Haematology and biochemistry of the San Cristóbal Lava Lizard (*Microlophus bivittatus*)

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The San Cristóbal lava lizard, *Microlophus bivittatus*, is one of nine species of lava lizards endemic to the Galápagos Islands of Ecuador. No information presently exists about baseline health parameters for any of these species. We analysed blood samples drawn from 47 lizards (25 males and 22 females) captured at two locations on San Cristóbal Island. A portable blood analyser (iSTAT) was used to obtain near-immediate field results for total CO₂, lactate, sodium, potassium, ionized calcium, glucose and haemoglobin. Standard laboratory haematology techniques were employed for differential white blood cell counts and haematocrit determination. Body temperature, heart rate and body measurements were also recorded. We found significant differences in haematocrit values between males and females. The values reported in this study provide baseline data that may be useful in detecting changes in health status among lava lizards affected by natural disturbances or anthropogenic threats. Our findings might also be helpful in future efforts to demonstrate associations between specific biochemical or haematological parameters and disease. Because there are several related species on different islands in the Galápagos archipelago, comparisons between populations and species will be of interest.

**Key words**: Biochemistry, Galápagos, haematology, health assessment, *Microlophus bivittatus*, San Cristóbal lava lizard

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**Introduction**

The measurement of biochemical and haematological parameters can serve as a valuable tool for evaluating and monitoring the health of wild reptile populations (Stacy *et al.*, 2011; Campbell, 2014). However, a major obstacle to conducting wildlife health assessments is a lack of baseline data against which new data can be compared (Calle *et al.*, 2017). Without an understanding of typical species-specific (or taxon-specific) variation in biochemical and haematological parameters, researchers are unable to identify potential effects of disease, injury, pollutants or other changing environmental conditions (Lewbart *et al.*, 2015). This issue is particularly important for regions with large numbers of...
endemic species that are experiencing rapid change, such as the Galapagos Archipelago.

The Galapagos Archipelago has nine endemic species of lava lizard in the South American genus *Microlophus* (Family: Tropiduridae) (Benavides et al., 2009; Jiménez-Uzcátegui et al., 2017). *Microlophus bivittatus* (Fig. 1), which is restricted to the island of San Cristóbal and nearby Islote Lobos, inhabits xeric, low-elevation areas, such as coastal scrubland and rocky beaches. This lizard is listed as near threatened (Márquez and Cisneros-Heredia, 2016) and is particularly vulnerable to predation by feral cats (Carrión Avilés, 2012; Carrión and Valle, 2018). At present, no blood chemistry or haematology data have been acquired for the genus *Microlophus*, which complicates efforts to evaluate or monitor the health of wild lava lizard populations. In this study, we report baseline biochemical and haematological values, along with basic physiological measures, for the San Cristóbal lava lizard.

Methods

Ethics statement

This study was conducted on San Cristóbal Island in the Galápagos archipelago of Ecuador as part of a population health assessment authorized by the Galápagos National Park Service (Permit No. PC-23-17, PI Carlos A. Valle, PhD) and approved by the Universidad San Francisco de Quito ethics and animal handling protocol. All handling and sampling procedures were consistent with standard vertebrate ethics and animal handling protocol. All handling and sampling procedures were consistent with standard vertebrate ethics and animal handling protocol. All handling and sampling procedures were consistent with standard vertebrate ethics and animal handling protocol.

Capture and marking

Lizards were captured in locations within 2 km of the Galapagos Science Center on San Cristobal Island. Twenty-six lizards (\(N_{\text{male}} = 13, N_{\text{female}} = 13\)) were captured along a walking trail to Punta Carola (0°53’32” and 89°36’43”) on 5 July 2017. On the following day, 21 lizards (\(N_{\text{male}} = 12, N_{\text{female}} = 9\)) were captured along Tijeretas trail (0°53’34” and 89°36’32”).

Each lizard was captured by noose, placed in a cloth bag, and transported to a temporary field laboratory for processing (see below). Afterwards, to avoid recapturing the same individuals, each was marked on its dorsum with a spot of non-toxic, red acrylic paint used previously in other studies (Berriozabal et al., 2017; Keogh et al., 2012; Pasek and Collier, 2001) and known to wash or rub off within 10 days of application (C.A. Valle, personal observation). Because the study was conducted outside of the breeding season and the paint fades quickly, the marking was unlikely to affect the behaviour, fitness or survival of the lizards.

Morphological measurements and body temperature

A flexible measuring tape was used to determine snout-vent length (SVL) and total length (TL). Head length (HL), head width (HW), head depth (HD), forelimb length (FLL) and hindlimb length (HLL) measurements were made using digital calipers. Body weight was measured with a spring scale (Pesola®). An EBRO® Compact J/K/T/E Thermocouple Thermometer was used to obtain all temperature readings (model EW-91 219–40; Cole-Parmer, Vernon Hills, IL, USA). Core body temperatures were recorded from the cloaca using the probe T PVC epoxy tip 24GA, usually within five minutes of capture. Finally, sex was determined on the basis of external sexual dimorphism: males are larger and have two white bands on each side of the body, while females are smaller with orange coloration on the ventral–frontal area (Troya-Zuleta, 2012).

Blood sample collection and handling

Within five to ten minutes of capture, each lizard was manually restrained while 0.03–0.2 ml of blood was obtained from the coccygeal vein or the heart using a heparinized 31–29 gauge needle attached to a 1.0-ml syringe. The blood was immediately divided into several samples: (1) for making blood films on clean glass microscope slides, (2) for filling microhaematocrit tubes and (3) for loading the lactate strip or the CG8+ iSTAT cartridge within 5 min of sample collection. Any remaining blood was stored on ice and then maintained at −20°C in a freezer at the Galápagos Science Center for future analysis. In some cases, we were only able to extract enough blood to prepare slides and fill microhaematocrit tubes.

Biochemistry parameters

Blood gas, electrolyte and biochemistry results were obtained using an iSTAT Portable Clinical Analyzer (Heska Corporation, Fort Collins, CO, USA) with CG8+ cartridges.
The iSTAT is a portable, hand-held, battery-operated electronic device that measures a wide variety of blood gas, chemistry and haematology parameters using only a few drops (0.095 ml) of whole, non-coagulated blood. The following parameters were measured: anion gap, TCO2, haematocrit, haemoglobin, sodium (Na), chloride (Cl), potassium (K), ionized calcium (iCa) and glucose. Mean corpuscular haemoglobin concentration (MCHC) was also calculated [Hb (g/L)/Htc (%) * 100].

Haematology

Heparinized whole blood was stored on ice immediately after collection. Time-sensitive analyses were completed on the day of sampling. Haematocrit was determined using high-speed centrifugation of blood-filled microhaematocrit tubes. Differential white blood cell counts were made by examining 100 white blood cells on a peripheral smear stained with Diff-Quick stain (Campbell, 2014).

Statistical analysis

We calculated standard summary statistics of all parameters for each sex before testing for differences in morphometrics, biochemistry and haematology between the sexes using t-tests. All statistical analyses were run using IBM SPSS.α level of 0.05.

Results

Morphometrics and body temperature

Males were larger than females in all morphometric measurements. There were significant differences between sexes in SVL (P < 0.0001), TL (P < 0.0001), HL (P < 0.0001), HW (P < 0.0001), HD (P < 0.0001), FLL (P < 0.0001) and HLL (P < 0.0001) (see Table 1). The mean body mass for males was 23 g (14.5–31 g) and 10 g (6.5–14 g) for females. This difference was also significant (P < 0.0001).

The mean internal body temperature for males (n = 20) was 34.37°C (range 32.4°C–36.1°C). For females (n = 17), it was 33.14°C (range 29.3°C–36.2°C).

Biochemistry parameters

Summary statistics of the biochemistry data are provided in Table 2. The Cl values of 20 individuals exceeded the maximum detectable value of the iSTAT (140 mmol/l). While calculating means for Cl, we used 140 mmol/l for the samples that exceeded the upper limit of the reportable range. Thus, our procedure likely underestimates the mean Cl level for both males and females in the population.

We looked for sex differences between all the biochemistry analytes but did not find differences in lactate (P = 0.95), total protein (P = 0.2), Na (P = 0.32), K (P = 0.27), Cl (P = 0.94), iCa (P = 0.28), tCO2 (P = 0.21) and MCHC values (P = 0.26). Significant differences were found in glucose values (P = 0.011), in haematocrit values (P = 0.009) and in haemoglobin (P = 0.005). In all three of these cases, values in males were higher than those of females (Fig. 2).

Haematology

Leucocyte values are presented in Table 3. No sex differences were detected for lymphocytes (P = 0.49), heterophils (P = 0.57) or monocytes (P = 0.79). We also noted the presence of an intraerythrocytic haemoparasite while examining the blood slides of one female (Fig. 3).

Brief descriptions of leucocytes

Lymphocytes: Round cells with a round basophilic nucleus, a variable nucleus to cytoplasm ratio and usually non-visible cytoplasm (Fig. 3).

| Table 1: Morphometric measurement of San Cristóbal Lava Lizards (Microlophus bivittatus) separated by sex |
|---------------------------------------------------------------|
| Morphometrics       | Male      | Female     |
|---------------------|-----------|------------|
| TL (mm)             | 195.7     | 156.4      |
| (30.3)              | (19.8)    |            |
| 127.0–237.0         | 96.0–182  |            |
| SVL (mm)            | 80.6      | 64.7       |
| (5.3)               | (3.5)     |            |
| 69.6–90.0           | 57.0–71.8 |            |
| HL (mm)             | 16.0      | 13.8       |
| (0.9)               | (0.9)     |            |
| 13.7–17.4           | 11.6–16.0 |            |
| HW (mm)             | 12.6      | 10.2       |
| (0.96)              | (0.9)     |            |
| 11.1–14.7           | 7.6–11.8  |            |
| HD (mm)             | 10.1      | 8.2        |
| (0.8)               | (0.8)     |            |
| 8.4–11.8            | 7.1–10.5  |            |
| FLL (mm)            | 33.2      | 26.2       |
| 2.4                 | 1.7       |
| 29.0–39.0           | 24.0–29.0 |            |
| HLL (mm)            | 53.4      | 41.8       |
| 3.9                 | 2.5       |
| 46.0–60.0           | 37.0–47.0 |            |

Values represent means, standard deviation (parentheses) and range (minimum-value)
Monocytes: Large round to amoeboid cells, nucleus semi-lobed with less condensed chromatin and a pale blue cytoplasm (Fig. 3).

Heterophils: Round with eosinophilic granules and a bilobed (sometimes four lobules) nucleus (Fig. 3).

Eosinophils: Large amoeboid to round cells with rather purple conspicuous granules and round nuclei (Fig. 3).

Basophils: Small round cells with purple granules obscuring the nucleus.

**Discussion**

Our results provide the first data on the morphometrics, body temperature, biochemistry and haematology of San Cristóbal lava lizards (*M. bivittatus*). Such baseline data on the morphology and physiology of wild animals is crucial to understanding various aspects of a population’s biology and health (Innis, 2014) and can be especially important in evaluating the cause of morbidity events and population declines.

Morphometrics can be helpful in evaluating cases of disease or environmental stress, as optimal body condition can be calculated using body weight and size (Donoghue, 2006; Lazić et al., 2013). Similarly, the typical ranges of body temperatures and heart rates of a species are critical metrics useful to veterinary professionals during medical interventions (e.g. anaesthesia and surgery). These parameters are known to vary with handling stress in reptiles (e.g. Murray, 2006), so the values reported here should be used only as approximations.

The measurement of biochemical and haematological parameters can serve as a valuable tool for evaluating and monitoring the health of wild reptile populations (Stacy et al., 2011; Campbell, 2014). To determine the significance of

Table 2: Blood biochemical values of San Cristobal Lava Lizards (*Microlophus bivittatus*) separated by sex

| Analyte      | Male                      | Female                     |
|--------------|---------------------------|----------------------------|
| Na (mmol/l)  | n = 23                    | n = 9                      |
|              | 165.77–168.26             | 149–180                    |
|              | (6.99)–(3.66)             | (1.90)–(0.97)              |
| K (mmol/l)   | n = 22                    | n = 9                      |
|              | 4.26–4.31                 | 131–140                    |
|              | (1.90)–(0.97)             | (1.31–1.9)                 |
| Cl (mmol/l)  | n = 21                    | n = 9                      |
|              | 138.44–138.52             | 131–140                    |
|              | (2.87)–(3.12)             | (1.4–2.24)                 |
| iCa (mmol/l) | n = 23                    | n = 9                      |
|              | 1.56–1.67                 | 9.17–10.44                 |
|              | (0.14)–(0.25)             | (2.55)–(2.50)              |
| tCO2 (mmol/l)| n = 23                    | n = 9                      |
|              | 9.17–9.44                 | 6–15                       |
|              | (2.55)–(2.50)             | (1.31–1.9)                 |
| Glucose (mg/dl) | n = 23                    | n = 9                      |
|              | 272.30–241.22             | 199–201                    |
|              | (45.96)–(19.79)           | (41.96–49.79)              |
| Lactate (mmol/l)| n = 24                    | n = 22                     |
|              | 17.08–17.42               | 13.6–22.2                  |
|              | (2.06)–(2.62)             | (8.8–21.1)                 |
| Total protein (mg/dl)| n = 22                    | n = 21                     |
|              | 8.10–8.77                 | 5–10.2                     |
|              | (1.06)–(2.07)             | (1.2–2.1)                  |
| Haemoglobin (g/l) | n = 22                    | n = 9                      |
|              | 12.14–12.50               | 8.5–14.3                   |
|              | (1.65)–(1.33)             | (7.8–12.2)                 |

Values represent n, means, standard deviation (parenthesis) and range (minimum–maximum). Sample sizes vary because some females were too small to extract the amount of blood required for all analyses.

(Continued)
changes in biochemical and haematological values associated with factors such as disease, injury, pollutants or starvation, it is essential to establish species-specific (or at least taxon-specific) normal values for parameters of interest (Lewbart et al., 2015). The sole published haematological study of a neotropical ground lizard (Tropidurus torquatus) reported only erythrocyte values and morphology (Scorza, 1971), and no data have previously been reported for Microlophus.

In general, the biochemistry values reported in Table 2 were very similar to those of other lizards (Divers et al., 1996; Wagner and Wetzel, 1999; Dennis et al., 2001; Harr et al., 2001; James et al., 2006; Maria et al., 2007; Dallwig et al., 2011; Lewbart et al., 2015). Because the iStat cannot measure chloride concentrations greater than 140 mmol/l and 20 individuals exceeded this limit, we suspect that chloride levels are high in clinically healthy individuals. We note that similarly high values exceeding 140 mmol/l have been reported in other lizards such as Pogona vitticeps and Iguana iguana (Ellman, 1997; Harr et al., 2001).

For lactate values, we found higher levels than reported by González-Morales et al. (2015) in Sceloporus torquatus, González-Morales et al. (2017) in S. grammicus, and Lewbart et al. (2015) for marine iguanas (Amblyrhynchus cristatus). Very few studies have reported lactate levels in squamate reptiles (Lewbart et al., 2015; González-Morales et al., 2015, 2017), and most evaluated lactate production after exercise in diving reptiles (Bartholomew et al., 1976; Seymour, 1979; Harms et al., 2003; Warren and Jackson, 2008). In squamates, blood lactate levels may be affected by altitude (González-Morales et al., 2015, 2017), exercise (Bennett et al., 1981; Gleeson and Dalessio, 1989; Schuett and Grober, 2000) and handling (Lewbart et al., 2015). Lactate levels may also be influenced by glucose and oxygen.

**Table 3:** Leucocyte counts of San Cristobal Lava Lizards (Microlophus bivittatus) separated by sex

| Cell type | Male | Female |
|-----------|------|--------|
|           | n = 25 | n = 22 |
| Lymphocyte (%) | 86.04 (5.43) | 84.81 (6.61) |
| Monocyte (%)  | 7.16 (3.14) | 7.45 (4.54) |
| Heterophil (%) | 5.4 (4.98) | 6.18 (4.42) |
| Eosinophil (%) | 1.08 (1.58) | 0.32 (0.65) |
| Basophil (%)  | 0.64 (1.22) | 0.54 (1.22) |

Values represent means, standard deviation (parenthesis) and range (minimum–maximum).

Figure 2: Haematocrit, haemoglobin and glucose box plots for males and females of the San Cristobal lava lizard (M. bivittatus). Significant differences were found between sexes. Haematocrit ($P = 0.009$), haemoglobin ($P = 0.005$), glucose ($P = 0.011$).
levels (Gleeson and Dalessio, 1989; Bennett, 1973), but apparently there is little dependence on body temperature (Bennett and Litch, 1972). In mammal medicine, hyperlacta-
temia usually correlates with disease severity and mortality (Gillespie et al., 2016) and with capture myopathy and mus-
cle damage in birds (Burgdorf-Moisuk et al., 2012). Little is
known, however, about its clinical use in reptile medicine
and further study is needed.

Glucose levels can vary in reptiles depending on nutri-
tional or environmental conditions (Campbell, 2014). In M.
bivittatus was significantly lower in females than males. Such sex-based variation was not identified in a study of the agamid genus Calotes (Chandavar and Naik, 2012), and the prevalence of this pattern in other lizard families, including Tropiduridae, is unknown. Because glucose meta-
bolism in reptiles is similar to that in mammals, a known dif-
ference between human sexes may provide insight (Anish et al., 2013; Mauvais-Jarvis, 2017). Compared to men of the same age, healthy women have lower skeletal muscle mass and higher adipose tissue mass, more circulating free fatty acids, and higher intramyocellular lipid content, all of which might promote insulin resistance in women relative to men (Mauvais-Jarvis, 2017). In addition, insulin sensitivity is
greater in women as a result of higher glucose disposal by skeletal muscles (Mauvais-Jarvis, 2017). The mechanisms for facilitated glucose homoeostasis are unclear, but could be due at least in part to the effect of circulating oestrogen (Mauvais-Jarvis, 2017). Although a similar process may explain our findings in Microlophus, it is important to note that Dickinson et al. (2002) found that male tortoises had higher glucose levels than females, raising questions about whether such patterns are conserved across amniotes.

Blood cell counts and morphology can vary greatly among species of reptile, even among members of the same genus (Stacy et al., 2011; Innis, 2014). In addition, numerous factors, including age, sex, environment, season, presence of environmental stressors, parasite load, nutritional state and restraint, can complicate the evaluation of haematological data in reptiles (Campbell, 2014). Therefore, published reference intervals provide only a baseline for interpretation, and veterinarians need to be aware of these factors to accurately interpret and correlate haematological and clinical findings in reptile patients (Stacy et al., 2011).

Cellular morphology of M. bivittatus is similar to that reported in the closely related families Iguanidae, Corytophanidae, and

Figure 3: Photographs of selected San Cristóbal lava lizard (Microlophus bivittatus) blood cells stained with Diff-Quick stain at 100x.
(a) Heterophil. (b) Monocyte. (c) The black arrow indicates an eosinophil and the red arrow indicates a lymphocyte. (d) Intraerythrocytic haemoparasite.
Liolemaidae. As in other lizards that have been studied [e.g. Cyclura nubila, (Alberts et al., 1998); Amblyrhynchos cristatus (Lewbart et al., 2015); Salvador (Tupinambis) merianae (Troiano et al., 2008); Pogona viticeps (Ellman, 1997)], the highest leucocyte population was the lymphocytes.

We could not analyse total erythrocyte counts due to logistical constraints. However, haematocrit, haemoglobin and MCHC were run as references for red cell values. Lizard haematocrits tend to be higher than those of reptiles (Campbell, 2014), and lava lizard values resembled those reported in other lizards. Differences were found between sexes; males had higher values, a phenomenon previously reported in reptiles (Harr et al., 2001). It is important to know normal values and differences between sexes to identify possible disease events. For example, low haematocrit may be due to anaemic processes (haemorrhagic, haemolytic or decreased red cell production), but a higher than normal value may be due to haemoconcentration, usually as a result of dehydration. Haemoconcentration also sometimes involves altitude (He et al., 2013; González-Morales, 2015, 2017) or body size and age (Dunlap, 2006). Anaemia has been reported in free-living birds and mammals, but is also often associated with traumatic events or ill health (e.g. severe dehydration or nutritional stress, toxicity, or high blood loss due to parasites (Williams et al., 2004). However, a decrease in haematocrit has also been observed in birds during ‘normal’ reproduction. Specifically, haematocrit has been found to drop routinely between pre-laying and egg-laying, possibly due to plasma vitellogenin levels, estradiol effects on erythropoiesis, nutritional stress and temperature (Williams et al., 2004). Similar processes may drive the differences observed in lizards.

The presence of hemoparasites in wild reptiles is common and is usually considered non-pathogenic (Stacy et al., 2011). The fact that just one individual had hemoparasites (an unknown species of haemogregarine) is surprising. It might be due to limitations of sample size, parasite prevalence, and susceptibility or resistance to infection of particular individuals (Maia et al., 2014). A study in wall lizards in Portugal with a similar sample size reported more than 50% prevalence using microscope diagnostics (Maia et al., 2014), suggesting that M. biivittatus might actually have low prevalence. Because hemoparasites can infect multiple species of sympatric reptile (Maia et al., 2014), the relatively low reptile diversity of San Cristóbal might limit hemoparasites on the island.

One caveat about our study is that the iSTAT unit used to analyse blood chemistry was designed as a fast and efficient way to determine blood gas and chemistry parameters in humans. For this reason, future work should involve corroborating these results with methods that are more commonly used for reptile work in veterinary laboratories (Steinmetz et al., 2007; Harter et al., 2015), which was impractical in our study due to export constraints and logistical challenges.

In sum, our study represents an initial step toward producing a foundation for future health assessment work on Microlophus lava lizards, a small and interesting group of reptiles in the Galápagos. Because there are several closely related species on various islands in the Archipelago, future studies should determine the extent to which the parameters measured here vary across species.

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References

Alberts AC, Oliva ML, Worley MB, Telford SR, Morris PJ, Janssen DL (1998) The need for pre-release health screening in animal translocations: a case study of the Cuban iguana (Cyclura nubila). In Animal Conservation Forum, Vol. 1. Cambridge University Press, England, pp 165–172.

Anish TS, Shahulhameed S, Vijayakumar K, Joy TM, Sreelakshmi PR, Kuriakose A (2013) Gender difference in blood pressure, blood sugar, and cholesterol in young adults with comparable routine physical exertion. J Fam Med Prim Care 2: 200.

Bartholomew GA, Bennett AF, Dawson WR (1976) Swimming, diving and lactate production of the marine iguana, Amblyrhynchos cristatus. Copeia 1976: 709–720.

Benavides E, Baum R, Snell HM, Snell HL, Sites JW Jr (2009) Island biogeography of Galápagos lava lizards (Tropiduridae: Microlophus); species diversity and colonization of the archipelago. Evolution 63: 1606–1626.

Bennett AF (1973) Blood physiology and oxygen transport during activity in two lizards, Varanus gouldii and Sauromalus hispidus. Comp Biochem Physiol A Physiol 46: 673–690.
Research article

Bennett AF, Licht P (1972) Anaerobic metabolism during activity in lizards. J Comp Physiol A Neuroethol Sens Neural Behav Physiol 81: 277–288.

Bennett AF, Gleeson TT, Gorman GC (1981) Anaerobic metabolism in a lizard (Anolis bonaiensis) under natural conditions. Physiol Zool 54: 237–241.

Berriozabal-Islas C, Badillo-Saldana IM, Ramírez-Bautista A, Moreno CE (2017) Effects of habitat disturbance on zoonotic functional diversity in a tropical dry forest of the Pacific coast of Mexico. Trop Conserv Sci 10: 1–11.

Burgdorf-Moisuk A, Wack R, Ziccardi M, Larsen RS, Hopper K (2012) Validation of lactate measurement in American flamingo (Phoenicopterus ruber) plasma and correlation with duration and difficulty of capture. J Zoo Wildl Med 43: 450–458.

Calle P, Rodríguez J, Matamoros Y. (Eds.) With the collaboration of: Bennett AF, Licht P, (1972) Anaerobic metabolism during activity in lizards. J Comp Physiol A Neuroethol Sens Neural Behav Physiol 81: 277–288.

Gillespie I, Rosenstock PG, Hughes D (2016) Update: clinical use of plasma lactate. Vet Clin: Small Anim Pract 47: 325–342.

Gleeson TT, Dalessio PM (1989) Lactate and glycogen metabolism in the lizard Dipsosaurus dorsalis following exhaustive exercise. J Exp Biol 144: 377–393.

González-Morales JC, Quintana E, Díaz-Albíter H, Guevara-Fiore P, Fajardo V (2015) Is erythrocyte size a strategy to avoid hypoxia in Wiegmann’s torquise lizards (Scoloporus torquatus)? Field evidence. Can J Zool 93: 377–382.

Innis CJ (2014) Conservation issues. In Mader DR, Divers SJ, eds. Current Therapy in Reptile Medicine and Surgery. Iowa State University Press, Elsevier, Canada, pp 70–92.

Jacobson ER (2001) Morphologic and cytochemical characteristics of blood cells and hemolytic and plasma biochemical reference ranges in green iguanas. J Am Vet Med Assoc 218: 915–921.

Harms CA, Mallo KM, Ross PM, Segars AL (2003) Venous blood gases and lactates of wild loggerhead sea turtles (Caretta caretta) following two capture techniques. J Wildl Dis 39: 366–374.

Harr KE, Alleman AR, Dennis PM, Maxwell LK, Lock BA, Bennett RA, Jacobson ER (2001) Morphologic and cytochemical characteristics of blood cells and hemolytic and plasma biochemical reference ranges in green iguanas. J Am Vet Med Assoc 218: 915–921.

Harter TS, Morrison PR, Mandelman JW, Riemer JL, Farrell AP, Brill RW, Brauner CJ (2015) Validation of the i-STAT system for the analysis of blood gases and acid–base status in juvenile sandbar shark (Carcharhinus plumbeus). Conserv Physiol 3: cov002. doi:10.1093/conphys/cov002.

He J, Xiu M, Tang X, Yue F, Wang N, Yang S, Chen Q (2013) The different mechanisms of hypoxic acclimatization and adaptation in lizard Phrynocephalus vlangalii living on Qinghai-Tibet Plateau. J Exp Zoolog A Ecol Genet Physiol 319: 117–123.

James SB, Iverson J, Greco V, Raphael BL (2006) Health assessment of Allen Cays rock iguana, Cyclura clytus inornata. J Herpetol Med Surg 16: 93–8.

Keogh JS, Noble DWA, Wilson EE, Whiting MJ (2012) Activity predicts male reproductive success in a polygynous lizard. PLoS One 7, doi:http://dx.doi.org/10.1371/journal.pone.0038856.
Lazić MM, Kaliontzopoulou A, Carretero MA, Crnobrnja-Isailović J (2013) Lizards from urban areas are more asymmetric: using fluctuating asymmetry to evaluate environmental disturbance. PLoS One 8: e84190. doi:10.1371/journal.pone.0084190.

Lewbart GA, Hirschfeld M, Brothers JR, Muñoz-Pérez JP, Denkinger J, Vinueza L, Lohmann KJ (2015) Blood gases, biochemistry and haematology of Galápagos marine iguanas (Amblyrhynchus cristatus). Conserv Physiol 3: cov034. doi: 10.1093/conphys/cov034.

Maia JP, Harris DJ, Carranza S, Gómez-Díaz E (2014) A comparison of multiple methods for estimating parasitemia of hemogregarine hemoparasites (Apicomplexa: Adeleorina) and its application for studying infection in natural populations. PLoS One 9: e95010. doi:10.1371/journal.pone.0095010.

Maria R, Ramer J, Reichard T, Tolson PJ, Christopher MM (2007) Biochemical reference intervals and intestinal microflora of free-ranging Ricord’s iguanas (Cyclura ricordii). J Zoo Wildl Med 38: 414–419.

Márquez C, Cisneros-Heredia DF (2016) Microlophus bivittatus. The IUCN Red List of Threatened Species 2016.

Mauvais-Jarvis F (2017) Gender differences in glucose homeostasis and diabetes. Physiol Behav 187: 20–23.

Murray M (2006) Cardiopulmonary anatomy and physiology. In Mader DR, ed. Reptile Medicine and Surgery, Ed 2. Elsevier Canada, pp 124–134.

Pasek KM, Collver ME (2001) Technique for temporarily marking lizards that does not require capture. Herpetol Rev 32: 30.

Seymour RS (1979) Blood lactate in free-diving sea snakes. Copeia 1979: 494–497.

Schorza JV (1971) Some haematological observations on Tropidurus torquatus (Sauria, Iguanidae) from Venezuela. J Zool 165: 557–561.

Schuett GW, Grober MS (2000) Post-fight levels of plasma lactate and corticosterone in male copperheads, Agkistrodon contortrix (Serpentes, Viperidae); differences between winners and losers. Physiol Behav 71: 335–341.

Stacy NI, Alleman AR, Sayler KA (2011) Diagnostic hematology of reptiles. Clin Lab Med 31: 87–108.

Steinmetz HW, Vogt R, Kästner S, Riond B, Hatt JM (2007) Evaluation of the i-STAT portable clinical analyzer in chickens (Gallus gallus). J Vet Diagn Invest 19: 382–388.

Troyano JC, Gould EG, Gould I (2008) Hematological reference intervals in argentine lizard Tupinambis merianae (Sauria—Teiidae). Comp Clin Pathol 17: 93.

Troya-Zuleta MA (2012) Genética poblacional de la lagartija de lava endémica (Microlophus bivittatus) de la Isla San Cristóbal e islet Lobos, Galápagos-Ecuador, mediante microsatélites como parte de la línea base para su manejo y conservación. Bachelor's thesis. USFQ, Quito.

Wagner RA, Wetzel R (1999) Tissue and plasma enzyme activities in juvenile green iguanas. Am J Vet Res 60: 201–203.

Warren DE, Jackson DC (2008) Lactate metabolism in anoxic turtles: an integrative review. J Comp Physiol B 178: 133–148.

Williams TD, Challenger WO, Christians JK, Evanson M, Love O, Vezina F (2004) What causes the decrease in haematocrit during egg production? Funct Ecol 18: 330–336.