such as possible differences in distribution of body fat between juveniles and adults.

RESULTS

In 2013, the weights and weight:wing ratios of penguins sampled were normally distributed ($P = 0.70$ and 0.88, respectively). Juveniles had a lower weight:wing ratio than adults ($\bar{x} = 0.27$ and 0.33, respectively; $P < 0.001$), although the 95%CI between the two groups are close to overlapping (Table 1). There is no difference between the BCS of juveniles and adults using the single-variable scale ($P = 0.70$), but the novel multi-variable BCS generally scores adults higher than juveniles ($P = 0.02$). Overall, males show higher weight:wing ratios than females ($\bar{x} = 0.33$ and 0.31 respectively; $P = 0.04$), although the overlapping 95% CI between sexes indicates that this difference may not be biologically significant (Table 1). Both BCS systems were tested for disproportionate BCS assignment based on gender. The multi-variable BCS shows a non-significant trend of assigning males higher BCS ($P = 0.06$). The single-variable BCS does not demonstrate a difference between the sexes (0.76) When comparing weight:wing ratio among age classes and sexes, the multi-variable BCS generally has a smaller 95%CI than the single-variable scale (Table 1). Both the multi-variable and single-variable BCS categorize all

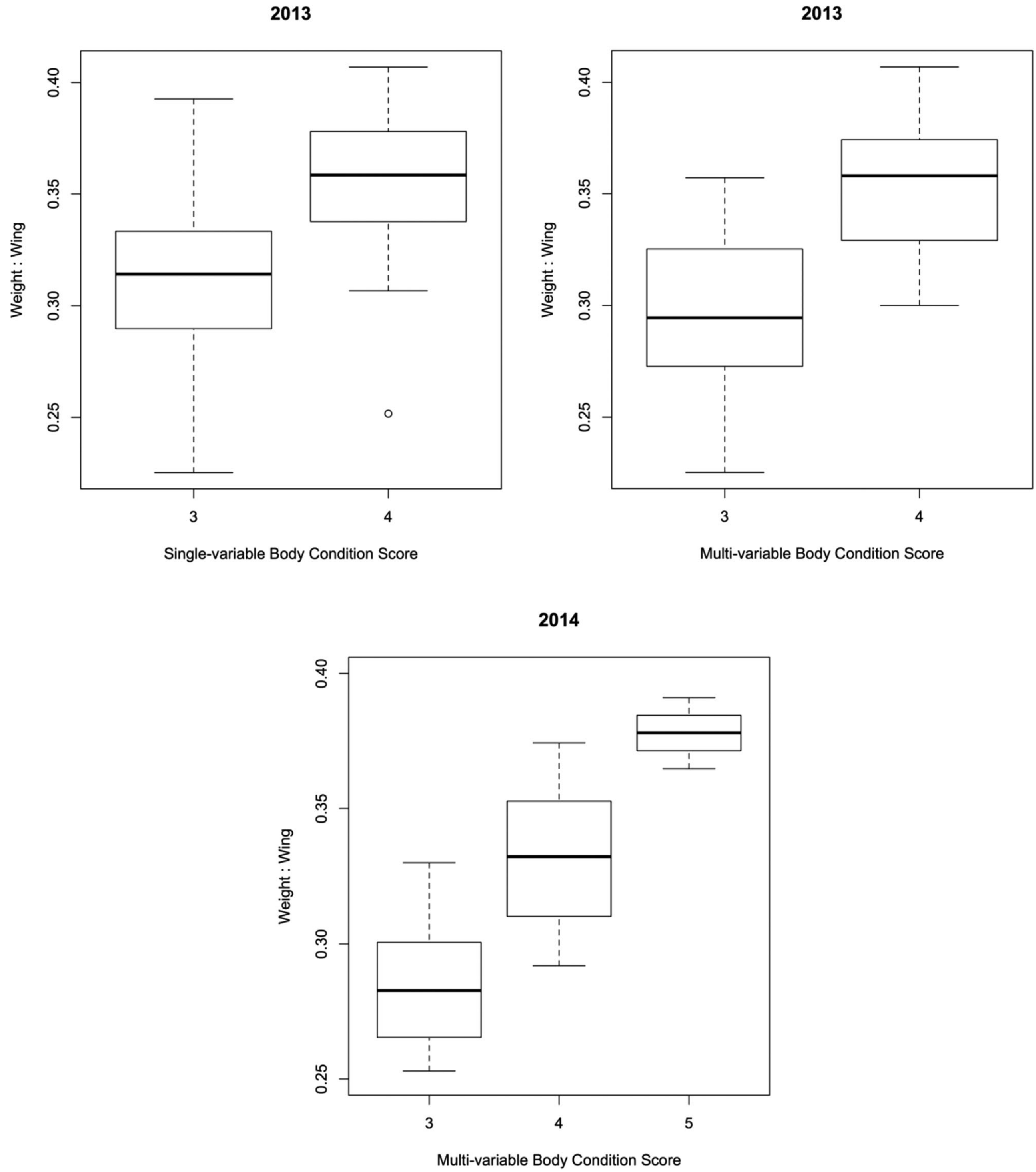

Fig. 3. Boxplot of Magellanic penguin (*Spheniscus Magellanicus*) body condition scores using single and multi-variable scales, 2013–2014.

penguins as BCS 3 or 4 and had fair agreement on the categorization of individuals ($K = 0.37$, $P = 0.007$). However, the multi-variable BCS score has better correlation with the predicted BCS score ($K = 0.50$, $P < 0.001$).

When juveniles (3 females, 3 males) are removed from analyses of the 2013 data, no difference is detected in the weight:wing between males and females ($\bar{x} = 0.34$ and 0.32 respectively; $P = 0.06$) and the 95%CI between sexes still overlaps (Table 1). Neither the multi-variable nor the single-variable BCS demonstrates a difference between the sexes ($P = 0.06$ and 0.92 respectively). When comparing weight:wing ratio between the sexes, the multi-variable BCS is generally a smaller 95%CI than the single-variable scale (Table 1). Both the multi-variable and single-variable BCS

TABLE 1. Ratio of body mass (kg) to ante brachium ("wing") length measurements (cm) (mean ± 95%CI) for different groups of Magellanic penguins (*Spheniscus magellanicus*) during February 2013 and February 2014 research period, San Francisco Zoo, California, USA. In 2013 analyses were performed including animals of all age groups ($n = 48$), and repeated with just adults ($n = 42$). In 2014 all animals sampled were in the adult age class ($n = 42$)

		Ratio of body mass to wing length (mean ± 95%CI)		
Variables	Groups	2013	2013	2014
	All penguins	0.298 ± 0.013	0.330 ± 0.012	0.319 ± 0.012
Sex	Females	0.308 ± 0.018	0.318 ± 0.016	0.300 ± 0.014
	Males	0.333 ± 0.018	0.340 ± 0.016	0.332 ± 0.016
Age	Adults	0.330 ± 0.012	0.330 ± 0.012	0.318 ± 0.012
	Juveniles	0.265 ± 0.028	N/A	N/A
Multi-variable body condition scale	BCS 3	0.298 ± 0.013	0.307 ± 0.013	0.284 ± 0.013
	BCS 4	0.353 ± 0.015	0.353 ± 0.015	0.333 ± 0.011
	BCS 5	N/A	N/A	0.378 ± 0.033
Single-variable body condition scale	BCS 3	0.312 ± 0.13	0.318 ± 0.012	N/A
	BCS 4	0.352 ± 0.026	0.360 ± 0.020	N/A

categorize all penguins as BCS 3 or 4 and show fair agreement on the categorization of individuals ($K = 0.38$, $P = 0.007$). However, the multi-variable BCS score shows better correlation with the predicted BCS score ($K = 0.43$, $P < 0.003$).

In the 2014 data set, the weights and weight:wing ratios of penguins sampled are normally distributed ($P = 0.15$ and 0.50, respectively). Similar to the 2013 data, males generally have larger weight:wing ratios than females ($\bar{x}$ = 0.33 and 0.30 respectively; $P = 0.004$), although the nearly overlapping 95%CI between sexes indicates that this difference may not be strongly biologically significant (Table 1). The multi-variable BCS did not score the sexes significantly differently ($P = 0.14$). The multi-variable BCS categorized all penguins as BCS 3, 4, or 5. The multi-variable BCS is again in moderate agreement with theoretical BCS score on the categorization of individuals, but the kappa score increased, reflecting greater agreement ($K = 0.56$, $P < 0.001$).

DISCUSSION

This novel, multi-variable scale shows overall agreement with the previously used single-variable scale but was more precise, with smaller confidence intervals, and better agreement with the "golden standard" of weight:wing ratio. Data from 2014 supports the trend observed in 2013, and even shows improved agreement between BCS and weight:wing ratio.

The inclusion of juveniles in the 2013 analyses did not result in significant changes in the multi-variable BCS test results, demonstrating that this scale can be utilized in growing penguins. However, it is noted that this population of penguins primarily consists of animals that are in ideal condition (BCS 3), or slightly over-conditioned (BCS 4). Only three of the 90 scores recorded are BCS 5. A narrow range of body condition scores is expected in a zoo population, but limits our ability to thoroughly test the multi-variable scale at the far extremes of body condition. However, we anticipate that very emaciated or obese Magellanics are easier to score and less subjective than scoring penguins that fall into the middle range where physical differences may be more subtle.

Some of the statistically significant relationships detected, such as greater weight:wing ratios in adults compared to juveniles in 2013 and males compared to females in 2014, may not reflect biological relevance. We found that adults and males had larger body masses relative to their skeletal structures, and therefore higher BCS scores. The differences detected are small but warrant further investigation before drawing conclusions.

Training in BCS categorization is important to reproduce accurate scores between and within assessors. Specific BCS training utilizing the tool we created for Magellanic penguins appears to reduce the variation seen in BCS scoring from 2013 to 2014. In 2013 two blinded observers, one trained and one untrained, demonstrated the need for a deeper understanding of body scoring this species. BCS by the untrained observer had lower agreement with weight:wing ratio (less accurate) and more overlap among groups (less precise). The trained observer utilizing the novel BCS system showed better agreement with the weight:wing ratio in 2013, increased accuracy from 2013 to 2014, and less overlap among BCS groups. Understanding the potential for observational bias is also necessary in the zoo setting. A tendency to "favorably" score may be a driving factor in variability for staff closely bonded with individuals in a zoo population. Using this novel, multi-variable BCS visual scale as a training tool may mitigate bias and improve accuracy of scoring in the zoo setting.

Observers should expect some overlap between BCS categories, as in the calculated predicted BCS scores. Individual animals have unique body proportions and fat distributions, which inherently means that there will be some animals whose weight:wing ratio falls between BCS categories. Which group they are assigned to will depend on the observer's assessment of fat distribution over the seven body landmarks described in this study.

Recent studies have shown that penguins may eat more than their energetic needs [Wilson et al., 2007; Sala et al., 2012]. The dominant theory is to feed penguin species ad libitum because they are self-regulating [Crissey et al., 2002]. As our knowledge and science evolve to better understand the metabolic requirements of Magellanic penguins in the zoo setting, a more complex feeding strategy taking into account the normal seasonal variation may be beneficial. It is possible that carefully monitored, moderate food restriction for individuals with high body condition scores may have positive short- and long-term health implications. A visual BCS is a quick and convenient method to determine nutritional health status and assess weight loss or gain. In the zoo setting, weighing every individual in a colony monthly is not always practical but the use of a BCS system as a tool for guidance and training staff may be an efficient way to monitor individuals and adjust food intake.

For some species, there is a body condition that is ideal to maintain year-round. For example, horses used for sport are generally maintained at a relatively static body condition throughout the year [Faerber, 2005]. For migratory species, fluctuating food availability drives adaptive feeding strategies. Many migratory bird species gain significant weight seasonally taking advantage of available food sources [Newton, 2008]. As described above, penguins spend part of the year offshore following the availability of prey and part of the year on land fasting. The variability of seasonal body condition in the Magellanic penguin is important to take into account when assessing health [Penguin TAG 2014]. The scale described in this study is predicated on the fact that a score of 2–5 is ideal at different points of the year for the Magellanic penguin.

This tool was created for use during any point of a Magellanic penguin's annual nutritional cycle (Fig. 4). Our study, however, was conducted during a single annual time-point. During the time of data collection, this Magellanic zoo colony was in one of its most conditioned states (just prior to mate selection and nesting). The only other time of year they are more conditioned is just prior to molt. The BCS data collected in this study reflects an over-conditioned state for this colony. Ideally we would recommend validating this chart through each of the nutritional stages for this species. It must be noted that during a year, it is possible that a healthy penguin may be categorized as a BCS 2 just after molt and a BCS 5 just prior to molt. These categorical assignments are not intended to be a sign of poor health in normal birds. It is therefore important that this chart be used in the context of each colony's seasonal weight change. For this study, taking multiple weight measurements throughout the year was not feasible at the time due to colony accessibility and management constraints. Ideally, each point of the year could be validated with the same methods used during the winter-foraging period.

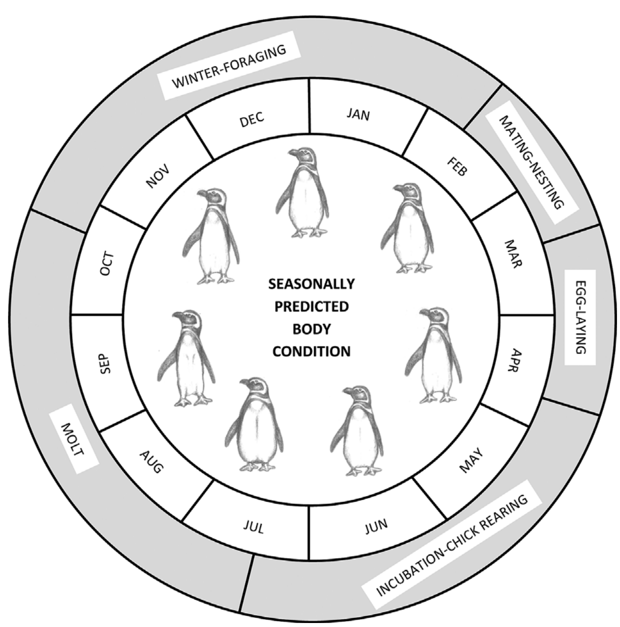

Fig. 4. Theoretical seasonally predicted body condition score for the San Francisco Zoo Magellanic penguin colony (*Spheniscus magellanicus*). Expected average BCS during winter-foraging through chick rearing is 3–4, prior to molt 4–5, and post molt 2–3. This illustration offers an alternative chart format combining season, natural behavior, and theoretical body condition score. Based on the percentage of San Francisco Zoo Magellanic penguins fasting per day from 2008–2012 through egg laying, chick hatching, and molting. The extended molt period here represents this colony's range of molting with the youngest individuals starting late July and ending with the last adults in October.

CONCLUSIONS

Over the course of two seasons, our study showed improvement in accuracy and precision with the use of a multi-variable body condition scoring system primarily based on visual assessment. The use of a multi-variable illustrated guide is a novel approach for this species. The body condition chart has proved useful as a training tool for new assessors and as a refresher for experienced staff. This study specifically targeted body condition in the Magellanic penguin during the well-conditioned winter season. Further study of body condition at each major seasonal weight change is ideal. Future research should inform how each BCS category defines health risks and benefits.

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REFERENCES

AZA Taxon Advisory Group. 2014. Penguin (*Spheniscidae*) Care Manual. Silver Spring, MD: Associations of Zoos and Aquariums. pp 30-31.

Bavelaar FJ, Beynen AC. 2011. Atherosclerosis in parrots. A review. Vet Q 26:50–60. doi: 10.1080/01652176/2004/9695168.

Boersma PD, Stokes D, Yorio P. 1990. Reproductive variability and historical changes of Magellanic Penguins (*Spheniscus magellanicus*) at Punta Tombo, Argentina. In: Davis L S, editor. Penguin biology. San Diego: Academic Press. pp 15–43.

Borboroglu PG, Boersma PD. 2013. Penguins: Natural history and conservation. University of Washington Press.

Burkholder WJ. 2000. Use of body condition scores in clinical assessment of the provision of optimal nutrition. J Am Vet Med Assoc 217:650–653.

Cooper J. 1978. Moult of the black-footed penguin Spheniscus demerus. Int Zoo Yearbook 18:22–27.

Crissey S, Slifka K, McGill P. 2001. 2002. Penguins: Nutrition and dietary husbandry. Nutrition advisory group handbook fact sheet 012. pp 3.

Davis LS, Darby JT, Groscalos R. 1990. Penguin Biology: Metabolic adaptations to fasting. p 275–282.

Dawson C, Vincent JFV, Jeronimidis G, Rice G, Forshaw P. 1999. Heat transfer through penguin feathers. J Theor Biol 199:291–295.

Erlacher-Reid C, Dunn JL, Macha L, Mazzaro L, Tuttle AD. 2011. Evaluation of potential variables contributing to the development and duration of plantar lesions in a population of aquarium-maintained African penguins (*Spheniscus demersus*). Zoo Biol 10:1002.

Fahlmann A, Halsey LG, Butler PJ, et al. 2005. Accounting for body condition improves allometric estimates of resting metabolic rates in fasting king penguins, *APtenodytes patagonicus*. Polar Biol (2006) 29:609–614.

Faerber C. 2005. Equine medicine and management. 7th edition. Animal health publications. pp 3.

Fowler GS, Wingfield JC, Boersma PD, Sosa RA. 1994. Reproductive endocrinology and weight change in relation to reproductive success in the magellanic penguin (*Spheniscus magellanicus*). Gen Comp Endocrinol 94:305–315.

Fowler ME, Cubas ZS. 2001. Biology, Medicine, and Surgery of South American wild animals. Wiley. pp 60.

Gandini P, Frere E, Boersma PD. 1996. Status and conservation of Magellanic penguins Spheniscus Magellanicus in Patagonia, Argentina. Bird Conserv Int 6:307–316.

Gregory NG, Robins JK. 1998. A body condition scoring system for layer hens. N Z J Ag Res 41:555–559.

Hood LC, Doersma DP, Wingfield JC. 1998. The Adrenocortical response to stress in incubating Magellanic penguins (*Spheniscus Magellanicus*). The Auk 115:76–84.

Hickman DL, Swan M. 2010. Use of body condition score technique to assess health tatus in a rat model of polycystic kidney disease. J Am Assoc Lab Anim Sci 49:155–159.

The IUCN Red List of *Threatened Species* Version. 2015. 2. http://www.iucnredlist.org.

Kaiser A. 1992. A new multi-category classification of subcutaneous fat deposits of songbirds. J Field Ornithol 64:l246–l255.

Khan MM, Kraemer A. 2009. Factors associated with being underweight, overweight and obese among ever-married non-pregnant urban women in Bangladesh. Singapore Med J 50:804–813.

Miller ER, Murray EF, Wallace RS. 2015. Fowlers's zoo and wild animal medicine: Sphenisciformes (Penguins). Elsevier Saunders 8 pp. 82–87.

Moreno J, Yorio P, Garcis-Borboroglu P, Villar S. 2002. Health state and reproductive output in Magellanic penguins (*Spheniscus magellanicus*). Ethol Ecol Evol 14:19–28.

Morfeld KA, Lehnhardt J, Alligood C, Bolling J, Brown JL. 2014. Development of a body condition scoring index for female African elephants validated by ultrasound measurements of subcutaneous fat. PLoS ONE 9: e93802.doc: 10.1371/journal.pone. 0093802.

Newton Ian. 2008. The Migration Ecology of Birds. Elsevier. pp 787–793.

Olsen GH, Orosz SE. 2000. Manual of Avian medicine: Diagnostic workup plan. Mosby Inc. p 7.

Peig J, Green A. 2009. New perspectives for estimating body condition from mass/length data: The scaled mass index as an alternative method. Oikos 118:1883–1891.

Sala JE, Wilson RP, Quintana F. 2012. How much is too much? Assessment of prey consumption by Magellanic penguins in Patagonian colonies. PLoS ONE 7:e51487. doi: 10.1371/journal.pone:7

Scolaro JA, Wilson RP, Laurenti S, et al. 1999. Feeding preferences of the Magellanic penguin over its breeding range in Argentina. Waterbirds: Int J Waterbird Biol 22:104–110.

Stringer EM, Stoskopf MK, Simons T, O'Connell A, Walstein A. 2010. Ultrasonic measurement of body fat as a means of assessing body condition in free-ranging raccoons *(Procyon lotor)*. Int J Zool doi: 10.1155/2010/972380

Tully TN, Jr., Dorrestein GM, Jones AK. 2009. Handbook of Avian Medicine. 2nd Edition. Edinburgh: Saunders Elsevier. pp 384.

Viblanc VA, Bize P, Criscuolo F, et al. 2012. Body girth as an alternative to body mass for establishing condition indexes in field studies: A validation in the king penguin. Physiol Biochem Zool 85:533–542.

Videan EN, Fritz J, Murphy J. 2007. Development of guidelines for assessing obesity in captive chimpanzees *(Pan troglodytes)*. Zoo Biol 2:93–104.

Vleck CM, Bucher TL, Reed WL, Kristmundsdottir AY. 1999. Changes in reproductive hormones and body mass through the reproductive cycle in the Adelie penguin Pygoscelis adeliae, with associated data on courting-only individuals. BirdLife South Africa. Proc: International Ornithology congress, Johannesburg 22: 1210–1223.

Wallace R, Walsh M. 2005. Penguin Taxon Advisory Group: Penguin Husbandry Manual Third Edition. AZA 6:87.

Wilson RW, Jackson S, Thor Straten M. 2007. Rates of food consumption in free-living Magellanic penguins *Spheniscus Magellanicus*. Marin Ornithol 35:109–111.

Yorio P, Boersma PD. 1994. Causes of nest desertion during incubation in the Magellanic penguin *(Spheniscus magellanicus)*. Condor 96:1076–1083.

Yorio P, Borboruglu G, Potti J, Moreno J. 2001. Breeeding biology of Magellanic penguins *Sphenisucs magellanicus* at Golfo San Jorge, Patagonia, Argentina. Marine Ornithol 29:75–79.

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