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RESEARCH

No evidence for sampling bias caused by capture method or time in *Apteryx mantelli*

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Abstract: Sampling bias can have dire consequences for research. One potential source of bias is combining different sampling methods in the same study. However, combining methods can be unavoidable, for instance, when sampling method selection depends upon factors such as population density or terrain. A case at hand is the use of night-time encounter catching by people or daytime catching using certified dogs for studies of *Apteryx mantelli*, North Island brown kiwi, in Aotearoa New Zealand. Here, we compare these sampling methods to determine whether (1) combining them risks inducing a demographic bias to the sample set, and (2) they differ in regards to blood parameters used for comparing populations (packed cell volume, glucose, plasma protein, haemoglobin). Sixty-five birds were caught during the day from their roosts using a certified dog, and 62 birds were caught at night while foraging. The results suggest that both methods capture a comparable subset of a population, with the potential exception that more very young juveniles were caught using the day method. Furthermore, no physiological effects were evident from comparing haematological parameters. We also found no difference in blood sampling success between night and day, but observed that blood extraction was more difficult at night. Hence, we demonstrate that either method, or a combination of both, can be considered for future studies. Notably, we found that night-time encounter catching had a superior success rate in very high-density populations. Since this method also negates dependency on the limited number of certified dogs, we suggest that benefits may exist through increasing the utilisation of night-time encounter catching in *A. mantelli* research. We suggest that future studies should consider measuring the stress levels caused by each of the methods, and quantify the effects of habitat type and terrain on sampling success.

Keywords: Aves, age distribution, blood sampling, catching birds, kiwi, New Zealand, population comparison, sample collection, sampling effort, size distribution

Introduction

The risk of sampling bias is an ever-present worry in ecology research. Some authors even argue that as long as sampling is not a total population census bias is inevitable (Stuber et al. 2013). One scenario of bias-concern is when results obtained using two or more sampling methods are combined. Specifically, combining more than one sampling method risks introducing bias if the methods (1) differ in the subset of the population they capture, which may result in a biased representation of sex, age, personality, social status, or health (Weatherhead & Greenwood 1981; Borràs & Senar 1986; Domènech & Senar 1997; Stuber et al. 2013; Michelangeli et al. 2015; Camacho et al. 2017), (2) differently affect parameters of interest, for instance, by being conducted at a different time of day or year, or causing different levels of stress (Wilson & Wilson 1989; Romero & Romero 2002; Angelier et al. 2010; Michelangeli et al. 2015), or (3) have different success rates, either in the sampling itself or for further processing (Marion et al. 1981; Davis 2005; Ronconi et al. 2010; Benítez-López et al. 2011).

While such biases are undesirable, utilising several sampling methods can be hard to avoid, for instance, when method selection is driven by factors such as habitat, accessibility, and/or population density (DeGraaf et al. 1991; Buckland et al. 2008; Gottschalk & Huettmann 2011). When this is the case, the optimal sampling method might naturally differ between populations and/or sites of interest. Consequently, method-induced sampling bias can be of particular concern when studying population-level differences (Faanes & Bystrak 1981; Domènech & Senar 1997; Lyra-Jorge et al. 2008; Pacheco et al. 2013). Different methods may also be unavoidable when a study combines samples collected at

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different points in time. The longer the time between sampling events, the more likely it is that common practice, technology, and/or method recommendations changed (Ronconi et al. 2010; Benítez-López et al. 2011). However, combining more than one method can also provide an important opportunity to rule out or counteract effects of sampling bias if the respective strengths, weaknesses, and biases of the methods are known.

One taxon for which data sampled at different time points are frequently combined is *Apteryx*, kiwi birds (Burbidge et al. 2003; Weir et al. 2016; Undin et al. 2021). In addition, wild, untagged *A. mantelli* are commonly caught using two different capture methods: (1) daytime catching using a certified dog that finds roosting birds by scent, and (2) night-time encounter-catching that relies on humans spotting foraging birds and catching them either by grabbing their legs or by lowering a net over them (Robertson & Colbourne 2017). The latter can also be combined with attracting birds using playback calls or shepherd's whistles (Robertson & Colbourne 2017). Method selection is mainly related to population density, habitat accessibility, resource availability, and, to some extent, personal preference (Robertson & Fraser 2009; Robertson & Colbourne 2017). Previous work has shown that samples caught by certified dogs represent the true age composition of a population (Robertson & Fraser 2009). However, to our knowledge, there has not yet been a detailed comparison of results obtained by night-time encounter catching and those from catching with certified dogs during the day.

Many questions remain unsolved regarding the biology, health, behaviour, and management of *Apteryx* and since the successful conservation of this iconic genus receives much attention many *Apteryx* studies are currently underway. For instance, ongoing research on North Island brown kiwi, *A. mantelli*, is evaluating population differences in genetic diversity and signs of inbreeding or outbreeding depression across this species (Undin 2021). For such studies to be accurate, it is crucial to ensure that the populations are represented by comparable data sets regarding factors such as age, sex, and health status (Danchin et al. 1995; Blanckenhorn et al. 1999; Kidd et al. 2015).

We identified four factors that could potentially lead to issues with combining daytime catching with a certified dog and night-time encounter catching. First, bird detectability could differ between night and day, as well as between moving and roosting birds, and, potentially, such differences may introduce detection biases between sex, size, and/or age group (Colbourne & Kleinpaste 1983; Halterman 2009; Alves et al. 2017). Second, bird extractability and sampling accessibility could differ between roosting and foraging birds and between different age groups and sexes while roosting. For instance, during the day adult kiwi are more likely to be located in deep burrows while juveniles are more commonly found on the surface potentially making the latter more extractable; at night females have been reported more frequently in open pasture compared to males potentially making them more accessible for sampling (Wilson 2014; Dixon 2015; Jamieson et al. 2016). Third, previous work has raised concerns about the potential for female-biased samples from night-time encounter catching resulting from differences in behaviour (e.g. running pattern and weariness) between sexes affecting their catchability (Colbourne & Kleinpaste 1983). However, such a bias has never been reliably demonstrated. In addition to sex, it is plausible that night-time catchability relates to health status if health affects the amount of time birds spend foraging in the open, their alertness, or their speed potentially causing a bias towards either healthier or less healthy individuals (Weatherhead & Greenwood 1981; Gorney et al. 1999; Bisi et al. 2011). Such behavioural and/or health differences, if present, would unlikely come into play during daytime catching. Finally, it is possible that the different timing of the two methods introduces bias in health and body condition parameters. Studies of other species have, for instance, found haematological differences linked to activity level, temperature, and time since last feeding all of which could lead to an effect of time of sampling on such parameters (Jenni-Eiermann & Jenni 1997; Downs et al. 2010; Lill 2011). Another example is that, for some bird species, amount of food present in the stomach (hence time since feeding) can significantly affect body mass unless controlled for (Hidalgo-Rodríguez et al. 2021).

Herein we present the first ever comparison of the sex and age distribution of sample sets of *A. mantelli* obtained using daytime catching with a certified dog or night-time encounter catching. Further, to investigate time of day effects on the quantification of haematology-parameters and thus the estimation of the individual- as well as the population-level health, we compared haemoglobin concentration (HB), packed cell volume (PCV), glucose concentration, and total protein level between birds caught in the daytime vs night-time. For the haematology comparison we also included a small number of birds captured during the daytime using fitted radio transmitters. To clarify the effectiveness of each method and facilitate making recommendations for future *Apteryx* research projects we also compared the two capture methods with respect the success rate and related this to population density.

Methods

Samples used in this study were collected as part of the Kiwi Whakapapa Program lead by Te Patukeha and Ngati Kuta Hapū in collaboration with Massey University. The aim of this program is to increase our understanding of kiwi genetics and thus provide guidance for the management and research of kiwi in Ipipiri (Bay of Islands; Castro 2021) and throughout Aotearoa New Zealand. No birds were caught solely for the purpose of this comparison of catching methods.

A total of 146 North Island brown kiwi (*Apteryx mantelli*) were captured during the non-breeding seasons (Jan to May) of 2019 and 2020 from nine populations: Motuarohia, Moturoa, Moturua, Puketi Forest (Puketi), Purerua Peninsula (Purerua), Rakaumangamanga (also known as Cape Brett), Trounson Kauri Park (Trounson), Pūkaha National Wildlife Centre (Pūkaha), and Remutaka Forest Park (Remutaka; Fig. 1). All belong to the *A. mantelli* Northland management unit (Craig et al. 2011; Germano et al. 2018), except Remutaka and Pūkaha where birds are of mixed origin (Scrimgeour & Pickett 2011). Birds were found, caught, extracted, handled, and released following the kiwi best practice manual (Robertson & Colbourne 2017).

Birds were caught either (1) in the daytime using a certified dog that located roosting birds by scent and then (when possible) extracted birds from the roost by certified handlers, or (2) in the night-time through encounter-catching where certified humans spot and catch foraging birds by grabbing their legs or lowering a net over them (Robertson & Colbourne 2017). In four populations all birds were caught during the daytime, in one population all birds were caught at night, and in the remaining four populations both methods were used (Table 1). In addition, attracting birds using a shepherd's whistle was attempted but

was found to be unsuccessful and this approach was abandoned (Table 1). Lastly, a few additional samples were collected from birds located using their radio-transmitters (Table 1). These transmitted birds were only included in analyses of the effect of time of day on haematological parameters and not in the comparisons between the two catching methods.

Blood sampling and analyses

Blood sampling was initiated immediately after capture from the metatarsal vein in accordance with the kiwi best practice manual (Robertson & Colbourne 2017). After blood extraction we collected five body measurements: weight was measured using a 2.5 kg or 5 kg Pesola® precision scale. Bill length (bill),

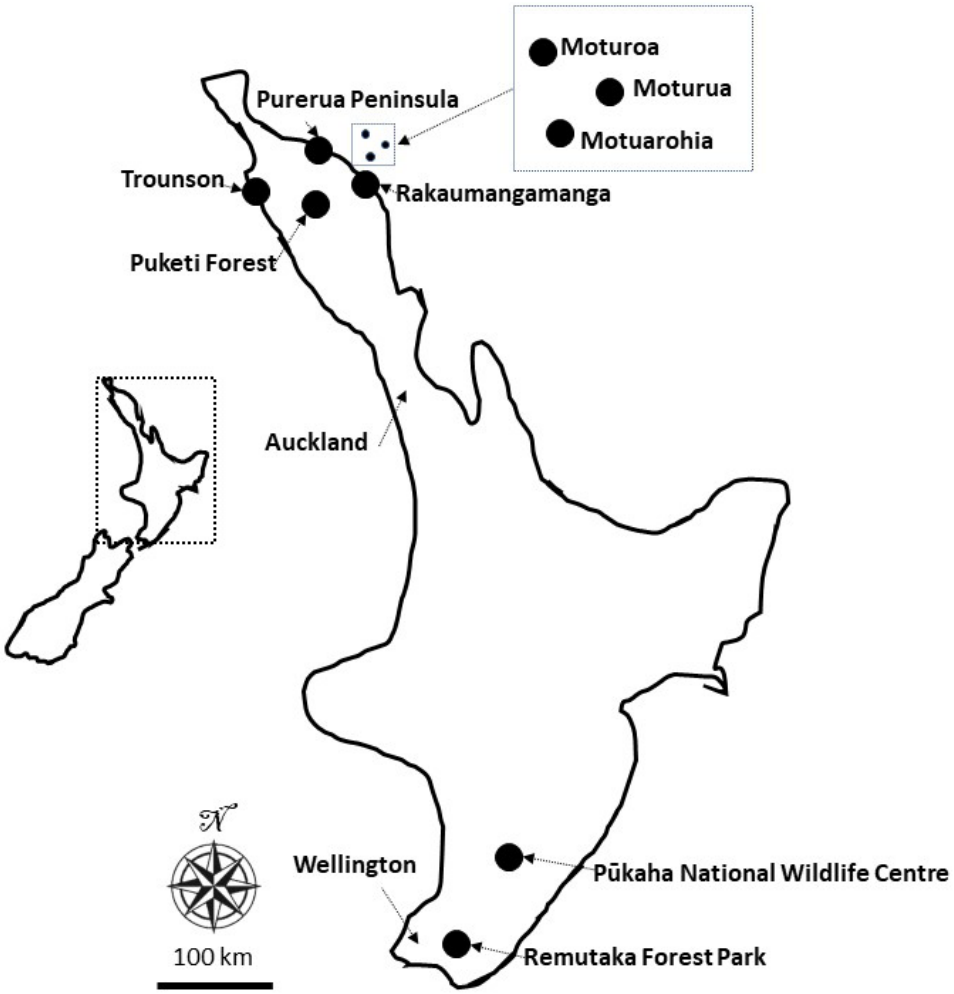

Figure 1. North Island Aotearoa New Zealand with black dots indicating the locations of the nine populations sampled in this study.

Table 1. Populations, methods of capture, and the year(s) and month(s) of sampling. Sample sizes in parentheses. 'Encounter' refers to night-time encounter catching of foraging *Apteryx mantelli*. 'Dog' refers to birds located in the daytime by a certified dog and then extracted from their roost by trained handlers. 'Tx' refers to birds located using radio transmitters.

Population	Night-time (*n*)	Daytime (*n*)	Year	Month
Motuarohia	(0)	Dog (20)	2019–2020	January; February
Moturoa	Encounter (18)	Dog (4)	2020	January
Moturua	Encounter (12)	Dog (9)	2019	January; May
Pūkaha	(0)	Tx (7)*	2020	February; March
Puketi Forest	(0)	Dog (5)	2019	March
Purerua Peninsula	Encounter (22)	(0)	2019	May
Rakaumangamanga	Whistle¥ and encounter (9)	Dog (6)	2019–2020	January; February
Remutaka Forest Park	Whistle¥ and encounter (1)	Tx (5); dog (4)	2020	February; March
Trounson Kauri Park	(0)	Tx (3); dog (17)	2020	February

*4 of these birds were held in an enclosure and not actually fitted with transmitters, but they were included in the tx-birds subset since they were retrieved from their burrows during the daytime but not found by a dog.
¥Whistling and playback was attempted, but unsuccessful and not further considered in the analyses.

tarsus depth (TD), tarsus width (TW), and tarsus length (TL) were all measured using manual or digital Vernier stainless steel callipers with three replicates per measure. We also calculated body condition (BC) based on tarsus width and weight, using equations 1–3 (Taborsky & Taborsky 1999), where weight is body mass (kg), TW is tarsus width (mm), and X refers to the reciprocal of the slope (k) found by relating log weight to log TW.

$$BC = \frac{Weight^X}{TW} \quad (1)$$

$$X = \frac{1}{k} \quad (2)$$

$$\log Weight = k * \log TW + m \quad (3)$$

Up to 0.5 ml of blood was collected per bird. About 10 μl were used to measure glucose level and haemoglobin concentration (HB) at the sample collection site using an EasyTouch® GHb dual-function monitoring system (Nephrocare©, Germany). Two heparinised haematocrits (capillary tubes) were filled with 60–100 μl of blood each. These were centrifuged for 5 minutes at 10 000 rpm 2–8 h after sampling to measure packed cell volume (PCV). Total serum protein level was measured from the plasma after centrifugation of the two haematocrits using a hand-held refractometer (Atago®, Tokyo, Japan). The remainder of each sample was stored for sexing (see below) and further genetic analyses not part of this study.

PCR sexing and defining age groups

It is not possible to sex *Apteryx* individuals with confidence based on morphology or behaviour before they have reached full size (at about four years old). Even then it remains challenging unless the same bird is tracked over multiple years, hence we used polymerase chain reaction (PCR) for sexing our samples (Huynen et al. 2002, 2003). In short, DNA was extracted from 5–50 µl thawed whole *A. mantelli* blood using a high pure PCR template preparation kit (Roche, Basel, Switzerland). The manufacturer's instructions were followed with the exception that the DNA was eluted twice using 50 µl of elution buffer for each centrifugation. For amplification, the primers w5 (5'-AAT CAC CCT TTA AAC AAG CTG TTA AAG CAA-3') and w7 (5'-CCT TTC TCA AAT CTC TCT TTT GTT CTA GAC AC-3') published by Huynen et al. (2003) were used. The amplified DNA was then analysed using agarose gel electrophoresis (1% agarose in 1X TAE buffer: 40 mM Tris, 20 mM Acetate and 1 mM EDTA at pH 8.6). This fragment size separating step results in two visible amplification products on the gel for female *Apteryx*: one of about 350 base pairs (bp) in length and one of about 200 bp. The shorter fragment represents a site on the female-defining W chromosome. For male *Apteryx*, only the 350 bp product is amplified since males lack a W chromosome, resulting in a single band visible on the gels.

Based on sex, bill length, tarsus length, and weight each bird was assigned to one of three age groups: juvenile, sub-adult, and adult based on Robertson and Colbourne (2017). All birds < 1000 g were considered juveniles. Females were considered adults if they had a weight > 2000 g, or a TW > 11 mm plus a weight > 1700 g, or a bill > 113 mm and a weight > 1700 g. Males were considered adults if they had a weight > 1700 g, or a TL > 90 mm plus a weight > 1400 g, or a bill > 90 mm plus a weight > 1400 g. All birds falling in neither the juvenile nor the adult categories were considered sub-adults. These groups approximately correspond to juveniles being less than six months, sub-adults being between six months and sexual maturity (at approximately four years of age), and adults being over four years old, respectively (Robertson & Colbourne 2017). The weight limits of 1400 g and 1700 g respectively are comparably low but were justified by the dry and harsh conditions affecting the birds in 2020 (Castro et al. 2020), and was only used in combination with measurements of size.

Effort and success

Catching success was defined as the number of birds caught per team per day. A team consisted of two to five people; at least two of these people had multiple years' experience of kiwi handling. During day-time catching, one of the experienced team members was a certified dog handler. In total, 40 people were involved in the catching and sampling, and six of these were certified dog handlers each using a different certified dog. There was never more than one dog-handler per team. A maximum of four teams were involved in catching within a given population; no more than two teams were catching at any time point in time. The lead author was involved in the catching of all populations included in the study.

Eight populations were used for the comparison of catching success; Pūkaha was excluded since all sampling there relied on birds being previously fitted with transmitters or held in an enclosure. Populations were grouped into three categories based on the relative density of *A. mantelli* individuals: "very high" (> 1 kiwi ha^{-1}: Moturoa, Purerua, and Trounson), "high" (Moturua and Motuarohia) and "medium" (< 1 bird 10-ha^{-1}: Puketi, Rakaumangamanga, and Remutaka). These categories were chosen to reflect that none of the populations sampled would be considered low density when taking the full range of *A. mantelli* population densities nationwide into account (McLennan & Potter 1992; Robertson & de Monchy 2012; Germano et al. 2018). To compare sampling success we also considered (1) the proportion of birds for which we successfully extracted the target blood volume of 0.5 ml, and (2) how handlers rated the sampling difficulty on a scale from 1 (easy) to 4 (hard). The latter was recorded immediately after sample collection. All birds in the Remutaka population have experience of being handled annually. In Trounson, the two transmitted males and the partner to one of them have previous experience of annual handling; six other birds caught here had been metal banded during surveys several years prior to this study. Three birds caught at Moturua had been banded many years ago. All other birds should have no previous experience of human handling.

Statistical analyses

Chi-square tests were conducted to compare the distribution of sexes and age groups (R version 4.2.2, R core team 2021) between the two capture methods. All six morphometric and four haematological parameters were found to be normally distributed by analyses of histograms and qqplots. Hence, the relationship between these variables and time of day of catching (continuous time as well as categorical 'night' and 'day') was analysed using linear mixed effect models with the package lme4 (Bates et al. 2015) in R version 4.2.2 (R core team 2021). Sampling across months and years were pooled since no effect of this was found (even though more day-birds were caught in February and more night-birds in May

and more day birds were caught in the substantially drier in 2020; Table 1; Appendix S1, S2 in Supplementary Material). Population was, however, kept as random factor for the final model. Analysis of variance (ANOVA; Fox & Weisberg 2019) was used to examine the effect time of day and population density on success rate (birds / (days*teams)).

Results

Overall, 84 birds were caught during the daytime (day-birds) and 62 at night (night-birds). Of the 84 day-birds, 19 were located by their own or their partners' radio transmitter (tx-birds), leaving 65 birds caught with the assistance of a certified dog (dog-birds) for comparison of sample composition and catching method (Table 2).

Sex, age and morphometrics

Based on PCR sexing 57 % of dog-birds and 58 % of night-birds were identified as females (Fig. 2a). Based on size and weight 72 % of dog-birds and 66 % of night-birds were identified as adults, 18 and 29 % as sub-adults respectively, and the rest as juveniles (Fig. 2b). These distributions were not found to be statistically different (sex: $\chi = 0.45$, df = 2, p-value = 0.800; age group: $\chi = 2.54$, df = 2, p-value = 0.280).

Of the six morphometrical characteristics measured no difference was found in weight, tarsus length, bill, or body condition between dog-birds and night-birds (Fig. 3; Table 3). However, night-birds had on average ca 5% larger tarsus width and depth. This was driven by a lack of birds in the smallest size segment among the night-birds (Fig. 3).

Success

Catching success (birds caught per team per day or night) was significantly related to categorical population density (Fig. 4; ANOVA: day vs night p-value = 0.584; density p-value < 0.001; interaction p-value = 0.151). Success rate was over eight times higher in the most dense population sampled than

Table 2. Definitions for *A. mantelli* groups and whether they were included in the analyses of sample set composition (sex and age groups), blood parameter values, or both.

Group	Definition	*n*	Included in
night-birds	All birds caught at night	62	Both comparisons
day-birds	All birds caught during the day; separated into dog-birds and tx-birds	84	
dog-birds	Sub-set of day-birds found using a certified dog	65	Both comparisons
tx-birds	Sub-set of day-birds found by tracking their own or their partner's radio transmitter	19	Only blood parameter comparison

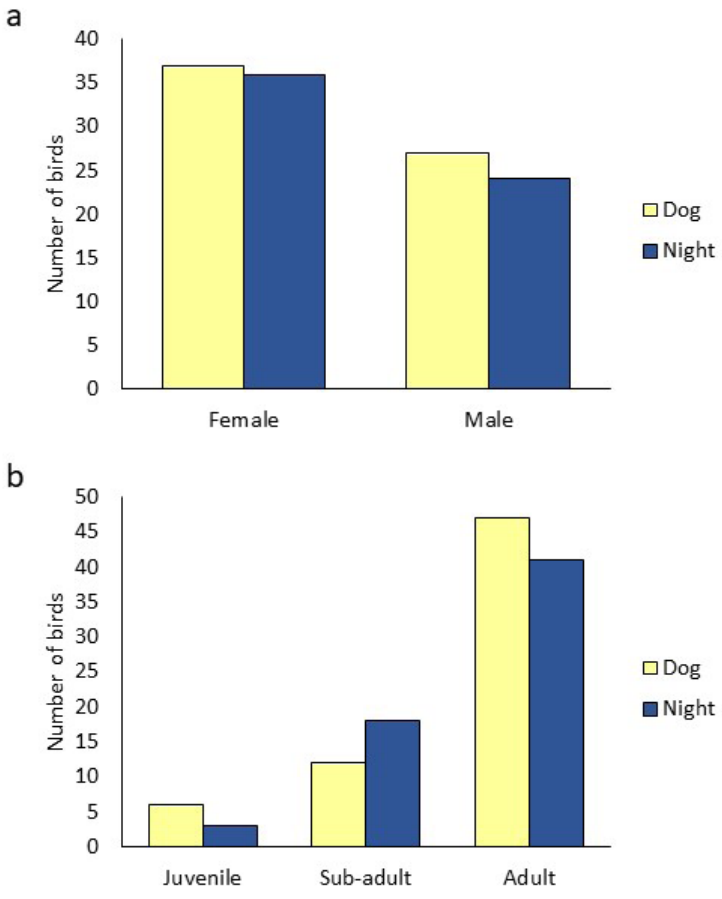

Figure 2. Sex- and age-group comparison between birds caught in the daytime using a certified dog (Dog; *n* = 65) versus through night-time encounter catching (Night; *n* = 62).

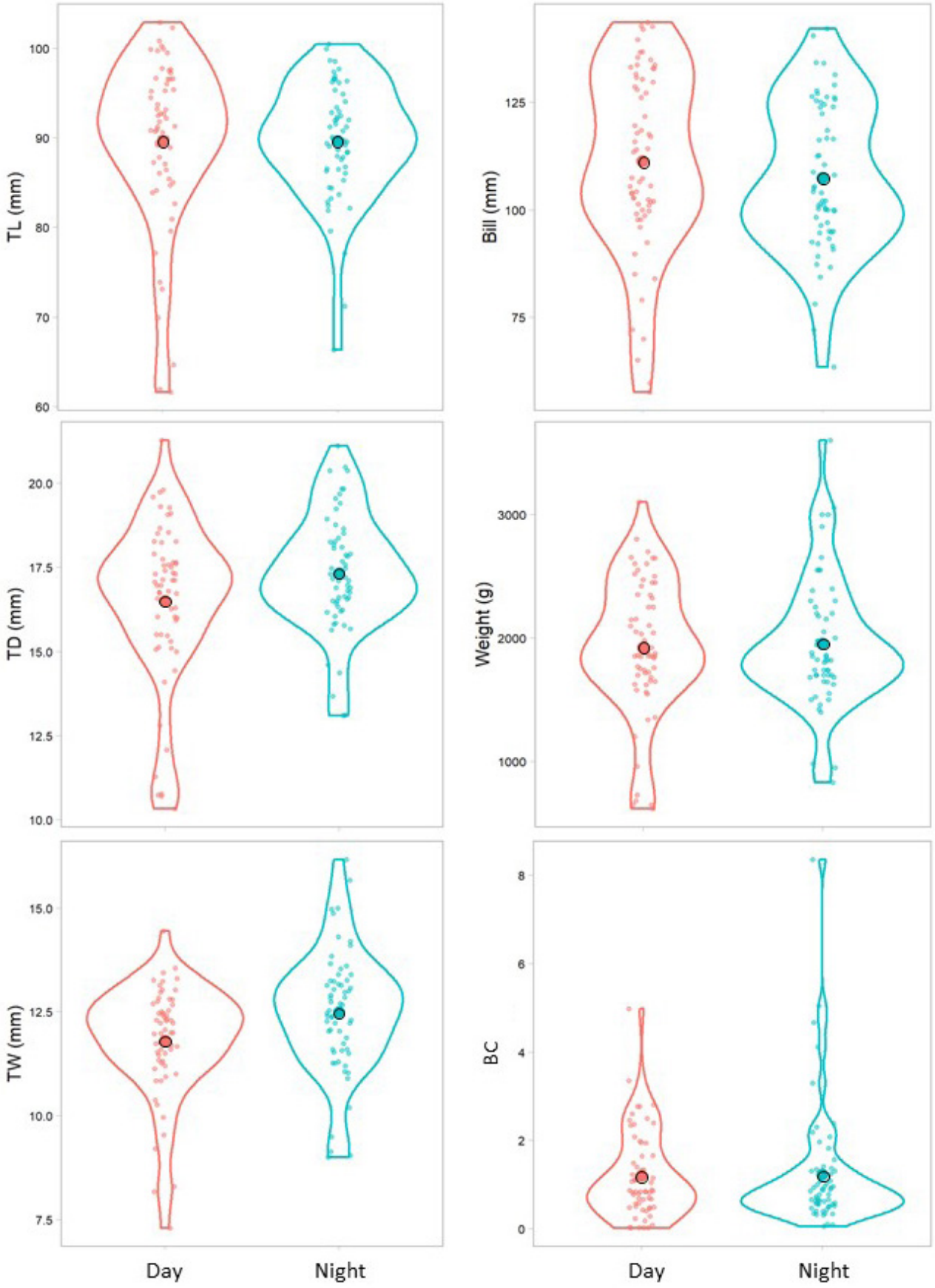

Figure 3. Comparison of tarsus length (TL), bill length (Bill), tarsus depth (TD), weight, tarsus width (TW), and Taborsky's body condition (BC) between birds caught in the daytime using a certified dog and night-time by encounter catching. Violin plots represents the distribution of obtained values, the small circles represent each individual bird, and the larger circles represents the average value for each parameter.

Table 3. Results for linear mixed effect models of haematological and morphometric differences between birds caught during the day and at night. Note: slightly different sample sets were used for each (see Table 2). Bold numbers indicate statistically significant difference.

	Estimate	Std. Error	t value	P-value
Protein	0.178	0.209	0.849	0.3957
PVC	1.793	1.033	1.735	0.0827
Glucose	2.145	5.674	0.378	0.7054
HB	0.454	0.853	0.532	0.5949
Weight	64.080	116.920	0.548	0.5837
TL	1.418	1.780	0.797	0.4257
TD	0.928	0.426	2.180	**0.0292**
TW	0.766	0.303	2.523	**0.0117**
Bill	−0.985	4.202	−0.234	0.8148
Taborskys BC	−0.0385	0.2764	−0.139	0.8894

the least dense. Overall, mean catching success was higher at night than during the day, but this was related to population density with the biggest difference between day and night in very high followed by medium density while success was similar for both methods in high density populations (Fig. 4; no low density populations were sampled). The higher success rate at night for very high density is particularly evident in populations where both methods were used (Fig. 4a). Once caught the target blood volume could be collected from an equivalent proportion of dog-birds and night-birds (38% and 36% respectively). However, night-time sampling was rated as more difficult; 69% of day time caught birds that were graded for ease of bleeding were rated easy or relatively easy, but only 52% of night-birds were rated the same.

Blood parameters

None of the four measured haematological parameters were found to differ significantly between day-birds and night-birds (Table 3; Appendix S3). The trend towards a difference in glucose concentration between day-birds and night-birds (Appendix S3) was found to be driven by a population difference

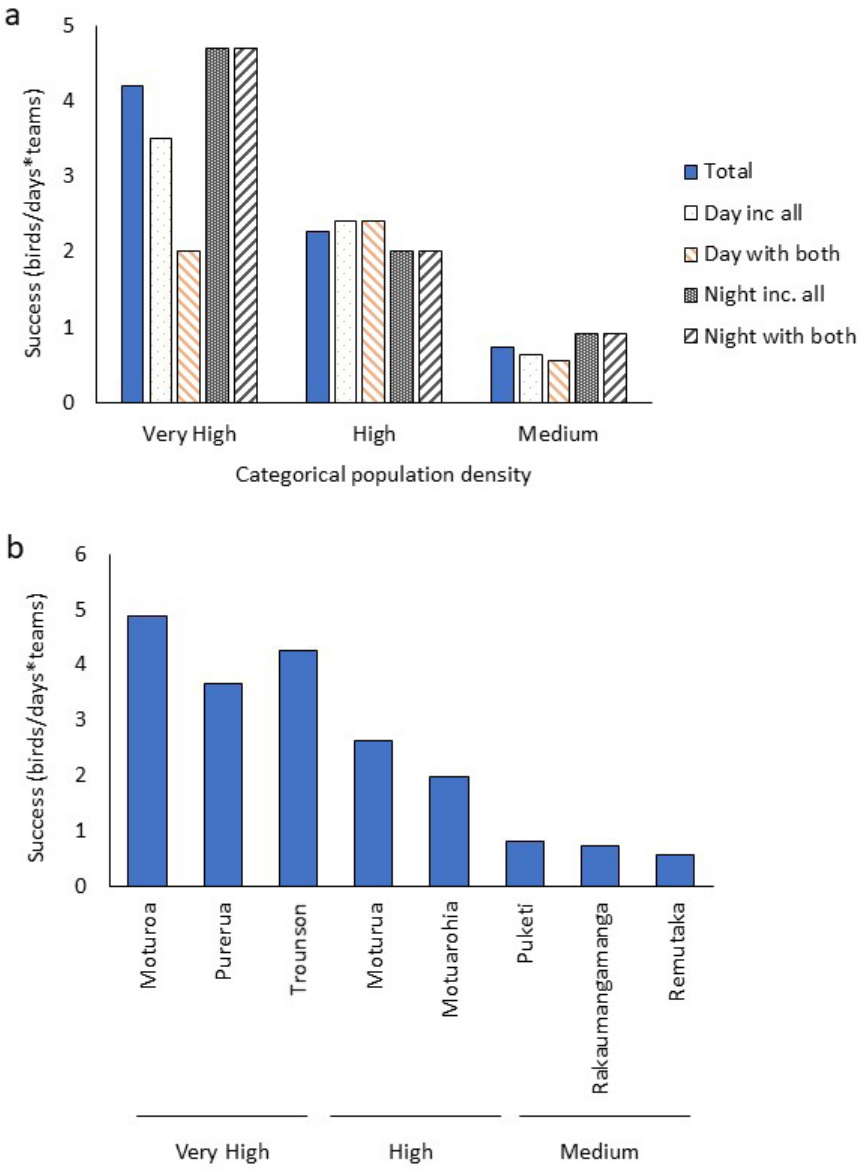

Figure 4. Comparison of catching success, total as well as daytime and night-time separately, with respect to categorical *A. mantelli* density. Panel (a) illustrates average catching success overall (filled bars), during the daytime and night-time when including all populations (light and dark dotted bars, respectively), and during the daytime and night-time when only including populations where both methods were used (light and dark striped bars, respectively). Panel (b) illustrates total success broken down by population. Populations are ordered by density with the highest density to the left.

(Appendix S4) that was independent of catching time and/or method. Lastly, no correlations were found between any of the haematological parameters and continuous time of sampling (Fig. 5).

Discussion

In this study we show that the sex and age group distribution was remarkably similar between *A. mantelli* caught using night-time encounter catching and daytime catching with a certified dog. In addition we found no evidence for time of day affecting any of the four blood parameters analysed: packed cell volume (PCV), total protein content, glucose concentration, and haemoglobin concentration (HB). Furthermore, we found that blood extraction was equally successful at night and during the day. Based on this we conclude that combining these different sampling methods in a single study will unlikely bias the results.

The fact that the sex and age distributions were so similar between dog-birds and night-birds is particularly encouraging since Robertson and Fraser (2009) concluded that searching with a certified dog results in a sample set representative of the true sex and age composition of a population. As we found no differences between dog-catching and night-catching, we suggest that night-time encounter catching is likely to also generate sample sets representative in this way. If correct, this would indicate that the populations sampled here had a female bias and that on average about two thirds of the birds in each population were adults. However, we did find a small but significant difference in tarsus width and depth between dog-birds and night-birds. Our data suggest that these may have been caused by a higher detection of the youngest juveniles during the daytime, but the sample size of this age class was very small.

The lack of time related differences for the haematology-parameters is somewhat surprising since there are examples of bird studies having found diurnal differences for all four measured parameters (Rehder et al. 1982; García-Rodríguez et al. 1987; Dawson & Bortolotti 1997; Sepp et al. 2010; Nazifi et al. 2012). However, other studies have found no such difference (Dawson & Bortolotti 1997; Sepp et al. 2010; Nazifi et al. 2012), or that the degree of difference differs

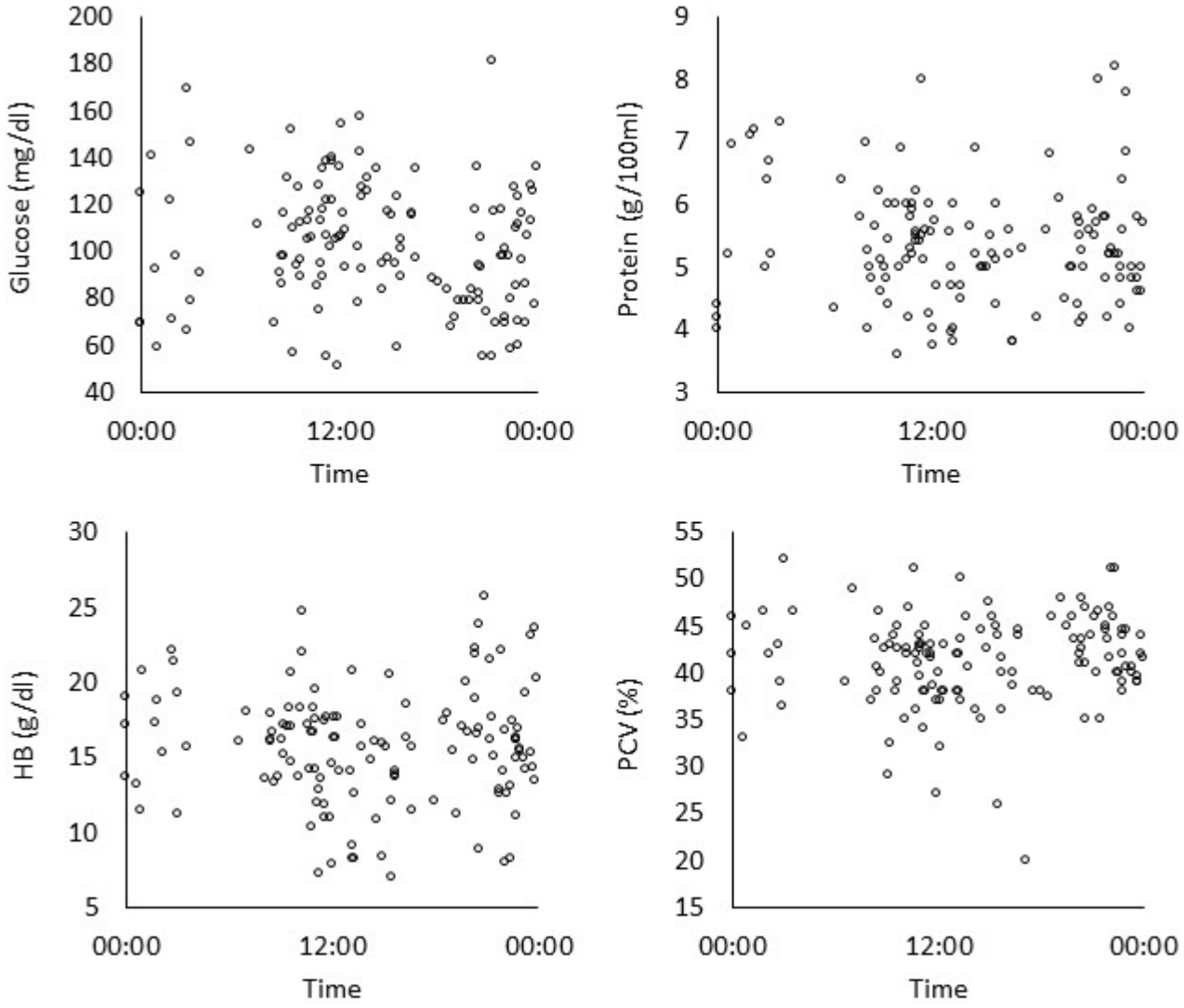

Figure 5. Scatterplots illustrating the lack of relationships between time of blood sampling (hh:mm) and blood glucose level (Glucose), total blood protein level (Protein), haemoglobin concentration (HB), and packed cell volume (PCV) for *Apteryx mantelli* (n = 128–133 birds).

between species and age groups (Rehder et al. 1982; García-Rodríguez et al. 1987; Dawson & Bortolotti 1997). The lack of time related difference found in this study is encouraging since population comparisons of these parameters can provide important information. For instance, studies of other birds have found glucose concentration differences linked to habitat quality and/or diet (Machın et al. 2004; Kaliński et al. 2014), and that high haemoglobin is a reliable indicator of health, food abundance, and habitat quality in birds (Bańbura et al. 2007; Lill et al. 2013a, b; Minias 2015, 2016; Kaliński et al. 2015; Glądalski et al. 2016). Hence our results suggest that we can use both or either kiwi catching methods for *A. mantelli* population health studies.

In many situations population studies will benefit from maximising samples size, thus, in addition to bias, sampling efficiency and success rate should also be considered when choosing methodology (Marion et al. 1981; Kritzer et al. 2001; Benítez-López et al. 2011). We found that catching success was positively related to *A. mantelli* population density, but also that under very high and medium densities success was higher at night than during the day. However, we are calling for more studies on this since our sample sets included relatively few populations from each density category and completely lacked low density populations. In addition we deem it likely that several other factors affect the relative success rate of the two methods beyond population density, for instance, habitat or terrain and these needs to be explored. We noted that the higher success at night was associated with birds congregating and utilising more accessible areas such as open grassland and/or tracks for foraging. In such microhabitats humans could see the birds well using lights and capture could proceed safely and efficiently. Thus dense forest, dense undergrowth, as well as steep and uneven terrain will make night-time encounter catching more difficult and even potentially dangerous. Terrain and habitat in combination with weather will also govern the success rate during daytime catching with certified dogs. Odour molecules released from kiwi accumulate inside the burrow or vegetation thicket where the bird is roosting and would over time come out of the entrance and be spread by the wind. Given that windspeed is generally negatively correlated with forest density, high vegetation density will result in scent available for the certified dog being localised to a very small area around the roost. This in turn will result in dogs having to cover a large area to detect kiwi, especially on calm days or when searching against the wind. In addition, when birds are located, the vegetation type, soil structure, and forest age all affect the difficulty of the terrain immediately around the roost sites and/or the layouts of the roosts themselves. This can result in increased time spent extracting the birds from the roosts and hence less time available to locate more birds. In addition, access to certified dogs and handlers is limited and thus waiting times and hire costs can be circumvented through night-time catching. In terms of blood sampling extraction was rated more difficult at night. However, the targeted volume was obtained as often as during the day suggesting that the increased difficulty was not sufficient to impede a successful outcome.

Our method of night-catching was encounter catching. Another common way of catching kiwi at night is attracting birds via whistling or playback calls. The reason we did not utilise the latter method further was that our initial success with calls was very low and we stopped using this method. However, it is possible that some birds in the Rakaumangamanga population may have been caught through a combination of the two approaches, i.e. that the playing of calls increased our success during encounter catching by causing birds to move closer to us and the track. Playback and/or whistling at night has previously been very successful for some kiwi projects and with some kiwi species. One possibility is that our lack of success with calling birds in was related to time of year. Peter Kirkman (pers. comm.) found that time of year was an important factor when using calls to catch Tokoeka *A. australis* and this may also be the case for other kiwi species. We suggest that more research is needed to identify what factors make playback and whistling successful and what sample set of the population this attracts. Such studies could focus on factors such as time of year, area, terrain, kiwi taxon, and call types used. Previously, it has been discussed whether playback risks causing sex and age bias in the captured sample (Robertson & Colbourne 2017), but this has, to our knowledge, never been tested.

Kiwi are taonga (treasured) species and national icons in Aotearoa New Zealand. One way of showing respect for this status is to make sure studies are as informative, efficient, and effective as possible to maximise the justification for disturbing the birds. We suggest that, based on bias alone, either or a combination of both daytime catching with certified dogs and night-time encounter catching can be recommended for future studies. This also implies that we see no issues with combining new and old samples into one analysis if these two methods have been used during sample collection.

However, when accounting for catching success we suggest that night-time encounter catching should be the recommended method when maximising sample size is important. A crucial caveat to this recommendation is that night-time encounter catching must be limited to sites where moving around, catching, and handling birds in the dark can be done in a way that is safe for birds as well as practitioners. We do also recognise that there are other aspects of sampling that are important to consider. For example, our study does not include information regarding stress levels. It is plausible that night-birds may suffer higher welfare costs from being chased and handled while out foraging; on the other hand, day-time birds may suffer stress linked to being wakened and removed from the safety of their roost. Consequently, we call for more studies to be done that focus on stress, but also for ones focusing on the effect of habitat and terrain on catching success. On additional caveat is that our results suggest that when the focus is very young juveniles, then day-time catching may be more successful.

Taken together, we hope that our results will pave way for future *A. mantelli* studies with larger sample sizes from more populations. Such increased sampling resolution would arguably be the best way to learn more about the elusive *A. mantelli* and how to ensure long-term sustainable management of this iconic species. Furthermore, the studies of all species will benefit from optimising catching and/or sampling methods. Thus we hope that this study has highlighted that the possibility of utilising widely different methods should not be excluded until the risk of inducing bias has been investigated. On the contrary, combining methods can be an asset that allows for wider sampling, leading to more robust results. Consequently we hope this study inspires others to conduct side-by-side comparisons of catching and/or sampling methods and that, ultimately, this will contribute to more studies of wildlife that are able to minimise bias while optimising efficiency.

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Additional information and declarations

Author contributions: All authors jointly developed the concept for the article. RW led the iwi and landowner consultation process and the coordination of the logistics that enabled the collection of samples. MU and IC led the collection of samples. MU analysed and interpreted the data and wrote the first draft of the manuscript. All authors commented on previous versions of the manuscript and approved the final version.

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Data and code availability: Kiwi are taonga (treasures) to the indigenous Māori people of Aotearoa New Zealand. All individuals of taonga species, as well as samples or other data obtained from these have whakapapa (genealogy, connections, and belonging) and are thus considered taonga in their own right. Tikanga Māori (Māori customary practices) determines their use. To ensure this, the datasets underlying the results presented herein have not been made publicly available, but requests for the datasets can be made to Richard Witehira: richardwitehira@xtra.co.nz or Andre Witehira: andre.witehira@gmail.com. Upon such requests, permission will be sought from the kaitiaki (guardians) representing hapū (sub-tribes) that affiliate with the areas of sample collection.

Ethics: This research was conducted with permission form the Massey University Animal Ethics Committee (permits 18/83 and 18/84) and Department of Conservation (permits 70875-RES and 70826-CAP).

Conflict of interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

Additional supporting information may be found in the supplementary material file for this article:

Appendix S1. Boxplot illustrating the lack of difference in body weight of birds caught in 2019 and 2020 respectively.

Appendix S2. Example boxplot illustrating the lack of difference in haematological parameters between birds caught in February and May respectively.

Appendix S3: Comparisons of haematological parameters between *A. mantelli* caught daytime (red) and night-time (blue).

Appendix S4: Comparison of blood glucose concentration between nine *A. mantelli* populations.

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