Physiological implications of life at the forest interface of oil palm agriculture: blood profiles of wild Malay civets (*Viverra tangalunga*)

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Agricultural development is a major threat to global biodiversity, and effective conservation actions are crucial. Physiological repercussions of life alongside human-modified landscapes can undermine adaptable species’ health and population viability; however, baseline data are lacking for many wildlife species. We assessed the physiological status of a generalist carnivore, the Malay civet (*Viverra tangalunga*), persisting within an extensively human-modified system in Sabah, Malaysian Borneo. We characterized hematology and serum biochemistry panels from civets sampled across a mosaic landscape comprising tropical forest fragments and oil palm plantations. Intra-population variation in certain blood parameters were explained by expected biological drivers such as sex, age category and sampling season. Furthermore, we determined several erythrocyte measures, immune cell counts and dietary biochemistry markers significantly varied with proximity to oil palm plantation boundaries. These findings were supported by a case study, whereby blood profiles of GPS collared male civets were contrasted based on their exclusive use of forests or use of oil palm plantations. These data provide robust and valuable first insights into this species’ physiological status and suggest agricultural landscapes are impacting the persisting population.

**Key words**: Habitat fragmentation, hematology, health status, Malay civet, oil palm agriculture, serum biochemistry

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**Introduction**

Habitat loss, degradation and fragmentation pose significant threats to global biodiversity, and rates of species extinctions are at an all-time high (*Ceballos et al.*, 2017; *IPBES*, 2018). Species face suites of both global and local stressors from human activities, which combine to undermine the survival capabilities of many wildlife populations. Determining the explicit mechanisms of species loss following anthropogenic change is complicated, yet critical for the design and execution of effective conservation management strategies (*Laurance et al.*, 2012; *Ripple et al.*, 2017).
Conservation physiology aims to link individual physiological fitness to anthropogenically mediated population declines, often, and ideally, prior to the manifestation of measurable losses (Cooke et al., 2013; Wikelski and Cooke, 2006). Some species display an apparently greater ecological resilience to anthropogenic pressures, at least when assessed by more traditional ecological metrics such as species presence or localized abundance counts (Miller et al., 2015; Sih, 2013). Individuals, and by extension, populations, surviving within fragmented and degraded habitats can however be chronically stressed (Johnstone et al., 2011), malnourished (Birnie-Gauvin et al., 2017), immunosuppressed (Messina et al., 2018), at elevated risk of pathogen or parasite exposure (Bready et al., 2013) or fail to successfully reproduce (Banks et al., 2007). It is therefore critical to assess the physiological health of individuals, and by extension, species, persisting alongside the interface of natural and human-modified landscapes. Such assessments enable effective conservation actions to be crafted through the identification of otherwise cryptic threats to the long-term survival of a population (e.g. Cooke et al., 2012; Madliger et al., 2017).

The determination of wildlife health is a complex and developing field (Kindig and Stoddart, 2003; Stephen, 2014), and multiple metrics have evaluated species’ physiological responses to life in a changing world (Ellis et al., 2012; Johnstone et al., 2017; Madliger et al., 2018). The evaluation of hematology and serum biochemistry profiles is one of the most informative assessments in determining the health and condition of wild species (Couch et al. 2017; Johnstone et al. 2017). Mammalian blood is a highly dynamic and reactive fluid composed of erythrocytes, leukocytes, thrombocytes and a suite of circulating pathophysiological markers such as minerals and hormones; all of these components can react to and reflect the overall status of an individual (Kerr, 2002). Natural variation in the absolute quantification of blood parameters collected from healthy individuals exists (Friedrichs et al., 2012), and these reference ranges frequently depend upon intrinsic factors such as the sex, age and reproductive status of an individual (Keohane et al., 2016). Clinically, changes in blood parameters away from relative baselines can be indicative of disease, malnutrition, toxicant exposure or chronic stress (Davis and Maney, 2018; Johnstone et al., 2017; Maceda-Veiga et al., 2015). Intrapopulation variation in blood parameters such as erythrocyte characteristics, white blood cell (WBC) counts, stress indices and lipid profiles of species persisting in fragmented and degraded habitats have quantified some of the physiological prices of persistence (e.g. García-Feria et al., 2017; Irwin et al., 2010; Johnstone et al., 2012; May-Júnior et al., 2009; Tyagi et al., 2019). However, established blood profiles are still severely lacking for most wildlife species (Deem et al., 2001), due at least in part to the invasive nature of sample collection and processing (Maceda-Veiga et al., 2015). Thus, the collection and assessment of blood profiles of wild species are both warranted and crucial as the human impact continues to increase across the globe (Haddad et al., 2015).

The loss and degradation of Bornean lowland tropical rainforests via the establishment of oil palm (Elaeis guineensis) plantations pose a direct threat to the rich faunal diversity of the region (Meijaard et al., 2018). Generalist species, such as long- and pig-tailed macaques (Macaca fascicularis; M. nemestrina), wild pigs (Sus scrofa), Asian water monitor lizards (Varanus salvator) and civets (Viverridae spp.) are observed within the agricultural matrix and in small patches of degraded forests alongside plantations; some researchers go so far as to postulate these species may thrive in such landscapes (Guerrero-Sanchez, 2019; Holzner et al., 2019; Luskin et al., 2017; Twining et al., 2017). There are, however, scant, if any, studies specifically evaluating the physiological health status of these species within anthropogenically modified landscapes. Indeed, very little is known concerning the basic ecology of Bornean generalists, particularly the enigmatic small carnivores (Mathai et al., 2016). One such species is the Malay civet (Viverra tangalunga), a 3–7 kg ground-dwelling, nocturnal and omnivorous small carnivore. This species is frequently documented within disturbed landscapes, including alongside agriculture (Jennings and Veron, 2009; Ross et al. 2016). There is evidence, however, that the species’ persistence within and adaptability to human-modified landscapes comes at an ecological cost; collared individuals using oil palm plantations hold significantly larger home ranges than those exclusively using remnant forest patches (Evans et al., in review). There are currently no captive standardized reference intervals for this species within the Species360 database (Species360, 2019), or peer-reviewed reports of wild sampling efforts; thus, in order to more thoroughly determine the physiological repercussions of this species’ flexibility to human-modified ecosystems, baseline data are critically required.

Through the deployment of a multi-year trapping and sampling campaign, we evaluated the physiological status of Malay civets persisting within the agriculturally fragmented landscape of the Lower Kinabatangan Floodplain. We robustly describe, for the first time, the hematological and serum biochemistry parameters for a wild Bornean viverrid. This study further aimed to evaluate how variations in civet blood parameters were related to landscape and seasonal factors, while identifying and statistically controlling for natural physiological variation from the age and sex of an animal. Finally, we compared the results from the population-level modelling with the blood profiles of GPS collared adult male civets with known spatial movements.

Methods

Study site

This study was based in the Lower Kinabatangan Floodplain in eastern Sabah, Malaysian Borneo (Fig. 1). The climate of the area is considered humid tropical; daily temperatures ranged from 22–24°C during the study period. Mean (± SE) annual rainfall measured 2680 ± 210.5 mm, with
wetter months typically spanning October through March. The mosaic landscape of the Floodplain comprises fragments of protected albeit degraded lowland forests surrounded by commercial oil palm plantations. Trapping occurred within the Lower Kinabatangan Wildlife Sanctuary, a series of 10 discontinuous lots totaling 270 km² alongside the Kinabatan-
gan River; animals were specifically sampled from lots 5–7. The protected area network includes an additional seven forest reserves, managed by the Sabah Forestry Department, and altogether covers a total area of 450 km². These patches contain a mixture of dry lowland, semi-inundated, swamp and mangrove forests interspersed with grasslands (Abram et al., 2014). The majority of the Floodplain has been con-
verted into agricultural land use, particularly large-scale oil palm plantations (Abram et al., 2014); as of 2014, over 98% of the remaining forested areas are within 1 km of an edge (Francis, 2017).

Animal capture and sampling

Civet live trapping began in April 2015 and concluded in July 2019. Civets were captured using custom-built treadle-
activated box traps (110 cm × 35 cm × 40 cm) and commer-
cial spring-loaded traps (91 cm × 30 cm × 30 cm). Trap sets were carefully selected based on adequate canopy cover and high dry ground, and each was covered with foliage to provide additional shelter. We baited traps with audio lures and used cooking oil by 18:30 h. Sites were checked between 07:00 h and 08:00 h the following morning and were closed during the day to avoid diurnal captures of non-target species.

Upon capture, animals were carefully subdued within the trap with the aid of a purpose-built wooden squeeze door, whereupon a qualified veterinarian administered anesthesia via intramuscular injection. Animals were sedated with either 5 mg kg⁻¹ tiletamine/zolazepam (Zoletil™, Virbac Laboratories, France) or a mixture of equal parts 1.5 mg kg⁻¹ ketamine (Narketan™, Vétoquinol UK Limited, UK), xylazine (Ilium Xylazil™, Troy Laboratories PTY Limited, Australia) and tiletamine/zolazepam. In the case of the latter drug combina-
tion, the reversal agent yohimbine (Reverzine™, Bomac Pty Limited, Australia) was administered (1:1–1:3 xylazine vol-
ume: reversal volume ratio) once the animal was safely placed in a pet carrier to recover. All animal handling protocols and sampling procedures were approved by the Sabah Wildlife Department and the Sabah Biodiversity Centre (license ref. no: JKM/MBS.10000–2/2 JLD.6[8]). Our capture and GPS collar deployment techniques followed the guidelines set by the American Society of Mammalogists (Sikes et al., 2016).

Throughout the sampling procedures, we monitored the animal’s vital signs (respiration rate, heart rate, rectal tem-
perature and peripheral oxygen saturation [SpO₂]) every 5 min. Once the anesthetic plane was deemed adequate, we collected ~1 ml kg⁻¹ of blood from each individual via cephalic, brachial or femoral venipuncture (23-gauge/3-cc syringe or 25-gauge/1-cc syringe). Blood aliquots were immediately stored in plain and ethylenediaminetetraacetic
This process instead robustly evaluated the drivers behind parameter is considered healthy or normal for this species; no assumptions regarding whether the magnitude of each agriculture, as defined by those plantations on the same delineated as wet (October–March) or dry (April–September) subadult) or mature (adult 4

3.5.0, R Core Team, 2018). Individuals were binned into a two-level classification scheme of immature (juvenile + milk teeth), subadult (small in size, transitional dentition), adult (large body size, signs of active reproduction, mature dentition) or old (slight body condition despite large size, poor or worn teeth); all assessments were made by the same observer (M. Evans). A radio-frequency identification microchip was subcutaneously implanted between the shoulder blades of each anesthetized individual (Trovan Ltd, UK). We fitted GPS collars on select adult males to determine individual patterns of habitat use. Briefly, these units collected hourly nocturnal locations from tagged animals for an average of 120 nights. For tag specifications and performance, see details provided in Evans et al. (2016); spatial data handling protocols and home range results were reported in Evans et al. (in review).

Data analysis
We assessed the effects of Malay civet sex, age category, sampling season and oil palm plantation proximity on recorded blood parameters with generalized linear models in R (version 3.5.0, R Core Team, 2018). Individuals were binned into a two-level classification scheme of immature (juvenile + subadult) or mature (adult + old), and sampling season was delineated as wet (October–March) or dry (April–September) months. The distance from the capture site of an animal to the nearest oil palm plantation was determined with ArcGIS 10.1 (ESRI, 2011) from digitized Google Earth Pro satellite imagery; these measurements only determined accessible agriculture, as defined by those plantations on the same riverbank as civet capture site. This statistical approach makes no assumptions regarding whether the magnitude of each parameter is considered healthy or normal for this species; this process instead robustly evaluated the drivers behind the observed parameter variations within the sampled population. All individuals were visibly healthy (in good body condition with no clinically apparent symptoms of illness); for individuals with multiple capture events, only blood parameters from the first sampling event were included in model development.

The specific blood parameter data type determined each model family, and link functions were selected based on AIC minimization and best normalization of model residual plots (Supplementary Table 1). Count data were first modeled with Poisson model families; however, as all were found to be over-dispersed (over-dispersion statistic >20; Thomas et al., 2017), models were instead fit with negative binomial structures with the MASS package (Venables and Ripley, 2002). Proportional datasets were modeled using binomial generalized linear models fitted with ‘logit’ link functions (Thomas et al., 2017). Lastly, due to reported values below laboratory detection limits for uric acid, bilirubin and GGT, these data were conservatively binned into binomial classes; models thus evaluated the factors influencing values below versus above the limit of detection within the sample population.

The most parsimonious model for each blood parameter was determined by multi-model inference, whereby candidate model structures were generated and small-sample size corrected Akaike's Information Criteria (AICc) values compared using the ‘dredge’ function in the MuMIN package (Barton, 2018). The top models were selected as those with a ΔAICc <2 and were averaged using the natural average method to more wholly account for uncertainty in the model structure selection process (Burnham and Anderson, 2002). Prior to model averaging, oil palm proximity measurements were standardized to a mean of 0 and standard deviation of 0.5 to allow for direct comparison between terms (Grueber et al., 2011).

GPS collared male Malay civets were grouped according to the habitat types accessed throughout their collaring periods ('forest only' or 'mixed' habitat individuals, per Evans et al., in review). Mixed habitat individuals accessed both protected forests and industrial oil palm plantations in their total home ranges. Blood parameters of these groups were compared using either t-tests or Mann–Whitney U tests, as appropriate based on normality of each parameter. Results

Total population
We captured and collected samples from 58 Malay civet individuals within the Lower Kinabatangan Floodplain (Fig. 1). Hematology profiles were successfully established for 51 unique Malay civets (25 males, 26 females). Serum biochemistry panels were successfully determined for 56 unique Malay civets (25 males, 31 females). Of these, 17 samples were removed from potassium, calcium and alkaline phosphatase...
datasets; these values were statistically extreme in a pattern consistent with suspected K-EDTA contamination during sample collection (Bowen and Remaley, 2014).

A total of seven hematology and eight biochemistry parameters were significantly influenced by sex, age category, sampling season or proximity to oil palm plantation; the remaining parameters were not significantly related to any of these variables (Tables 1–2). Summary descriptions of the blood parameters of the sampled population, partitioned and annotated as appropriate given the GLM results, are displayed in Supplementary Tables 2–4.

Only hematology parameters significantly varied between civet sexes (Tables 1–2). Hemoglobin (Haem) concentration was significantly depressed in males compared to females. Total red blood cell (RBC) counts and packed cell volume (PCV) values were also elevated in males compared to females, and in animals trapped in the dry compared to the wet season. In contrast, females expressed significantly elevated lymphocyte (Lymp) counts compared to males, as did immature compared to mature individuals.

Civet age was the only biological term that significantly described variations in serum biochemistry parameters (Tables 1–2). Phosphate (P) and alkaline phosphatase (AlkPho) levels were significantly elevated in immature compared to mature civets. Mature animals, in contrast, expressed significantly higher creatinine (Creat), total protein (TotProt) and globulin (Glo) levels than immature animals.

Finally, the distance between oil palm plantation boundaries and capture sites significantly related to variations in both hematology and biochemistry parameters (Tables 1–2). Malay civets captured closer to plantations expressed significantly depressed mean corpuscular hemoglobin concentration (MCHC), WBC counts and neutrophil (Neut) counts. Measured high density lipoprotein (HDL) decreased as the distance between the capture site and plantation increased. In contrast, civet total cholesterol to HDL ratio (Ratio) and urea (Ur) levels increased with increasing distance from agriculture.

**GPS collared males**

In total, we successfully collected blood from 13 GPS collared adult males. Malay civets that did not access oil palm (n = 5) expressed significantly elevated MCHC, decreased mean corpuscular volume and elevated serum urea concentrations compared to those that used both forests and oil palm plantations (n = 8; Fig. 2; Supplementary Tables 5–6).

Malay civets that used only forests expressed significantly elevated MCHC compared to those individuals that entered agriculture (t = 3.213, df = 11, P < 0.01). Specifically, forest only males expressed a mean MCHC value 27 g/L greater than those that entered oil palm plantations. Civet MCV significantly varied between civet habitat usages (Mean ± SD; forest only animals: 50.8 ± 2.7 fl; mix habitat animals: 54.9 ± 3.4 fl; t = –2.264, df = 11, P < 0.05). Civets that resided solely in the forests expressed significantly elevated urea concentrations compared to those individuals that entered the agriculture (t = 4.393, df = 11, P < 0.01); forest only animals expressed a mean urea concentration 4.01 mmol/L greater than those that entered oil palm plantations.

**Discussion**

This study provides insights into the physiological status of a small carnivore species persisting within the agriculturally fragmented Lower Kinabatangan Floodplain. By conducting the longest running field study of this species to date, a multifaceted narrative regarding the risks and possible rewards of persistence in the mosaic Kinabatangan landscape is presented. We report the first hematology and serum biochemistry profiles for this species; the establishment of these values, although not to be directly interpreted as healthy reference intervals in the clinical sense, provides a foundation for future studies to contextualize their findings. Civet blood parameter measurements were influenced by sex, age, sampling season and proximity to oil palm plantation; these findings were supported by a case study approach evaluating the blood profiles of GPS collared civets with known spatial behaviours. Modeling results suggest intrapopulation variation in blood parameters is attributed, in addition to expected physiological drivers, to anthropogenically mediated processes.

**Biological effects**

At the population level, civet blood parameter measurements were influenced by biological factors, reinforcing the importance of acknowledging these traits in wild animal health assessments. Males expressed elevated hemoglobin levels, RBC counts and PCV compared to females. These parameters are frequently naturally elevated in male mammals (Iberian lynx, Lynx pardina, Beltrán et al., 1991; grizzly bear, Ursus arctos, Brannon, 1985; Tasmanian devil, Sarcophilus harrisii, Hope and Peck, 2016; reviews by Kerr, 2002; Murphy, 2014); this is largely attributed to the stimulating effects of sex hormones, specifically androgens, on RBC production processes (Kerr, 2002; Zitzmann and Nieschlag, 2004). RBC count and PCV were further influenced by capture season, whereby individuals sampled in the dry season expressed elevated values relative to those captured in the wetter season. This likely suggests civet hydration status decreases during the dry season, as both PCV and RBC measurements are clinically elevated through a reduction in circulating plasma volume in dehydrated individuals (Kerr, 2002; Nayak et al., 2012). Interestingly, these were the only parameters for the species to vary with season, in contrast to other carnivore blood profile studies (e.g. Eastern quoll, Dasyurus viverrinus, Fancourt and Nicol, 2019; Tasmanian devil, Stannard et al., 2016; brown hyena, Parahyaena brunnea, Wiesel et al., 2018). This could be due to the lack
Table 1: Standardized parameter estimates for statistically significant averaged models describing variation in Malay civet (*Viverra tangalunga*) hematology and serum biochemistry parameters. NS denotes statistically non-significant \((P > 0.05)\) terms. Bold terms emphasize significant variables. SeasonW = wet season; SexM = male; Plant = distance to nearest oil palm plantation; AgecatM = mature civets. Intercept is the standardized reference level for factorized predictor variables (e.g. dry season, female, immature). Shorthand notation for response variables matches those in Supplementary Table 1. \# denotes a non-averaged final model (i.e. there were 0 additional models whereby ΔAICc < 2)

| Parameter | Variable | Estimate | Std. Error | z value | P value |
|-----------|----------|----------|------------|---------|---------|
| Haem      | (Intercept) | 110.52 | 2.26 | 47.68 | <0.00001 |
|           | SeasonW   | -4.906 | 5.28 | 0.919 | NS      |
|           | SexM      | 18.104 | 4.531 | 3.896 | <0.001  |
| RBC       | (Intercept) | 797.49 | 35.93 | 21.70 | <0.00001 |
|           | SeasonW   | -78.73 | 35.19 | 2.18  | <0.05   |
|           | SexM      | 105.36 | 34.74 | 2.960 | <0.005  |
|           | AgecatM   | -9.34  | 27.33 | 0.34  | NS      |
| PCV\#     | (Intercept) | -0.362 | 0.046 | -7.909 | <0.00001 |
|           | SexM      | 0.261  | 0.057 | 4.591  | <0.001  |
|           | SeasonW   | -0.153 | 0.058 | -2.622 | <0.01   |
| MCHC      | (Intercept) | 5.556  | 0.00848 | 639.35 | <0.00001 |
|           | Plant     | 0.05032 | 0.01712 | 2.866 | <0.005  |
|           | SeasonW   | 0.00708 | 0.01402 | 0.497 | NS      |
| WBC       | (Intercept) | 7.084  | 0.078 | 88.84 | <0.00001 |
|           | Plant     | 0.1651 | 0.0744 | 2.164 | <0.05   |
|           | SeasonW   | -0.0458 | 0.0736 | 0.614 | NS      |
|           | AgecatM   | -0.0343 | 0.0727 | 0.465 | NS      |
| Neut      | (Intercept) | 6.702  | 0.076 | 86.27 | <0.00001 |
|           | Plant     | 0.267  | 0.1035 | 2.513 | <0.005  |
|           | SeasonW   | -0.138 | 0.0953 | 0.592 | NS      |
|           | SexM      | 0.0412 | 0.0839 | 0.484 | NS      |
| Lymp      | (Intercept) | 5.916  | 0.167 | 34.59 | <0.00001 |
|           | AgecatM   | -0.3622 | 0.164 | 2.145 | <0.05   |
|           | SexM      | -0.3335 | 0.135 | 2.398 | <0.02   |
|           | SeasonW   | -0.0417 | 0.100 | 0.409 | NS      |
| HDL       | (Intercept) | 0.7659 | 0.02779 | 26.931 | <0.00001 |
|           | Plant     | -0.1500 | 0.05839 | 2.513 | <0.005  |
|           | AgecatM   | 0.05666 | 0.07082 | 0.791 | NS      |
|           | SexM      | -0.07444 | 0.06924 | 1.063 | NS      |
| Ratio     | (Intercept) | 0.4615 | 0.01668 | 27.048 | <0.0001  |
|           | SeasonW   | 0.02843 | 0.03753 | 0.75  | NS      |
|           | Plant     | 0.10402 | 0.03403 | 2.987 | <0.005  |
|           | SexM      | 0.00933 | 0.02352 | 0.391 | NS      |

(Continued)
of environmentally driven breeding season for the species (indeed, we failed to detect any discernable temporal patterns in female pregnancy rates during our sampling efforts [Evans, 2019]). Alternatively, our simplified binary categorization of the rainfall patterns in lowland rainforests may not fully encompass the nuances in daily weather patterns relevant to blood metrics.

With respect to immune system parameters, female Malay civet lymphocyte counts were elevated compared to males, as were levels for immature civets. There is established clinical evidence that mammalian immunology naturally varies between males and females (Klein and Flanagan, 2016). Mechanistically, testosterone levels of male civets may suppress lymphocyte production rates relative to those of female civets (Foo et al., 2017). Alternatively, circulating estrogen and progesterone could biochemically enhance female civets’ adaptive immune responses (Foo et al., 2017; Klein, 2000). Lower male lymphocyte counts have been similarly recorded in Tasmanian devils (Hope and Peck, 2016). Further, elevated lymphocyte counts are reported in young and developing animals (Kerr, 2002; Nussey et al., 2011), suggesting civet immune systems may follow patterns expected from targeted studies. Alternatively, these results may be related to reproductive activity; indeed, as early term pregnancy was unable to be determined for sampled civets, there could be a cryptic exacerbating effect of pregnancy on adult female lymphocyte counts (Roved et al., 2017).

Similarly, the elevation of phosphate and alkaline phosphatase concentrations in immature Malay civets compared to adults was not unexpected and can be explained by physiological growth processes. Both the mineral and enzyme increase in circulation during bone growth and development processes occurring in young individuals (Fernandez and Kidney, 2007). This age effect has been documented in many wild mammalian carnivores (common palm civet, Paradoxurus hermaphroditus, Ahmad et al., 2017; grizzly bear, Brannon, 1985; Florida panther, Puma concolor coryi, Dunbar et al., 1997; Iberian lynx, García et al., 2010; Tasmanian devil, Hope and Peck, 2016; Peck et al., 2015; Culpeo fox, Lycalopex culpaeus, Rubio et al., 2014; grey wolf, Canis lupus, Seal et al., 1975; brown hyena, Wiesel et al., 2018). Further, lower globulin and total protein

| Parameter | Variable | Estimate | Std. Error | z value | P value |
|-----------|----------|----------|------------|---------|---------|
| Ur | (Intercept) | 8.2232 | 0.2813 | 28.55 | <0.0001 |
| Plant | | 2.0806 | 0.6012 | 3.382 | <0.001 |
| SexM | | 0.5154 | 0.6237 | 0.817 | NS |
| SeasonW | | −0.2304 | 0.4476 | 0.508 | NS |
| Creat | (Intercept) | 4.1823 | 0.0269 | 151.72 | <0.0001 |
| AgecatM | | 0.1559 | 0.0647 | 2.354 | <0.02 |
| SeasonW | | −0.0169 | 0.0407 | 0.408 | NS |
| P | (Intercept) | 0.4408 | 0.03258 | 13.22 | <0.0001 |
| AgecatM | | −0.3074 | 0.08171 | 3.681 | <0.0005 |
| SeasonW | | −0.0865 | 0.08291 | 1.02 | NS |
| Plant | | −0.0572 | 0.07029 | 0.804 | NS |
| TotProt | (Intercept) | 79.537 | 0.9338 | 83.23 | <0.0001 |
| AgecatM | | 6.5099 | 2.1661 | 2.938 | <0.005 |
| Plant | | 1.9261 | 2.1472 | 0.887 | NS |
| SexM | | −0.3715 | 0.0647 | 2.354 | <0.02 |
| SeasonW | | 0.5751 | 1.4097 | 0.401 | NS |
| Glo | (Intercept) | 50.73 | 0.9665 | 51.208 | <0.0001 |
| AgecatM | | 6.671 | 2.1227 | 3.068 | <0.005 |
| SexM | | −3.041 | 1.1369 | 0.323 | NS |
| Plant | | 2.026 | 2.3921 | 0.839 | NS |
| AlkPho | (Intercept) | 4.0505 | 0.2600 | 15.581 | <0.0001 |
| AgecatM | | −0.7534 | 0.2907 | −2.592 | <0.02 |
Table 2: Top candidate (ΔAICc < 2) model structures included in model averaging, log-likelihood (LogL), Akaike’s Information Criterion with the small sample bias adjustment (AICc) and Akaike weights (wi) for predicting relationships between standardized independent biological and spatial variables and Malay civet hematology and serum biochemistry parameters. Season = dry or wet capture season; Sex = male or female civet; Agecat = immature or mature civet; Plant = distance from capture site to nearest accessible oil palm plantation. Refer to Supplementary Table 1 for parameter shorthand reference. *denotes a non-averaged final model (i.e. there were 0 additional models whereby (ΔAICc < 2))

| Parameter | Candidate model | df | LogL | AICc | ΔAICc | wi |
|-----------|-----------------|----|------|------|-------|----|
| Haem      | Season + Sex    | 4  | -213.14 | 435.14 | 0 | 0.6 |
| Sex       |                 | 3  | -214.72 | 435.96 | 0.81 | 0.4 |
| RBC       | Season + Sex    | 4  | -317.7 | 644.28 | 0 | 0.72 |
| Agecat + Season + Sex | 5  | -317.41 | 646.15 | 1.87 | 0.28 |
| PCV*      | Season + Sex    | 3  | -163.11 | 326.46 | 0 | 1   |
| MCHC      | Plant           | 3  | -211.25 | 429.02 | 0 | 0.63 |
| Plant + Season |         | 4  | -210.60 | 430.08 | 1.06 | 0.37 |
| WBC       | Plant           | 3  | -363.93 | 734.36 | 0 | 0.39 |
| Plant + Season |           | 4  | -363.15 | 735.17 | 0.81 | 0.26 |
| Agecat + Plant |        | 4  | -363.53 | 735.93 | 1.57 | 0.18 |
| Agecat + Plant + Season | 5  | -362.35 | 736.04 | 1.68 | 0.17 |
| Neut      | Plant           | 3  | -346.56 | 699.65 | 0 | 0.38 |
| Plant + Season |       | 4  | -345.70 | 700.31 | 0.67 | 0.27 |
| Plant + Sex |             | 4  | -345.95 | 700.82 | 1.17 | 0.21 |
| Plant + Season + Sex | 5  | -345.08 | 701.56 | 1.91 | 0.14 |
| Lymp      | Agecat + Sex    | 4  | -296.5 | 601.91 | 0 | 0.69 |
| Agecat + Season + Sex | 5  | -296.06 | 603.51 | 1.59 | 0.31 |
| HDL       | Agecat + Sex + Plant | 5  | -29.61 | 70.43 | 0 | 0.38 |
| Sex + Plant |             | 4  | -31.05 | 70.88 | 0.45 | 0.3  |
| Agecat + Plant |         | 4  | -31.66 | 72.11 | 1.68 | 0.16 |
| Plant     | 3  | -32.87 | 72.21 | 1.78 | 0.16 |
| Ratio     | Season + Plant  | 4  | 12.35 | -15.91 | 0 | 0.33 |
| Plant     | 3  | 10.94 | -15.42 | 0.49 | 0.26 |
| Sex + Plant |             | 4  | 11.37 | -13.96 | 1.95 | 0.12 |
| Agecat + Plant |         | 4  | 11.36 | -13.93 | 1.98 | 0.12 |
| Ur        | Sex + Plant    | 4  | -113.63 | 236.07 | 0 | 0.36 |
| Plant     | 3  | -115.12 | 236.70 | 0.64 | 0.26 |
| Creat     | Agecat         | 3  | -219.3 | 445.07 | 0 | 0.68 |
| Agecat + Season |       | 4  | -218.9 | 446.59 | 1.52 | 0.32 |

(Continued)
Table 2: Continued

| Parameter | Candidate model | df  | LogL  | AICc  | ΔAICc | wi  |
|-----------|-----------------|-----|-------|-------|-------|-----|
| P         | Agecat + Season + Plant | 5   | -19.88| 50.95 | 0     | 0.37|
|           | Agecat + Season   | 4   | -21.29| 51.36 | 0.41  | 0.30|
|           | Agecat + Plant    | 4   | -21.76| 52.31 | 1.35  | 0.19|
|           | Agecat            | 3   | -23.14| 52.71 | 1.79  | 0.15|
| TotProt   | Agecat + Plant    | 4   | -186.91| 382.60| 0     | 0.29|
|           | Agecat            | 3   | -188.21| 382.89| 0.29  | 0.25|
|           | Agecat + Sex + Plant | 5   | -186.24| 383.69| 1.09  | 0.17|
|           | Agecat + Season + Plant | 5   | -186.41| 384.01| 1.41  | 0.14|
|           | Agecat + Season   | 4   | -187.67| 384.12| 1.52  | 0.14|
| Glo       | Agecat + Sex + Plant | 5   | -174.08| 359.43| 0     | 0.53|
|           | Agecat + Sex      | 4   | -176.00| 360.83| 1.40  | 0.26|
|           | Agecat            | 3   | -177.41| 361.31| 1.88  | 0.21|
| AlkPho    | Agecat            | 3   | -148.79| 297.70| 0     | 1   |

Figure 2: Blood parameters of GPS-collared adult male Malay civets (Viverra tangalunga) using only forests (n = 5) or forest and oil palm plantations (mix, n = 8) that showed significant differences in (A) mean corpuscular hemoglobin concentration (MCHC); (B) mean corpuscular volume (MCV); and (C) urea concentrations based on habitat utilization. (Mann–Whitney U/t-test at P < 0.05)

measurements in immature relative to mature individuals are likely due to the development of immune responses and hepatic systems of maturing animals (Kerr, 2002). This is similarly in agreement with records in other carnivores (Amur leopard, Panthera pardus orientalis, Bodgener and Lewis, 2017; grizzly bear, Brannon, 1985; red panda, Ailurus fulgens, Burrel et al., 2018; Tasmanian devil, Hope and Peck, 2016; Peck et al., 2015; Stannard et al., 2016; Indian leopard, P. p. fusca, Shanmugam et al., 2017; and brown hyena, Wiesel et al., 2018). The documented elevation in mature civet creatinine levels likely relates to differences in muscle mass between adult and growing individuals (Kerr, 2002), as creatinine is a product of muscle catabolism (Delanaye et al., 2017). We suggest it is unlikely there is evidence of age-driven variation in Malay civet renal performance, as urea levels did not vary with animal age, as would be clinically expected from renal complications. Similar patterns were documented in Iberian lynx (Beltrán et al., 1991; Garcia et al., 2010), Amur leopard (Bodgener and Lewis, 2017), polar bear (Ursus maritimus, Fry et al., 2019) and Chinese pangolin (Manis pentadactyla, Khatri-Chhetri et al., 2013).

Landscape effects

In addition to the biological variations in Malay civet blood parameters, we documented landscape-level effects on carnivore physiology. MCHC significantly varied in relation to landscape configuration; civets captured closer to oil palm plantations expressed significantly lower MCHC compared to those sampled farther from agriculture. As the MCHC value directly relates to the oxygen transport potential of blood, a relative decrease of this index can clinically indicate hypochromic anemia (Johnstone et al., 2017). A decrease in MCHC can relate to difficulties in hemoglobin synthesis, which is most often attributed to insufficient iron levels (Keohane et al., 2016); indeed, iron deficiencies in wild carnivores persisting in degraded habitats have been reported...
Animal lipid profiles respond to food consumption, be it via changes in the selection of specific food items or changes in the nutritional quality of food, particularly fat and carbohydrate content (Shanmugam et al., 2011; Wiesel et al., 2018). Surprisingly, the ratio of total cholesterol to HDL–cholesterol levels were lower, and HDL–cholesterol higher, in civets captured nearer to oil palm plantations; such a lipoprotein balance is clinically indicative of a reduced risk of cardiovascular disease in mammals (Bruss, 2008). Interestingly, nutritional research claims consumption of oil palm products increases HDL–cholesterol in both humans and laboratory rats (Dauqan et al., 2011; Sun et al., 2015). Indeed, this is often a significant selling point of marketing campaigns lauding oil palm as a ‘healthier’ vegetable oil product (Kushairi et al., 2018). Guerrero-Sanchez (2019) recorded similar patterns in Asian water monitor lizards captured within the Kinabatangan plantation landscape. Malay civets are flexible dietary generalists and have been observed ingesting both oil palm fruits and small mammals within plantations (Joscelyne; unpublished data; Guharajan et al., 2019). Alternatively, there is evidence that circulating HDL–cholesterol can be increased by elevated cardiovascular exercise (Kraus et al., 2002). As GPS collared male civets accessing oil palm agriculture held larger home ranges than those individuals that remained within the forest (Evans et al., in review), the lipid profiles in this sampled population may reflect the more demanding foraging activities by animals persisting alongside agriculture.

Malay civet dietary flexibility across the Lower Kinabatangan Floodplain is further indicated by the positive relationship between blood urea concentration and distance from capture site to oil palm plantation. Serum urea is traditionally measured as part of a renal function panel, whereby elevation indicates dysfunction (Kerr, 2002). Civet creatinine levels, however, did not predictably vary with plantation proximity. Creatinine is the clinically more specific marker used in the diagnosis of renal dysfunction (Braun and Lefevre, 2008), thus this spatial variation in civet urea is most likely due to a factor not directly related to renal function. An increase in protein consumption can elevate circulating urea levels, as urea is a waste product of amino acid breakdown (Kerr, 2002). This suggests Malay civets captured closer to oil palm plantations may have diets lower in protein relative to those captured deeper in the forest. Depressed blood urea values measured from wildlife in fragmented and degraded landscapes have been attributed to deficiencies in dietary protein intake (maned wolf, Curi et al., 2015; howler monkey, García-Feria et al., 2017; diademed sifaka, Irwin et al., 2010; bobcat, Series et al., 2018). Further targeted research into Malay civet dietary habits relative to landscape composition is strongly required to untangle these findings; genetic assessments of civet feces (e.g. Cancio et al., 2017) could evaluate the degree of omnivory in the Kinabatangan civets relative to landscape composition.
Case study: GPS collared civets

The differences in blood parameters of the GPS collared Malay civets compared well to the modeled landscape patterns reported from the sampled population. The similarly depressed MCHC in males utilizing oil palm plantations compared to those remaining exclusively in the forest adds further weight to the above hypothesis of landscape-facilitated anemia in civets associating with agriculture. Intriguingly, this case study reported not just relative hypochromia within the animals accessing agriculture, but also a relative macrocytic MCV profile (Keohane et al., 2016); when considered together, these results may provide evidence of regenerative anemia within the population (Johnstone et al., 2017). This type of anemia is frequently the result of chronic stressors experienced by wild populations; following blood loss (e.g. parasitism, injury), exposure to certain toxins or elevation of circulating stress hormones, there is an increased release of reticulocytes (immature erythrocytes) from the bone marrow to keep up with the body’s demand for RBCs (Johnstone et al., 2011). Reticulocytes are, however, both larger in size and less capable of producing hemoglobin than fully mature erythrocytes, which could explain the relative macrocytic and hypochromic characteristic patterns described in these GPS collared animals (Doig, 2016; Fisher and Crook, 1962; Keohane et al., 2016). An examination of civet reticulocyte counts would provide more conclusive evidence of spatially-mediated regenerative anemia. Similar findings of anemia related to stress or parasite infections have been documented in other wild species (agile antechinus, Johnstone et al., 2012; hedgehog, Erinaceus europaeus, Paffele et al., 2009; Brazilian carnivore spp., Santos et al., 2018); further research is warranted, particularly evaluating if the scale of measured differences is indicative of physiological detriment to a given individual, such as diminished reproductive success or dispersal survival (e.g. Vitousek et al., 2014; Wingfield and Sapolsky, 2003).

In contrast, the leukocyte profiles of GPS collared civets did not reflect the population-level patterns of relative neutropenia-mediated leukocyte variation in individuals sampled nearer to oil palm plantations; however, collared individuals that accessed them expressed lower circulating monocyte counts relative to forest only civets, although this difference was not statistically significant. This does not immediately negate the hypothesis that oil palm agriculture may facilitate population-wide variations in immune function; these findings may indicate a shift in the mode of the condition from neutrophils to monocytes in this specific case. Confounding effects of stress, toxins and acute infections can all impact immune functioning (Davis et al., 2008; Repetto and Baliga, 1997). Given the relatively small sample size of collared animals paired with the complexity of intraspecific immune system responses (Roquez et al., 2016), we recommend further research into the specific biochemical processes that may result in landscape-mediated patterns of immunosuppression.

Lastly, urea values were significantly decreased in civets utilizing oil palm plantations compared to those that remained exclusively in the forest. This is similarly consistent with the population-level model findings, suggesting there may be dietary or lipid metabolism differences between the spatial groups. The collared males did not demonstrate any differences in measured HDL concentration or total cholesterol to HDL ratio; this may be similarly due to the small sample size.

As previously stated, there are no available reference intervals from Malay civets or closely related phylogenetic proxies against which to contextualize the magnitude of our results. The implications of this are 2-fold: it is possible our discussed concerns are not clinically indicative of individual fitness repercussions; or it is possible the population as a whole expresses abnormal blood profiles, and thus we under report the extent of the dangers facing this species. For example, the lack of spatial trends in liver enzymes could be due to the fact that the Kinabatangan population displays elevated enzyme activity indicative of liver damage, regardless of distance to agriculture. These findings further highlight the importance, and difficulty, of determining species-specific reference intervals. Widening the extent of sampling efforts to include captive animals and populations in less anthropogenically disturbed landscapes would begin to more fully contextualize the physiological threats oil palm agriculture may pose to this flexible species.

Overall, several logistical considerations were unable to be controlled and may influence the reported blood profiles for the species. First, it is important to acknowledge these animals were captured in traps at a remote field site. This process intensifies the acute stress experienced by an individual, and we were unable to control for the possible effects of varied capture, animal and sample handling times on blood parameter measurements. There is evidence that wild animal blood profiles can be influenced by trapping and anesthetic methodologies (Brockman, 1981; Santos et al., 2015), and although the parameters assessed here are less temporally sensitive than others such as hormone biomarkers, future comparative research should bear in mind the methodology employed in our study. Although all the animals included in this study were visually healthy, additional factors such as fasting status, endoparasite load, pathogen infection and pregnancy were not assessed, and thus unable to be accounted for; in this study design. Lastly, although utmost care was taken to minimize sample degradation due to improper storage temperatures or delays in clinical assessment, this study was conducted at a remote location without access to stable cold storage options such as liquid nitrogen, so some samples may cryptically be of subpar quality.

Despite these considerations, this study has provided evidence of landscape-facilitated variation in RBC, immune and biochemical dietary indicators within the Malay civet population of the Lower Kinabatangan Floodplain. This first
evaluation of civet hematology and biochemistry profiles has provided a powerful reference toolkit for the rapid assessment of the physiological status of this adaptable species in a fragmented ecosystem. Most notably, we highlight the potential physiological costs of carnivore persistence alongside oil palm agriculture, which may undermine the long-term population viability of this species.

**Supplementary material**

Supplementary material is available at *Conservation Physiology* online.

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**References**

Abram NK et al. (2014) Synergies for improving oil palm production and forest conservation in floodplain landscapes. *PLoS One* 9, e95388. doi: 10.1371/journal.pone.0095388.

Acevedo-Whitehouse K, Duffus ALJ (2009) Effects of environmental change on wildlife health. *Philos Trans R Soc B Biol Sci* 364: 3429–3438.

Ahmad AA, Jayarajah P, Han GWY, Yin SJOW, Rasedee A (2017) Hematology and serum biochemistry parameters for rescued common palm civets (*Paradoxurus hermaphroditus*) in different age groups. *J Vet Med* 79: 1134–1137.

Allen LC, Turmelle AS, Mendonça MT, Navara KJ, Kunz TH, McCracken GF (2009) Roosting ecology and variation in adaptive and innate immune system function in the Brazilian free-tailed bat (*Tadarida brasiliensis*). *J Comp Physiol B* 179: 315.

Banks SC, Piggott MP, Stow AJ, Taylor AC (2007) Sex and sociality in a disconnected world: a review of the impacts of habitat fragmentation on animal social interactions. *Can J Zool* 85: 1065–1079.

Bartón K (2018) *MuMIn: Multi-Model Inference*. R package version 1.40.4. https://CRAN.R-project.org/package=MuMIn.

Beltrán JF, Delibes M, Recio F, Aza C (1991) Hematological and serum chemical characteristics of the Iberian lynx (*Lynx pardina*) in southwestern Spain. *Can J Zool* 69: 840–846.

Birnie-Gauvin K, Peiman KS, Raubenheimer D, Cooke SJ (2017) Nutritional physiology and ecology of wildlife in a changing world. *Conserv Physiol* 5, cox300. doi: 10.1093/compus/cox300.

Bodgener J, Lewis JCM (2017) Haematological and serum biochemistry reference intervals for the Amur leopard (*Panthera pardus orientalis*). *J Zoo Aquar Res* 5: 142–150.

Bowen RAR, Remaley AT (2014) Interferences from blood collection tube components on clinical chemistry assays. *Biochem Medica* 24: 31–44.

Brannor RD (1985) Serum chemistry of central and northern Alaska grizzly bears. *J Wildl Manag* 49: 893–900.

Braun JP, Lefebvre H (2008) Kidney function and damage. In JJ Kaneko, JW Harvey, ML Bruss, eds, *Clinical Biochemistry of Domestic Animals*. Academic Press, Burlington, pp. 485–528.

Brearley G, Rhodes J, Bradley A, Baxter G, Seabrook L, Lunney D, Liu Y, McAlpine C (2013) Wildlife disease prevalence in human-modified landscapes. * Biol Rev 88*: 427–442.

Brockman RP (1981) Effect of xylazine on plasma glucose, glucagon and insulin concentrations in sheep. *Res Vet Sci* 30: 383–384.

Bruss ML (2008) Lipids and ketones. In JJ Kaneko, JW Harvey, ML Bruss, eds, *Clinical Biochemistry of Domestic Animals*. Academic Press, Burlington, pp. 81–115.

Burnham KP, Anderson DR (2002) *Model Selection & Multi-Model Inference: A Practical Information-Theoretic Approach*, Ed2nd. Springer, New York.

Burrell C, Aitken-Palmer C, Luo L, Jones MK, Freeman E, Lee A (2018) Hematology and serum biochemistry values of the red panda subspecies (*Ailurus fulgens styani*). *J Zoo Wildl Manag* 49: 384–395.

Cancio I, González-Robles A, Bastida JM, Isla J, Manzaneda AJ, Salido T, Rey PJ (2012) Conservation physiology: how physiological knowledge has improved our ability to sustainably manage Pacific salmon during up-river migration. *Philos Trans R Soc B Biol Sci* 367: 1757–1769.

Clark KS, Hippel TG (2016) Manual, semiautomated, and point-of-care testing in hematology. In EM Keohane, LJ Smith, JM Walenga, eds, *Rodak’s Hematology: Clinical Principles and Applications*. Elsevier Saunders, St. Louis, pp. 187–207.

Cooke SJ et al. (2012) Conservation physiology in practice: how physiological knowledge has improved our ability to sustainably manage Pacific salmon during up-river migration. *Philos Trans R Soc B Biol Sci* 367: 1757–1769.
increasingly integrated and essential science. *Conserv Physiol* 1, cot001. doi: 10.1093/conphys/cot001.

Couch CE, Movius MA, Jolles AE, Gorman ME, Rigas JD, Beechler BR (2017) Serum biochemistry panels in African buffalo: defining reference intervals and assessing variability across season, age and sex. *PloS One* 12, e0176830. doi: 10.1371/journal.pone.0176830.

NHDa C, MaltaMCC CCM, Silva VO, Soriano-Araújo A, Passamani M, Talamon SI (2015) Blood values diverge between two populations of a neotropical wild canid. *Comp Clin Pathol* 24: 435–439.

Daquen E, Sani HA, Abdullah A, Kasim ZM (2011) Effect of different vegetable oils (red palm olein, palm olein, corn oil and coconut oil) on lipid profile in rat. *Food Nutr Sci* 2: 253–258.

Davis AK, Maney DL (2018) The use of glucocorticoid hormones or leukocyte profiles to measure stress in vertebrates: what’s the difference? *Methods Ecol Evol* 9: 1556–1568.

Davis AK, Maney DL, Maerz JC (2008) The use of leukocyte profiles to measure stress in vertebrates: a review for ecologists. *Func Ecol* 22: 760–772.

Deem SL, Cavalier E, Pottel H (2017) Serum creatinine: not so simple! *Exerc Sport Sci Rev* 45: 1–8.

Dunbar MR, Nol P, Linda SB (1997) Hematologic and serum biochemical reference intervals for Florida panthers. *J Wildl Dis* 33: 783–789.

Doig K (2016) Disorders of iron kinetics and heme metabolism. In EM Keoheane, LJ Smith, JM Walenga, eds, *Rodak’s Hematology: Clinical Principles and Applications*. Elsevier Saunders, St. Louis, pp. 297–313.

Delanaye P, Cavalier E, Pottel H (2017) Serum creatinine: not so simple! *Nephron Clin Pract* 136: 302–308.

DelGiudice G, Mech D, Seal U (1991) Gray wolf density and its association with weights and hematology of pups from 1970 to 1988. *J Wildl Dis* 27: 630–636.

Fry TL, Friedrichs KR, Atwood TC, Duncan C, Simac K, Goldberg T (2019) Reference intervals for blood-based biochemical analytes of southern Beaufort Sea polar bears. *Conserv Physiol* 7, coz040. doi: 10.1093/conphys/coz040.

Garcia I, Napp S, Zorrilla I, Vargas A, Pastor J, Muñoz Á, Martínez F (2010) Determination of serum biochemical reference intervals for the Iberian lynx (*Lynx pardinus*). *Vet J* 183: 201–204.

Garcia-Feria LM, Chapman CA, Pastor-Nieto R, Serio-Silva JC (2017) Biochemical and hematological evaluations of black howler monkeys (*Alouatta pigra*) in highly degraded landscapes in Mexico. *J Med Primatol* 46: 304–310.

Fischer JW, Crook JJ (1962) Influence of several hormones on erythropoiesis and oxygen consumption in the hypophysectomized rat. *Blood* 19: 557–565.

Fon YZ, Nakagawa S, Rhodes G, Simmons LW (2017) The effects of sex hormones on immune function: a meta-analysis. *Biol Rev* 92: 551–571.

Francis O (2017) Quantifying and understanding rapid land use change in the Lower Kinabatangan floodplains, Malaysian Borneo. MSc dissertation, Cardiff University.

French SS, DeNardo DF, Moore MC (2007) Trade-offs between the reproductive and immune systems: facultative responses to resources or obligate responses to reproduction? *Am Nat* 170: 79–89.

Friedrichs KR, Harr KE, Freeman KP, Szladovits B, Walton RM, Barnhart KF, Blanco-Chavez J (2012) ASVCP reference interval guidelines: determination of de novo reference intervals in veterinary species and other related topics. *Vet Clin Pathol* 41: 441–453.

Fritsma GA (2016) Hemorrhagic disorders and laboratory assessment. In EM Keoheane, LJ Smith, JM Walenga, eds, *Rodak’s Hematology: Clinical Principles and Applications*. Elsevier Saunders, St. Louis, pp. 667–688.

Evans MN, Guerrero-Sanchez S, Bakar MSA, Kille P, Goossens B (2016) First known satellite collaring of a viverrid species: preliminary performance and implications of GPS tracking Malay civets (*Viverra tangalunga*). *Ecol Res* 31: 475–481.

Fancourt BA, Nicol SC (2019) Hematologic and serum biochemical reference intervals for wild eastern quolls (*Dasyurus viverrinus*): variation by age, sex, and season. *Vet Clin Pathol* 48: 114–124.

Fernandez NJ, Kidney BA (2007) Alkaline phosphatase: beyond the liver. *Vet Clin Pathol* 36: 1–11.

Garcia-Feria LM, Chapman CA, Pastor-Nieto R, Serio-Silva JC (2017) Biochemical and hematological evaluations of black howler monkeys (*Alouatta pigra*) in highly degraded landscapes in Mexico. *J Med Primatol* 46: 304–310.

Doig K (2016) Disorders of iron kinetics and heme metabolism. In EM Keoheane, LJ Smith, JM Walenga, eds, *Rodak’s Hematology: Clinical Principles and Applications*. Elsevier Saunders, St. Louis, pp. 297–313.

Evans MN, Guerrero-Sanchez S, Bakar MSA, Kille P, Goossens B (2016) First known satellite collaring of a viverrid species: preliminary performance and implications of GPS tracking Malay civets (*Viverra tangalunga*). *Ecol Res* 31: 475–481.

Fancourt BA, Nicol SC (2019) Hematologic and serum biochemical reference intervals for wild eastern quolls (*Dasyurus viverrinus*): variation by age, sex, and season. *Vet Clin Pathol* 48: 114–124.

Fernandez NJ, Kidney BA (2007) Alkaline phosphatase: beyond the liver. *Vet Clin Pathol* 36: 1–11.

Fisher JW, Crook JJ (1962) Influence of several hormones on erythropoiesis and oxygen consumption in the hypophysectomized rat. *Blood* 19: 557–565.

Fon YZ, Nakagawa S, Rhodes G, Simmons LW (2017) The effects of sex hormones on immune function: a meta-analysis. *Biol Rev* 92: 551–571.

Francis O (2017) Quantifying and understanding rapid land use change in the Lower Kinabatangan floodplains, Malaysian Borneo. MSc dissertation, Cardiff University.

French SS, DeNardo DF, Moore MC (2007) Trade-offs between the reproductive and immune systems: facultative responses to resources or obligate responses to reproduction? *Am Nat* 170: 79–89.

Friedrichs KR, Harr KE, Freeman KP, Szladovits B, Walton RM, Barnhart KF, Blanco-Chavez J (2012) ASVCP reference interval guidelines: determination of de novo reference intervals in veterinary species and other related topics. *Vet Clin Pathol* 41: 441–453.

Fritsma GA (2016) Hemorrhagic disorders and laboratory assessment. In EM Keoheane, LJ Smith, JM Walenga, eds, *Rodak’s Hematology: Clinical Principles and Applications*. Elsevier Saunders, St. Louis, pp. 667–688.

Fry TL, Friedrichs KR, Atwood TC, Duncan C, Simac K, Goldberg T (2019) Reference intervals for blood-based biochemical analytes of southern Beaufort Sea polar bears. *Conserv Physiol* 7, coz040. doi: 10.1093/conphys/coz040.

Garcia I, Napp S, Zorrilla I, Vargas A, Pastor J, Muñoz Á, Martínez F (2010) Determination of serum biochemical reference intervals for the Iberian lynx (*Lynx pardinus*). *Vet J* 183: 201–204.

Garcia-Feria LM, Chapman CA, Pastor-Nieto R, Serio-Silva JC (2017) Biochemical and hematological evaluations of black howler monkeys (*Alouatta pigra*) in highly degraded landscapes in Mexico. *J Med Primatol* 46: 304–310.

Goltzman D (2018) Diagnostic approach to hypocalcemia. https://www.uptodate.com/contents/diagnostic-approach-to-hypocalcemia. (last accessed 17 June 2020).

Grueber CE, Nakagawa S, Laws RJ, Jamieson IG (2011) Multimodel inference in ecology and evolution: challenges and solutions. *J Evol Biol* 24: 699–711.

Guerrero-Sanchez, S (2019) Ecology and health of the Asian water monitor lizard (*Varanus salvator*) in the fragmented landscape of the Kinabatangan Floodplain, Sabah, Malaysia. PhD dissertation, Cardiff University.

Guharan R, Abram NK, Magguna MA, Goossens B, Wong ST, Nathan SKS, Garshelis DL (2019) Does the vulnerable sun bear *Helarctos malayanus* damage crops and threaten people in oil palm plantations? *Oryx* 53: 611–619.

Haddad NM et al. (2015) Habitat fragmentation and its lasting impact on Earth’s ecosystems. *Sci Adv* 1, e1500052. doi: 10.1126/sciadv.1500052.

Hoffbrand AV, Moss PAH, Pettit JE (2006) *Essential Haematology*, Ed5th. Blackwell Publishing Ltd, Massachusetts.
Holzner A et al. (2019) Macaques can contribute to greener practices in oil palm plantations when used as biological pest control. Curr Biol 29: R1055–R1069. doi: 10.1016/j.cub.2019.09.011.

Hope KL, Peck S (2016) Hematological and serum biochemical values in anesthetized captive Tasmanian devils (Sarcophilus harrisii). J Zoo Wild Med 47: 564–572.

IPBES (2018) Summary for Policymakers of the Thematic Assessment Report on Land Degradation and Restoration of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES Secretariat, Bonn, pp. 1–31.

Irwin MT, Junge RE, Raharison JL, Samonds KE (2010) Variation in physiological health of diademed sifakas across intact and fragmented forest at Tsingy arivo, eastern Madagascar. Am J Primatol 72: 1013–1025.

Ishigame G, Baxter GS, Lisle AT (2006) Effects of artificial foods on the hematological and serum biochemical values in the estuarine ray, Aetomylus marginalis. J Appl Ichthyol 22: 372–375.

Jennings AP, Veron G (2009) Family Viverridae (civets, genets and oyans). In DE Wilson, RA Mittermeier, eds, Handbook of the Mammals of the World Volume 1: Carnivores. Lynx Edicions, Barcelona, pp. 174–233.

Johnstone CP, Lill A, Reina RD (2011) Response of the agile antechinus to habitat edge, configuration and condition in fragmented forest. PLoS One 6, e27158. doi: 10.1371/journal.pone.0027158.

Johnstone CP, Lill A, Reina RD (2012) Does habitat fragmentation cause stress in the agile antechinus? A haematomatological approach. J Comp Physiol B 182: 139–155.

Johnstone CP, Lill A, Reina RD (2017) Use of erythrocyte indicators of health and condition in vertebrate ecosphysiology: a review and appraisal. Biol Rev 92: 150–168.

Kaliński A, Barbura M, Gląbalski M, Markowski M, Skwarska J, Wawrzyniak J, Zielirski P, Barbura J (2017) Spatial and temporal variation in triglyceride concentration in the blood of nesting blue tits Cyanistes caeruleus. Avian Biol Res 10: 63–68.

Katavolos P, Staempfli S, Sears W, Ganzcy AY, Smith DA, Bienzle D (2007) The effect of lead poisoning on hematologic and biochemical values in trumpeter swans and Canada geese. Vet Clin Pathol 36: 341–347.

Keohane EM, Smith LJ, Walenga JM (2016) Rodak’s Hematology: Clinical Principles and Applications. Elsevier Saunders, St. Louis.

Kerr MG (2002) Veterinary Laboratory Medicine, Interpretation and Diagnosis, Clinical Biochemistry and Haematology. Blackwell Science Ltd, Oxford.

Khatri-Chhetri R, Sun CM, Wu HY, Pei KJ (2015) Reference intervals for hematolog, serum biochemistry, and basic clinical findings in free-ranging Chinese pangolin (Manis pentadactyla) from Taiwan. Vet Clin Pathol 44: 380–390.

Kindig D, Stoddard G (2003) What is population health? Am J Public Health 93: 380–383.

Klein SL (2000) The effects of hormones on sex differences in infection: from genes to behavior. Neurosci Biobehav Rev 24: 627–638.

Klein SL, Flanagan KL (2016) Sex differences in immune responses. Nat Rev Immunol 16: 626–638.

Kraus WE et al. (2002) Effects of the amount and intensity of exercise on plasma lipoproteins. N Engl J Med 347: 1483–1492.

Kushairi A, Loh S, Azman I, Hishamuddin E, Ong-Abdullah M, Izuddin ZBMN, Razmah G, Sundram S, Parvez GK (2018) Oil palm economic performance in Malaysia and R&D progress in 2017. J Oil Palm Res 30: 163–195.

Laurance WF et al. (2012) Averting biodiversity collapse in tropical forest protected areas. Nature 489: 290–294.

Longanbach S, Miers MK (2016) Automated blood cell analysis. In EM Keohane, LJ Smith, JM Walenga, eds, Rodak’s Hematology: Clinical Principles and Applications. Elsevier Saunders, St. Louis, pp. 208–234.

Luskin MS, Brashares JS, Ickes K, Sun IF, Fletcher C, Wright SJ, Potts MD (2017) Cross-boundary subsidy cascades from oil palm degrade distant tropical forests. Nat Comm 8: 2231. doi: 10.1038/s41467-017-01920-7.

Maceda-Veiga A, Figuerola J, Martinez-Silvestre A, Viscor G, Ferrari N, Pacheco M (2015) Inside the Redbox: applications of haematology in wildlife monitoring and ecosystem health assessment. Sci Total Environ 514: 322–332.

Madliger CL, Franklin CE, Hultine KR, Van Kleunen M, Lennox RJ, Love OP, Rummer JL, Cooke SJ (2017) Conservation physiology and the quest for a ‘good’Anthropocene. Conserv Physiol 5: 1–10. doi: 10.1093/consphys/cox033.

Madliger CL, Love OP, Hultine KR, Cooke SJ (2018) The conservation physiology toolbox: status and opportunities. Conserv Physiol 6, coy029. doi: 10.1093/consphys/coy029.

Mathai et al. (2016) Carnivore conservation planning on Borneo: identifying key carnivore landscapes, research priorities and conservation interventions. Raffles Bull Zool 33: 186–217.

May-Júnior JA, Songsasen N, Azevedo FC, Santos JP, Paula RC, Rodrigues FH, Rodden MD, With DE, Morato RG (2009) Hematology and blood chemistry parameters differ in free-ranging maned wolves (Chrysocyon brachyurus) living in the Serra da Canastra National Park versus adjacent farmlands, Brazil. J Wildl Dis 45: 81–90.

McCowen KC, Malhotra A, Bistrian BR (2001) Stress-induced hyperglycemia. Crit Care Clin 17: 107–124.

Meijaard E, Garcia-Ulloa J, Sheil D, Wich SA, Carlson KM, Juffe-Bignoli D, Brooks TM (2018) Oil Palm and Biodiversity: A Situation Analysis by the IUCN Oil Palm Task Force. IUCN Oil Palm Task Force, Gland, pp. 1–116.

Messina S, Edwards DP, Eens M, Costantini D (2018) Physiological and immunological responses of birds and mammals to forest degradation: a meta-analysis. Biol Conserv 224: 223–229.

Miller JED, Damschen EI, Harrison SP, Grace JB (2015) Landscape structure affects specialists but not generalists in naturally fragmented grasslands. Ecology 96: 3323–3331.
Murphy WG (2014) The sex difference in haemoglobin levels in adults—
mechanisms, causes, and consequences. Blood Rev 28: 41–47.

Nayak R, Rai S, Gupta A (2012) Essentials in Hematology and Clinical
Pathology. Jaypee Brothers Medical Publishers Ltd, New Delhi.

Nussey DH, Watt K, Pilkington JG, Zamoyska R, McNeilly TN (2011) Age-
related variation in immunity in a wild mammal population. Aging
Cell 11: 178–180.

Peck S, Corkrey R, Hamede R, Jones M, Canfield P (2015) Hematologic
and serum biochemical reference intervals for wild Taiwanese devils
(Sarcophilus harrisii). Vet Clin Pathol 44: 519–529.

Pfaffle M, Petney T, Elgas M, Skuballa J, Taraschewski H (2009) Tick-
induced blood loss leads to regenerative anaemia in the European
hedgehog (Erinaceus europaeus). Parasitology 136: 443–452.

Pfeifer M et al. (2017) Creation of forest edges has a global impact on
forest vertebrates. Nature 551: 187–191.

P Core Team (2018) R: A Language and Environment for Statistical Com-
puting. R Foundation of Statistical Computing, Vienna, Austria.

Repetto R, Baliga SS (1997) Pesticides and immunosuppression. Health
Policy Plan 12: 97–106.

Rippe JW et al. (2017) Conserving the world’s megafauna and biodiver-
sity: the fierce urgency of now. Bioscience 67: 197–200.

Roquiz W, Diffalha SA, Kini AR (2016) Leukocyte development, kinetics,
and functions. In EM Keohane, LJ Smith, JM Walenga, eds, Rodak’s
Hematology: Clinical Principles and Applications. Elsevier Saunders,
St. Louis, pp. 149–166.

Ross J et al. (2016) Predicted distribution of the Malay civet Viverra
tangalunga (Mammalia: Carnivora: Viverridae) on Borneo. Raffles Bull
Zool 33: 78–83.

Roved J, Westerdahl D, Hasselquist D (2017) Sex differences in immune
responses: hormonal effects, antagonist selection, and evolution-
ary consequences. Horm Behav 88: 95–105.

Rubio AV, Hidalgo-Hermoso E, Bonacc C (2014) Hematology and serum
biochemistry values of Culpeo foxes (Lycalopex culpaeus) from Central
Chile. J Zoo Wildl Med 45: 589–593.

Salvante KG (2006) Techniques for studying integrated immune function
in birds. The Auk 123: 575–586.

Santos FM et al. (2018) Outcomes of Trypanosoma cruzi and Try-
panosoma evansi infections on health of southern coati (Nasua
nasua), crab-eating fox (Cerdocyon thous), and ocelot (Leopardus
pardalis) in the Brazilian Pantanal. PLoS One 13, e0201357.
doi:10.1371/journal.pone.0201357.

Santos N et al. (2015) Hematology and serum biochemistry values of
free-ranging Iberian wolves (Canis lupus) trapped by leg-hold snares.
Eur J Wildl Res 61: 135–141.

Seal US, Mech LD, Van Ballenberghe V (1975) Blood analyses of wolf
pups and their ecological and metabolic interpretation. J Mammal
56: 64–75.

Selgrade MK (2007) Immunotoxicity- the risk is real. Toxicol Sci 100:
328–332.

Seltmann A, Czirjak GÁ, Courtiol A, Bernard H, Struebig MJ, Voigt CC
(2017) Habitat disturbance results in chronic stress and impaired
health status in forest-dwelling paleotropical bats. Conserv Physiol 5,
cox020. doi:10.1093/conphys/cox020.

Sereys LE et al. (2018) Urbanization and anticoagulant poisons pro-
mote immune dysfunction in bobcats. Proc R Soc B Biol Sci 285:
20172533.

Shanmugam AA, Kumar JK, Selvaraj I, Selvaraj V (2011) Effects of body
weight and season on serum lipid concentrations in sloth bears
(Melursus ursinus ursinus). J Zoo Wildl Med 42: 373–381.

Shanmugam AA, Muliya SK, Deshmukh A, Suresh S, Nath A, Kalaigned
P (2017) Baseline hematology and serum biochemistry results for
Indian leopards (Panthera pardus fusca). Vet World 10: 818–824.

Sih A (2013) Understanding variation in behavioural responses to
human-induced rapid environmental change: a conceptual overview.
Anim Behav 85: 1077–1088.

Sikes RS, Animal Care and Use Committee of the American Society of
Mammalogists (2016) 2016 guidelines of the American Society of
Mammalogists for the use of wild mammals in research and educa-
 tion. J Mammal 97: 663–688.

Species360, Zoological information management system, version 1.7.
Accessed Mar. 2019. Retrieved from http://zims.Species360.org.

Stannard RJ, Thompson P, Mcallan BM, Raubenheimer D (2016)
Hematology and serum biochemistry reference ranges of healthy
captive Tasmanian devils (Sarcophilus harrisii) and their associ-
ation with age, gender and seasonal variation. Mamm Biol 81:
393–398.

Stephen C (2014) Toward a modernized definition of wildlife health.
J Wild Dis 50: 427–430.

Sun Y, Neelakantan N, Wu Y, Lote-Oke R, Pan A, van Dam RM (2015) Palm
oil consumption increases LDL cholesterol compared with vegetable
oils low in saturated fat in a meta-analysis of clinical trials. J Nutr
145: 1549–1558.

Thomas R, Lello J, Medeiros R, Pollard A, Robinson P, Seward A, Smith J,
Vafidis J, Vaughan I (2017) Data Analysis With R Statistical Software: A
Guidebook for Scientists. Eco-Explore, Cardiff.

Twining JP, Bernard H, Ewers RM (2017) Increasing land-use intensity
reverses the relative occupancy of two quadrupedal scavengers. PLoS
One 12: e0177143. doi: 10.1371/journal.pone.0177143.

Tyagi A, Kumar V, Kittur S, Reddy M, Naidenko S, Ganswindt A,
Umaphathy G (2019) Physiological stress responses of tigers due to
anthropogenic disturbance especially tourism in two central Indian
tiger reserves. Conserv Physiol 7, coz045. doi: 10.1093/conphys/
coz045. 
Vitousek MN, Jenkins BR, Safran RJ (2014) Stress and success: individual differences in the glucocorticoid stress response predict behavior and reproductive success under high predation risk. *Horm Behav* 66: 812–819.

Wiesel I, Zimmerman DM, Suedmeyer WK (2018) Serum biochemistry values and select serologic screening of brown hyenas (*Parahyaena brunnea*) from the Namib Desert, Namibia. *J Zoo Wildl Med* 49: 931–942.

Wikelski M, Cooke SJ (2006) Conservation physiology. *Trends Ecol Evol* 21: 38–46.

Wingfield JC, Sapolsky RM (2003) Reproduction and resistance to stress: when and how. *J Neuroendocrinol* 15: 711–724.

Zitzmann M, Nieschlag E (2004) Androgens and erythropoiesis. In E Nieschlag, H Behre, S Nieschlag, eds, Testosterone: Action, Deficiency. Substitution. Cambridge University Press, Cambridge, pp. 283–296.