Malaysian Applied Biology
https://doi.org/10.55230/mabjournal.v54i2.3034

Research Article

Comparative Blood Profile Analysis of Captive Green (*Chelonia mydas*) and Hawksbill (*Eretmochelys imbricata*) Turtles

Afiqah Dharwisyah David[1], Mohd Uzair Rusli[2], Mohammad Fathullah Ruslan[3], Juanita Joseph[4], Syamsyahidah Samsol[2]*

1. Institute of Ocean and Earth Sciences, Universiti Malaya, Kuala Lumpur, Malaysia
2. Sea Turtle Research Unit (SEATRU), Institute of Oceanography and Environment, Universiti Malaysia Terengganu, Terengganu, Malaysia
3. Fisheries Research Institute Rantau Abang, Dungun, Terengganu, Malaysia
4. Borneo Marine Research Institute, Universiti Malaysia Sabah, Kota Kinabalu, Sabah, Malaysia

*Corresponding author: syamsyahidah@gmail.com

ABSTRACT

The green turtle (*Chelonia mydas*) and hawksbill turtle (*Eretmochelys imbricata*), classified as endangered and critically endangered, respectively, face significant survival threats. To assess their health status, a study was conducted using a portable blood analyzer on eight captive sea turtles kept at the Fisheries Research Institute of Rantau Abang (FRIRA), Terengganu, Malaysia. Blood gas, biochemical, and hematological parameters were analyzed. Findings were generally consistent with previously reported hematological values and morphology, except for total white blood cell (WBC) counts. Comparisons with published data on sea turtles worldwide showed higher ranges of mean values for lactate (Lac), glucose (Glu), creatinine (Crea), blood urea nitrogen (BUN), packed cell per volume (PCV), and WBC counts. Captive green and hawksbill turtles exhibited higher concentrations of Glu and Lac than previously documented values, with mean Glu and Lac levels of 100.50 mg/dL and 6.75 mmoL/L in green turtles and 121.00 mg/dL and 0.93 mmoL/L in hawksbill turtles. These variations were attributed to differences in life stage, diet, and environmental conditions. Glucose levels were indicative of dietary influence, while lactate concentrations suggested stress, emphasizing the importance of specialized dietary management and the potential stress experienced by green turtles in captivity. These findings provide invaluable reference points for monitoring the health of captive sea turtles in rehabilitation settings. Additionally, it also highlights the unique physiological characteristics of sea turtles in the South China Sea and the impact of captivity on their blood profiles, contributing to ongoing conservation efforts.

Key words: Blood biochemistry, blood gas, sea turtles, hematological morphology, South China Sea

INTRODUCTION

Sea turtles are marine reptiles that are commonly found in tropical, subtropical, and temperate oceans worldwide. There are a total of seven species of marine turtles globally, five of which have been recorded in Malaysia (Chan, 2006; Sidique *et al*., 2017; Mohd Salleh *et al*., 2018; Rahman *et al*., 2021; Jolis *et al*., 2023); the green turtle (*Chelonia mydas*), hawksbill turtle (*Eretmochelys imbricata*), olive ridley turtle (*Lepidochelys olivacea*), leatherback turtle (*Dermochelys coriacea*), and loggerhead turtle (*Caretta caretta*). While the leatherback turtle is now locally extinct in Malaysia (Joseph *et al*., 2021), juvenile loggerhead turtle has been recorded off Penang Island, suggesting the presence of potential foraging grounds in the Straits of Malacca and the Andaman Sea (Rahman *et al*., 2021).

Sea turtles play vital ecological roles in the ecosystem services that people derive from and depend on for their well-being (Patel *et al*., 2022). Sea turtles contribute to cultural services for communities that interact with them. They also contribute to provisioning services (food, medicine & ornaments) (Chandrasekar *et al*., 2013; Patel *et al*., 2022), regulating services (biodiversity regulation, habitat modification, and supporting services like nutrient cycling and nutrient transport) (Patel *et al*., 2022; Nishizawa *et al*., 2024). Despite their ecological and socio-ecological importance, sea turtles are endangered as they continue to face threats due to excess exploitation and anthropogenic activities. The hawksbill turtle is a critically endangered species whereas the green turtle, the dominant species in Terengganu is endangered (Ghazali & Jamil, 2019). The various factors contributing to the threats faced by the turtles included environmental pollution, plastic debris ingestion, habitat loss, entanglement in fishing nets, by-catch (Mazaris *et al*., 2017; Escobedo-Bonilla *et al*., 2022), poaching, and illegal wildlife trade (Joseph *et al*., 2014; Joseph *et al*., 2019). Historically, sea turtle eggs were harvested for subsistence, but over time, this practice has evolved into profit-oriented commercial sales, accelerating population declines (Jani *et al*., 2020; Ingram *et al*., 2022). Vessel strikes also threaten sea turtle populations as these strikes often result in mortality (Phu *et al*., 2019; Schoeman *et al*., 2020; Welsh & Witherington, 2023) or severe injuries such as fractures and lacerations (Welsh & Witherington, 2023). Efforts to address sea turtle extinction involve safeguarding nesting beaches and establishing marine protected areas, minimizing fisheries by-catch through the implementation of turtle excluder devices (TEDs) (Escobedo-Bonilla *et al*., 2022), gazettement of sea turtle

Article History
Accepted: 29 March 2025
First version online: 30 June 2025
Cite This Article:
David. A.D., Rusli, M.U., Ruslan, M.F., Joseph, J. & Samsol S. 2025. Comparative blood profile analysis of captive green (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricata*) turtles. Malaysian Applied Biology, 54(2): 119-127. https://doi.org/10.55230/mabjournal.v54i2.3034

sanctuaries (Poti *et al*., 2021); and the implementation of sea turtle rehabilitation or rescue centers to provide temporary care for injured or stranded turtles before their reintroduction to the wild (Escobedo-Bonilla *et al*., 2022).

Besides anthropogenic threats such as by-catch, habitat destruction, and egg exploitation, sea turtles are also susceptible to various diseases (Denkinger *et al*., 2013; Samsol *et al*., 2020), including fibropapillomatosis, pneumonia, neoplasm, hepatitis, meningitis, and septicemia (Oros *et al*., 2005; Denkinger *et al*., 2013; Samsol *et al*., 2020).

Injury and diseases in sea turtles require immediate medical care and attention. The rescue, rehabilitation, relocation, and release (often abbreviated as RRRR) approach has become an essential aspect of wildlife conservation and veterinary medicine (Sleeman & Clark, 2003; Innis *et al*., 2019). Within rehabilitation centers, sea turtles are monitored in a controlled environment due to their sensitivity to varying temperatures, salinity, pH, and overcrowding (Higgins, 2003). Despite extensive care, subclinical diseases and outbreaks of contagious pathogens have been documented among captive turtles (Herbest & Jacobson, 2003; Escobedo-Bonilla *et al*., 2022). Additionally, captivity may induce stress-related behaviors, particularly under high confinement levels (Wood, 2022). Proper handling, transportation protocols, quarantine procedures, enclosure design (Wood, 2022), and seawater quality management (Higgins, 2003) are critical for ensuring the welfare of captive turtles. At the Fisheries Research Institute Rantau Abang (FRIRA) in Terengganu, captive sea turtles are primarily rescued due to stranding incidents, disease, boat strikes, severe injuries, amputations, and mobility impairments.

Regular health assessments are essential for monitoring the well-being of captive sea turtles and identifying potential health risks. The evaluation of health indices can be employed to assess the health status of captive turtles (Page-Karijan & Perrault, 2021). Blood profiles serve as a useful diagnostic tool for evaluating health status, as blood parameters are influenced by factors such as sex, size, seasonal variation, and water temperature (Li *et al*., 2015). Blood biochemical markers, which are highly sensitive, provide early indicators of organ dysfunction (Labrada-Martagón *et al*., 2010). In addition to blood analyses, visual assessments can also be used to categorize health status (Labrada-Martagón *et al*., 2010). Hematological and plasma biochemistry profiles are particularly valuable for clinical management, especially during the recovery phase. Hematological assessments can detect abnormalities such as anemia, leukocytosis, monocytosis, and heterophilia (Stacy *et al*., 2011).

Establishing blood reference intervals (RIs) for sea turtles is crucial for assessing the health status of individuals in both captive and wild populations. The objectives of the study are to: (i) determine the blood gases, biochemistry, and hematological profiles of captive sea turtles in Terengganu, Malaysia, (ii) establish blood reference intervals for green and hawksbill turtles in the South China Sea, and (iii) compare blood analytes of captive sea turtles with those of wild sea turtles in the region. Additionally, the findings from this study will help assess the health of captive turtles in other rehabilitation centers by comparing blood reference intervals across different facilities.

MATERIALS AND METHODS

Fieldwork and sample collection

Captive sea turtles were obtained from the Fisheries Research Institute Rantau Abang (FRIRA), Terengganu, Malaysia (Figure 1). FRIRA is a research center under the Department of Fisheries Malaysia, and is dedicated to the research, conservation, and public education on sea turtles and marine mammals. All sea turtle examinations were conducted within the FRIRA facility.

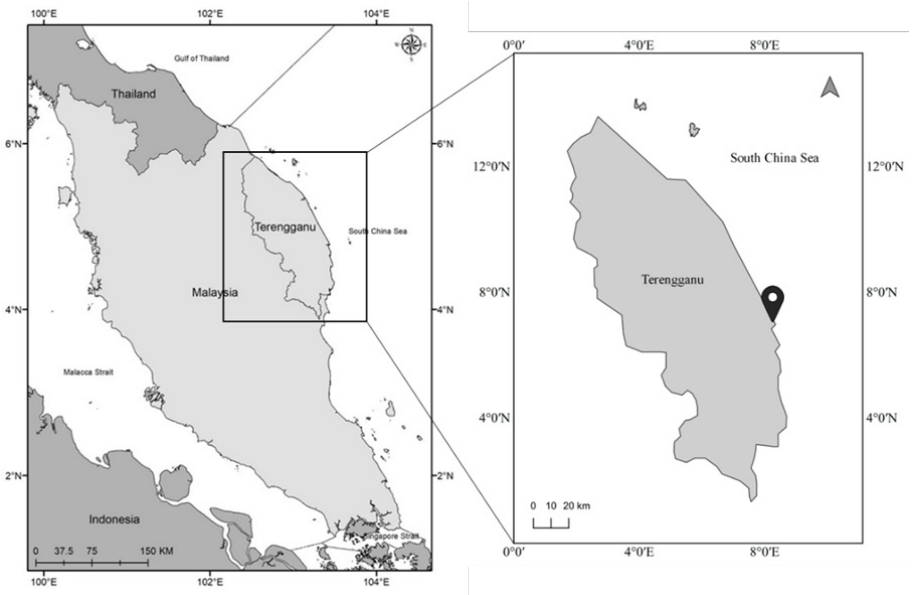

Fig. 1. Map of Peninsular Malaysia showing the location of Fisheries Research Institute Rantau Abang (FRIRA), Terengganu, Malaysia.

Sea turtles were carefully removed from their tanks by trained specialists. Gloves were used while handling sea turtles. Following the guidelines of Norton and Wyneken (2015), each turtle was securely and humanely restrained, with its vision covered to reduce stress. Species identification and visual body examinations were conducted, including body condition scoring (BCS) which was assessed on a one-to-five scale based on visual interpretation (Table 1).

Table 1. Body condition scoring (BCS) of sea turtles (Norton & Wyneken, 2015)

BCS Score	Characteristics / Visual Interpretation
1	Emaciated: Sunken eyes, lack of shoulder and neck musculature
2	Thin: Pronounced neck muscles, thin and wrinkled shoulders
3	Normal: Balanced body condition
4	Robust: Well-developed musculature, healthy body condition
5	Obesity: Excessive fat, particularly around the shoulders and neck

The presence of wounds, epibionts, fibropapillomatosis (FP) tumors, and scars was recorded before the turtles were returned to their tanks. Morphometric measurements, including curved carapace length (CCL) and curved carapace width (CCW), were taken using a flexible measuring tape.

A total of eight juvenile sea turtles (four green & four hawksbill turtles), measuring 30 – 60 cm, were selected for sampling, as they were potential candidates for release within the following months. The turtles were transferred to a sanitized area within the FRIRA facility for blood withdrawal. After physical examinations, they were placed on a soft foam board to ensure comfort, with their vision covered to minimize stress. The restraint method involved gentle pressure on the carapace, with two to four trained personnel assisting, depending on the turtle's size. The entire handling process, including blood withdrawal, was completed within one hr, and the turtles regained composure within 10–20 sec after release.

Blood collection was carried out in less than three min to reduce stress. During the process, the turtle's head was slightly tilted to facilitate blood sample collection from the dorsal cervical sinus. This method was common in withdrawing blood from sea turtles (Perpiñán, 2015; Joseph *et al*., 2016). A 22-gauge heparinized needle attached to a 5.0 mL syringe was used to collect approximately 2.5 mL of blood from either the left or right dorsal cervical sinus (Owens & Ruiz, 1980). Needles smaller than 22 gauge were not used to prevent hemolysis, as sea turtles have large red blood cells (RBC) (Norton & Mettee, 2020). The puncture site was disinfected before and after the procedure with 70% ethanol and iodine solutions (Li *et al*., 2015).

The collected blood samples were immediately divided into lithium heparin (LiHe) tubes for hematological and blood biochemical analyses. The samples were stored in a portable mini fridge (2 – 10°C) to maintain the optimal temperature before laboratory analyses. The body temperature of each turtle was also measured using an infrared thermometer to account for temperature-sensitive blood parameters.

Laboratory analysis

Blood smears were observed under the 40x objective for total white blood cell (WBC) counts and under a 1000x objective for blood cell morphology assessment. Packed cell volume (PCV) was determined manually via microhematocrit centrifugation at 12,000 rpm for 5 min (Samsol *et al*., 2020).

Blood gases, biochemistry, and hematological profiles analyzed in this study include lactate (Lac), sodium (Na), potassium (K), chloride (Cl), ionized calcium (iCa), glucose (Glu), pH, partial pressure of carbon dioxide (pCO_2), partial pressure of oxygen (pO_2), total carbon dioxide (TCO_2), bicarbonate (HCO3), base excess (BE), oxygen saturation (sO_2), creatinine (Crea), anion gap (AnGap), and blood urea nitrogen (BUN), hemoglobin (Hb) and hematocrit (Hct).

Blood samples were collected, handled, and processed according to standardized protocols to maintain sample quality. Blood was immediately transferred into heparinized syringes to prevent clotting and processed within 10 min using an i-STAT Portable Handheld Blood Analyzer (Abbott Laboratories, IL, USA) with CHEM-8+ and CG4+ i-STAT cartridges. The i-STAT analyzer, a battery-operated electronic device, can measure a wide variety of blood gases, biochemistry, and basic hematology parameters using a minimal blood volume (0.095 mL) (Lewbart *et al*., 2014). To ensure measurement accuracy, the analyzer was regularly calibrated as per the manufacturer's guidelines, with internal quality control checks conducted before each new batch of CHEM-8+ and CG4+ cartridges. Some studies (Chittick *et al*., 2002; Harms *et al*., 2003) have questioned the validity of i-STAT temperature correction. To address this, turtle body temperatures were entered for temperature-sensitive parameters (pH, pCO_2 & pO_2) following Lewbart *et al*. (2014). Additionally, auto-corrected temperature values were reported in this study for consistency and transparency.

Data analysis

Mean, standard deviation, maximum, and minimum values were recorded for each blood gas, biochemistry, and hematological parameter. Statistical analyses were conducted using IBM SPSS software version 26 (SPSS Inc., Chicago, IL. USA).

RESULTS

Body condition scoring

A total of four captive green turtles and four hawksbill turtles were examined at FRIRA. These turtles were identified as juveniles, with a CCL ranging from 30 to 60 cm. BCS ranged between 3 and 4, indicating that all turtles were in clinically healthy condition. No signs of FP, lesions, or severe epibiont load were observed.

Blood gases and biochemistry profiles

Table 2 shows the blood gases and biochemistry profiles of captive turtles from FRIRA. Auto-corrected values of certain temperature-sensitive analytes, as well as values generated by the iSTAT analyzer, were statistically significant (p<0.05). The analytes assessed included lactate (Lac), sodium (Na), potassium (K), chloride (Cl), ionized calcium (iCa), glucose (Glu), pH, partial pressure of carbon dioxide (pCO_2), partial pressure of oxygen (pO_2), total carbon dioxide (TCO_2), bicarbonate (HCO_3), base excess (BE), oxygen saturation (sO_2), creatinine (Crea), anion gap (AnGap), and blood urea nitrogen (BUN). Several inter-species variations in mean analyte levels were observed. For instance, Glu levels were lower in green turtles (100.50 mg/dL)

compared to hawksbills (121.00 mg/dL), while the mean of BUN levels was higher in green turtles (3.51 mmoL/L) compared to hawksbills (3.19 mmoL/L).

Additionally, pCO_2 and pO_2 were higher in green turtles, with mean values of 78.30 mmHg and 160.75 mmHg, respectively, compared to 54.95 mmHg and 105.00 mmHg in hawksbills. As for Lac levels, it was also significantly elevated in green turtles (6.75 mmoL/L) compared to hawksbills (0.93 mmoL/L). In contrast, BE was higher in hawksbills (8.00 mmoL/L) than in green turtles (2.25 mmoL/L). Other analytes exhibited comparatively similar mean values between the two species.

Table 2. Mean, standard deviation, range (minimum-maximum) values of blood biochemistry and blood gases of captive green and hawksbill turtles at FRIRA

Analyte	*Chelonia mydas* (*n*=4)		*Eretmochelys imbricata* (*n*=4)	
	Mean (±SD)	Range	Mean (±SD)	Range
Na (mmoL/L)	152.25 (±2.21)	150.00 – 155.00	151.75 (±1.50)	150.00 – 153.00
K (mmoL/L)	3.18 (±0.63)	2.60 – 3.90	2.85 (±0.34)	2.40 – 3.20
Cl (mmoL/L)	117.25 (±2.90)	113.00 – 120.00	116.25 (±4.27)	111.00 – 121.00
iCa (mmoL/L)	1.23 (±0.16)	1.03 – 1.41	1.21 (±0.17)	0.98 – 1.35
Glu (mg/dL)	100.50 (±13.77)	81.00 – 113.00	121.00 (±22.49)	95.00 – 148.00
BUN (mmoL/L)	3.51 (±1.04)	2.83 – 5.05	3.19 (±0.29)	2.89 – 3.40
Crea (mg/dL)	0.20 (±0.00)	0.20	0.20 (±0.00)	0.20
TCO^2 (mmoL/L)	28.50 (±5.20)	22.00 – 34.00	30.00 (±3.74)	26.00 – 35.00
AnGap (mmoL/L)	10.50 (±2.38)	7.00 – 12.00	9.00 (±2.94)	6.00 – 13.00
pH	7.19 (±0.15)	7.01 – 7.33	7.39 (±0.07)	7.32 – 7.48
pH*	7.30 (±0.20)	7.10 – 7.40	7.44 (±0.07)	7.37 – 7.53
pCO_2 (mmHg)	78.30 (±9.23)	64.80 – 85.70	54.95 (±10.98)	40.30 – 65.80
pCO_2* (mmHg)	74.95 (±8.84)	62.02 – 82.03	52.59 (±10.52)	38.57 – 62.98
pO_2 (mmHg)	160.75 (±51.87)	115.00 – 221.00	105.00 (±52.44)	60.00 – 170.00
pO_2* (mmHg)	158.62 (±51.20)	113.47 – 218.10	103.58 (±51.73)	59.20 – 167.70
Lac (mmoL/L)	6.75 (±6.82)	1.21 – 15.80	0.93 (±0.41)	0.46 – 1.33
HCO^{3-} (mmoL/L)	30.70 (±8.23)	20.60 – 39.90	32.93 (±3.58)	29.60 – 37.50
BEecf (mmoL/L)	2.25 (±10.56)	-11.00 – 13.00	8.00 (±3.56)	5.00 – 13.00
sO_2 (%)	98.25 (±1.70)	96.00 – 100.00	94.50 (±5.80)	89.00 – 100.00

# denotes manually corrected values for temperature using standard equations

Table 3 summarizes the hematological parameters of captive green and hawksbill turtles at FRIRA. The mean values for Hb, Hct, PCV, and WBC counts were relatively similar between the two species, except for WBC counts, which were higher in hawksbills (7.55×10^9 L) than in green turtles (6.13×10^9 L).

Table 3. Mean, standard deviation, range (minimum-maximum) values of hematological values of captive green and hawksbill turtles at FRIRA

Analytes	*Chelonia mydas*			*Eretmochelys imbricata*		
	n	Mean (SD)	Range	*n*	Mean (±SD)	Range
Hct* (L/L)	3	20.00 (±5.29)	16.00 – 26.00	3	21.30 (±5.51)	15.00 – 25.00
Hb* g/dL	3	6.77 (±1.80)	5.40 – 8.80	3	7.27 (±1.88)	5.10 – 8.50
PCV (%)	4	17.25 (±2.21)	15.00 – 20.00	4	17.25 (±6.08)	10.00 – 24.00
WBC ($\times 10^9$ L)	4	6.13 (±0.85)	5.28 – 7.20	4	7.55 (±4.88)	3.00 – 14.40

# denotes values obtained by iSTAT

Hematological morphology

Blood cell morphology assessments identified mature and immature erythrocytes, along with leukocytes such as heterophils, eosinophils, basophils, monocytes, and lymphocytes. Microscopic examination of red blood cells (Figure 2a-d) from both captive green and hawksbill turtles showed mild basophilic stippling and polychromasia, consistent with reports from wild-nesting turtles (Samsol *et al*., 2020) The absence of significant basophilic stippling or polychromasia suggests that the erythrocytes of the captive turtles were in a healthy state, as severe basophilic stippling and polychromasia are associated with erythroid tissue reactions in anemic sea turtles (Stacy & Boylan, 2014).

Microscopic images of leukocytes (Figure 3a-j) identified five distinct types of white blood cells that can be well-distinguished: heterophil, eosinophil, basophil, lymphocyte, and monocyte of both captive green and hawksbill turtles. In green turtles, the nucleus in heterophil was stained dark blue to purple under Wright's stain and it has an eccentrical shape. A difference in heterophil morphology can be observed in hawksbill turtles occasionally, where the nucleus is stained light purple, less dense, and the granules are scattered around the membrane of the cell. As for eosinophils, the cytoplasm is filled with granules and dense dark blue to purple nuclei will appear in the center or towards the corner of the cell. Basophils were mostly round to oval, with a densely packed cytoplasm of granules surrounding the nucleus. The monocyte appeared round, with purple-stained nuclei, located either centrally or eccentrically. The nuclei also had a dense heterochromatin and were occasionally round or kidney-shaped. Lymphocytes observed in captive sea turtles were small, round, and nucleated, with dark-stained nuclei and

thick heterochromatin clumps. All white blood cells observed in captive species are healthy as the morphology is similar to the normal hematologic morphology as reported by Stacy and Boylan (2014).

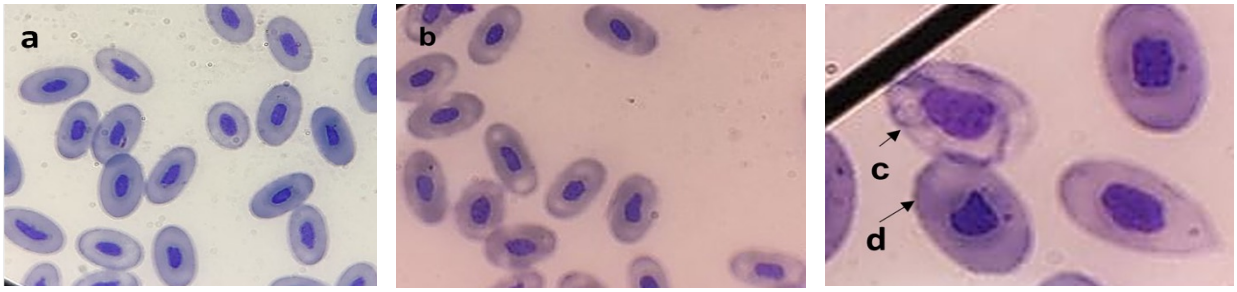

Fig. 2. Microscopic images of captive red blood cells of a) *Chelonia mydas* and b) *Eretmochelys imbricata*, c) immature red blood cells, and d) basophilic inclusions of *Eretmochelys imbricata*. Wright's stain, 1000x

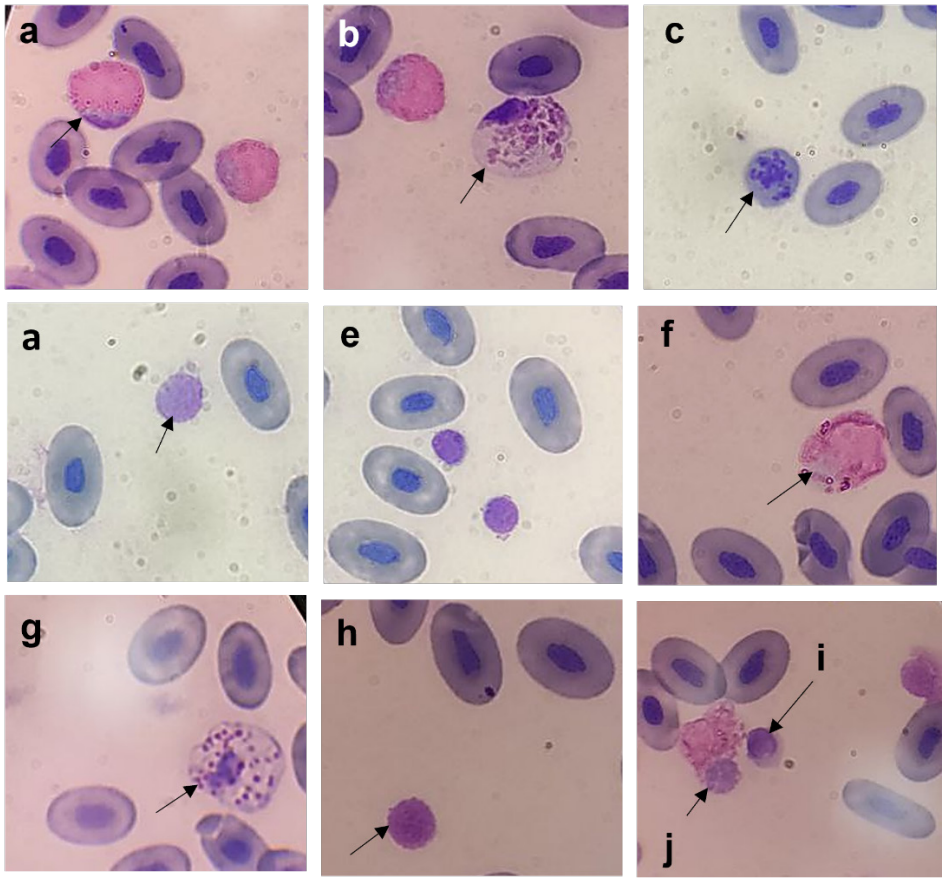

Fig. 3. Microscopic images of a) heterophils, b) eosinophil, c) basophil, d) lymphocyte, e) monocytes of captive green turtle and f) heterophil, g) eosinophil, h) monocyte, i) lymphocyte, j) basophil of the captive hawksbill turtle. Wright's stain, 1000x

DISCUSSION

Key analytes from this study were compared with those reported for captive sea turtles in different geographical locations due to the limited data available on captive sea turtle hematology in the South China Sea. Comparisons were made with plasma biochemical profiles from captive sea turtles reported by Swimmer (2000) (Mediterranean Sea), Basile *et al*. (2012) (Hawaii, USA), and Rousselet *et al*. (2013) (Texas, USA).

Comparatively, this study shows that the Glu levels in captive green and hawksbill turtles from FRIRA (100.5 mg/dL and 121.0 mg/dL, respectively) were higher than those reported for captive loggerhead turtles (93.9 mmoL/dL; Rousselet *et al*. (2013) but lower than captive loggerhead (131.0 mmoL/dL) from Basile *et al*. (2012). The variations in Glu levels across studies may be attributed to species differences and dietary composition (Pereira *et al*., 2013). Captive turtles should ideally be fed 1 to 3 times daily, with portions amounting to 1-5% of their body weight. While sea turtles are not very selective eaters, a nutritionally balanced diet is important to maintain optimal health (Bluvias & Eckert, 2010).

Glucose concentrations in captive turtles from this study were higher than those reported for free-ranging and wild-nesting

sea turtles (Goldberg *et al*., 2013; Munoz-Perez *et al*., 2017; Samsol *et al*., 2020; Page-Karijan *et al*., 2020). Elevated Glu levels in captive turtles may be attributed to protein and carbohydrate-rich diets (Labrada-Martagon *et al*., 2010; Suarez-Yana *et al*., 2016). Captive turtles at FRIRA were fed with locally sourced fish, which were gutted and decapitated, indicating a high-protein diet. In contrast, wild female turtles often limit or cease feeding during the nesting season (Goldberg *et al*., 2013), a condition known as hypophagia, which is influenced by limited foraging opportunities near nesting beaches (Carr *et al*., 1974; Goldberg *et al*., 2013). Additionally, Glu levels in wild-nesting turtles are lower than in juveniles due to high energy expenditure during nesting (Casal *et al*., 2019).

Values of Na, Cl, and K in captive turtles from this study fell within the ranges reported for captive loggerheads (Na: 102.00 -154.00 mmoL/L), Cl: 79.00 - 212.00 mmoL/L, K: 2.80 - 4.50 mmoL/L) (Rousselet *et al*., 2013). Among all measured analytes, Lac exhibited the most significant difference between species, with green turtles displaying markedly higher levels (6.75 mmoL/L) compared to hawksbill (0.93 mmoL/L). Levels of Lac are biomarkers for stress (Fonseca *et al*., 2020; Samsol *et al*., 2020).

Due to the small sample size, formal reference interval calculations were restricted, as at least 120 individuals are typically required for such analyses (Munoz-Perez *et al*., 2017). However, given the limited availability of published data on blood gases, biochemistry, and hematology in captive sea turtles from the South China Sea, the values obtained from FRIRA captive turtles provide preliminary reference data that may aid in health assessments and husbandry improvements for captive sea turtles.

Levels of Na in captive turtles were higher than those reported in wild-nesting turtles (Goldberg *et al*., 2013; Samsol *et al*., 2020; Page-Karijan *et al*., 2020). Values of Na and K tend to decline during nesting seasons, likely due to mineral depletion or physiological shifts associated with folliculogenesis (Goldberg *et al*., 2013; Honorvar *et al*., 2011).

Meanwhile, pO_2 and sO_2 levels in captive turtles from this study were higher than those in wild-nesting turtles (Munoz-Perez *et al*., 2017; Samsol *et al*., 2020). Variations in blood gases (pO_2, pCO_2, & sO_2) between captive and wild-nesting turtles may be influenced by activity levels, metabolic rates, body size, feeding behavior, and capture restraint (McNally *et al*., 2020).

Besides, PCV levels in captive turtles were significantly lower than those reported for wild turtles (Goldberg *et al*., 2013; Munoz-Perez *et al*., 2017; Samsol *et al*., 2020; Page-Karijan *et al*., 2020). Values of PCV increase with body mass, and since wild-nesting females are larger and more mature than the juveniles in FRIRA, lower PCV values in captive turtles are expected (Arango *et al*., 2021). Wild-nesting females are mature and bigger in comparison to the captive species of FRIRA, which were all juveniles.

Total WBC counts in wild-nesting green turtles (Page-Karijan *et al*., 2020) were higher than those in captive turtles from FRIRA, likely due to stress associated with nesting activities (Samsol *et al*., 2020). WBC counts are directly correlated with stress hormone levels, with elevated glucocorticoids increasing the proportion of heterophils in reptiles (Davis *et al*., 2008).

Hematology evaluation of reptilian blood cells can be difficult, as unlike mammalian blood cells, all blood cells are nucleated, including platelets and erythrocytes (Nardini *et al*., 2013). Thrombocytes and lymphocytes were also challenging to distinguish since they both can be of similar size with a high nucleus-to-cytoplasmic ratio. However, thrombocytes tend to have a more condensed and darker nucleus in comparison to lymphocytes. As observed in the chelonian species, the shape of thrombocytes is slightly more elongated than the lymphocytes, which were rounder in shape.

Red blood cells of captive greens and hawksbill turtles have very mild basophilic stippling and polychromasia. High basophilic stippling and polychromasia an indications of erythroid tissues in anemic sea turtles (Stacy & Boylan, 2014). The heterophils observed in captive hawksbill turtles are similar to the way the cells look in healthy wild hawksbill turtles (Stacy & Boylan, 2014) where the cells have a lighter purple nucleus, are less compact, and have granules spread around the cell's edge. The morphology of eosinophils for both captive and wild-nesting species was similar to previously reported eosinophils for chelonian species (Zhang *et al*., 2011) (Stacy & Boylan, 2014). In our study, some basophils may emerge as degranulated, clear, with pale purple cytoplasm. Basophils typically degranulate during blood collection, preparation of slides, or delayed blood analysis (Stacy *et al*., 2011). Monocytes in both captive species were also scarcely found in the blood. Monocytes usually consist of 0-10% of the total amount of leukocytes (Stacy *et al*., 2011). Lymphocytes tend to look slightly like thrombocytes, but a way to differentiate them is to identify the dark basophilic cytoplasm in lymphocytes. Unlike lymphocytes, thrombocytes have an elliptical shape, with dark-stained nuclei located in the centre and clear cytoplasm as indicated by Dilrukshi *et al*. (2019) in Sri Lankan testudines.

CONCLUSION

This study provides blood gases, biochemical, and hematological profiles of captive sea turtles from FRIRA, Terengganu, Malaysia. Comparisons between captive and wild sea turtles across different geographical regions contribute to a better understanding of their physiological differences, dietary impacts, and health status. Given the limited sample size and the lack of published data on captive sea turtle blood parameters in South China Sea, the values obtained serve as an initial reference for future research. Blood profiles of captive sea turtles can be used as a baseline for evaluating the health of juvenile turtles in other rehabilitation centers. This study highlights the importance of physiological assessments in sea turtle conservation and contributes valuable data for improving husbandry practices and rehabilitation efforts.

ACKNOWLEDGEMENTS

This study was supported by the Malaysian Ministry of Higher Education under the Fundamental Research Grants Scheme (FRGS/1/2019/WAB09/UMS/02/2), registered under Universiti Malaysia Sabah. We extend our gratitude to the members of the Sea Turtle Research Unit (SEATRU) of INOS-Universiti Malaysia Terengganu, as well as dedicated rangers, volunteers, interns, and the laboratory staff at the Faculty of Science and Marine Environment, Universiti Malaysia Terengganu, for their contributions. We also acknowledge the Department of Fisheries Terengganu, particularly the Fisheries Research Institute of Rantau Abang, for their direct and indirect support in the completion of this study. The iSTAT blood analyzer was generously donated by the Laboratory of the University of Queensland, Australia.

ETHICAL STATEMENT

This study was approved by the Ethics Committee of Universiti Malaysia Terengganu, (Approval No. UMT/JKEPHT/2019/37) and conducted with the support of the Department of Fisheries, Terengganu and the Fisheries Research Institute Rantau Abang, referral number of DOF.TR.TCIC.2689 (23).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Arango, B.G., Harfush-Melendez, M., Marmolejo-Valencia, J.A., Merchant-Larios, H.N. & Crocker, D.E. 2021. Blood oxygen stores of Olive Ridley Sea Turtles, *Lepidochelys olivacea*, are highly variable among individuals during arribada nesting. Journal of Comparative Physiology B, 191: 85-194. https://doi.org/10.1007/s00360-020-01321-1

Basile, F., Di Santi, A., Ferretti, L., Bentivegna, F. & Pica, A. 2012. Hematology of the Mediterranean population of sea turtle (*Caretta caretta*): Comparison of blood values in wild and captive, juvenile and adult animals. Comparative Clinical Pathology, 21: 401-406. https://doi.org/10.1007/s00580-011-1306-4

Bluvias, J.E. & Eckert, K.L. 2010. Marine turtle trauma response procedures: A husbandry manual. Wider Caribbean Sea Turtle Conservation Network (WIDECAST) Technical Report, 10: 1-100.

Carr, A., Ross, P. & Carr, S. 1974. Inter-nesting behavior of the Green Turtle, *Chelonia mydas*, at a mid-ocean island breeding ground. Copeia, 3: 703-706. https://doi.org/10.2307/1442684

Casal, A.B., Camacho, M., Lopez-Jurado, L.F., Juste, C. & Oros, J. 2009. Comparative study of hematologic and plasma biochemical variables in Eastern Atlantic juvenile and adult nesting Loggerhead Sea Turtles (*Caretta caretta*). American Society for Veterinary Clinical Pathology, 38(2): 213-218. https://doi.org/10.1111/j.1939-165X.2008.00106.x

Chan, E.H. 2006. Marine turtles in Malaysia: On the verge of extinction? Aquatic Ecosystem Health and Management, 9(2): 175-184. https://doi.org/10.1080/14634980600701559

Chandrasekar, K. & Srinivasan, M. 2013. Sea turtle exploitation from Tamil Nadu, southeast coast of India. Journal of Entomology and Zoology Studies, 1:11-14.

Chittick, E.J., Stamper, M.A., Beasley, J.F., Lewbart, G.A. & Horne, W.A. 2002. Medetomidine, ketamine, and sevoflurane for anesthesia of injured loggerhead sea turtles: 13 cases (1996-2000). Journal of American Veterinary Medical Association, 221: 1019-1025. https://doi.org/10.2460/javma.2002.221.1019

Davis, A.K., Maney, D.L. & Maerz, J.C. 2008. The use of leukocyte profiles to measure stress in vertebrates: A review for ecologists. Functional Ecology, 22(5): 760-772. https://doi.org/10.1111/j.1365-2435.2008.01467.x

Delcroix, E., Leveque, F., Coudret, J., Bonotto, S., Créantor, S. & Charrieau, M. 2009. Foraging by a gravid Green Turtle during the internesting interval in Guadeloupe, French West Indies. Marine Turtle Newsletter, 125: 12-13.

Denkinger, J., Parra, M., Munoz, J.P., Carrasco, C., Murillo, J.C., Espinosa, E., Rubianes, F. & Koc, V. 2013. Are boat strikes a threat to sea turtles in the Galapagos Marine Reserve? Ocean Coastal Management, 80: 29-35. https://doi.org/10.1016/j.ocecoaman.2013.03.005

Dilrukshi, N.H.N., Jayasooriya, A.P. & Prathapasinghe, G.A. 2019. Hematological parameters and morphological characteristics of blood cells in turtle and tortoise species within captivity in Sri Lanka. Journal of Advanced Veterinary and Animal Research, 6(3): 266-271. https://doi.org/10.5455/javar.2019.f343

Escobedo-Bonilla, C.M., Quiros-Rojas, N.M. & Rudín-Salazar, N. 2022. Rehabilitation of Marine Turtles and Welfare Improvement by Application of Environmental Enrichment Strategies. Animals, 12: 282. https://doi.org/10.3390/ani12030282

Fonseca, L.A., Fagundes, V., Girardi, F.M. & Dornelas, L.R.S. 2020. Blood values of cortisol, glucose, and lactate in healthy Green Turtle (*Chelonia mydas*) and affected by fibropapillomatosis. Comparative Clinical Pathology, 29: 1099-1105. https://doi.org/10.1007/s00580-020-03148-2

Ghazali, A.F. & Jamil, N. 2019. Population and trend analysis for Green Turtle (*Chelonia mydas*) and Hawksbill Turtle (*Eretmochelys imbricata*) in Marine Park Centre Redang, Terengganu and Marine Park Centre Rusukan Besar, Labuan, Malaysia. Pertanika Journal of Science and Technology, 27: 1061-1076.

Goldberg, D.W., Leitao, S.A.T., Godfrey, M.H., Lopez, G.G., Santos, A.J.B., Neves, F. A., de Souza, P.G., Moura, A.S., Bastos, J.C. & Bastos, V.L.F. 2013. Ghrelin and leptin modulate the feeding behavior of the Hawksbill Turtle (*Eretmochelys imbricata*) during nesting season. Conservation Physiology, 1: 1-13. https://doi.org/10.1093/conphys/cot016

Harms, C.A., Mallo, K M., Ross, P.M. & Segars, A. 2003. Venous blood gases and lactates of wild Loggerhead Sea Turtles (*Caretta caretta*) following two capture techniques. Journal of Wildlife Diseases, 39(2): 366-372. https://doi.org/10.7589/0090-3558-39.2.366

Herbest, L.H. & Jacobson, E.R. 2003. Practical Approaches for Studying Sea Turtle Health and Disease. The Biology of Sea Turtles, 2: 391-437.

Higgins, B.M. 2003. Sea turtle husbandry. In: The Biology of Sea Turtles. P.L. Lutz, J.A., Musick and J. Wyneken (Eds.). CRC Press, Boca Raton. pp. 411-440. https://doi.org/10.1201/9781420040807.ch16

Hirth, H.F. 1980. Some aspects of the nesting behavior and reproductive biology of sea turtles. American Zoologist, 20: 507-523. https://doi.org/10.1093/icb/20.3.507

Honorvar, S., Brodsky, M.C., Fitzgerald, D.B., Rosenthal, K.L. & Hearn, G.W. 2011. Changes in plasma chemistry and reproductive output of nesting Leatherbacks. Herpetologica, 67: 222-235. https://doi.org/10.1655/HERPETOLOGICA-D-10-00061.1

Ingram, D.J., Prideaux, M., Hodgins, N.K., Frisch-Nwakanma, H., Avila, I.C., Collins, T., Cosentino, M. & Keith-Diagne, L.W. 2022. Widespread use of migratory Megafauna for aquatic wild meat in the tropics and subtropics. Frontiers in Marine Science, 9: 837447. https://doi.org/10.3389/fmars.2022.837447

Innis, C.J., Finn, S., Kennedy, A., Burgess, E., Norton, T., Manire, C.A. & Harms, C. 2019. A summary of sea turtles released

from rescue and rehabilitation programs in the United States, with observations on re-encounters. Chelonian Conservation and Biology, 18(1): 3-9. https://doi.org/10.2744/CCB-1335.1

International Union for the Conservation of Nature (IUCN). 2010. IUCN Red List of Threatened Species, 2010. http://www.iucnredlist.org. (accessed April 22, 2020)

Jani, J.M., Jamalludin, M.A. & Long, S.H. 2020. To ban or not to ban? Reviewing an ongoing dilemma on sea turtle egg trade in Terengganu, Malaysia. Frontiers in Marine Science, 6: 762. https://doi.org/10.3389/fmars.2019.00762

Jolis, G., Joseph, J., Nishizawa, H., Isnain, I. & Muin, H. 2023. Marine turtle nesting and hatching in Tun Mustapha Park, Malaysia, revealed by community-based monitoring. Herpetological Conservation and Biology, 18(2): 275-289.

Joseph, J., Chong, Y.K., Palaniappan, P.M. & Liew, H.C. 2014. Genetic investigation of green turtles (*Chelonia mydas*) harvested from a foraging ground at Mantanani, Sabah, Malaysia. Herpetological and Conservation Biology, 9(3): 516-523.

Joseph, J., Jolis, G., Kirishnamoorthie, J., Jalimin, S.N., Nishizawa, H., Muin, H., Isnain, I. & Saleh, E. 2021. Chapter 7: Research and conservation of marine turtles at nesting and foraging grounds. In: The Marine Ecosystems in Sabah. T. Yoshida and B.M. Manjaji-Matsumoto (Eds.). Penerbit Universiti Malaysia Sabah. pp. 95-123.

Joseph, J., Nishizawa, H., Alin, J.M., Othman, R., Jolis, G., Isnain, I. & Nais, J. 2019. Mass sea turtle slaughter at Pulau Tiga, Malaysia: genetic studies indicate poaching locations and its potential effects. Global Ecology and Conservation, 17: e00586. https://doi.org/10.1016/j.gecco.2019.e00586

Joseph, J., Nishizawa, H., Arshaad, W.M., Syed Kadir, S.A., Jaaman, S.A., Bali, J., Jamaludin, N.A. & Katoh, M. 2016. Genetic stock compositions and natal origin of green turtle (*Chelonia mydas*) foraging at Brunei Bay. Global Ecology and Conservation, 6: 16-24. https://doi.org/10.1016/j.gecco.2016.01.003

Joseph, V. 2015. Reptilian clinical pathology. Exotics Conference. https://cdn.ymaws.com/members.arav.org/resource/resmgr/Files/Proceedings_2015/Pre_Conference/121.pdf. (accessed September 17, 2020).

Labrada-Martagon, V., Mendez-Rodriguez, L.C., Gardner, S.C., Lopez-Castro, M. & Zenteno-Savin, T. 2010. Health indices of the Green Turtle (*Chelonia mydas*) along the Pacific Coast of Baja California Sur, Mexico. I. Blood biochemistry values. Chelonian Conservation and Biology, 9(2): 162-172. https://doi.org/10.2744/CCB-0806.1

Lewbart, G.A., Hirschfield, M., Denkinger, J., Vasco, K., Guevara, N. & Munoz, J. 2014. Blood gases, biochemistry, and hematology of Galapagos Green Turtles (*Chelonia mydas*). PLoS ONE, 9(5): e96487. https://doi.org/10.1371/journal.pone.0096487

Li, T.H., Chang, C.C., Cheng, I.J. & Lin, S.C. 2015. Development of a summarized health index (SHI) for use in predicting survival in sea turtles. PLoS ONE, 10(3): e0120796. https://doi.org/10.1371/journal.pone.0120796

Mazaris, A.D., Schofield, G., Gkazinou, C., Almpanidou, V. & Hays, G.C. 2017. Global sea turtle conservation successes. Science Advances, 3: e1600730. https://doi.org/10.1126/sciadv.1600730

McNally, K.L., Mott, C.R., Guertin, J.R., Gorham, J.C. & Innis, C.J. 2020. Venous blood gas and biochemical analysis of wild captured Green Turtles (*Chelonia mydas*) and Kemp's Ridley Turtles (*Lepidochelys kempii*) from the Gulf of Mexico. PLoS ONE, 15(8): e0237596. https://doi.org/10.1371/journal.pone.0237596

Mohd Salleh, S., Nishizawa, H., Mohd Sah, S.A. & Safri, M.F. 2018. Spatiotemporal preferences in nesting of the Hawksbill Turtle (*Eretmochelys imbricata*) in Melaka, Malaysia. Journal of the Marine Biological Association of the United Kingdom, 98(8): 2145-2152. https://doi.org/10.1017/S0025315417001734

Munoz-Perez, J.P., Lewbart, G., Hirschfeld, M., Alarcon-Ruales, D., Denkinger, J., Castaneda, J.G., Garcia, J. & Lohmann, K.J. 2017. Blood gases, biochemistry and hematology of Galapagos Hawksbill Turtles (*Eretmochelys imbricata*). Conservation Physiology, 5: 1-9. https://doi.org/10.1093/conphys/cox028

Nardini, G., Leopardi, S. & Bielli, M. 2013. Clinical hematology in reptilian species. Veterinary Clinics: Exotic Animal Practice, 16(1): 1-30. https://doi.org/10.5455/javar.2019.f343

Nishizawa, H., Joseph, J., Jolis, G., Isnain, I., Muin, H., Johari, S. & Saleh, E. 2024. Variations in body condition of Green Turtles (*Chelonia mydas*) in two nearby foraging grounds indicate their sensitivity to foraging habitats. Aquatic Conservation: Marine and Freshwater Ecosystems, 34(1): e4038. https://doi.org/10.1002/aqc.4038

Norton, T. & Mettee, N. 2020. Marine Turtle Trauma Response Procedures: A Veterinary Guide WIDECAST Technical Report No. 20. Online only. http://seaturtleguardian. org. (accessed September 13, 2020)

Norton, T. & Wyneken, J. 2015. Body condition scoring the sea turtle. LafeberVet. https://lafeber.com/vet/body-condition-scoring-the-sea-turtle/ (accessed August 27, 2021)

Oros, J., Torrent, A., Calabuig, P. & Deniz, S. 2005. Diseases and causes of mortality among sea turtles stranded in the Canary Islands, Spain (1998-2001). Diseases of Aquatic Organisms, 63: 13-24. https://doi.org/10.3354/dao063013

Owens, W.D. & Ruiz, R.J. 1980. New methods of obtaining blood and cerebrospinal fluid from marine turtles. Herpetologica, 36(1): 17-20.

Page-Karjian, A. & Perrault, J.R. 2021. Sea turtle health assessments: Maximizing turtle encounters to better understand health. In: Sea Turtle Research and Conservation: Lessons from Working in the Field. B. Nahill (Ed.). Academic Press, St. Louis. pp. 31-44. https://doi.org/10.1016/B978-0-12-821029-1.00004-0

Page-Karjian, A., Chabot, R., Stacy, N.I., Morgan, A.S., Valverde, R.A., Stewart, S., Coppenrath, C.M., Manire, C.A., Herbst, L.H., Gregory, C.R., Ritchie, B.W. & Perrault, J.R. 2020. Comprehensive health assessment of Green Turtles *Chelonia mydas* nesting in southeastern Florida, USA. Endangered Species Research, 42: 21-35. https://doi.org/10.3354/esr01036

Patel, E., Kotera, M. & Phillott, A. 2022. The roles of sea turtles in ecosystem processes and services. Indian Ocean Turtle Newsletter, 36: 23-31.

Pereira, C.M., Booth, D.T., Bradley, A.J. & Limpus, C.J. 2013. Blood concentrations of lactate, glucose and corticosterone in dispersing hatchling sea turtles. Biology Open, 2(1): 63-67. https://doi.org/10.1242/bio.20123046

Perpiñán, D. 2015. Blood collection in turtles. VetCom Publication, 52: 38-39.

Phu, J.L. & Palaniappan, P. 2019. Recaptured wild Green Turtles Chelonia mydas with newly documented boat strike injuries in Mabul Island, Sabah, Malaysia. Chelonian Conservation and Biology, 18(2): 265-272. https://doi.org/10.2744/CCB-1363.1

Poti, M., Long, S.H., Rusli, M.U., Mohd Jani, J., Hugé, J. & Dahdouh-Guebas, F. 2021. Changing trends and perceptions of sea turtle egg consumption in Redang Island, Malaysia. Ecology and Society, 26(4): 14. https://doi.org/10.5751/ES-12717-260414

Rahman, R.A., Wong, E.P., Joseph,J., Salleh, S.M., Khoo, S.N., Ismail, M.S., Rahim, M.A., Ramli, R., Ang, T.L., Lee, B.H., Chan, Z.S. & Long, S.L. 2021. First record of a stranded loggerhead turtle (*Caretta caretta*) in a ghost net off Penang, Malaysia. Marine Turtle Newsletter, 162: 22-24.

Rousselet, E., Stacy, N.I., LaVictorie, K., Higgins, B.M., Tocidlowski, M.E. & Flanagan, J.P. 2013. Hematology and plasma biochemistry analytes in five age groups of immatures, captive-reared Loggerhead Sea Turtles Caretta caretta. Journal of Zoo and Wildlife Medicine, 44(4): 859-874. https://doi.org/10.1638/2012-0162R1.1

Samour, J. 2006. Diagnostic value of hematology. Clinical Avian Medicine, 2: 588-610.

Samsol, S., Wahid, M.E.A., Li, T.H. & Rusli, M.U. 2020. Hematology, blood gases and biochemistry profiles of wild-nesting sea turtles in Terengganu, Malaysia. Malaysian Applied Biology, 49(4): 25-31. https://doi.org/10.55230/mabjournal.v49i4.1564

Schoeman, R.P., Patterson-Abrolat, C. & Plön, S. 2020. A global review of vessel collisions with marine animals. Frontiers in Marine Science, 7: 292. https://doi.org/10.3389/fmars.2020.00292

Sidique, S.N., Azuddin, N.F. & Joseph, J. 2017. First report of Fusarium species at nesting sites of endangered sea turtles in Terengganu and Melaka, Malaysia. Malaysian Applied Biology, 46(23): 195-205.

Sleeman, J.M. & Clark, E.E. 2003. Clinical wildlife medicine: a new paradigm for a new century. Journal of Avian Medicine and Surgery, 17:33-37. https://doi.org/10.1647/1082-6742(2003)017[0033:CWMANP]2.0.CO;2

Stacy, N.I. & Boylan, S. 2014. Clinical Pathology of Sea Turtles. In: Mettee, Nancy. 2014. Clinical Pathology. Marine Turtle Trauma Response Procedures: A Veterinary Guide. WIDECAST Technical Report No. 17. Online only. https://seaturtleguardian.org/clinical-pathology-of-sea-turtles (accessed September 28, 2021)

Stacy, N.I., Allerman, A.R. & Sayler, K.A. 2011. Diagnostic hematology of reptiles. Clinics in Laboratory Medicine, 31: 87-108. https://doi.org/10.1016/j.cll.2010.10.006

Suarez-Yana, T., Montes, D.I., Zuniga, R., Mangel, J.C. & Shigueto, J.A. 2016. Hematologic, morphometric and biochemical analytes of clinically healthy Green Sea Turtles (*Chelonia mydas*) in Peru. Chelonian Conservation and Biology, 15(1): 153-157. https://doi.org/10.2744/CCB-1160.1

Swimmer, J.Y. 2000. Biochemical responses to fibropapilloma and captivity in the Green Turtle. Journal of Wildlife Diseases, 36(1): 102-110. https://doi.org/10.7589/0090-3558-36.1.102

Welsh, R.C. & Witherington, B.E. 2023. Spatial mapping of vulnerability hotspots: Information for mitigating vessel-strike risks to sea turtles. Global Ecology and Conservation, 46: e02592. https://doi.org/10.1016/j.gecco.2023.e02592

Wood, L. 2022. Managing long-term wellness in captive sea turtles. Animal Welfare, 31(4): 423-432. https://doi.org/10.7120/09627286.31.4.007

Zhang, F., Hexiang, G.U. & Pipeng, L.I. 2011. A review of Chelonian hematology. Asian Herpetological Research, 2(1): 12-20. https://doi.org/10.3724/SP.J.1245.2011.00012