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Rapid Assessment of Bottlenose Dolphin (*Tursiops truncatus*) Body Condition: There's an App for That

Leslie B. Hart,[1] Kerry Wischusen,[2] and Randall S. Wells[3]

[1]*Department of Health and Human Performance, College of Charleston, 66 George Street, Charleston, SC 29424, USA*
E-mail: hartlb@cofc.edu
[2]*Department of Biochemistry, College of Charleston, 66 George Street, Charleston, SC 29424, USA*
[3]*Chicago Zoological Society's Sarasota Dolphin Research Program, c/o Mote Marine Laboratory, 1600 Ken Thompson Parkway, Sarasota, FL 34236, USA*

Abstract

Many recent studies have demonstrated that the health of bottlenose dolphins (*Tursiops truncatus*) can serve as an important indicator of hazards in the marine environment. A convenient and accurate way to get a "snapshot" of a dolphin's health is to compare biological and physiological measurements to known reference intervals (RIs), which are ranges of values often considered normal or healthy. Measurements that fall above or below RI thresholds are usually considered abnormal and may indicate a health concern. Biological and physiological parameters of individuals sampled during field health assessments are often compared to RIs, but this is usually conducted post-fieldwork, following veterinary evaluation and biological sampling, which limits the ability to quickly diagnose problems and immediately perform more telling tests. The objective of this study was to develop a mobile application (app) that allowed instantaneous comparison of bottlenose dolphin morphometrics (i.e., length, mass, and girth) to previously published body condition RIs *in situ*. Furthermore, for bottlenose dolphins with mass and girth within normal ranges, the mobile app was programmed to compare field measurements to newly derived percentiles (25th, 50th, and 75th). The app was developed using *MIT App Inventor 2*© software. Functions were validated using historical and simulated data and were field tested during a bottlenose dolphin capture-release health assessment to evaluate feasibility for field use and to gain information for feature enhancements. An app that can rapidly evaluate body condition will significantly enhance veterinary evaluations of bottlenose dolphins (in the wild and under human care), as well as enhance epidemiologic studies of population health as coastal environments become increasingly stressed from pollution and other anthropogenic disturbances.

Key Words: cetacean, marine mammal, health, technology, length, mass, girth

Introduction

A reference interval (RI) for a health parameter is a statistically derived range of values considered to be normal or healthy because they represent expected values for a certain percentage of a population (Friedrichs et al., 2012). RIs are based on observations from a large sample of individuals and are often influenced by factors such as sex, reproductive condition, or age. They are routinely used in human and veterinary medicine to evaluate the health of individuals relative to "normal" values for a population (Friedrichs et al., 2012). In fact, RIs can be used to diagnose health conditions by identifying individuals with measurements that are out-of-range. For example, anemia is often diagnosed when blood hemoglobin concentrations are below an established RI (Izaks et al., 1999).

Recently, RIs have been used in epidemiologic studies of bottlenose dolphins (*Tursiops truncatus*) to identify animals suffering health impacts from short- and long-term environmental stressors. These RIs serve as quantitative guides to assess an individual's physical and physiological well-being following exposure to a health hazard in their natural environment. For example, following the *Deepwater Horizon* oil spill in 2010, dolphins sampled in a heavily oiled bay in the northern Gulf of Mexico were found to have severe health conditions, including poor body condition (i.e., underweight), inflammation, hypoglycemia, abnormal iron concentrations, and impacted liver function, according to comparisons with associated RIs (Schwacke et al., 2014; Smith et al., 2017).

Presently, evaluations of wild dolphin health using RIs are conducted during final data analysis, after field-based data collection. This is not efficient, especially if sampling procedures and protocols are dependent on an individual's general health (i.e., if a measurement falling outside of an RI would trigger additional tests). Additionally, a mobile evaluation tool would be incredibly useful to help with disposition decisions (e.g., euthanasia, rehabilitation, or release) for marine mammals that wash ashore. The objective of this project was to develop a mobile application (app) to instantaneously evaluate bottlenose dolphin body condition by comparing morphometrics collected during veterinary assessments to previously published reference intervals for mass-to-length (mass:length) and girth-to-length (girth:length) ratios (Hart et al., 2013).

Methods

Bottlenose Dolphin Health Assessment

Bottlenose dolphin health assessments in Sarasota Bay, Florida, have been described in detail elsewhere (Wells et al., 2004). Briefly, free-swimming dolphins were encircled in shallow water using a 500 × 4 m seine net. Following restraint by trained personnel, a brief examination by veterinarians, and a blood draw to measure other health parameters, individual dolphins were placed in a sling for transport onto a sampling vessel. While in the sling, total mass (to the nearest 0.1 kg) was collected using a load cell, followed by measurements of total length (to the nearest 0.1 cm) and maximum girth (to the nearest 0.1 cm) following methods described elsewhere (Read et al., 1993; Tolley et al., 1995).

Derivation of Additional Percentiles

Reference intervals, based on 95th percentiles, have been previously reported for mass:length and girth:length for bottlenose dolphins (Hart et al., 2013). These RIs have been used to identify individual dolphins with abnormal mass or girth measurements, according to an expected range for 95% of a normal, healthy population. Additional percentiles (25th, 50th, and 75th) were derived for this project to obtain further information for dolphins with mass and girth measurements within the boundaries of the 95th percentile. Following the same methods described in Hart et al. (2013), length (to nearest 0.1 cm), mass (to nearest 0.1 kg), and girth (to nearest 0.1 cm) measurements from dolphins sampled in Sarasota Bay (1987 to 2009) during the months of May, June, and July were used to derive additional percentiles. The

Table 1. Parameter estimates (*a* and *b*) for calculations of length-specific mass and girth percentile thresholds for free-ranging bottlenose dolphins (*Tursiops truncatus*)

Percentile	Tau (τ)	Length unit	Mass unit	Girth unit	*a*	*b*
Males						
2.5	0.025	cm	kg	--	-5.523	3.232
25	0.25	cm	kg	--	-5.658	3.301
50	0.50	cm	kg	--	-5.604	3.291
75	0.75	cm	kg	--	-5.253	3.154
97.5	0.975	cm	kg	--	-5.472	3.271
2.5	0.025	cm	--	cm	-12.059	0.568
25	0.25	cm	--	cm	-15.000	0.600
50	0.50	cm	--	cm	-21.451	0.648
75	0.75	cm	--	cm	-11.495	0.624
97.5	0.975	cm	--	cm	-15.754	0.697
Females						
2.5	0.025	cm	kg	--	-5.029	3.010
25	0.25	cm	kg	--	-4.517	2.817
50	0.50	cm	kg	--	-4.622	2.871
75	0.75	cm	kg	--	-4.032	2.634
97.5	0.975	cm	kg	--	-4.570	2.881
2.5	0.025	cm	--	cm	2.500	0.500
25	0.25	cm	--	cm	-13.754	0.596
50	0.50	cm	--	cm	-7.471	0.588
75	0.75	cm	--	cm	5.984	0.551
97.5	0.975	cm	--	cm	18.384	0.530

mass:length nonlinear quantile regression models used the following equation (Innes et al., 1981):

(1)
$$\textit{Estimated Total Mass (ETM)} = 10^a \times \textit{Total Length}^b$$

while girth:length linear quantile regression models were based on (Hart et al., 2013)

(2)
$$\textit{Estimated Maximum Girth (EMG)} = a + (b \times \textit{Total Length})$$

where a and b are parameters estimated by the quantile regression models with tau (τ) adjusted for respective percentiles (e.g., $\tau = 0.025$ for 2.5th percentile; $\tau = 0.25$ for 25th percentile, $\tau = 0.50$ for 50th percentile, etc.; Table 1).

"Cetacean Health" App Development

The "Cetacean Health" app was developed using *MIT App Inventor 2*© software (Massachusetts Institute of Technology, 2012-2013), a cloud-based programming platform that uses "events-based" blocks or pre-programmed functions to perform specific tasks. Key functions of the app included short-term storage of data collected during field assessments (i.e., total length, mass, maximum girth, and sling mass; Figure 1), comparison of real-time measurements to sex- and length-specific 95th percentile RIs, and visualization of real-time measurements using graphical displays of percentile and RI curves.

Textbox fields were created for morphometric data collected during health assessments (e.g., "Total length," "Mass with sling," "Maximum girth," and "Mass of sling"; Figure 1). The "Total mass (calculate)" button was programmed to subtract the mass of the sling used to weigh the animal from the "Mass with sling" measurement (or gross total mass; Figure 1), providing a net total mass for each sampled dolphin. Within the app, these data were converted to numerical variables for comparisons to estimates of total mass and maximum girth, based on algorithmic calculations of upper and lower bounds for sex- and length-specific 95th percentile RIs using programmed evaluation buttons (e.g., "Mass evaluation" and "Girth evaluation"; Figure 1).

To rapidly identify individual dolphins with mass and girth measurements outside of the 95th percentile RI, the app was programmed to output "overweight" or "high girth" in red-colored font for individuals with total mass or maximum girth measurements above the estimate calculated for the 97.5th quantile ($\tau = 0.975$), given the individual's total length measurement. Similarly, the app was programmed to display "underweight" or "low girth" in yellow font for dolphins with total mass or maximum girth measurements below the girth/mass estimates for the 2.5th quantile ($\tau = 0.025$). For individuals considered to be "normal weight" or "normal girth" (i.e., within the 95th percentile; green font), the app was programmed to compare total mass and maximum girth field measurements to sex- and length-specific algorithmic estimates of percentiles between 2.5% and 97.5% (i.e., "2.5-25%," "25-50%," "50-75%," and "75-97.5%"; Figure 2), given quantile regression estimates for a and b in Equations 1 and 2. Estimates of sex-specific body mass indices (BMI) using the equation from Hart et al. (2013),

(3)
$$BMI = \frac{Total\ Mass}{(Total\ Length)^b} \times 10{,}000$$

were also included as an app function to further enhance the evaluation of bottlenose dolphin body condition during health assessments (Figures 1 & 2).

Graphs depicting the RI and additional percentile algorithms were included as additional display screens to provide users with a visual comparison of field measurements to computed percentiles (Figure 3).

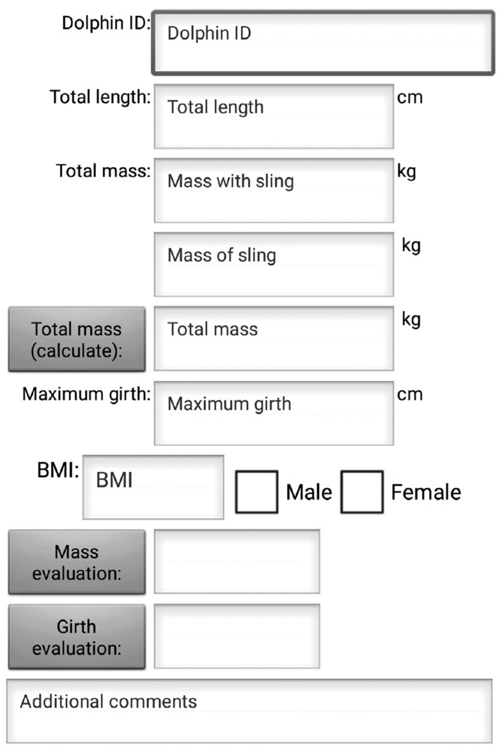

Figure 1. "Cetacean Health" data input screen

App Validation
The traditional assessment of body condition for bottlenose dolphins sampled during field health assessments involves a manual comparison of field measurements to sex- and length-specific equations stored in a database or spreadsheet. App evaluations of mass and girth relative to 95th percentile RIs (i.e., high mass/girth, normal mass/girth, or low mass/girth) were validated using historical bottlenose dolphin morphometric data from Sarasota Bay (1987 to 2009; $N_{females} = 72$, $N_{males} = 88$; Hart et al., 2013), as well as randomly simulated ($N_{females} = 100$, $N_{males} = 100$) measurements of length, girth, and mass. For both the historical Sarasota Bay data and the simulated data, measurements of mass and girth were compared to sex-specific predicted mass and girth, using the following equations from Hart et al. (2013):

(3)
Underweight: $TM_{actual} < ETM_{0.025} = 10^{a0.025} \times TLactual^{b0.025}$

(4)
Overweight: $TM_{actual} > ETM_{0.975} = 10^{a0.975} \times TLactual^{b0.975}$

(5)
Low girth: $MG_{actual} < EMG_{0.025} = a_{0.025} + (b_{0.025} \times TL_{actual})$

(6)
High girth: $MG_{actual} > EMG_{0.975} = a_{0.975} + (b_{0.975} \times TL_{actual})$

where TM_{actual}, TL_{actual}, and MG_{actual} are the measured total mass, total length, and maximum girth of each individual, respectively.

Field Test
The feasibility of using an app to evaluate body condition *in situ* was field tested in May 2016 during a bottlenose dolphin capture-release health assessment in Sarasota Bay, which coincided with the general timeframe (i.e., summer months) of observations used to derive the original RIs (Hart et al., 2013). In total, nine individuals (five females, four males) were measured, providing the opportunity to test the utility of the app and gather information for function enhancements.

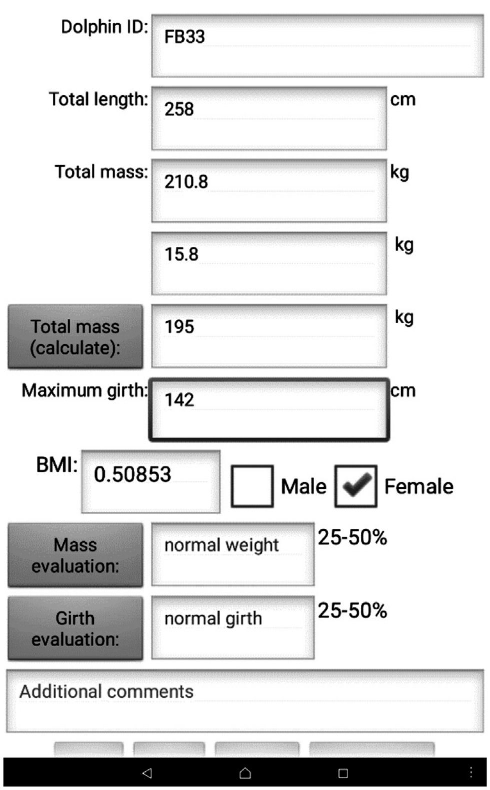

Figure 2. "Cetacean Health" data output screen

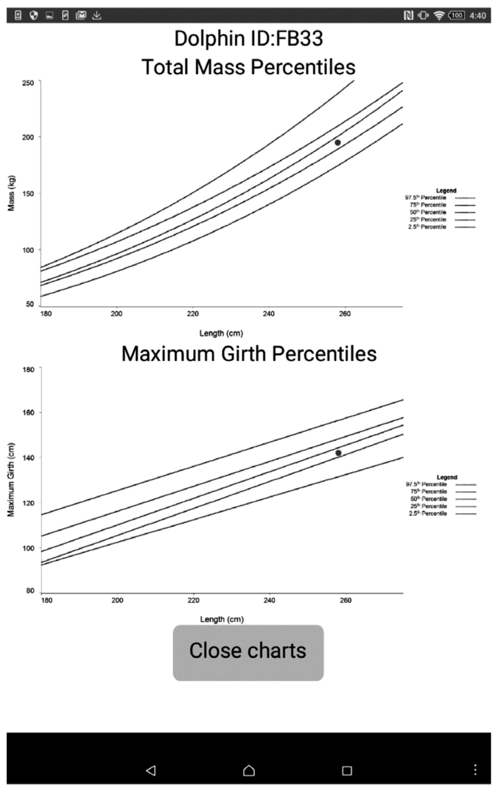

Figure 3. "Cetacean Health" chart display. **Note:** Lines (top to bottom) represent 97.5th, 75th, 50th, 25th, and 2.5th percentiles. The gray circle indicates the measured length and mass or girth for a bottlenose dolphin sampled during the 2016 Sarasota Bay, Florida, health assessment.

Results

App Validation

Sex-specific upper and lower bounds for ETM and EMG were calculated by hand for lengths ranging between 170 and 280 cm using Equations 1 and 2, as well as the parameter estimates (*a* and *b*) for the upper (τ = 0.975) and lower (τ = 0.025) 95% RI bounds from Table 1. The actual mass and girths measured for Sarasota Bay dolphins sampled between 1987 and 2009 ($N_{females}$ = 72, N_{males} = 88) were manually compared to the 95th percentile RI bounds to determine if a dolphin was above ("overweight/high girth") or below ("underweight/low girth") the threshold values. These manual evaluations were compared to results produced by the app for the same cohort of Sarasota Bay dolphins, revealing 100% concordance. Similarly, 100% concordance was achieved for the evaluation of 200 simulated measurements of length and mass (100 male, 100 female).

Similar methods were used to validate the app's ability to accurately categorize measurements within the new percentile ranges. The sex- and length-specific ETM and EMG estimates were calculated by hand for each percentile category (i.e., "2.5-25%," "25-50%," "50-75%," and "75-97.5%) using parameter estimates in Table 1 and Equations 1 and 2. If TM_{actual} and MG_{actual} were between the upper and lower ETM/EMG estimates for each percentile category, the dolphin was considered to have a mass or girth within the specific percentile category. These evaluations were manually conducted for the Sarasota Bay 1987-2009 sample, as well as the simulated measurements of length, mass, and girth. Results from the manual categorization of historical data were compared to the output generated by the app, also revealing 100% concordance.

The graphing feature of the app was validated using data from stranded Sarasota Bay dolphins ($N_{females}$ = 7, N_{males} = 3) presented in Hart et al. (2013). The length, mass, and girth of each stranded dolphin were entered into the app and plotted against the 95th percentile RI curves generated by the charting function. The RI curves represented an accurate range of values, and the location of each point representing an individual dolphin's suite of measurements were in the correct location, according to the axis units. The results from these validation measures demonstrated that the app reliably evaluated indicators of body condition, with results matching those associated with traditional methods used in other studies specific to estuarine bottlenose dolphins (Schwacke et al., 2014; Smith et al., 2017)

Field Test

Each individual's length, mass, and girth were entered into the text fields, and mass and girth evaluations were instantaneously conducted, as well as BMI calculations (Table 2).

The mass and girth of all sampled dolphins were within the 95th percentile RIs, with more dolphins between the 25th and 50th percentiles for mass (44.4%; N = 4) and 50th and 75th percentiles for girth (33.3%; N = 3), as compared to the other percentile categories (Table 3). Three of the five sampled female dolphins were between the 2.5th and 25th percentiles for mass (Tables 2 & 3), with

Table 2. "Cetacean Health" output from field test during a bottlenose dolphin health assessment in Sarasota Bay, May 2016

ID	Sex	Length (cm)	Mass (kg)	Girth (cm)	BMI	Mass evaluation	Mass %	Girth evaluation	Girth %
F294	M	202	95	113.5	0.040	Normal	25-50	Normal	50-75
F188	M	257	229	150	0.044	Normal	75-97.5	Normal	75-97.5
F178	M	272	248	149	0.040	Normal	25-50	Normal	25-50
F292	M	216	124	124	0.042	Normal	50-75	Normal	75-97.5
F255	F	192	81	108	0.473	Normal	2.5-25	Normal	50-75
F223	F	251	160	131	0.450	Normal	2.5-25	Normal	2.5-25
F259	F	216	100	112	0.424	Normal	2.5-25	Normal	2.5-25
F209	F	236	154	135	0.512	Normal	25-50	Normal	50-75
FB33	F	258	195	142	0.509	Normal	25-50	Normal	20-50

Note: "Length," "Mass," and "Girth" were measurements collected during sampling of individual dolphins ("ID"), while "BMI," "Mass evaluation," "Mass %," "Girth evaluation," and "Girth %" were calculated/determined by the app functions. "Normal" indicates a mass or girth measurement within the boundaries of the 95th percentile reference interval per Hart et al. (2013).

Table 3. Mass and girth evaluations using newly derived percentile estimates for bottlenose dolphins sampled during 2016 Sarasota Bay health assessment

	2.5-25%	25-50%	50-75%	75-97.5%
Mass				
Total (*N* = 9)	33.3%	44.4%	11.1%	11.1%
Males (*N* = 4)	0	50.0%	25.5%	25.5%
Females (*N* = 5)	60.0%	40.0%	0	0
Girth				
Total (*N* = 9)	22.2%	22.2%	33.3%	22.2%
Males (*N* = 4)	0	25.0%	25.0%	50.0%
Females (*N* = 5)	40.0%	20.0%	40.0%	0

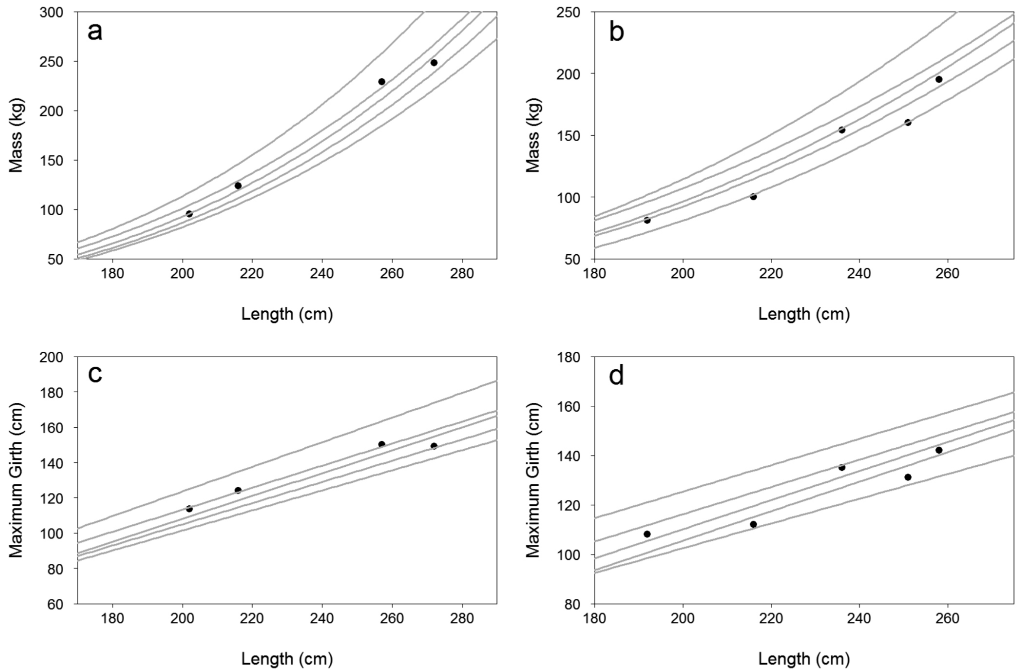

Figure 4. Percentile plots with Sarasota Bay field test data (May 2016) for male mass:length (a), female mass:length (b), male girth:length (c), and female girth:length (d). **Note:** Lines (top to bottom) represent 97.5th, 75th, 50th, 25th, and 2.5th percentiles. Black circles indicate the measured length and mass or girth for bottlenose dolphins sampled during the 2016 Sarasota Bay health assessment.

one individual near the threshold of being "underweight" for her respective length (Figure 4).

In the field, measurements of length, mass, and girth for each individual, as well as the calculations of BMI and mass/girth evaluations, were stored in a temporary database contained in the app. Once connected to the Internet, these data were exported to a cloud-based fusion table for permanent storage. As an additional validation step, the app results from the field test were compared to traditional evaluation methods previously discussed, again revealing 100% agreement.

Discussion

The objective of this study was to use published RI algorithms to develop an app that can instantaneously evaluate estuarine bottlenose dolphin morphometrics indicative of overall body condition. The *MIT App Inventor 2*© software provided a user-friendly framework to connect events that included calculations based on user input, as well as logic steps to identify individuals with morphometrics that were not within the numerical range of the 95th percentile RI. Measurements of length, mass, and girth previously collected from bottlenose dolphins sampled in Sarasota Bay, Florida, as well as simulated measurements of each type of metric facilitated the validation process of specific app functions. Finally, the field test that relied upon real-time measurements of live bottlenose dolphins sampled during a capture-release project was instrumental in determining the feasibility of use during bottlenose dolphin health assessments.

Results from the validation measures revealed that the app functions were coded and operated correctly. In fact, all of the output from the app matched traditional evaluation measures, suggesting that the app could be used in conjunction with or replace current practices for assessing individual body condition for estuarine bottlenose dolphins. The primary advantage of using the app rather than traditional evaluation methods is the ability to evaluate an individual's body condition during the actual sampling event. Previous studies have indicated that poor body condition could be a marker of other adverse health conditions such as nutritional deficiencies (Calkins et al., 1998) and impaired immunity (Brock et al., 2013), as well as an indicator of calving stress, entanglement, or poor survival (Pettis et al., 2004; Schick et al., 2013). As part of their model validation process, Hart et al. (2013) used the 95th percentile RIs to evaluate the body condition of dead stranded bottlenose dolphins. Among the stranded dolphins with poor body condition, there was evidence of trauma from human interaction (i.e., fishing gear ingestion) or stingray barb puncture, both of which could impair feeding or result in systemic infections. Therefore, the ability to identify free-ranging or live-stranded individuals with poor body condition, in real-time, could enhance veterinary evaluations by indicating the need for additional tests or measures of overall health before the animal is released and such follow-up is no longer feasible. Secondarily, this app will also help to minimize errors that may occur during data collection or transcription, automate and centralize data storage using cloud-based mechanisms, and establish consistency in formatting among users of the app.

The field test demonstrated the ability and utility of receiving instantaneous feedback on an important gauge of health. For the dolphins sampled during the 2016 field test, the app indicated that all of them had mass and girth measurements within the 95th percentile RI, although one female was borderline "normal weight" for her length. The ability to visualize length-specific mass and girth measurements with respect to the 95th and other percentiles provided an enhanced understanding of the actual body condition of each individual relative to expected sizes. Finally, the app's storage features were also tested during the 2016 capture-release project, which demonstrated the ease of short-term storage of data and evaluation results, thereby reducing elements of the post-assessment data processing and analysis.

Despite the expeditious evaluation of bottlenose dolphin body condition, the generalizability of this app to other bottlenose dolphin stocks and other cetacean species is likely limited due to differences in morphology. Length, mass, and girth measurements used to derive the app's algorithms were from bottlenose dolphins sampled in an estuary on the west coast of Florida (Hart et al., 2013). Thus, body condition evaluations conducted by the app are probably most relevant to common bottlenose dolphins residing in bays, sounds, or estuaries due to size differences between stocks (Hayes et al., 2017); however, applicability to other stocks or settings could be tested in future studies using morphometric data from other populations. Similarly, evaluations by the app are probably best suited for bottlenose dolphins sampled during warmer months of the year as morphometrics used to derive the RIs in Hart et al. (2013) were based on measurements collected between May and July, as this was the time period in which health assessments were conducted with greatest frequency (thus providing the most robust dataset). Given that bottlenose dolphin health assessments and stranding events can occur during different seasons of the year, additional research to determine the applicability of these intervals during other time periods is warranted. Pregnant female dolphins were also excluded from the derivation of the original RIs because of changes in mass and girth that accompany pregnancy (Hart et al., 2013); therefore, this app is unable to accurately evaluate the body condition of pregnant females, a population with increased vulnerability to health hazards.

Although the utility of this app may be limited to a single species and a specific time period, the ability to generate RIs is a result of data acquired from long-term, capture-release health assessments of free-ranging bottlenose dolphins, which are largely unavailable for other species. While it would be beneficial to have an app that could evaluate the health condition of other species that wash ashore, the calculation of RIs requires a substantial amount of data from individuals sampled from a healthy population. Unfortunately, this is not available or even logistically possible for the vast majority of marine mammal species due to factors such as size (e.g., large whales) or habitat (e.g., pelagic species). However, should sufficient data on length, mass, and girth become available for other species, a framework is now in place for the development of similar apps for additional species.

As depicted in Figures 1 and 2, the app also automatically calculates BMI for each animal sampled, based on measurements of length and mass and an algorithm from Hart et al. (2013). BMI can also be used as an indicator of body condition, evidenced by the strong agreement between dolphins considered to be in poor body condition based on mass and girth RI evaluations vs BMI cutoff values (Hart et al., 2013). Recent human health studies have suggested that waist circumference may be more indicative of adverse health effects than BMI (Janssen et al., 2004) or should at least be used in conjunction with BMI-based health predictions (Janssen et al., 2002; Zhu et al., 2004), but to our knowledge, we do not have evidence of this limitation for dolphins. However, since this app reports calculations of BMI as well as girth and mass percentiles, we hope the combined use of these metrics would help to control for any similar discrepancies when evaluating bottlenose dolphin body condition should they exist.

We expect that this technology will appeal to any individual monitoring the health of bottlenose dolphins, including wildlife biologists and veterinarians, as well as medical staff caring for dolphins in zoological settings. We have already demonstrated the utility of the app for real-time evaluations of body condition during a health assessment project, and we believe that biologists and veterinarians will find the app useful when making decisions about live-stranded bottlenose dolphins (i.e., to release, rehabilitate, or euthanize). For bottlenose dolphins under human care, medical staff may be interested in using the app to monitor body condition following medical or therapeutic interventions.

As the marine and estuarine environments become increasingly stressed by coastal development and other anthropogenic disturbances, we expect to see more frequent bottlenose dolphin health assessments that use epidemiological methods to link health impacts with exposure to these stressors. For example, recent assessments have been conducted to evaluate health effects from naturally occurring algal bloom toxins (Twiner et al., 2012), anthropogenic pollutants (e.g., PCBs) (Schwacke et al., 2012), infectious disease outbreaks, and environmental disasters such as the *Deepwater Horizon* oil spill (Schwacke et al., 2014). Thus, developing technology to enhance veterinary evaluations of dolphin health will ultimately improve our ability to understand impacts from marine and coastal ecosystem hazards.

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