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Morphometric Body Condition Indices of Wild Florida Manatees (*Trichechus manatus latirostris*)

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Abstract

In many species, body weight (W) increases geometrically with body length (L), so W/L^3 provides a body condition index (BCI) that can be used to evaluate nutritional status once a normal range has been established. No such index has been established for Florida manatees (*Trichechus manatus latirostris*). This study was designed to determine a normal range of BCIs of Florida manatees by comparing W in kg with straight total length (SL), curvilinear total length (CL), and umbilical girth (UG) in m for 146 wild manatees measured during winter health assessments at three Florida locations. Small calves to large adults of SL from 1.47 to 3.23 m and W from 77 to 751 kg were compared. BCIs were significantly greater in adult females than in adult males ($p < 0.05$). W scaled proportionally to L^3 in females but not in males, which were slimmer than females. The logarithms of W and of each linear measurement were regressed to develop amended indices that allow for sex differences. The regression slope for log W against log SL was 2.915 in females and 2.578 in males; $W/SL^{2.915}$ ranged from 18.9 to 29.6 (mean 23.2) in females and from 24.6 to 37.3 (mean 29.8) in males. Some BCIs were slightly (4%), but significantly ($p \leq 0.05$), higher for females in Crystal River than in Tampa Bay or Indian River, but there was no evidence of geographic variation in condition among males. These normal ranges should help evaluate the nutritional status of both wild and rehabilitating captive manatees.

Key Words: body condition, morphometrics, nutrition, allometry, Florida manatee, *Trichechus manatus latirostris*

Introduction

The Florida manatee (*Trichechus manatus latirostris*) is an endangered species that is susceptible to both anthropogenic and natural causes of injury, disease, and death. Among wild manatees, the inability to ingest sufficient food can result in weight loss, metabolic compromise, illness, and death. Injured and sick manatees are rescued and transported to oceanaria where they receive care until they are deemed ready for release back into their natural habitat by the Manatee Rescue/Rehabilitation Partnership (MRP), a cooperative group of more than two dozen private entities and governmental agencies that pool resources to rehabilitate injured manatees and then monitor their success after release (http://public.wildtracks.org/about). Manatees may be underweight when first brought to these facilities, but they can become overweight over time because they are less active in enclosures than in the wild and are fed a diet comprised mainly of romaine lettuce, other vegetables, and fruits. Such a diet provides more readily available energy because it contains more soluble sugars and less plant fiber than the natural diet (Siegal-Willott et al., 2010). This excess energy intake sometimes leads to obesity or other health-related problems in manatees held in captivity for long periods of time (Smith et al., 2015). Additionally, there is the potential for more dominant manatees housed in groups to consume a disproportionate amount of the available food and become overfed at the expense of subordinate individuals. Currently, there is no method of assessing whether rehabilitating or long-term captive manatees are over- or underweight when compared to conspecifics in the wild because the relationship between body weight and length has not been established for Florida manatees.

One method of objectively assessing nutritional status is to compare morphometric measurements such as length (L) or height (H) with body weight (W) in healthy populations of a species to obtain a normal range of body condition index (BCI) values (Muchlisin et al., 2010). The relationship between W and L is typically represented by Equation 1, where K represents the proportionality constant and b represents the allometric exponent (Biswas et al., 2011):

$$W = K \times L^b \qquad \text{(Equation 1)}$$

Rearranging Equation 1, the proportionality constant, K, obtained by dividing W by L^b, can be used as a BCI that is independent of size. Assuming that animals maintain geometric similarity irrespective of size, their volume should be proportional to L^3; and if density remains constant, then b should approximate 3. For example, in fish, Fulton's condition factor, K in Equation 2, has been well established as a measure of the nutritional status of fish (Anderson & Neumann, 1996; Stevenson & Woods, 2006; Biswas et al., 2011):

$$K = W/L^3 \qquad \text{(Equation 2)}$$

Fulton's condition factor has been used to compare body condition during different physiological time periods, such as spawning and growth, in several species of fish (Godinho, 1997; Yildirim et al., 2008; Iqbal & Suzuki, 2009; Percin & Akyol, 2009; Muchlisin et al., 2010; Biswas et al., 2011). This index assumes that animals maintain a similar geometric shape and density as size increases, but the mean allometric exponent in fish and mammals sometimes differs from the cubic value in different ecological circumstances and may differ among sexes at different reproductive stages (Silva, 1998; Offem et al., 2008). For example, in human beings, the body mass index (BMI) used to assess the degree of obesity relative to H does not assume geometric similarity but instead uses an exponent of 2 (Keys et al., 2014):

$$BMI = W/H^2 \qquad \text{(Equation 3)}$$

Alternative BCIs can also be developed that take account of differences in girth (G). For example, mass may be related to G and L, assuming body shape approximates an ellipsoid with a volume proportional to L multiplied by the square of maximum G (Castellini & Calkins, 1993; Amaral et al., 2010). The proportionality constant, K, from that relationship provides a BCI (Equation 4) independent of size in which the exponent *b* would be expected to approximate 2 if animals are geometrically similar and uniformly dense:

$$K = W/(G^b \times L) \qquad \text{(Equation 4)}$$

G should also increase in proportion to L, so the proportionality constant, K, from the relationship of G to L should represent another potential BCI (Equation 5) in which the exponent *b* should approximate 1 assuming geometric similarity:

$$K = G/L^b \qquad \text{(Equation 5)}$$

L-W relationships have been evaluated in other aquatic animal species, including other marine mammals (Ridgway & Fenner, 1982; McBain, 2001; Perrin et al., 2005; Hart et al., 2013), but there have been only a few studies of sirenians to date (Spain & Heinsohn, 1975; Lanyon et al., 2010). Age-specific growth curves and L-W relationships have been determined for the Amazonian manatee (*Trichechus inunguis*) (Amaral et al., 2010; Vergara-Parente et al., 2010). Although the relationship between L and age has been modeled for the Florida manatee (Schwarz & Runge 2009), only a preliminary L-W relationship has been reported based on salvaged carcasses (Odell et al., 1978). Blubber measurements have also been used in conjunction with L and W measurements to develop BCIs for Florida manatees (Ward-Geiger, 1997), but obtaining blubber measurements is not always possible. To date, the relationship between L and W has not been used to establish a BCI for live, healthy, wild Florida manatees.

The purpose of this study was to compare L, W, and G measurements of wild manatees in order to define a normal range of body conditions for the Florida manatee. This study also sought to determine whether BCIs change as manatees increase in size and whether there are any differences between sexes or among geographic areas.

Methods

Measurements were obtained from wild manatees of all age classes and both sexes during winter health assessments at three sites in Florida: (1) Apollo Beach, Tampa Bay (27.7935° N, 82.4187° W) during December and January from 2002 through 2006, led by the Florida Fish and Wildlife Conservation Commission (FWC); (2) Kings Bay, Crystal River (28.8911° N, 82.5972° W) during January, February, October, and December from 2007 through 2011, led by the U.S. Geological Survey (USGS) Sirenia Project; and (3) the northern Indian River near Port St. John, Brevard County (28.4833° N, 80.7666° W) during December of 2009-2010, co-led by

FWC and USGS. All lengths were measured in cm using an open reel tape measure. Straight length (SL) and curvilinear length (CL) were measured over the entire length of the animal, from the tip of the snout to the end of the tail paddle, and umbilical girth (UG) as the circumference at the umbilicus. The tape measure was laid flat over the animal for CL, whereas it was held straight at the level of the back to determine SL, with the middle of the tape measure lying flat on the animal's dorsal surface. Body weight (W) was measured in lbs using a hanging scale (Crystal River: Model EDjunior, Dillon 2,500 lbs/1,000 kg, Data Weighing Systems, Inc., Elk Grove, IL, USA; Indian River and Tampa Bay: Model MSI-7200, Dyna-link 2,000 lbs/1,000 kg, Measurement Systems International Inc., Seattle, WA, USA) and converted to kg. The responsible veterinarian or biologist scored the body condition of the animal using a qualitative scale of 1 to 5, with a score of 1 representing an emaciated animal and 5 representing an obese animal. Manatees were also assigned an overall qualitative descriptor of apparent health ranging from poor to excellent. Manatees were only included in the analysis if they had a visual condition score of 2 to 4, representing normal to fat conditions, and a qualitative descriptor of fair, good, or excellent. Manatees with abnormal health parameters or that were visually determined to be in late-term pregnancy were excluded from analyses.

Analyses were conducted on L or G in m and W in kg. Statistical comparisons and linear regressions were performed using *SAS® for Windows®*, Version 9.3 (SAS Institute, Inc., Cary, NC, USA). Data distributions were first assessed for normality both visually and using the Shapiro-Wilk test. Any datasets that were not normally distributed were log-transformed before analysis. Four different indices were considered as potential objective measures of body condition:

$$K_{SL} = W/SL^3 \quad \text{(Equation 6)}$$

$$K_{CL} = W/CL^3 \quad \text{(Equation 7)}$$

$$K_{SL*UG} = W/(SL \times UG^2) \quad \text{(Equation 8)}$$

$$K_{UG} = UG/SL \quad \text{(Equation 9)}$$

Indices were compared using a general linear model procedure with sex and location as factors, and an interaction between the two was also considered. *Post hoc* contrasts were evaluated to compare means between locations.

To establish whether these BCIs change with size, K_{SL}, K_{SL*UG}, and K_{UG} were regressed against SL, and K_{CL} was regressed against CL, separately for each sex. In addition, the logarithm of W was regressed against the logarithms of SL and CL to establish exponents for amended BCIs that would accommodate changes in body density and shape with changes in size. The logarithm of W/SL was regressed against the logarithm of UG to the same end. An ANCOVA was used to compare the slopes of these regression lines between sexes. The logarithm of UG was also regressed against the logarithm of SL, and the slopes were compared between sexes using an ANCOVA to determine whether males were more streamlined than females.

Also, amended sex-specific indices of body condition using the new exponents were compared among the different locations using a general linear model procedure. A probability of error ≤ 5% was considered significant when rejecting the null hypothesis.

Results

Measurements were obtained from 146 manatees: 33 females and 23 males from Tampa Bay (TB); 22 females and 48 males from Crystal River (CR); and 8 females and 12 males from the northern Indian River (IR). SLs of these manatees ranged from 1.47 to 3.23 m, and CLs ranged from 1.62 to 3.49 m; this sample encompassed small calves to large adults. UGs of individuals ranged from 1.13 to 2.53 m, and Ws ranged from 77 to 751 kg. Only one manatee was excluded from the analyses for being in late-term pregnancy; none were excluded due to abnormal condition or health. There was no evidence of a difference in SL between sexes or among locations, or of an interaction between sex and location ($p = 0.3$).

All four initial BCIs (K_{SL}, K_{CL}, K_{SL*UG}, and K_{UG}) were significantly greater in females than males ($p \leq 0.05$) (Table 1). There was no evidence of a significant difference among locations ($p = 0.055$, 0.19, and 0.088, for the first three BCIs, respectively), but K_{UG} was significantly different among locations, with manatees at CR having a higher mean K_{UG} (0.75) than manatees at IR (0.73) or TB (0.74) ($p \leq 0.004$). There was no evidence of an interaction between sex and location ($p \geq 0.3$). There was no evidence of a change in either K_{SL}, K_{CL}, or K_{UG} with L in females ($p \geq 0.2$), but K_{SL}, K_{CL}, and K_{UG} decreased significantly ($p < 0.0001$) with increasing L in males ($r^2 = 0.38$, 0.31, and 0.22, respectively; illustrated for K_{SL} in Figures 1 & 2). Males of different sizes were not geometrically similar, therefore, and using L^3 in the BCI provided a poor fit. The BCI K_{SL*UG} decreased slightly but significantly with increasing L in both females ($r^2 = 0.17$, $p = 0.0007$) and males ($r^2 = 0.10$, $p = 0.004$), making it unsuitable as an index of condition, which ideally needs to be independent of L.

The increase in W with L was significantly greater in females than in males for both SL and CL ($p = 0.0004$ and $p = 0.0006$, respectively; Table 2). Consequently, adult females were heavier than adult males of the same L. Thus, for example, the relationship between untransformed W and SL for the two sexes (Figure 3) is best represented by the following equations:

$$W_{female} = 23.10 \times SL^{2.915} \quad \text{(Equation 10)}$$

$$W_{male} = 29.73 \times SL^{2.578} \quad \text{(Equation 11)}$$

The regression slopes for the log-transformed values for W against SL and CL were not significantly different from 3 for females but were significantly less than 3 for males ($p < 0.05$; Table 2). There was no evidence of a difference between sexes in the slopes of the regressions for the logarithm of W/SL against the logarithm of UG ($p = 0.7$), and the slopes were significantly less than 2 in both sexes (Table 2). The UG increased less with SL in males than it did in females ($p < 0.0005$; Figure 4), and the regression slope for the logarithm of UG against the logarithm of SL was

Table 1. Body condition indices (BCIs) for wild Florida manatees (*Trichechus manatus latirostris*) of each sex

	Females			Males			
	Mean	SD	Range	Mean	SD	Range	*p* value
$K_{SL} = W/SL^3$	21.4	2.2	17.1 - 27.1	19.9	2.2	16.0 - 29.0	0.0007
$K_{CL} = W/CL^3$	17.2	1.3	14.2 - 20.1	16.4	1.4	13.8 - 21.9	0.004
$K_{SL*UG} = W/(SL \times UG^2)$	38.1	2.9	31.9 - 55.0	36.4	1.9	31.0 - 42.6	0.009
$K_{UG} = UG/SL$	0.75	0.04	0.67 - 0.88	0.74	0.04	0.66 - 0.89	0.045

K_{SL}, K_{CL}, and K_{SL*UG} represent the ratio in kg/m^3 of body weight (W) to the cube of straight length (SL^3), cube of curvilinear length (CL^3), and SL times the square of the umbilical girth (UG^2), respectively. BCIs were all higher in females than males (*p* values are shown). Values are for all locations combined. There was no evidence of a significant difference among locations ($p > 0.05$) for K_{SL}, K_{CL}, or K_{SL*UG}, but K_{UG} differed significantly ($p = 0.003$) among manatees from Crystal River, Indian River, and Tampa Bay (K_{UG} means were 0.75, 0.73, and 0.74 for those locations, respectively).

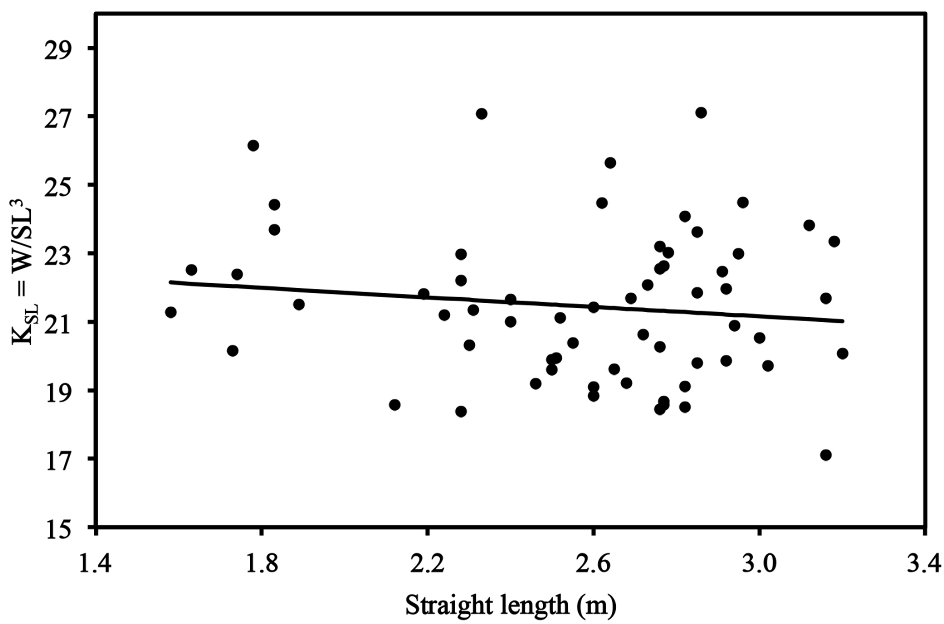

Figure 1. Regression of body condition index (BCI) K_{SL} (W/SL^3) against straight length (SL) for female manatees (*Trichechus manatus latirostris*) (of weight [W]) at all locations; there was no evidence that the index changes with SL ($p = 0.31$), suggesting that it is a suitable BCI for females of all lengths.

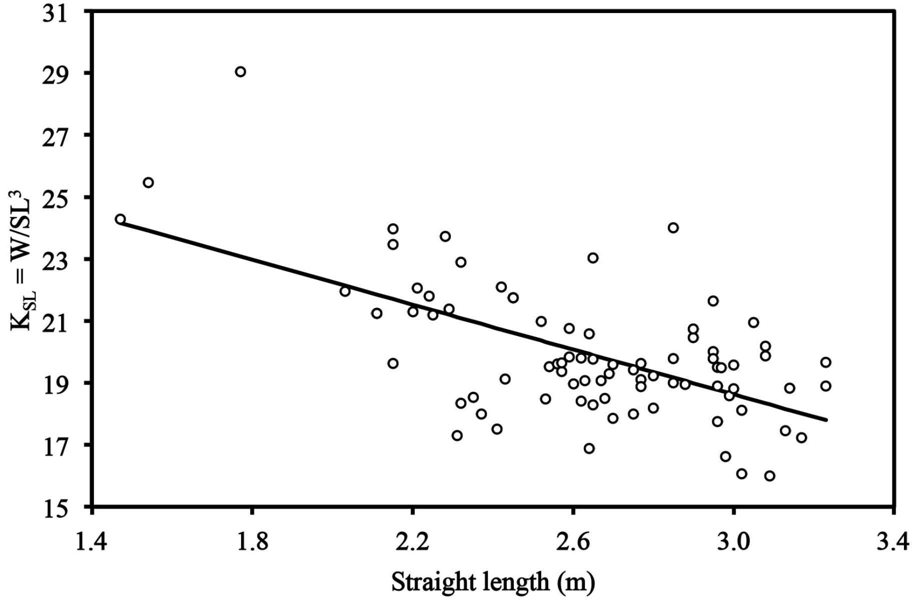

Figure 2. Regression of BCI K_{SL} (W/SL^3) against SL for male manatees (of weight [W]) at all locations; the index decreases with SL ($p < 0.0001$), suggesting that it is not a suitable BCI for males of all lengths.

Table 2. Intercepts and slopes of regression lines of the $logarithm_{10}$ of body weight or umbilical girth against $logarithm_{10}$ of morphometric measurement of wild Florida manatees of each sex

	Females				Males			
Measurement (y axis)	W	W	W/SL	UG	W	W	W/SL	UG
Measurement (x axis)	SL	CL	UG	SL	SL	CL	UG	SL
Intercept of $\log_{10}$ W	1.364	1.254	1.632	-0.144	1.473	1.352	1.608	-0.067
Antilog of intercept	23.10	17.93	42.82	0.718	29.73	22.48	50.55	0.857
Slope	2.915	2.957	1.815	1.045	2.578	2.689	1.835	0.844
Lower CI of slope	2.768	2.845	1.734	0.971	2.460	2.587	1.760	0.780
Upper CI of slope	3.063	3.070	1.896	1.120	2.696	2.792	1.910	0.908
r^2	0.96	0.98	0.97	0.93	0.96	0.97	0.97	0.89

The measurements SL, CL, and UG are the straight length, curvilinear length, and umbilical girth of manatees, respectively, in m and W is the body weight in kg. Intercept and slope refer to the equation of the regression line for each of the measurements with $\log_{10}$ measurement on the x axis and $\log_{10}$ measurement on the y axis. Intercept is the value of $\log_{10}$ measurement on the y axis when $\log_{10}$ measurement on the x axis is 0. Lower and upper CIs represent the 95% confidence intervals for each slope. Slopes are significantly different from 3, 2, or 1 where the CIs of the slope do not encompass 3, 2, or 1, respectively. As an example, the equation of the regression line for W vs SL for females would be $\log_{10} W = 1.364 + 2.915 \times \log_{10} SL$ or $W = 23.1 \times SL^{2.915}$.

significantly less than 1 in males but not females ($p < 0.05$; Table 2).

The regression slopes were used to generate amended sex-specific BCIs: $K_{SLf} = W/SL^{2.915}$, $K_{CLf} = W/CL^{2.957}$, $K_{SL*UGf} = W/(SL \times UG^{1.815})$, and $K_{UGf} = UG/SL^{1.045}$ for females; and $K_{SLm} = W/SL^{2.578}$, $K_{CLm} = W/CL^{2.689}$, $K_{SL*UGm} = W/(SL \times UG^{1.835})$, and $K_{UGm} = UG/SL^{0.844}$ for males (Table 3). The indices K_{SLf} and K_{UGf} were slightly, but significantly, different among locations ($p \leq 0.05$), with values for CR females being slightly higher than IR ($p \leq 0.03$) and TB ($p \leq 0.05$; Table 3) females for both K_{SLf}

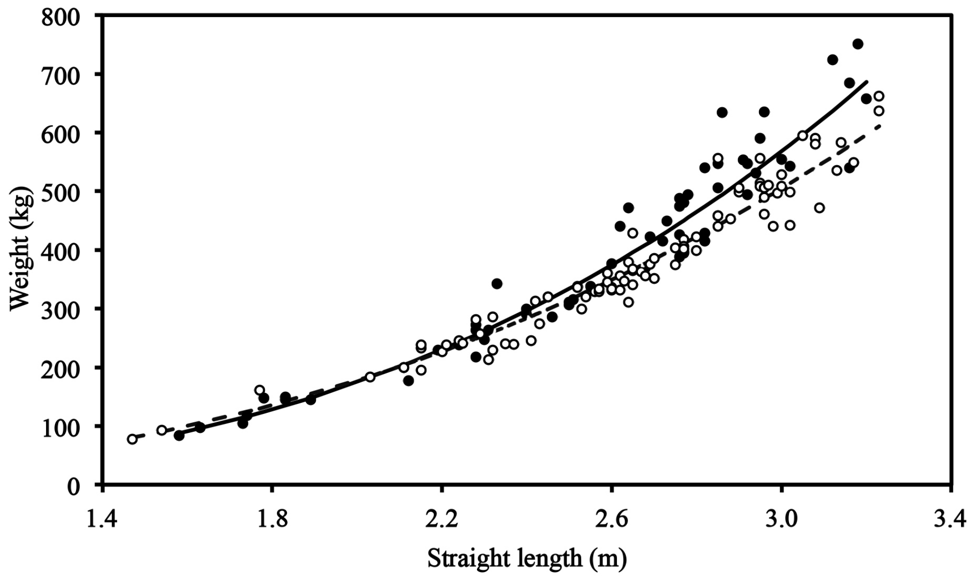

Figure 3. Plot of manatee W against SL showing regression lines obtained from log-transformed data for females (solid circles, solid line) and males (open circles, dashed line). The regression line for females is $W = 23.10 \times SL^{2.915}$, and the regression line for males is $W = 29.73 \times SL^{2.578}$. The increase in W with SL was significantly greater in females than in males ($p < 0.001$).

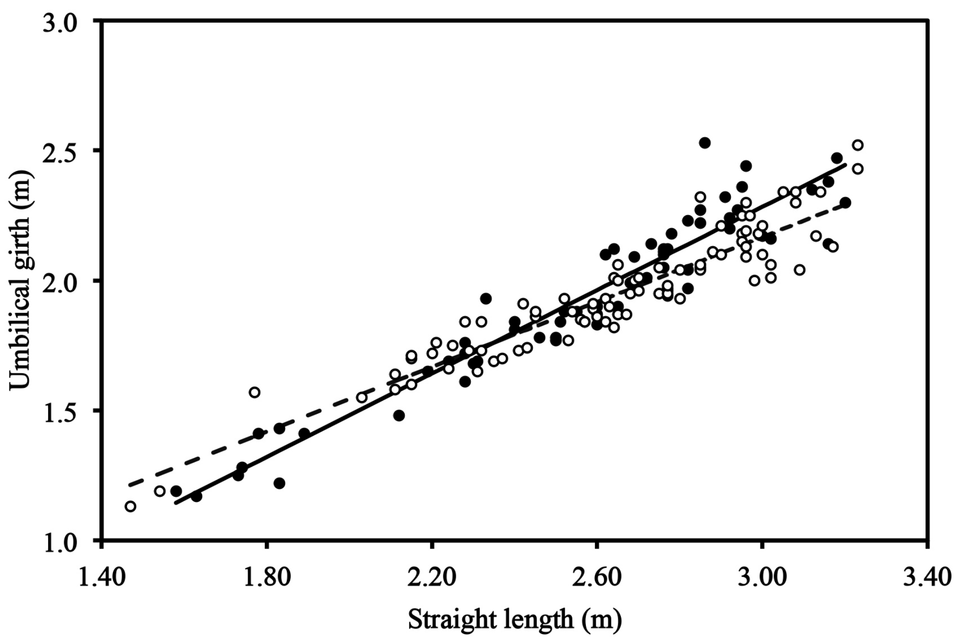

Figure 4. Regression of umbilical girth (UG) against SL for females (solid circles) and males (open circles); slope for females (solid line) was significantly greater than that for males (dashed line; $p < 0.001$). Regression equation for females: $UG = 0.782 \times SL - 0.078$, $R^2 = 0.91$. Regression equation for males: $UG = 0.634 \times SL + 0.271$, $R^2 = 0.86$.

Table 3. Amended BCIs of wild manatees of different sexes at three locations in Florida

Index	Location	Mean	SD	Range	CV (%)
Females					
$K_{SLf} = W/SL^{2.915}$	CR	24.2	2.6	19.7 - 29.6	10.8
	IR	22.1	2.5	20.2 - 26.5	11.5
	TB	22.9	2.0	18.9 - 27.8	8.7
	All	23.2	2.4	18.9 - 29.6	10.2
$K_{CLf} = W/CL^{2.957}$	All	18.0	1.4	15.0 - 21.2	7.6
$K_{SL*UGf} = W/(SL \times UG^{1.815})$	All	42.9	2.7	36.6 - 57.0	6.3
$K_{UGf} = UG/SL^{1.045}$	CR	0.74	0.04	0.68 - 0.84	5.2
	IR	0.71	0.03	0.67 - 0.77	4.9
	TB	0.71	0.03	0.64 - 0.77	4.4
	All	0.72	0.04	0.64 - 0.84	5.1
Males					
$K_{SLm} = W/SL^{2.578}$	All	29.8	2.4	24.6 - 37.3	8.1
$K_{CLm} = W/CL^{2.689}$	All	22.5	1.5	18.3 - 26.5	6.8
$K_{SL*UGm} = W/(SL \times UG^{1.835})$	All	40.6	1.8	36.1 - 44.7	4.5
$K_{UGm} = UG/SL^{0.844}$	All	0.86	0.04	0.79 - 0.97	4.4

Amended BCIs are ratios of body weight (W) to either straight length (SL), curvilinear length (CL), or SL multiplied by umbilical girth (UG), using amended exponents for each sex (from Table 2). Values are shown for means, standard deviation, minimum and maximum, and coefficient of variation (CV). Mean BCIs using SL and CL for female manatees at Crystal River (CR) were higher ($p < 0.05$) than for females at Indian River (IR) and tended to be higher ($p = 0.05$) than females in Tampa Bay (TB). The values for all three locations for other indices are combined because there was no evidence of a significant difference among locations.

and K_{UGf}. No other significant differences were evident among locations.

Discussion

Morphometric data from wild, healthy Florida manatees during winter were used to establish normal ranges of BCIs for both sexes at three different locations in Florida. These indices can be used to help evaluate the nutritional status of rescued, rehabilitating, and long-term captive manatees. They also provide a valuable baseline which can be used in the future to assess changes in condition associated with an increasing manatee population or altered ecological conditions.

Sex Differences in Body Condition

Separate BCIs had to be developed for each sex because W and G increased more rapidly with L in females than in males. In contrast to most mammals, where males tend to be larger than females (Lindenfors et al., 2007), female Florida manatees were on average heavier than male manatees at Ls over 2.1 m (the point at which the regression lines crossed; Figure 3). The difference in W between the sexes increased exponentially with increasing L, becoming substantial among adults (i.e., > 2.65 m SL). For example, a medium-sized adult female with an SL of 3.0 m weighs, on average, 12.5% more than an adult male of the same SL (Figure 3). This is consistent with the report by Bonde et al. (2012) for manatees at Crystal River, which also reported data from the CR animals used in this paper. In contrast, no sex difference in the relationship between W and L was detected for wild dugongs in Australia (Spain & Heinsohn, 1975; Lanyon et al., 2010).

In the wild, adult male Florida manatees have thinner blubber layers than females (Ward-Geiger, 1997); they are more active than females for most of the year (Deutsch et al., 2003), and their more streamlined shape may be beneficial in chasing estrous females and outcompeting other males for a chance to mate (Bonnet et al., 2010). Adult females, on the other hand, spend more time foraging than males (Flora, 2012) and may benefit from being heavier relative to length because they need larger body stores to support gestation and lactation (Silva, 1998).

High progesterone concentrations in three females in our TB dataset suggest that they were pregnant (Tripp et al., 2008). It is likely that some other females in our dataset were also in the early to middle stages of pregnancy. Pregnant adult female manatees have the thickest backfat layers of any age, sex, or reproductive class (Ward-Geiger, 1997), and this contributes to larger Gs and heavier Ws among mature females. It is possible, therefore, that pregnancy may explain some of the differences between the sexes.

Table 4. Distributions of BCIs for wild manatees derived from morphometric measurements

BCI	Minimum	5%	10%	25%	Median	75%	90%	95%	Maximum
Females									
$K_{SL} = W/SL^3$	17.1	18.5	18.7	19.8	21.3	23.0	24.4	25.6	27.1
$K_{SLf} = W/SL^{2.915}$	18.9	20.1	20.4	21.5	22.9	24.7	26.3	27.5	29.6
$K_{UG} = UG/SL$	0.67	0.70	0.71	0.72	0.75	0.78	0.80	0.80	0.88
$K_{UGf} = UG/SL^{1.045}$	0.64	0.67	0.68	0.69	0.72	0.74	0.76	0.77	0.84
Males									
$K_{SLm} = W/SL^{2.578}$	24.6	25.7	26.6	28.2	29.7	31.0	32.5	33.6	37.3
$K_{UGm} = UG/SL^{0.884}$	0.79	0.80	0.81	0.83	0.85	0.88	0.90	0.92	0.97

BCIs are ratios of body weight (W) or umbilical girth (UG) to straight length (SL) raised to the appropriate exponent.

Allometric Scaling

Body weight increases geometrically in proportion to the L^3 in most mammals, including other aquatic or semi-aquatic mammals (Cetacea and Pinnipedia; e.g., Haley et al., 1991), and it increases more rapidly than the L^3 in some larger terrestrial mammals (Silva, 1998). Only the Myrmecophagidae and Canidae display a similar allometry to that of male manatees (Silva, 1998) in which W increases *less* rapidly than the L^3.

The Amazonian manatee is the smallest of the extant sirenian species. The L (m)-W (kg) relationship for the Amazonian manatee (both sexes combined) is represented by the following equation (Amaral et al., 2010):

$$W = 18.77 \times SL^{3.122} \qquad \text{(Equation 12)}$$

The exponent, 3.122, is significantly higher ($p <$ 0.05) than that for both female and male Florida manatees in the study presented herein, but most of the Amazonian manatee data were obtained from healthy individuals in captivity. The diet offered to captive Amazonian manatees is similar to that for captive Florida manatees, which is nutritionally different from a natural diet and, therefore, may influence body mass and condition. Furthermore, captive manatees are less active than their wild counterparts, and, therefore, animals remaining in captivity for long periods are often overweight or at least heavier than conspecifics in the wild. Unlike Florida manatees, there was no sex difference in the L-W relationship for Amazonian manatees (Amaral et al., 2010). This is consistent with the lack of obvious sexual dimorphism in that species (Rosas, 1994).

Comparison of Body Condition Indices

Which index is used is likely to depend on ease of use in the field and whether an index proves to accurately represent the nutritional status of over- or undernourished animals. Three indices (K_{SL}, K_{CL}, and K_{UG}) have potential utility for quickly evaluating body condition of females because they are easy to calculate and do not vary significantly with body size. Alternatively, the amended sex-specific BCIs have a slightly lower coefficient of variation (CV) and should be unbiased because the exponents were determined empirically rather than theoretically and can be applied to both sexes (Tables 2 & 3). Because these indices do not change with L, the ratio of the BCI of any given animal (K) to the mean BCI of this population $(\hat{K})$ will provide an indication of the ratio of current weight of that animal (W) to the average weight $(\hat{W})$ for an animal of that length:

$$\mathrm{K} / K = \mathrm{W} / W \qquad \text{(Equation 13)}$$

These ratios can also be represented as a percentage by multiplying by 100. For example, a female with a K_{SLf} of only 11.6, that is half (50%) of the population mean of 23.2, has a W that is half (50%) of the population mean for its body length and will have to double its weight to reach the population mean. To help with the evaluation of an individual animal, the population distributions of BCIs based on SL are provided in Table 4.

BCIs that include UG had the lowest CVs (Tables 1 & 3). This is to be expected because inclusion of UG should provide a better measurement of body volume. Similarly, indices based on CL had smaller CVs than indices based on SL because CL partly takes into account the animal's G (Tables 1 & 3). In Steller sea lion (*Eumetopias jubatas*) pups, G was found to not be a reliable predictor of body condition, and only comparison of W and L could distinguish between starving and non-starving pups (Trites & Jonker, 2000). Both Steller sea lions and manatees have thinner layers of blubber than other marine mammals, which may influence the relationship between G and W as these animals lose or gain body weight (Trites & Jonker, 2000). G may also fluctuate with pregnancy, as noted above, or with the amount of gas, food, or fluid in the gut of healthy animals or outside the gut in injured animals (Willemsen & Hailey, 2002).

The BCIs presented in this paper measure different aspects of body condition, so each has merit for a particular purpose. A BCI that compares W to SL, such as K_{SLm} or K_{SLf}, can vary because of changes in geometric shape, volume, or density. The BCIs that compare W to volume (K_{SL*UGm} and K_{SL*UGf}) vary primarily with density, assuming a similar geometric shape. Thus, an animal with a higher percentage of body fat or more gas in its bowel should have a lower K_{SL*UG} because fat and gas are less dense than lean tissue. Whether that is true in practice would require calibration against estimates of body fat from either live or freshly dead animals. The BCIs that compare W to CL (K_{CLm} and K_{CLf}) correlate quite well to those based on SL ($r^2 = 0.76$), as expected due to the high correlation between SL and CL ($r^2 = 0.99$); however, CL also incorporates some portion of shape, so interpretation is not as clear-cut. The BCIs that compare W to volume (K_{SL*UG}) correlated poorly with BCIs that compared W to L ($r^2 < 0.15$) or UG to L ($r^2 < 0.05$). The BCI based on a comparison of UG to SL (K_{UG}) takes variation in shape (G) into account but not variation in density. This may have utility when W cannot be measured. For example, assuming that UG is a circle of diameter D and circumference πD, then a new BCI, K_D, can be generated by dividing K_{UG} by π (3.14). This K_D (mean for both sexes of 0.24 and range of 0.21 to 0.28) represents the ratio of width to SL and could be of utility in assessing populations of manatees through aerial photogrammetry (Flamm et al., 2000). Which BCI is best depends on the question of interest and what is possible to measure under various circumstances.

Habitat Effects on Body Condition

Variation in mean BCIs across habitats has been used to infer corresponding variation in the quality of those habitats for growth in fish (Muchlisin et al., 2010). It is possible that Crystal River provides better habitat for manatees than the Indian River or Tampa Bay because two indices were greater for females in this area. Crystal River is also further north than the other two sites; the population of manatees that overwinters there generally consists of residents that remain within the general area throughout the year and individuals that disperse throughout the coastal waters of the northern Gulf of Mexico (Fertl et al., 2005) during the summer. These manatees may compensate for cooler water temperatures by increasing body fat stores and reaching an overall larger body size than those living in waters further south.

In other marine mammals, body condition provides insights into the health of the population and its relationship to key ecological factors. Long-term data from ringed seals (*Phoca hispida*), for example, revealed that lower BCIs correlated with more severe ice years and lower food availability (Harwood et al., 2000). Female polar bears (*Ursus maritimus*) similarly had poorer body condition when the ice they use as foraging habitat broke up earlier than usual in the reproductive season (Stirling et al., 1999). In dugongs (*Dugong dugon*), widespread seagrass loss has been documented to have profound effects on body condition, mortality, reproduction, and large-scale emigration (Preen & Marsh, 1995). A recent dramatic loss of seagrass, the manatee's principal forage, in the northern IR due to prolonged phytoplankton blooms from 2011 to 2013 (Phlips et al., 2014) has generated concern among managers for the health of manatees and for the status of the macrophyte-based ecosystem. Monitoring of body condition is one means of assessing impacts of loss of forage habitat on the population before any demographic effects become apparent.

Caveats and Conclusions

A potential limitation of our study is that Ws and Ls were measured only during the winter season. During the winter, food sources are generally more limited than at other seasons, so manatees may weigh less as they use up energy reserves during periods of fasting in cold weather. This issue should not be much of a concern, however, because most captures took place in early winter before the animals could have depleted reserves.

It is also possible that the distribution of manatee age differed with sex and location. However, adult survival rates do not differ significantly between sexes, with relative adult age, or among regions in Florida (Langtimm et al., 1998; Runge et al., 2015). Furthermore, the means and distributions of SL, a surrogate measure of age class, were similar among groups in the present study.

Another caveat is related to the fact that body weight includes non-body tissues (i.e., digesta in the gastro-intestinal tract) that can account for ~8% of W in sirenians (Marsh et al., 2011); therefore, some variation in a BCI could result from how much foraging the animals engaged in during the week or two prior to the health assessment. We suggest that that should be considered if the capture followed a prolonged period of cold when the manatees may have been forced to fast in a warm-water refuge. Nevertheless, the normal ranges of BCIs for wild, healthy Florida manatees established herein can provide a reference for comparison with health assessments conducted in other seasons and at other locations.

Our study provides information that can be used by ecologists and managers as a baseline nutritional index for wild Florida manatees, and by veterinarians and husbandry staff at oceanaria to quantitatively assess the body conditions of rehabilitating, captive manatees. Indices can be used to estimate the degree to which rescued individuals are depleted of energy stores, relative to healthy manatees in the wild, or to monitor how the body conditions of long-term captive manatees change over time. The BCIs for captive individuals that have become obese should lie well above the upper end for the wild population, and this can also present health concerns. These L-W relationships may additionally prove useful to observe body condition changes in the overall population of wild Florida manatees in years to come, especially if forage resources become limiting.

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