Veterinary Integrative Sciences 2026; 24(2): e2026051-1-17. DOI: 10.12982/VIS.2026.051

Veterinary Integrative Sciences
ISSN; 2629-9968 (online)

Research article

Field-based body condition scoring system for dugongs (*Dugong dugon*): development using morphometric indices and blubber thickness

Piyarat Khumraksa[1], Santi Ninwat[1] and Watcharapol Suyapoh[2,3]

[1] Marine and Coastal Resources Research Center (Lower Andaman Sea), Trang 92150, Thailand
[2] Department of Veterinary Science, Faculty of Veterinary Science, Prince of Songkla University Songkhla, 90110, Thailand
[3] Dugong and Seagrass Research Station, Prince of Songkla University, Songkhla 90110, Thailand

Abstract

The dugong (*Dugong dugon*) is a protected marine mammal in Thailand, yet body condition score (BCS) assessments remain subjective and lack standardized benchmarks. This study aimed to identify key morphometric and blubber predictors of body condition score (BCS) in dugongs to develop a standardized, field-based assessment framework. To achieve this, necropsy records of 82 stranded dugongs from the Andaman Sea (2019–2025) were analyzed, summarizing morphometric and blubber data across age classes and BCS levels. Univariable and penalized ordinal logistic regression identified predictors associated with BCS, which were combined with descriptive statistics to construct heuristic thresholds. Although predictors of BCS differed across age classes, their common ground highlighted parameters that were most consistent across stages. For field application, average blubber thickness, body weight, and body condition index (BCI) were therefore selected as the robust predictors for developing heuristic thresholds. These were consolidated into BCS charts and lookup tables, providing practical morphometric cutoffs for necropsy and stranding investigations. This study represents the first attempt to establish field-based BCS assessment tools for dugongs, improving objectivity and consistency in condition evaluation. While not intended as definitive diagnostics, the thresholds enhance comparability across cases, with extreme categories (BCS 1 and 5) still requiring expert confirmation and further validation through larger sample sizes and longitudinal studies.

Keywords: Body condition score, Dugong, Field-based, Heuristic thresholds, Ordinal logistic regression.

*Corresponding author: Watcharapol Suyapoh, Department of Veterinary Science, Faculty of Veterinary Science, Prince of Songkla University, Songkhla 90110, Thailand. E-mail: watcharapol.s@psu.ac.th.

Funding; *This research was financially supported by the Prince of Songkhla University (Contract No. VET6702022S).*

Article history; *received manuscript: 29 August 2025,*
revised manuscript: 15 October 2025,
accepted manuscript: 23 October 2025,
published online: 29 October 2025,
Academic editor; *Korakot Nganvongpanit*

INTRODUCTION

The dugong (*Dugong dugon*) is currently classified as a Vulnerable species on the IUCN Red List of Threatened Species (IUCN, 2025). In Thailand, it is afforded the highest level of legal protection under national wildlife conservation laws and is widely regarded as a flagship species for marine biodiversity and seagrass ecosystem protection (Government of Thailand, 2019). Owing to its ecological significance and conservation status, the dugong has become a focal species for marine research, conservation management, and health monitoring. Despite these protections, dugong populations have experienced rapid declines over recent decades, with increasing reports of stranding and mortality events across their range (Raghunathan et al., 2012; Woolford et al., 2015; Kayanne et al., 2022; Lin et al., 2022; Eiamcharoen et al., 2025; Sukkarun et al., 2025). In Thailand alone, 125 dugongs were reported stranded and dead over the past six years (Daochai et al., 2024), underscoring the urgent need for enhanced monitoring and targeted conservation measures.

Postmortem examinations are essential for determining causes of death in stranded marine mammals, including cetaceans and dugongs, with the assessment of body condition score (BCS) constituting a critical component of necropsy protocols (Geraci et al., 2005; Daochai et al., 2024). In veterinary pathology, BCS serves as an indicator of nutritional status and provides valuable context for interpreting disease processes and mortality factors (Burkholder, 2000; Raverty et al., 2020; Zachary, 2022). Translating this principle into wildlife pathology, BCS assessment has been incorporated into dugong necropsy practice; however, the evaluation has relied predominantly on qualitative approaches (Department of Marine and Coastal Resources, 2013). Such methods are constrained by inter-observer variability, subjective interpretation, and the absence of standardized morphometric benchmarks. These limitations underscore the need for improved and refined BCS assessment protocols to generate more objective, reliable, and reproducible indicators of body condition in dugongs.

Subjective BCS assessment may bias health interpretation due to observer variability. Differences in experience and visual judgment can lead to inconsistent scoring and misclassification of nutritional status, emphasizing the need for standardized, quantitative approaches to improve reliability in wildlife health evaluations (Castrillon and Bengtson Nash, 2020). Heuristic thresholds are a problem-solving approach that relies on trial and error, rules of thumb, or approximations to provide rapid insights without requiring large datasets or complex analyses (Desale et al., 2015). In field contexts, they serve as approximate cutoff values that guide practical decision-making, often derived from descriptive morphometric data and statistical models (Desmet, 2018). Although not absolute diagnostic standards, their use enhances BCS assessment by incorporating quantitative information, improving consistency across observers, and supporting timely necropsy and stranding decisions. In this study, heuristic thresholds were therefore developed to provide field-based guidelines for evaluating dugong BCS.

The aim of this study was to identify key morphometric and blubber predictors of BCS across different life stages of stranded dugongs in Thailand, and to integrate these predictors into heuristic thresholds for practical field application. Specifically, the study sought to generate field-ready BCS charts and lookup tables that can support necropsy assessments, and provide a framework for future validation of BCS as a health indicator in dugongs.

MATERIALS AND METHODS

Ethical clearance and sample use authorization

All procedures involving the use of recorded data were conducted in accordance with institutional guidelines and applicable national regulations. The study did not involve animal tissues; only previously recorded data were accessed and analyzed. Authorization for the use of these data was granted by the Department of Fisheries of Thailand (MOAC Document No. 0510.5/12652), in compliance with Section 73(1) of the Wildlife Preservation and Protection Act, B.E. 2562 (2019).

Study data

This study was based on recorded data of stranded dugongs recovered along the coastlines of four Andaman Sea provinces in southern Thailand (Phang Nga, Trang, Satun, and Krabi) between January 2019 and May 2025. Necropsies of all carcasses were previously conducted by trained veterinarians from the Andaman Coastal Research Center (Lower Andaman Sea), Department of Marine and Coastal Resources (DMCR), following standardized marine mammal postmortem protocols (Pugliares-Bonner et al., 2007). The degree of postmortem change was evaluated according to established guidelines (Eros et al., 2007), and carcasses in an advanced state of decomposition were excluded to ensure the reliability of body condition score (BCS) assessment.

Body condition was evaluated at necropsy using the Dugong Necropsy Manual of Thailand (Department of Marine and Coastal Resources, 2013). For each carcass, the attending veterinarian assigned a BCS on a five-point scale, where 1/5 indicates very thin and 5/5 indicates obese. The assessment was based on three external parameters: cervical depression, dorsal musculature, and lateral body profile. Specifically, a BCS of 1/5 (very thin) is characterized by a deep neck groove, a sharp vertebral outline, and a markedly emaciated profile; a BCS of 2/5 (thin) presents with a visible neck groove, a flattened back, and reduced body fullness; a BCS of 3/5 (healthy) shows no obvious neck groove, a slightly flattened but full back, and a gently rounded profile; a BCS of 4/5 (overweight) is defined by the absence of a neck groove, a fully rounded back, and increased girth; and a BCS of 5/5 (obese) is indicated by the absence of a neck groove, a broad and rounded back, and a markedly distended body.

Along with BCS assessment, biological and morphometric parameters were systematically documented at the postmortem stage to support quantitative analyses. These included sex, total body length (m), chest girth (m), body weight (kg), and body condition index (BCI). Blubber thickness was measured at four anatomical sites: (A) the dorsal region directly opposite the navel, (B) the lateral body wall, (C) the external abdominal wall between the ribs, and (D) the ventral region posterior to the navel. The mean of these four measurements was calculated as the average blubber thickness. All measurements were obtained by the DMCR team and subsequently made available for analysis in this study.

Finally, the age of each dugong was estimated from body length and chest girth and classified into five age classes following Marsh (1980): new-born calf, dependent calf, juvenile, sub-adult, and adult.

Experimental Design

This study followed a three-stage workflow progressing from statistical analysis to field application of BCS assessment in dugongs. In the first stage (descriptive), morphometric and blubber thickness data, including weight, chest girth, body length, and blubber thickness at multiple sites, were summarized using mean ± SD. Data were stratified by age class and, when available, further categorized by BCS levels (1–5). In the second stage (modeling), associations between predictors and BCS were examined using OLR. Univariable OLR analyses were performed for all predictors, while two-variable OLR models were selectively applied in age classes with sufficient sample size. Multivariable models including more than two predictors were not considered appropriate given the limited data, and this decision was supported by model selection criteria such as AIC and BIC. Model outputs included odds ratios (OR), 95% confidence intervals (CI), p-values, and tests of the proportional odds assumption. In the final stage (translation-to-guideline), statistically significant predictors were combined with descriptive results to construct heuristic thresholds suitable for field use. Thresholds for BCS levels 2–4 were derived directly from observed mean ± SD values, while thresholds for extreme categories (BCS 1 and 5) were extrapolated from adjacent means or quantile distributions. Cases where predictors indicated contradictory directions were flagged as "uncertain" and designated for expert confirmation. The resulting thresholds were then translated into simplified BCS charts and tables to guide field assessment, accompanied by cautionary notes indicating that low-confidence categories require expert verification and further validation. The overall experimental flow is illustrated in Figure 1.

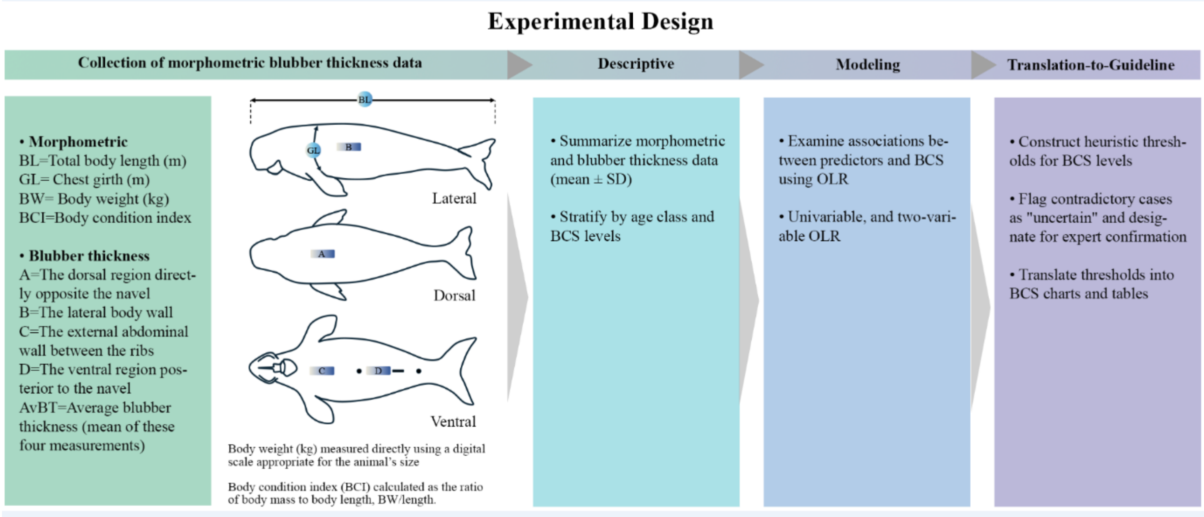

Figure 1 Experimental design illustrating a four-stage workflow for developing field-based body condition score (BCS) guidelines in dugongs (*Dugong dugon*). The workflow included: (1) Descriptive analysis of morphometric and blubber thickness data, (2) Modeling of predictors using ordinal logistic regression, (3) Development of heuristic thresholds by combining statistical outputs with descriptive results, and (4) Field translation into simplified BCS charts and tables with cautionary notes for application during necropsy and stranding investigations.

Statistical analysis

All statistical analyses were performed to evaluate the relationship between morphometric and blubber variables and BCS. In the descriptive analysis, continuous variables were summarized as mean ± SD, or as median and interquartile range (IQR) in cases of non-normal distributions, and were stratified by age class and BCS category.

Ordinal logistic regression (OLR) was applied to assess associations between independent predictors and BCS. Univariable OLR was conducted for all predictors across age classes, and OR with 95% CI and p-values were reported. The proportional odds assumption was examined for each model to confirm the validity of OLR. In age classes with sufficient sample sizes, two-variable penalized OLR models were further explored to evaluate the combined effects of key predictors. Multivariable models with more than two predictors were not considered due to limited sample size, and model selection criteria including Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC) supported this decision. Penalization was applied to reduce the risk of overfitting and improve stability of parameter estimation. All statistical analyses were performed using R version 4.3.2 (R Core Team, 2023) with the packages *MASS* (Venables and Ripley, 2002) and *ordinalNet* (Wurm et al., 2021). Statistical significance was defined at $p < 0.05$.

Application of heuristic thresholds

In this study, heuristic thresholds were developed as a practical tool to guide field-based BCS in dugongs, aiming to provide applicable cutoff values rather than definitive diagnostic criteria. The process followed a stepwise approach:

Selection of predictors

Significant predictors of BCS identified through OLR were selected as the baseline variables for field application (Semakula et al., 2021). These included morphometric and blubber measurements shown to have positive associations with BCS across life stages.

Descriptive statistics by BCS level

For categories with sufficient empirical data, the mean and SD of each predictor were calculated within each BCS level. These descriptive statistics provided the foundation for heuristic thresholds.

Extrapolation for missing categories

For BCS levels lacking empirical observations, linear extrapolation was applied to estimate mean values by extending the differences between adjacent categories. Standard deviations for these extrapolated categories were imputed from the nearest available BCS within the same age class. This approach aligns with standard imputation methods used for handling missing data (Farhan, 2015).

Ensuring monotonic trends

The observed mean values across BCS levels were then checked for monotonicity (i.e., increasing order with higher BCS). In cases where non-monotonic patterns were detected, isotonic regression was applied to adjust the means, enforcing a strictly increasing order while retaining the original SD values (de Leeuw et al., 2009). This adjustment ensured biological plausibility and consistency across BCS levels.

Conversion into practical thresholds

Finally, each mean ± SD value was expressed as a range (mean – SD to mean + SD), producing interpretable intervals for field use. These ranges were consolidated into lookup tables and charts, providing practical cutoffs for necropsy and stranding assessments. Presenting reference values as ranges has been recommended in field-based marine mammal health evaluations (Geraci et al., 2005).

In instances where predictors demonstrated contradictory directions of association, the outcomes were flagged as “uncertain” and referred for expert confirmation, applying structured expert elicitation methods widely used in wildlife health risk assessment (Martin et al., 2012; Hemming et al., 2018). The finalized thresholds were consolidated into field-ready BCS charts and lookup tables, providing practical cutoffs for dugong stranding and necropsy evaluations. Consistent with recommendations for marine mammal health assessments (Geraci et al., 2005), a cautionary note was included emphasizing that these thresholds are heuristic tools and that extreme categories, require expert confirmation and further validation through prospective studies.

RESULTS

Sex- and age-class distribution of dugongs and their body condition scores

For this study, a total of 82 dugongs were included in the analysis and categorized according to sex and age class. Of these, 43 individuals (52.4%) were males, 38 (46.3%) were females, and 1 (1.2%) was of undetermined sex. Based on age classification, 28 individuals (34.1%) were identified as adults, 25 (30.5%) as sub-adults, 18 (22.0%) as juveniles, 7 (8.5%) as dependent calves, and 4 (4.9%) as new-born calves.

Using the estimated BCS guidelines from the Dugong Necropsy Manual in Thailand, BCS distribution by age class, adults (n = 28) included 2 out of 28 (7.1%) individuals with BCS 1, 5 out of 28 (17.9%) with BCS 2, 14 out of 28 (50.0%) with BCS 3, 6 out of 28 (21.4%) with BCS 4, and 1 out of 28 (3.6%) with BCS 5. Sub-adults (n = 25) comprised 2 out of 25 (8.0%) individuals at BCS 1, 7 out of 25 (28.0%) at BCS 2, 11 out of 25 (44.0%) at BCS 3, 4 out of 25 (16.0%) at BCS 4, and 1 out of 25 (4.0%) at BCS 5. Juveniles (n = 18) included 1 out of 18 (5.6%) individuals at BCS 1, 6 out of 18 (33.3%) at BCS 2, 9 out of 18 (50.0%) at BCS 3, and 2 out of 18 (11.1%) at BCS 4, with no individuals classified as BCS 5. Dependent calves (n = 7) comprised 1 out of 7 (14.3%) individuals at BCS 1, 2 out of 7 (28.6%) at BCS 2, and 4 out of 7 (57.1%) at BCS 3, with no cases of BCS 4 or 5. All four new-born calves (100%) were scored as BCS 2. A complete summary of these results is provided in Figure 2.

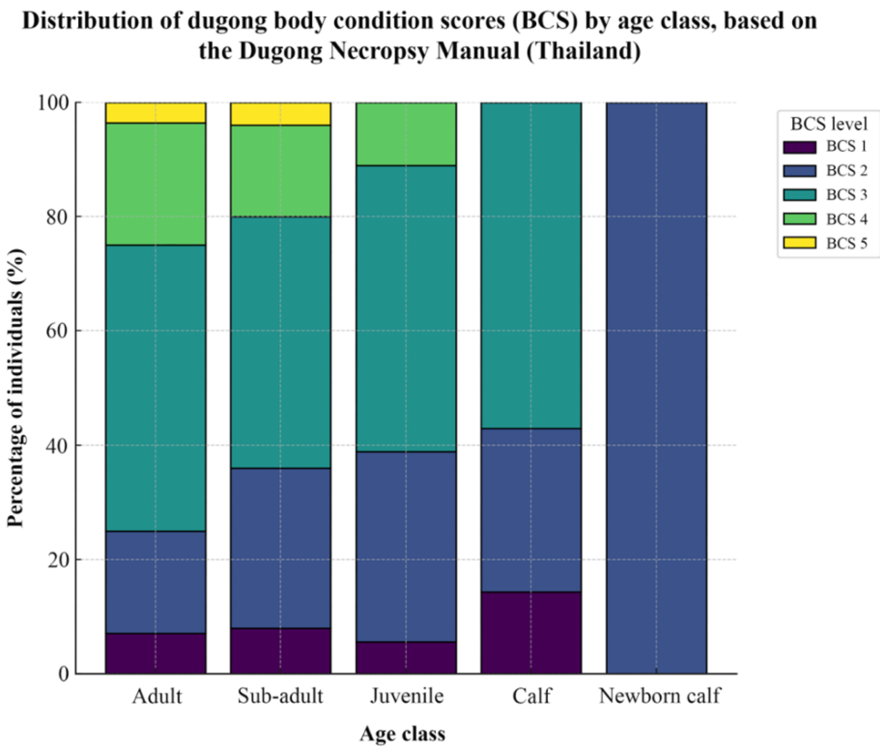

Figure 2 Distribution of dugong body condition scores (BCS) by age class according to the Dugong Necropsy Manual (Thailand).

Descriptive statistics of morphometric and blubber parameters

After grouping dugongs into age classes—newborn calf, calf, juvenile, subadult, and adult—we evaluated the distribution of BCS within each class and summarized the corresponding morphometric and blubber thickness values. Descriptive statistics were applied to present the mean and standard deviation (SD) as representative measures for each group (Table 1). In cases where only a single individual was available (n = 1), the observed value was reported together with "± NA" to indicate the absence of variation. In general, animals with higher BCS exhibited larger body dimensions (weight, chest girth, and length) and greater blubber thickness, whereas those with lower BCS showed reduced morphometric values. In juveniles, mean weight increased progressively from 91.6 ± 31.3 kg at BCS 2 to 117.7 ± 36.3 kg at BCS 3, and further to 190.0 kg at BCS 4. Chest girth also increased steadily from 0.99 ± 0.06 m at BCS 2 to 1.09 ± 0.05 m at BCS 3, and 1.20 m at BCS 4. Among adults, chest girth ranged from 1.23 ± 0.06 m at BCS 1 to 1.68 m at BCS 5, with parallel increases observed for weight and blubber thickness. In subadults, both body length and average blubber thickness demonstrated stepwise increases across BCS 2 to BCS 4. For newborn calves and calves, the sample sizes were limited and data were incomplete across all BCS categories. Nevertheless, preliminary patterns indicated that chest girth and body weight tended to increase with higher BCS categories.

Taken together, these descriptive findings support the biological plausibility that morphometric dimensions and blubber thickness are positively associated with body condition status across age groups.

Evaluation of associations between independent variables and body condition scores

To evaluate the associations between independent variables and BCS, both univariable OLR and two-variable OLR models were performed. Penalized regression was applied to reduce the risk of overfitting, improve model stability, and ensure more reliable estimation of predictor effects, particularly given the limited sample size.

Univariable penalized ordinal logistic regression models

To evaluate whether the independent variables were associated with body condition scores (BCS) as defined in the Dugong Necropsy Manual in Thailand, we applied univariable penalized proportional-odds logistic regression (L2/ridge) within each age class. This approach was chosen to mitigate the effects of small sample sizes and quasi-complete separation, thereby improving the stability of effect estimates.

In newborn calves and calves, none of the morphometric or blubber predictors showed statistically significant associations with BCS, consistent with the restricted sample sizes and the narrow range of condition observed in these age groups.

In juveniles, blubber thickness variables consistently showed positive associations with BCS, with two parameters reaching statistical significance. Specifically, average blubber thickness (OR = 2.06, 95% CI: 1.09–3.90, $p = 0.03$) and blubber D thickness (OR = 1.95, 95% CI: 1.14–3.33, $p = 0.02$) were significantly associated with higher BCS. Other blubber sites (A–C) showed positive but non-significant associations. Among morphometric parameters, none demonstrated significant effects: body condition index (OR = 1.01, 95% CI: 1.00–1.01, $p = 0.20$), girth (OR = 0.98, 95% CI: 0.94–1.02, $p = 0.34$), length (OR = 2.72, 95% CI: 0.39–19.08, $p = 0.31$), and weight (OR = 1.01, 95% CI: 1.00–1.01, $p = 0.15$).

In subadults, blubber thickness parameters emerged as the most informative predictors of body condition. Average blubber thickness (OR = 0.21, 95% CI: 0.06–0.74) and blubber D thickness (OR = 0.64, 95% CI: 0.49–0.89) each demonstrated a significant association with higher BCS ($p < 0.05$).

In adults, several morphometric parameters were significantly associated with higher BCS. Body condition index (OR = 1.03, 95% CI: 1.01–1.04), chest girth (OR = 1.06, 95% CI: 1.00–1.12), and body weight (OR = 1.01, 95% CI: 1.01–1.02) all demonstrated significant positive associations with BCS ($p < 0.05$). In addition, blubber thickness parameters—particularly blubber A thickness (OR = 2.46, 95% CI: 1.21–4.44)—showed a strong and statistically significant association with BCS ($p < 0.01$).

Table 1 Descriptive statistics (mean ± SD) of morphometric parameters (length, chest girth, and weight), body condition index, and blubber thickness (sites A–D and average) across body condition score (BCS) categories within each age class of dugongs (*Dugong dugon*). For categories with only a single individual (n = 1), the observed value is reported as “mean ± NA.”

Age group	BCS	Length (m)	Girth (m)	Weight (kg)	Body condition index	Blubber thickness				
						Area A	Area B	Area C	Area D	Average thickness
Newborn calf	1	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2	1.22 ± NA	0.5 ± NA	30.4 ± NA	24.92 ± NA	2.0 ± NA	2.0 ± NA	0.8 ± NA	0.8 ± NA	3.6 ± NA
	3	0.96 ± 0.08	0.56 ± 0.02	14.0 ± 5.23	14.48 ± 4.3	1.8 ± 1.13	1.1 ± 0.14	0.6 ± 0.14	0.55 ± 0.21	3.21 ± 0.41
	4	1.2 ± NA	0.6 ± NA	32.0 ± NA	26.67 ± NA	2.0 ± NA	2.0 ± NA	1.8 ± NA	2.2 ± NA	4.2 ± NA
	5	NA	NA	NA	NA	NA	NA	NA	NA	NA
Calf	1	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2	1.41 ± 0.01	0.76 ± 0.01	92.0 ± 67.88	65.49 ± 48.8	2.5 ± 0.71	1.75 ± 0.35	0.9 ± 0.57	0.65 ± 0.21	2.15 ± 0.28
	3	1.34 ± 0.06	0.82 ± 0.02	60.24 ± 34.42	45.73 ± 28.41	1.76 ± 0.25	1.6 ± 0.38	0.84 ± 0.22	0.86 ± 0.13	1.96 ± 0.16
	4	NA	NA	NA	NA	NA	NA	NA	NA	NA
	5	NA	NA	NA	NA	NA	NA	NA	NA	NA
Juvenile	1	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2	1.72 ± 0.0	0.99 ± 0.0	58.12 ± 0.0	114.5 ± 0.0	2.5 ± 0.0	1.5 ± 0.0	1.0 ± 0.0	0.5 ± 0.0	1.38 ± 0.0
	3	1.81 ± 0.06	1.09 ± 0.05	54.19 ± 17.37	98.39 ± 33.33	2.04 ± 0.44	1.84 ± 0.47	1.19 ± 0.39	0.97 ± 0.26	1.51 ± 0.21
	4	1.83 ± 0.11	1.2 ± 0.06	68.2 ± 24.43	122.74 ± 43.29	2.34 ± 0.29	2.04 ± 0.21	1.29 ± 0.37	1.21 ± 0.31	1.72 ± 0.27
	5	NA	NA	NA	NA	NA	NA	NA	NA	NA
Subadult	1	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2	2.28 ± 0.1	1.25 ± 0.14	195.1 ± 47.63	85.96 ± 22.43	2.0 ± 0.41	1.7 ± 0.36	1.35 ± 0.51	1.12 ± 0.63	2.84 ± 0.42
	3	2.19 ± 0.15	1.27 ± 0.09	154.03 ± 50.37	69.95 ± 20.13	2.41 ± 0.59	2.24 ± 0.78	1.15 ± 0.47	1.14 ± 0.41	3.03 ± 0.37
	4	2.17 ± 0.18	1.33 ± 0.08	196.45 ± 46.8	89.84 ± 15.91	2.49 ± 0.63	2.29 ± 0.76	1.73 ± 0.71	1.86 ± 0.62	3.39 ± 0.55
	5	NA	NA	NA	NA	NA	NA	NA	NA	NA
Adult	1	2.63 ± 0.13	1.23 ± 0.06	242.5 ± 22.17	92.34 ± 9.28	2.58 ± 0.51	2.25 ± 0.29	2.2 ± 0.73	1.7 ± 0.6	5.18 ± 0.47
	2	2.66 ± 0.12	1.37 ± 0.17	235.89 ± 38.04	88.98 ± 15.21	2.86 ± 0.45	2.47 ± 0.59	1.94 ± 0.46	2.19 ± 0.43	5.36 ± 0.38
	3	2.69 ± 0.14	1.48 ± 0.09	275.06 ± 57.38	101.59 ± 16.33	2.7 ± 0.38	2.48 ± 0.7	1.6 ± 0.35	1.83 ± 0.66	5.15 ± 0.33
	4	2.94 ± 0.27	1.61 ± 0.05	334.7 ± 81.8	112.89 ± 17.15	3.3 ± 0.27	2.66 ± 0.42	1.68 ± 0.56	1.46 ± 0.78	5.28 ± 0.37
	5	2.69 ± NA	1.68 ± NA	303.3 ± NA	112.75 ± NA	3.5 ± NA	2.0 ± NA	3.0 ± NA	3.0 ± NA	5.88 ± NA

Collectively, these results indicate that although predictors were not significant in neonatal and calf groups, clear morphometric and blubber determinants of BCS were identified in juveniles, subadults, and adults. The penalized OLR approach provided more stable and interpretable effect estimates compared with conventional models, particularly under conditions of small sample size and separation. The detailed results of all predictors across age groups are presented in Table 2.

Table 2 Univariable penalized proportional-odds logistic regression (L2/ridge) results for the association between body condition score (BCS) and individual morphometric or blubber predictors across age classes of dugongs (*Dugong dugon*). Odds ratios (OR) with 95% confidence intervals (CI) are shown for each predictor. A penalized approach was applied to mitigate issues of quasi-complete separation and small sample sizes.

Age group	Predictor	OR	95% CI	P-value	Note
Newborn calf	All predictors	NA	NA	NA	Insufficient data (n<5 or BCS<3 levels)
Calf	All predictors	NA	NA	NA	Insufficient data (n<5 or BCS<3 levels)
Juvenile	Average blubber thickness	2.06	1.09–3.90	**0.03**	
	Blubber A thickness	1.32	0.85–2.03	0.21	
	Blubber B thickness	1.43	0.93–2.21	0.11	
	Blubber C thickness	1.21	0.876–1.93	0.41	
	Blubber D thickness	1.95	1.14–3.33	**0.02**	
	Body condition index	1.01	1.00–1.01	0.20	
	Girth (m)	0.98	0.94–1.02	0.34	
	Length (m)	2.72	0.39–19.08	0.31	
	Weight (kg)	1.01	1.00–1.01	0.15	
Sub adult	Average blubber thickness	4.78	1.88–12.17	**0.001**	
	Blubber A thickness	1.95	0.97–3.96	0.063	
	Blubber B thickness	1.59	0.92–2.75	0.096	
	Blubber C thickness	2.35	1.15–4.77	**0.018**	
	Blubber D thickness	4.6	2.12–9.98	**0.000**	
	Body condition index	1.00	0.96–1.03	0.81	
	Girth (m)	3.49	0.94–1.04	0.30	
	Length (m)	0.32	0.95–1.01	0.17	
	Weight (kg)	1.00	0.98–1.01	0.65	
Adult	Average blubber thickness	1.39	0.37–4.53	0.77	
	Blubber A thickness	2.46	1.21–4.44	**0.01**	
	Blubber B thickness	1.0	0.95–1.04	0.82	
	Blubber C thickness	0.68	0.06–3.09	0.70	
	Blubber D thickness	0.84	0.23–2.11	0.67	
	Body condition index	1.03	1.01–1.04	**0.01**	
	Girth (m)	1.06	1.00–1.12	0.07	
	Length (m)	1.01	1.00–1.01	0.18	
	Weight (kg)	1.01	1.01–1.02	**0.01**	

Note. Blubber A corresponds to the dorsal region directly opposite the navel; Blubber B, the lateral body wall; Blubber C, the external abdominal wall between the ribs; and Blubber D, the ventral region posterior to the navel. The average blubber thickness represents the mean value calculated from measurements at sites A–D.

Two-variable penalized ordinal logistic regression models

To identify the best-fitting models, we primarily considered those with the lowest AIC values and ΔAIC < 2. To evaluate the strength of association, we examined McFadden's R^2 and Cox–Snell's R^2, with higher values (closer to 1 but not approaching 0) indicating stronger explanatory power. Negative values of McFadden's R^2 or Cox–Snell's R^2 were interpreted as equivalent to a null model, reflecting no explanatory improvement over the baseline.

Among the two-variable models, only a limited number met the selection criteria. In juveniles, the models including Weight + Blubber D thickness (AIC = 155.23, ΔAIC = 0.00) and BCI + Blubber D thickness (AIC = 156.11, ΔAIC = 0.88) were identified as the best-fitting candidates, with ΔAIC < 2. However, their explanatory performance was modest, as indicated by McFadden's R^2 of 0.18–0.19 and Cox–Snell's R^2 of 0.27, suggesting that these models explained only a small proportion of the variance in BCS. Other juvenile models had substantially higher AIC values (ΔAIC > 5) and therefore received little support. In sub-adults, none of the models demonstrated explanatory strength, with negative pseudo-R^2 values indicating equivalence to the null model. By contrast, in adults, the model including Girth + Average blubber thickness (AIC = 76.99, ΔAIC = 0.00) emerged as the best-fitting candidate, supported by higher pseudo-R^2 values (McFadden's R^2 = 0.29; Cox–Snell's R^2 = 0.66). Nevertheless, interpretation of this adult model should be approached cautiously due to the small sample size. Collectively, these results indicate that while blubber thickness variables—particularly Blubber D—consistently appeared in the best-performing juvenile models, the overall explanatory power of two-variable models remained limited across age classes. The detailed results of all predictors across age groups are presented in Table 3.

Table 3 Penalized two-variable ordinal logistic regression models with information criteria and pseudo-R^2 statistics for body condition score (BCS) across age classes.

Age group	Model	McFadden R2	CoxSnell R2	AIC	ΔAIC
Juvenile	Body condition index + Blubber D thickness	0.18	0.27	156.11	0.88
	Weight (kg) + Blubber D thickness	0.19	0.27	155.23	0.00
	Body condition index + Average blubber thickness	0.15	0.22	163.00	7.78
	Length (m) + Body condition index	0.05	0.08	180.59	25.36
	Weight (kg) + Average blubber thickness	0.16	0.24	160.53	5.30
	Body condition index + Blubber B thickness	0.08	0.13	174.51	19.28
	Length (m) + Weight (kg)	0.06	0.09	178.92	23.69
Sub adult	Girth (m) + Blubber D thickness	-0.09	-0.22	57.16	0.0
	Body condition index + Blubber D thickness	-0.10	-0.24	57.88	0.71
	Weight (kg) + Blubber D thickness	-0.11	-0.26	58.10	0.93
Adult	Girth (m) + Average blubber thickness	0.29	0.66	76.99	0.0

Identification of key predictors of BCS across life stages

To identify the key predictors relevant to each life stage, we relied on the univariable proportional-odds logistic regression results, selecting only those variables that showed statistically significant associations with BCS. In juveniles, blubber measures were the most informative, with Blubber D thickness and average blubber thickness showing significant positive associations with BCS, while morphometric variables such as length, weight, and BCI exhibited only weak or non-significant effects. Building on this, the analysis in subadults revealed that average blubber thickness, together with Blubber C and Blubber D thickness, emerged as significant positive predictors of BCS, suggesting that both localized and overall fat deposition are more reliable indicators of body condition than morphometric measures during this transitional stage. Extending these findings to adults, Blubber A thickness, BCI, and body weight were identified as the principal positive predictors of BCS, reflecting a shift toward combined reliance on both blubber and morphometric indicators in fully grown individuals. Taken together, these life-stage–specific patterns highlight Blubber D and average blubber thickness as key predictors in juveniles, average blubber thickness, Blubber C, and Blubber D as the most informative in subadults, and Blubber A thickness, BCI, and body weight as the best predictors in adults, thereby providing a basis for subsequent modeling and interpretation. However, for practical application, we did not select site-specific blubber thickness measures, as localized variation can be influenced by measurement error and anatomical heterogeneity, which may limit their consistency in field assessments. Instead, we selected broader predictors—average blubber thickness, body weight, and BCI—as the most robust parameters for the application of heuristic thresholds in field-based BCS assessment of dugongs.

Application of heuristic thresholds for field BCS assessment in dugongs

To utilize the results from the identification of key predictors, heuristic thresholds were applied to establish a practical field BCS assessment guide for dugongs. The development of this guide employed the significant positive predictors as the baseline for constructing reference thresholds.

The results demonstrated that, by applying heuristic thresholds, available data were expressed as Mean ± SD, while missing levels were extrapolated and shown in the same format to ensure continuity across BCS categories. As expected, variables identified as significant predictors in OLR analyses (e.g., body weight and average blubber thickness in juveniles, blubber thickness measures in subadults, and BCI in adults) showed monotonic increases across BCS levels, reflecting their biological relevance as indicators of body condition. In contrast, variables that were not significant in OLR tended to exhibit less consistent ordering across BCS levels, reflecting weaker predictive power and greater biological or measurement variability. Therefore, isotonic regression was applied to adjust non-monotonic observed means, ensuring a strictly increasing order across BCS levels, while standard deviations were retained from the original descriptive data. The final thresholds are presented in Table 4.

Table 4 Heuristic thresholds (ranges derived from mean ± SD) of key morphometric and blubber variables across BCS levels (1–5) and age classes in dugongs for field-based condition assessment.

Age class	Variable	Body condition score				
		1	2	3	4	5
Juvenile	Body weight (kg)	34.20–96.90†	60.30–123.00†	81.40–153.90†	91.44–129.50†	116.80–154.86†
	Body condition index	1.82–2.44†	1.88–2.50*	1.73–2.65*	2.02–2.94*	2.02–2.94*
	Average blubber thickness	1.97–2.43†	2.15–2.61†	2.28–2.74†	2.44–3.00†	2.44–3.00†
Sub adult	Body weight (kg)	55.53–100.39*	55.53–100.39*	57.83–98.09*	73.93–105.75†	73.93–105.75†
	Body condition index	1.67–2.93*	1.67–2.93*	1.71–2.89*	1.89–2.71*	1.89–2.71*
	Average blubber thickness	2.54–3.64*	2.54–3.64*	2.72–3.46*	2.67–3.51*	2.67–3.51*
Adult	Body weight (kg)	81.38–99.94*	75.45–105.87*	85.26–117.92†	95.67–129.97*	95.67–129.97*
	Body condition index	2.07–3.09†	2.33–3.23*	2.40–3.16*	3.03–3.57†	3.03–3.57†
	Average blubber thickness	4.71–5.65†	4.88–5.64*	4.93–5.59*	4.91–5.65†	5.51–6.25†

† indicates original calculated values that were not adjusted by isotonic regression; * indicates values adjusted by isotonic regression to enforce a monotonic increase across BCS levels. All values are presented as ranges derived from mean ± SD

Add-on criteria for dugong carcass body condition score (BCS) assessment

In addition to the standard BCS descriptors outlined in the Dugong Necropsy Manual, supplementary indices were applied to enhance consistency. For juvenile dugongs, total length (m) was recorded, and carcass weight (kg) was also recommended as an additional measure. For sub-adult and adult dugongs, girth (m) was recommended as a more reliable indicator of body condition. In adults, the use of average blubber thickness was further recommended, calculated as the mean of four anatomical sites: (i) the dorsal region directly opposite the navel, (ii) the lateral body wall, (iii) the external abdominal wall between the ribs, and (iv) the ventral region posterior to the navel. However, average blubber thickness was not applied in juveniles or sub-adults, likely due to age-related variability in fat deposition patterns.

BCS determination followed the original descriptive criteria, with the supplementary indices serving as supporting evidence in cases where the visual assessment yielded borderline classifications. Additionally, blubber thickness at the ventral region posterior to the navel could be used as an inverse decision modifier in juveniles and sub-adults, where greater thickness indicated a tendency toward leanness. For newborn calves and dependent calves, no supplementary indices were applied owing to insufficient data for reliable analysis. An updated diagram of the body condition scoring system for dugongs is presented in Figure 3.

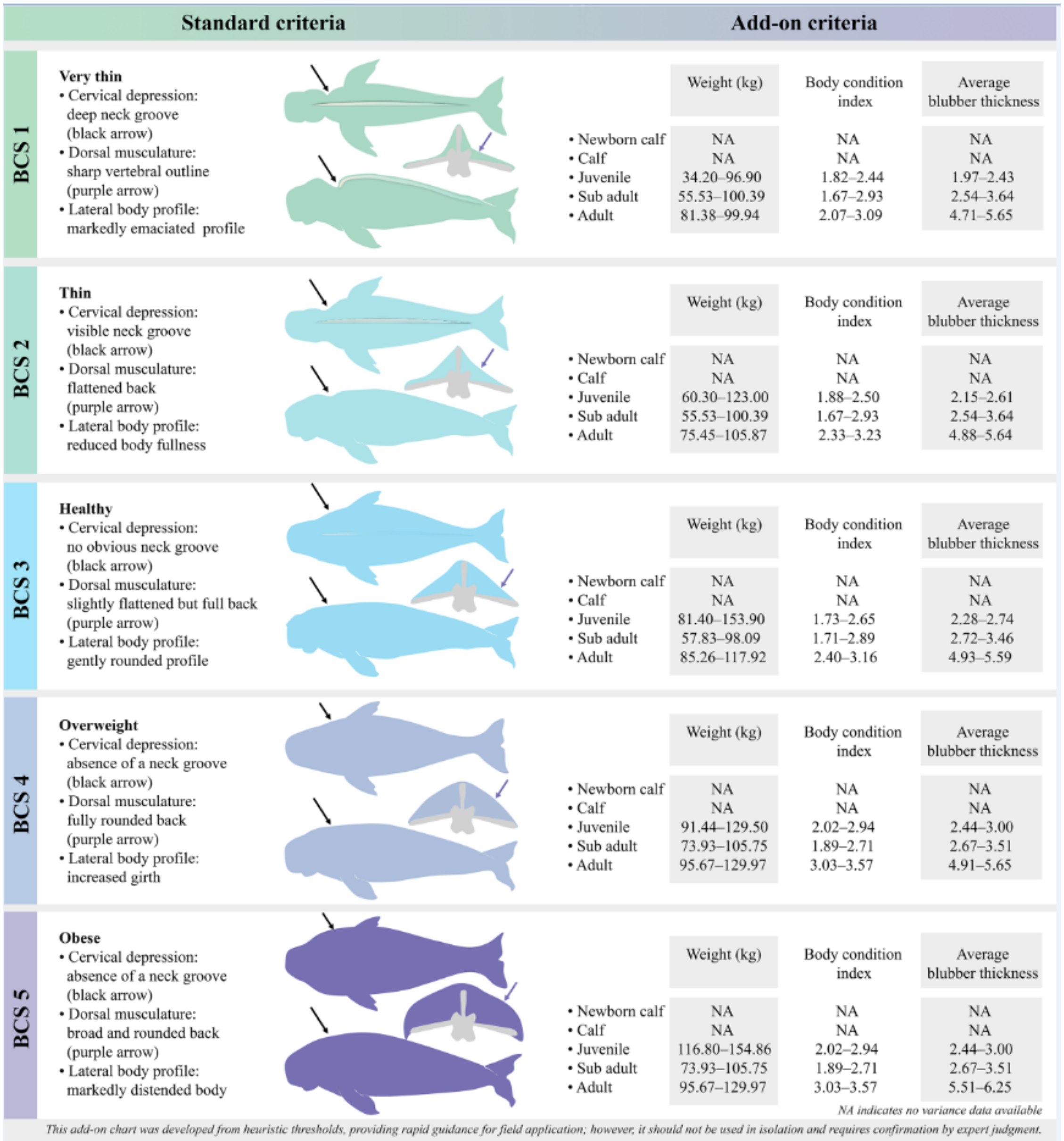

Figure 3 Supplementary (add-on) criteria for dugong carcass body condition score (BCS) assessment, presented alongside the standard descriptors defined in the Dugong Necropsy Manual of Thailand. These additional morphometric indicators (length, weight, girth, and blubber thickness) were incorporated to support and refine the visual-based scoring system, providing greater objectivity and consistency in BCS evaluation across age classes.

DISCUSSION

The dugong (*Dugong dugon*) is an endangered marine mammal species and is designated as a protected animal under Thai law due to its conservation importance and declining population (Government of Thailand, 2019). In recent years, dugong mortality in Thailand has been increasingly attributed to a combination of anthropogenic threats and natural causes (Daochai, 2024; Eiamcharoen et al., 2025). Determining the cause of death in stranded individuals requires a comprehensive necropsy approach, within which BCS evaluation represents a critical component (Geraci et al., 2005; Daochai, 2024). In veterinary pathology, BCS is widely recognized as an indicator of nutritional status and provides important context for interpreting disease processes and mortality events (Burkholder, 2000; Raverty et al., 2020; Zachary, 2022). In this study, the conventional BCS framework provided in the Dugong Necropsy Manual of Thailand was applied across age classes, including dependent calves, juveniles, sub-adults, and adults, all of which exhibited variation in BCS distribution. In contrast, newborn calves were consistently recorded with a BCS of 2, with no representation of other categories. This pattern likely reflects the physiological state of neonates, similar to that observed in ruminant calves, which are born with limited energy reserves and are highly dependent on colostrum for both nutritional and immune support, thereby predisposing them to lower body condition scores relative to older animals (Meale et al., 2017; Silva et al., 2024). In addition, this traditional observation may in part reflect the subjective nature of BCS evaluation and its susceptibility to inter-observer bias (Swartz et al., 2025).

Importantly, the OLR analyses highlighted age-specific differences in morphometric and blubber predictors of BCS. In juveniles, average blubber thickness and ventral blubber thickness posterior to the navel (Blubber D) were consistently identified as positive predictors, suggesting that both overall lipid reserves and ventral abdominal fat deposition are critical indicators of nutritional condition during early growth (Aguilar and Borrell, 1990). In subadults and adults, a similar pattern was observed, with most positive predictors derived from blubber indices. This underscores the importance of both localized and overall blubber reserves as reliable proxies of body condition during the transitional stage to maturity and throughout adulthood, when energy allocation supports somatic growth, reproduction, and long-term survival (Lockyer et al., 1985). These statistical findings align with the broader biological understanding of blubber as a multifunctional tissue. Beyond reflecting energy reserves, blubber also acts as a major lipid reservoir involved in the accumulation and mobilization of lipophilic contaminants, thereby linking tissue-specific fat distribution with whole-body pollutant burden in marine mammals (Yordy et al., 2010). Thus, the consistent association of blubber measures with BCS in our models reinforces its central role in mammalian adaptation to the aquatic environment, where it functions simultaneously as insulation and as an energy store (Koopman et al., 2002). Moreover, variations in blubber thickness and lipid parameters—such as lipid content, adipocyte size, and adipocyte number—are known to occur across ontogeny, reproductive states, and seasonal or regional differences in water temperature, further emphasizing its dynamic role as a biological indicator of condition (Struntz et al., 2004; Dunkin et al., 2005; Meagher et al., 2008; Montie et al., 2008; Noren and Wells, 2009). Therefore, the relative contribution of blubber to body mass is considered a reliable indicator of body condition (Aguilar and Borrell, 1990). Taken together, these findings underscore the need for integrated predictors that combine both blubber-based and morphometric measures for robust BCS assessment.

This study represents the first attempt to establish a field-based body condition scoring (BCS) system for dugongs through necropsy by integrating morphometric indices and blubber measurements into a standardized framework. The use of morphometric parameters such as body body weight, and body condition index, together with blubber thickness measurements, has been widely recognized as a valuable approach for evaluating body condition in marine mammals (Castellini et al., 2009; Joblon et al., 2014; Siebert et al., 2022). In agreement with previous studies, our findings identified body weight, body condition index, and average blubber thickness as key morphometric and blubber-based indices for assessing BCS. These characteristics are particularly suitable for condition assessment because they serve as fundamental indicators of animal biology, contributing to the understanding of behavior, physiology, ecology, evolutionary processes, and biomechanical function (Woodward et al., 2006; Brose, 2010; Rabosky et al., 2013). In marine mammals, assessments of body volume and mass are particularly critical, as they reflect health condition, energetic capacity, metabolic expenditure, thermoregulatory demands, diving physiology, onboard oxygen storage, and locomotor costs (Gillooly et al., 2001; Porter and Kearney, 2009). Total body mass and volume are highly correlated, with their conversion defined by average tissue density (Moya-Laraño et al., 2008). While direct measurements of body mass and volume are considered the "gold standard" for evaluating condition (Farriol et al., 1997; Hughes, 2005), obtaining such data is logistically challenging in fully aquatic mammals (Barratclough et al., 2014; Christiansen et al., 2019). Consequently, indirect morphometric and blubber-based indices provide a practical and informative alternative for BCS assessment in these species, and in the present study, their application in dugongs is further validated. Building upon these validated indices, this study introduces a field-based body condition scoring system using holistic heuristic thresholds, which translates statistical outputs into practical reference ranges for application during necropsy and stranding assessments. Unlike conventional frameworks for cetaceans or pinnipeds that rely primarily on external morphology or photographic evaluation (Castrillon and Bengtson Nash, 2020; Russell et al., 2023), this system integrates morphometric and blubber measurements to produce data-driven thresholds specific to dugongs. This approach improves consistency and objectivity in field assessment by providing quantitative guidance that minimizes observer bias and enhances comparability across sites and age classes. However, as with any heuristic model, intermediate or ambiguous cases should be interpreted cautiously and verified through expert judgment to ensure diagnostic reliability.

Overall, this framework enhances the objectivity and reproducibility of BCS assessment in dugongs and offers a practical decision-support tool for conservation and health monitoring. However, further validation with larger sample sizes, especially in calves and extreme BCS categories, as well as prospective studies in live animals, will be essential to refine and standardize this approach. Moreover, the uneven distribution of samples across age classes and BCS levels (especially calves and BCS 1 and 5) may have affected regression stability and the accuracy of extrapolated thresholds, which should be considered when interpreting and applying these models. Although this system was primarily developed for postmortem evaluation, its framework could potentially be extended to live dugongs by integrating significant morphometric predictors (e.g., body weight, BCI, and blubber thickness) into non-invasive assessment methods, such as drone-based photogrammetry or ultrasound imaging. Such applications would further support long-term health monitoring and conservation management of free-ranging populations.

CONCLUSIONS

This study presents the first field-based body condition scoring system for dugongs, developed by integrating morphometric and blubber-based indices into heuristic thresholds. Average blubber thickness, body weight, and body condition index (BCI) were identified as the most consistent predictors across life stages, enabling the creation of practical lookup tables for necropsy and stranding investigations. This add-on data in the chart was developed from heuristic thresholds, providing rapid guidance for field application; however, it should not be used in isolation and requires confirmation by expert judgment. Although further validation in calves, extreme BCS categories, and live animals is needed, this system enhances the objectivity and reproducibility of BCS assessment and provides a valuable tool for dugong conservation and health monitoring.

ACKNOWLEDGEMENTS

We sincerely thank the Department of Marine and Coastal Resources (DMCR) for providing access to the data utilized in this study. We are especially grateful to the veterinarians and caretakers involved in the rescue, rehabilitation, and postmortem examination of dugongs. We also acknowledge the valuable technical and veterinary support provided by Prince of Songkla University.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Piyarat Khumraksa: Data curation (supporting); formal analysis (lead); methodology (equal); resources (equal).
Santi Ninwat: Resources (lead).
Watcharapol Suyapoh: Conceptualization (lead); data curation (lead); formal analysis (supporting); funding acquisition (lead); investigation (lead); methodology (supporting); project administration (lead); software (lead); supervision (lead); validation(lead); visualization (lead); writing – original draft preparation (lead); writing – review & editing (lead).

REFERENCES

Aguilar, A., Borrell, A., 1990. Patterns of lipid content and stratification in the blubber of fin whales (Balaenoptera physalus). J. Mammal. 71, 544-554.

Barratclough, A., Jepson, P.D., Hamilton, P.K., Miller, C.A., Wilson, K., Moore, M.J., 2014. How much does a swimming, underweight, entangled right whale (Eubalaena glacialis) weigh? Calculating the weight at sea, to facilitate accurate dosing of sedatives to enable disentanglement. Mar. Mamm. Sci. 30(4), 1589–1599.

Brose, U., 2010. Body-mass constraints on foraging behaviour determine population and food-web dynamics. Funct. Ecol. 24(1), 28–34.

Burkholder, W., 2000. Use of body condition scores in clinical assessment of the provision of optimal nutrition. J. Am. Vet. Med. Assoc. 217, 650–654.

Castellini, M., Trumble, S., Mau, T., Yochem, P., Stewart, B., Koski, M., 2009. Body and blubber relationships in Antarctic pack ice seals: Implications for blubber depth patterns. Physiol. Biochem. Zool. 82, 113–120.

Castrillon, J., Bengtson Nash, S., 2020. Evaluating cetacean body condition: a review of traditional approaches and new developments. Ecol. Evol. 10, 6144–6162.

Christiansen, F., Sironi, M., Moore, M.J., Di Martino, M., Ricciardi, M., Warick, H.A., Uhart, M.M., 2019. Estimating body mass of free-living whales using aerial photogrammetry and 3D volumetrics. Methods Ecol. Evol. 10(12), 2034–2044.

Daochai, C., Keawchana, N., Manmoo, S., Khumraksa, P., Kaewmong, P., Ninwat, S., Upanoi, T., Sukkarun, P., Suyapoh, W., 2024. Investigation into the causes of mortality in cetaceans and sirenian populations in the Andaman Sea, Thailand: a retrospective analysis spanning 2018–2023. Vet. World. 17(12), 2889–2898.

de Leeuw, J., Kurt, H., Mair, P., 2009. Isotone optimization in R: Pool-adjacent-violators algorithm (PAVA) and active set methods. J. Stat. Softw. 32, 1-24.

Department of Marine and Coastal Resources, 2013. Dugong necropsy manual in Thailand. Department of Marine and Coastal Resources, Bangkok, Thailand. (in Thai)

Desale, S.A., Rasool, A., Andhale, S., Rane, P.V., 2015. Heuristic and meta-heuristic algorithms and their relevance to the real world: a survey. Int. J. Comput. Eng. Res. Trends. 2(5), 296–304.

Desmet, P.G., 2018. Using landscape fragmentation thresholds to determine ecological process targets in systematic conservation plans. Biol. Conserv. 221, 257–260.

Dunkin, R.C., McLellan, W.A., Blum, J.E., Pabst, D.A., 2005. The ontogenetic changes in the thermal properties of blubber from Atlantic bottlenose dolphin Tursiops truncatus. J. Exp. Biol. 208(8), 1469–1480.

Eiamcharoen, P., Khumraksa, P., Ninwat, S., Suttiboon, T., Keawchana, N., Sornying, P., Suyapoh, W., 2025. Novel insight into dugong mortality: First report of systemic Achromobacter xylosoxidans infection, disseminated intravascular coagulation, and associated pathogenesis. Animals. 15(16), 2441.

Eros, C., Marsh, H., Bonde, R., O'Shea, T., Beck, C., Recchia, C., Pears, R., 2007. Procedures for the salvage and necropsy of the dugong (Dugong dugon). Great Barrier Reef Marine Park Authority, Great Barrier Reef, Townsville.

Farhan, J., 2015. Overview of missing physical commodity trade data and its imputation using data augmentation. Transp. Res. Part C Emerg. Technol. 54, 1–14.

Farriol, M., Rosselló, J., Schwartz, S., 1997. Body surface area in Sprague-Dawley rats. J. Anim. Physiol. Anim. Nutr. 77(1–5), 61–65.

Geraci, J.R., Lounsbury, V.J., Yates, N., 2005. Marine mammals ashore: a field guide for strandings, 2nd edition. National Aquarium, Baltimore.

Gillooly, J.F., Brown, J.H., West, G.B., Savage, V.M., Charnov, E.L., 2001. Effects of size and temperature on metabolic rate. Science. 293(5538), 2248–2251.

Government of Thailand, 2019. Wild Animal Conservation and Protection Act, B.E. 2562 (2019). Available online: https://data.opendevelopmentmekong.net/th/laws_record/ wildlife-conservation-and-protection-act-b-e-2562-2019.

Hemming, V., Burgman, M.A., Hanea, A.M., McBride, M.F., Wintle, B.C., 2018. A practical guide to structured expert elicitation using the IDEA protocol. Methods Ecol. Evol. 9(1), 169–180.

Hughes, S.W., 2005. Archimedes revisited: A faster, better, cheaper method of accurately measuring the volume of small objects. Phys. Educ. 40(5), 468.

UCN, 2025. The IUCN red list of threatened species. Version 2025-1. Available online: https://www.iucnredlist.org.

Joblon, M., Pokras, M., Morse, B., Harry, C.T., Rose, K.S., Sharp, S., Moore, M.J., 2014. Body condition scoring system for delphinids based on short-beaked common dolphins (Delphinus delphis). J. Mar. Anim. Ecol. 7, 5–13.

Kayanne, H., Hara, T., Arai, N., Yamano, H., Matsuda, H., 2022. Trajectory to local extinction of an isolated dugong population near Okinawa Island, Japan. Sci. Rep. 12(1), 6151.

Koopman, H.N., Pabst, D.A., McLellan, W.A., Dillaman, R., Read, A., 2002. Changes in blubber distribution and morphology associated with starvation in the harbor porpoise (Phocoena phocoena): Evidence for regional differences in blubber structure and function. Physiol. Biochem. Zool. 75(5), 498–512.

Lin, M., Turvey, S., Han, C., Huang, X., Mazaris, A., Liu, M., Li, S., 2022. Functional extinction of dugongs in China. R. Soc. Open Sci. 9, 211994.

Lockyer, C., McConnell, L., Waters, T., 1985. Body condition in terms of anatomical and biochemical assessment of body fat in North Atlantic fin and sei whales. Can. J. Zool. 63(10), 2328–2338.

Marsh, H., 1980. Age determination of the dugong (Dugong dugon (Müller)) in northern Australia and its biological implications. Rep. Int. Whal. Commn. 3, 181-201.
Martin, T.G., Burgman, M.A., Fidler, F., Kuhnert, P.M., Low-Choy, S., McBride, M., Mengersen, K., 2012. Eliciting expert knowledge in conservation science. Conserv. Biol. 26(1), 29–38.
Meagher, E.M., McLellan, W.A., Westgate, A.J., Wells, R.S., Blum, J.E., Pabst, D.A., 2008. Seasonal patterns of heat loss in wild bottlenose dolphins (Tursiops truncatus). J. Comp. Physiol. B. 178(4), 529–543.
Meale, S.J., Chaucheyras-Durand, F., Berends, H., Guan, L.L., Steele, M.A., 2017. From pre- to postweaning: Transformation of the young calf's gastrointestinal tract. J. Dairy Sci. 100(7), 5984–5995.
Montie, E.W., Garvin, S.R., Fair, P.A., Bossart, G.D., Mitchum, G.B., McFee, W.E., Hahn, M.E., 2008. Blubber morphology in wild bottlenose dolphins (Tursiops truncatus) from the Southeastern United States: Influence of geographic location, age class, and reproductive state. J. Morphol. 269(4), 496–511.
Moya-Laraño, J., Macías-Ordóñez, R., Blanckenhorn, W.U., Fernández-Montraveta, C., 2008. Analysing body condition: Mass, volume or density? J. Anim. Ecol. 77(6), 1099–1108.
Noren, S.R., Wells, R.S., 2009. Blubber deposition during ontogeny in free-ranging bottlenose dolphins: Balancing disparate roles of insulation and locomotion. J. Mammal. 90(3), 629–637.
Porter, W.P., Kearney, M., 2009. Size, shape, and the thermal niche of endotherms. Proc. Natl. Acad. Sci. U.S.A. 106(suppl. 2), 19666–19672.
Pugliares-Bonner, K., Bogomolni, A., Touhey, K., Herzig, S., Harry, C., Moore, M., 2007. Marine mammal necropsy: an introductory guide for stranding responders and field biologists. Woods Hole Oceanographic Institution, Woods Hole, MA.
R Core Team, 2023. R: A language and environment for statistical computing. Available online: https://www.R-project.org.
Rabosky, D.L., Santini, F., Eastman, J., Smith, S.A., Sidlauskas, B., Chang, J., Alfaro, M.E., 2013. Rates of speciation and morphological evolution are correlated across the largest vertebrate radiation. Nat. Commun. 4, 1958 (2013), 1-8.
Raghunathan, C., Venkataraman, K., Rajan, P.T., 2012. Status of sea cow, dugong (Dugong dugon) in Andaman and Nicobar Islands. Nature Environ. Pollut. Technol. 11, 105–112.
Raverty, S., St Leger, J., Noren, D.P., Burek Huntington, K., Rotstein, D.S., Gulland, F.M.D., Gaydos, J.K., 2020. Pathology findings and correlation with body condition index in stranded killer whales (Orcinus orca) in the northeastern Pacific and Hawaii from 2004 to 2013. PLoS One. 15(12), e0242505.
Russell, G., Christiansen, F., Colefax, A., Sprogis, K.R., Cagnazzi, D., 2023. Comparisons of morphometrics and body condition between two breeding populations of Australian humpback whales. Wildl. Res. 51, 1–10.
Semakula, J., Corner-Thomas, R.A., Morris, S.T., Blair, H.T., Kenyon, P.R., 2021. Application of machine learning algorithms to predict body condition score from liveweight records of mature Romney ewes. Agric. 11(2), 162.
Siebert, U., Grilo, M.L., Kesselring, T., Lehnert, K., Ronnenberg, K., Pawliczka, I., Gilles, A., 2022. Variation of blubber thickness for three marine mammal species in the southern Baltic Sea. Front. Physiol. 13, 880465.
Silva, F.G., Silva, S.R., Pereira, A.M.F., Cerqueira, J.L., Conceição, C., 2024. A comprehensive review of bovine colostrum components and selected aspects regarding their impact on neonatal calf physiology. Animals. 14(7), 1130.
Struntz, D., McLellan, W.A., Dillaman, R., Blum, J.E., Kucklick, J.R., Pabst, D.A., 2004. Blubber development in bottlenose dolphins (Tursiops truncatus). J. Morphol. 259(1), 7–20.

Sukkarun, P., Arnuphapprasert, A., Khumraksa, P., Daochai, C., Jantrakajorn, S., Keawchana, N., Suyapoh, W., 2025. Identification and Pathological Assessment of Mycobacterium spp. Infections in Wild Marine Mammals from the Andaman Sea, Thailand. In The 26th Khon Kaen Veterinary Annual International Conference (KVAC 2025): Trend & Innovation in Veterinary Practice, Pullman Khon Kaen Raja Orchid, Khon Kaen, Thailand, 16-17 July 2025.

Swartz, D., Shepley, E., Caixeta, L.S., Cramer, G., 2025. A descriptive analysis of inter- and intraobserver agreement of body condition scoring methods in dairy cattle. J. Dairy Sci. 108(9), 9712–9727.

Venables, W.N., Ripley, B.D., 2002. Modern applied statistics with S, 4th edition. Springer, New York.

Woodward, B.L., Winn, J.P., Fish, F.E., 2006. Morphological specializations of baleen whales associated with hydrodynamic performance and ecological niche. J. Morphol. 267(11), 1284–1294.

Woolford, L., Franklin, C., Whap, T., Loban, F., Lanyon, J.M., 2015. Pathological findings in wild harvested dugongs Dugong dugon of central Torres Strait, Australia. Dis. Aquat. Org. 113(2), 89–102.

Wurm, M., Rathouz, P., Hanlon, B., 2021. Regularized ordinal regression and the ordinalNet R package. J. Stat. Softw. 99(6), 1–42.

Yordy, J.E., Pabst, D.A., McLellan, W.A., Wells, R.S., Rowles, T.K., Kucklick, J.R., 2010. Tissue-specific distribution and whole-body burden estimates of persistent organic pollutants in the bottlenose dolphin (Tursiops truncatus). Environ. Toxicol. Chem. 29(6), 1263–1273.

Zachary, J.F., 2022. Pathologic basis of veterinary disease, 7th edition. Elsevier, St. Louis, Missouri.

How to cite this article;

Piyarat Khumraksa, Santi Ninwat and Watcharapol Suyapoh. Field-based body condition scoring system for dugongs (*Dugong dugon*): development using morphometric indices and blubber thickness. Veterinary Integrative Sciences. 2026; 24(2): e2026051-1-18.