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Morphometric analysis of resident green sea turtles (*Chelonia mydas*) in Mabul Island, Sabah, Malaysia

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Abstract
A morphometric analysis was conducted on the resident green turtles (*Chelonia mydas*) caught in the waters of Mabul Island, located on the east coast of Sabah, Malaysia. The data was collected from eight field trips conducted between August 2010 through December 2011 and the turtles were caught at seven established dive sites. A series of body size measurements were obtained from 124 juvenile to adult turtles (straight carapace length range 390 – 980 mm). The results showed that juvenile turtles (79.0%) (p = 0.0011) were the dominant size class in this population, therefore the body measurements of the turtles were skewed towards the smaller sizes. The adult male (n = 7) and female (n = 10) turtles were not significantly different in size (p = 0.5248). Regression equations were developed for six single attributes in predicting the Straight Carapace Lengths (SCL) of these green turtles.

Keywords: Morphometrics, Straight Carapace Length (SCL), regression equations, Borneo

1. Introduction
Sea turtles are suited for morphometric analyses due to the rigidity of their main body structures – their shell and skull – which enables precise measurements to be taken [1]. Morphometric data are important with regard to evolution and taxonomy as well as for growth studies [2]. Studies on morphometrics have been conducted on three of the seven extant species of sea turtles [3-5]. Growth patterns of the carapace length and width of captive-reared Kemp's ridley turtles in Texas, USA [3] were similar. Regression analyses showed that the carapace length and width, as well as the plastron length and width yielded strong correlations. Wild hawksbill turtles in Puerto Rico [4] were noted to have a disproportionate increase in Curved Carapace Width (CCW) measurements. This was attributed to greater carapace curvature or "doming" in larger turtles. Adult green turtles in the wild in Brazil [5] were shown to demonstrate positive allometric growth, especially for weight increment when associated with Curved Carapace Length (CCL). In juveniles, the weight-CCL relationship was isometric.
There are four species of sea turtles that can be found in Malaysia, namely the leatherback turtle (*Dermochelys coriacea*), green turtle (*Chelonia mydas*), hawksbill turtle (*Eretmochelys imbricata*), and olive ridley (*Lepidochelys olivacea*) [6]. The dominant species of sea turtles in Sabah is the green turtle, however hawksbills and olive ridleys can also be found here [7]. There are various studies on the nesting activity of the adult female turtles in Malaysia [8-11], however there are only two publications on at-sea populations of sea turtles in this country [12-13], mainly due to the high costs and intensive amount of labor required for such studies. At present there is a paucity of morphometric data on the population of sea turtles in Malaysia, hence the importance of the current study.
Four size classes of sea turtles can be found in the waters of Mabul Island – juveniles, sub-adults, adult males and adult females. The main objective of this study is to characterize the morphometry of the resident green sea turtle population of Mabul Island. The data from this study will be used towards the management and conservation of the sea turtles of this island.

2. Materials and Methods
Mabul Island (4.25°N, 118.63°E) is located off the coast of Semporna, east coast of Sabah, Malaysia, and part of the Coral Triangle [14]. The sea turtles here live and forage in the coral reef and seagrass habitats of this island. A mark-recapture study was conducted on the sea turtles found in these waters from August 2010 through December 2011.

A total of 16 days of field work was completed in 2010 (August, October and December) and 2011 (February, April, June, October and December). The turtles were caught by hand while scuba diving during the day at the seven established dive sites at depths not exceeding 20m. The turtles were photographed, measured and tagged on board the research vessel. The details of the turtle measurements taken are shown in Table 1. All the straight measurements were taken using a 1.0m Mitutoyo stainless steel vernier caliper (0.5 mm with an accuracy of ±0.15mm) and 150mm Mitutoyo stainless steel vernier caliper (0.02 mm with an accuracy of ±0.03mm), whereas all the curved measurements were taken with a 1.5m plastic measuring tape (1 mm with an accuracy of ±0.5mm). The turtles were tagged with Inconel tags (National Band and Tag Company, Newport, Kentucky, USA) which were attached to the posterior edge of both front flippers.

The dataset was corrected if errors were made during transcription. All the data was checked to ensure that there were no outliers. Outliers are data that are more than three standard deviations from the mean, and should be removed for statistical reasons. Linear regressions were used to derive predictive relationships between Straight Carapace Length (SCL) and six other attributes - Head Length (HL), Head Width (HW), Straight Carapace Width (SCW), Plastron Length (PL), Curved Carapace Length (CCL) and Curved Carapace Width (CCW), and were in the form:

$Y = A + BX \pm SEE$

Where Y is SCL (in mm), X is the Predictor variable, A is the Y value (SCL) when X is zero (i.e. the Y intercept), B is the slope of the regression line and SEE is the standard error of the estimate (the square root of the residual mean square). Significance was at the 0.05 level for all the statistical tests used to analyze the data collected in this study.

Table 1: Morphological end-points for each of the measurements of the turtles taken with the resolution of measurement (in brackets).

Attribute	Description
Head Length (HL)	From the anterior-most part of the upper jaw to the posterior tip of the skull (1 mm).
Head Width (HW)	At the widest point of the head (1 mm).
Straight Carapace Length (SCL)	From the anterior point at midline (nuchal scute) to the posterior tip of the supracaudals (1 mm).
Straight Carapace Width (SCW)	At the widest point of the carapace (1 mm).
Plastron Length (PL)	Along the midline from the anterior to the posterior margin of the plastron (1 mm).
Curved Carapace Length (CCL)	From the junction of skin and scute to the posterior tip of the supracaudals along the midline (1 mm).
Curved Carapace Width (CCW)	At the widest point of the carapace (1mm).

3. Results and Discussion

The total number of green turtles caught in this study from August 2010 through December 2011 was 124, comprising of four size classes – juveniles, sub-adults, adult males and adult females (Fig. 1). The morphometric details of all the turtles are shown in Table 2 whereas the breakdown of the turtle captures at the seven specific dives sites in Mabul Island with regard to size classes in shown in Table 3.

Fig 1: The four size classes of green turtles (*Chelonia mydas*) in Mabul Island - juvenile (A); sub-adult (B); adult male (C) and adult female (D).

Table 2: Details of the green turtle morphometric database (N = 124).

Attribute	Mean (± s. d.) (mm)	Range (mm)
Head Length (HL)	147.3 ± 32.2	100 – 223
Head Width (HW)	91.2 ± 20.6	61 – 139
Straight Carapace Length (SCL)	610.0 ± 163.6	390 – 980
Straight Carapace Width (SCW)	493.7 ± 115.9	324 – 747
Plastron Length (PL)	499.5 ± 134.3	313 – 791
Curved Carapace Length (CCL)	662.6 ± 180.7	417 – 1057
Curved Carapace Width (CCW)	593.0 ± 158.2	381 – 928

Table 3: Details of the green turtle captures at seven established dive sites in Mabul Island, Sabah.

Dive Site (GPS Location)	Juvenile	Sub-Adult	Adult Male	Adult Female	Total
Borneo Divers' Jetty (4.24°N, 118.63°E)	14	2	0	1	17
Ribbon Valley 1 (4.23°N, 118.64°E)	2	0	0	1	3
Eel Garden (4.23°N, 118.64°E)	8	1	0	1	10
Lobster Wall (4.23°N, 118.62°E)	30	2	5	2	39
Panglima Reef (4.24°N, 118.62°E)	4	1	0	1	6
Paradise II (4.24°N, 118.63°E)	8	1	0	3	12
Ray Point (4.23°N, 118.64°E)	32	2	2	1	37
Total	98	9	7	10	124

The results from this study (Tables 2 and 3) showed that the dominant size class of the sea turtles captured in Mabul Island was juveniles (79.0%) (ANOVA F (3, 24) = 7.400; p = 0.0011) indicating a healthy recruitment into the green turtle population in this area. These results concur with those from another study [13] conducted at this island over a longer period (five years). There were 98 captures of juvenile green turtles in Mabul Island, and the smallest was 390mm SCL whereas the largest was 826mm SCL (mean ± s.d. = 540.5 ± 99.7mm). These results are very similar to those reported in Mantanani Island located on the west coast of Sabah [12], where the SCL of 75 turtles ranged from 360 to 799mm (mean ± s.d. = 474 ± 66.0mm). There was only one size class of turtles in Mantanani – juveniles. In Brazil [5], the highest number of turtle captures were also of juveniles (n = 368) and the SCL ranged from 300 to 650mm (mean ± s.d. = 310 ± 22.0mm). The resident green turtle population in Mabul Island also consisted of other size classes of turtles, namely sub-adults (n = 9), adult males (n = 7) and adult females (n = 10). There were no adult turtles in Mantanani Island [12] however, in Brazil [5], adult males (n = 113) and adult females (n = 331) were also present.

The series of body size measurements chosen for this study correspond to those commonly taken of sea turtles using distances between precisely definable points on the carapace and head. The carapace measurements (Straight Carapace Length (SCL), Straight Carapace Width (SCW), Curved Carapace Length (CCL) and Curved Carapace Width (CCW)) of the Mabul green turtle population is comparable to those reported in Mantanani Island [12] and Brazil [15]. The scattergram shown in Fig. 2 highlights the Straight Carapace Lengths of all the size classes of the Mabul green turtle population. There is an overlap between the SCL of the sub-adult and adult male turtles: sub-adults 712 to 930mm (mean ± s.d. = 827.2 ± 58.4mm); adult males 827 to 980mm (mean ± s.d. = 886.9 ± 52.1mm). A statistical test shows that there is no significant difference between these two size classes (unpaired t-test: t = 2.120, df = 14, p = 0.523). The SCL of the adult female turtles in Mabul Island ranges from 811 to 952mm (mean ± s.d. = 901 ± 37.8mm). Statistical tests however prove that the differences in SCL between the sub-adults and adult females are significant (unpaired t-test: t = 3.304, df = 17, p = 0.0042), but this is not so between the adult males and females (unpaired t-test: t = 0.651, df = 15, p = 0.5248).

The results from Mabul Island are dissimilar to the findings in Brazil [15] which found that on average, the males were smaller than the females. This could be due to the small sample size in Mabul where only seven adult males and 10 adult females were caught. The study in Brazil had sample sizes of 113 adult male green turtles and 331 adult females. In Mantanani, the juvenile male turtles were also reported to be smaller than the female turtles [12]. This could also be due to the small sample size as there were only 15 males and 60 juvenile female turtles.

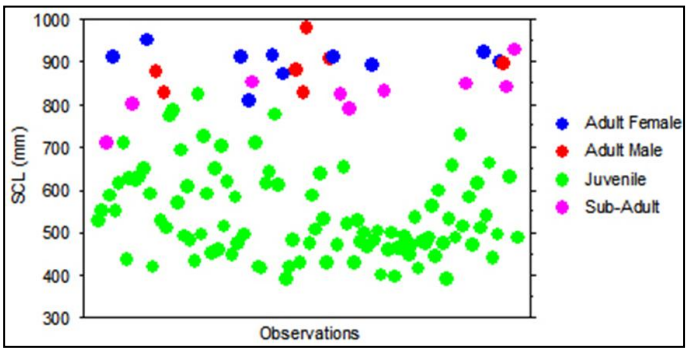

Fig 2: A scattergram showing the Straight Carapace Lengths (SCL) of the four size classes of green turtles (*Chelonia mydas*) in Mabul Island.

Most sea turtle studies tend to use carapace length (straight or curved) more frequently than other variables [3-5], hence Straight Carapace Length (SCL) was chosen as the attribute for the predictive relationships. The predictive relationships derived from linear regressions (Fig. 3) are shown in Table 4. For example, if one had a skull of a green turtle with the Head Length (HL) of 150mm, Equation 1 predicts that the Straight Carapace Length (SCL) would equal 870 ± 33.7 mm (95% Confidence Interval). Another example uses Equation 4 to derive the SCL of 611 ± 16.9 mm (95% Confidence Interval) from a Plastron Length (PL) of 500mm. The equations provided in Table 4 allow the accurate reconstruction of a green turtle (*Chelonia mydas*) from single-attribute measurements. Predicting the Straight Carapace Lengths (SCL) of the green turtles in Mabul Island from these equations can be useful when parts of turtle carcasses (turtle skulls or plastrons) wash up on shore or are confiscated from illegal poachers by the authorities. A study conducted [2] in Australia shows that such equations also allow the reconstruction of a freshwater crocodile (*Crocodylus johnstoni*) from single attributes.

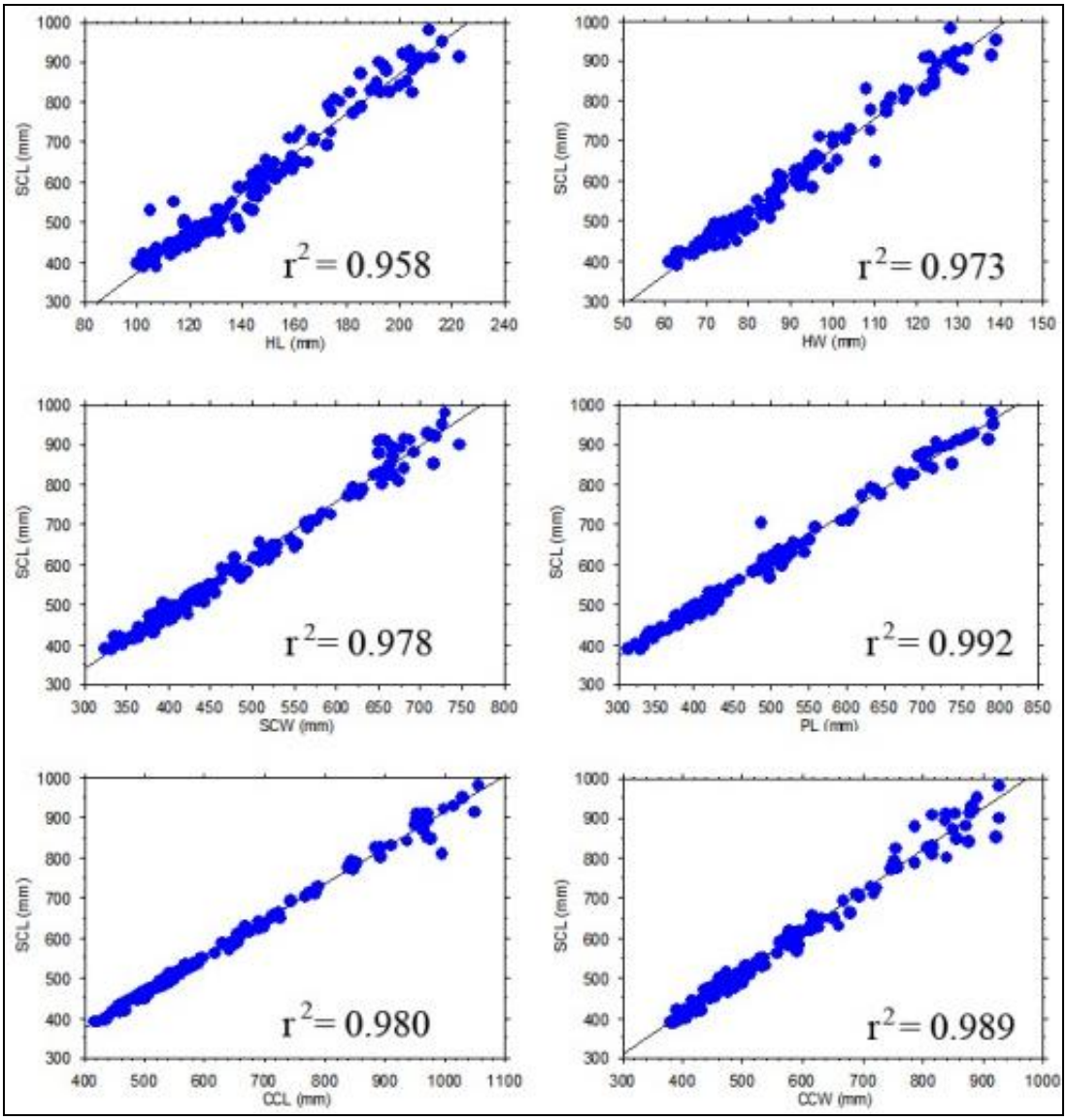

Fig 3: Bivariate plots showing the different attributes (Head Length (HL), Head Width (HW), Straight Carapace Width (SCW), Plastron Length (PL), Curved Carapace Length (CCL) and Curved Carapace Width (CCW)) as a function of Straight Carapace Length (SCL) in the green turtles of Mabul Island. Lines indicate linear regression relationships.

Table 4: Coefficients for predicting Straight Carapace Length (Y) from 6 single attributes (X) by linear regression analysis (Y = A + BX ± SEE), *p*-values for all equations are $p<0.0001$, N = 124. SEE = Standard Error of the Estimate.

Equation No.	Predictor (X)	Predictor range (mm)	A ± SE	B ± SE	SEE	r^2
1	Head Length (HL)	100 – 223	123.158 ± 14.199	4.977 ± 0.094	33.659	0.958
2	Head Width (HW)	61 – 139	105.664 ± 11.162	7.849 ± 0.119	27.268	0.973
3	Straight Carapace Width (SCW)	390 – 980	80.302 ± 9.551	1.398 ± 0.019	24.214	0.978
4	Plastron Length (PL)	324 – 747	3.668 ± 5.881	1.214 ± 0.011	16.936	0.992
5	Curved Carapace Length (CCL)	313 – 791	11.570 ± 4.997	0.903 ± 0.007	14.586	0.980
6	Curved Carapace Width (CCW)	417 – 1057	1.997 ± 8.214	1.025 ± 0.013	23.483	0.989

4. Conclusions

The results presented here represent the baseline data collected over a span of two years. As juvenile green turtles were the dominant size class, the measurements were skewed towards the smaller sizes. It is hoped that long-term datasets will provide a more balanced profile of the resident green turtle population in Mabul Island. The results of this study are comparable to the green turtle population in Mantanani Island (west coast Sabah, Malaysia) and in Brazil – where juveniles were the dominant size class, however the adult turtles in Mabul Island are similar in size whereas the males were generally smaller than females in Mantanani Island and Brazil. These findings will be used by the relevant authorities towards the management and conservation of the green turtle population in Mabul Island.

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