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Short communication

Short communication: Levels of land use and land cover in Phoenix, Arizona are associated with elevated plasma triglycerides in the Gambel's Quail, *Callipepla gambelii*

Alexander Funk[a], Pierce Hutton[a], Stevan Earl[b], Pierre Deviche[a], Karen Sweazea[a,c,*]

[a] School of Life Sciences, Julie Ann Wrigley Global Institute of Sustainability, Tempe, AZ, United States of America
[b] Julie Ann Wrigley Global Institute of Sustainability, Tempe, AZ, United States of America
[c] College of Health Solutions, Arizona State University, Phoenix, AZ, United States of America

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ABSTRACT

Gambel's Quail, *Callipepla gambelii*, are gregarious birds commonly found in the southwestern deserts of the United States and Northwestern Mexico. With expanding urbanization, these birds are often found in exurban and suburban areas where they have access to food sources that may differ from those used by birds living in rural habitats and, as a result, also differ morphologically and physiologically. To investigate this hypothesis, we compared the morphology and nutritional physiology of quail sampled at sites varying with respect to land use and cover. We hypothesized that quail living in more developed areas have access to a greater variety of and to more stable food resources, and predicted that morphology and nutritional physiology would be associated with degree of urbanization. We sampled adult birds at locations in the greater Phoenix metropolitan, Arizona (USA) area that vary with respect to land use and cover types. At the time of capture, birds were weighed and chest circumference was recorded. We also collected a blood sample from the jugular vein of each individual for analysis of plasma glucose, total proteins, triglycerides, and free glycerol. Consistent with the hypothesis, birds living in more developed environments had larger chest circumferences and higher circulating lipid concentrations than birds living in less developed areas, suggesting greater access to lipid-rich foods. In addition, the areal proportion of grass and lakes was negatively correlated to plasma free glycerol ($r = -0.46$, $p = .031$), and positively, but not significantly, correlated to plasma protein concentrations ($r = 0.388$, $p = .073$). These results suggest that quail living in areas with more grass have access to less dietary fats than urban birds. The findings are the first to indicate an association between urbanization and the morphology and nutritional physiology of Gambel's Quail, but further study using more and larger samples is needed before these findings can be generalized.

1. Introduction

Birds naturally have high blood sugar concentrations compared to mammals (Braun and Sweazea, 2008) and so are valuable models in which to examine extreme tolerance to high glucose. Birds also are useful models to investigate the impact of environmental factors, such as urbanization, on nutrient regulation (Braun and Sweazea, 2008). Indeed, many households provide food to wild birds (Cowie and Hinsley, 1988; Cox and Gaston, 2016; Davies et al., 2009; Galbraith et al., 2014; Martinson and Flaspohler, 2003), mainly in the form of bread and seeds (Galbraith et al., 2015). In addition, human wastes often serve as unintentional food sources for wild animals living in urban environments. As a result, many birds living in these environments have greater food access and availability than those living in corresponding rural locations.

Gambel's Quail (*Callipepla gambelii)* are resident ground-dwelling and -foraging birds that are native to the Southwest United States and Northwestern Mexico deserts (Gullion, 1960). These birds commonly reside in urban and rural settings. An analysis of food ingested by Gambel's Quail from southeastern Arizona showed these birds to be largely granivorous, but also consumers of legumes and succulent plants (Hungerford, 1962). Similarly, the crop of Gambel's Quail living in New Mexico contained 91.5% seeds and fruits, 6.5% greens, and 1.6% insects (Campbell, 1957). Studies have reported greater

* Corresponding author at: College of Health Solutions and School of Life Sciences, Arizona State University, 427 E Tyler Mall, Mail Code 4501, Tempe, AZ 85287-4501, United States of America.
E-mail address: Karen.Sweazea@asu.edu (K. Sweazea).

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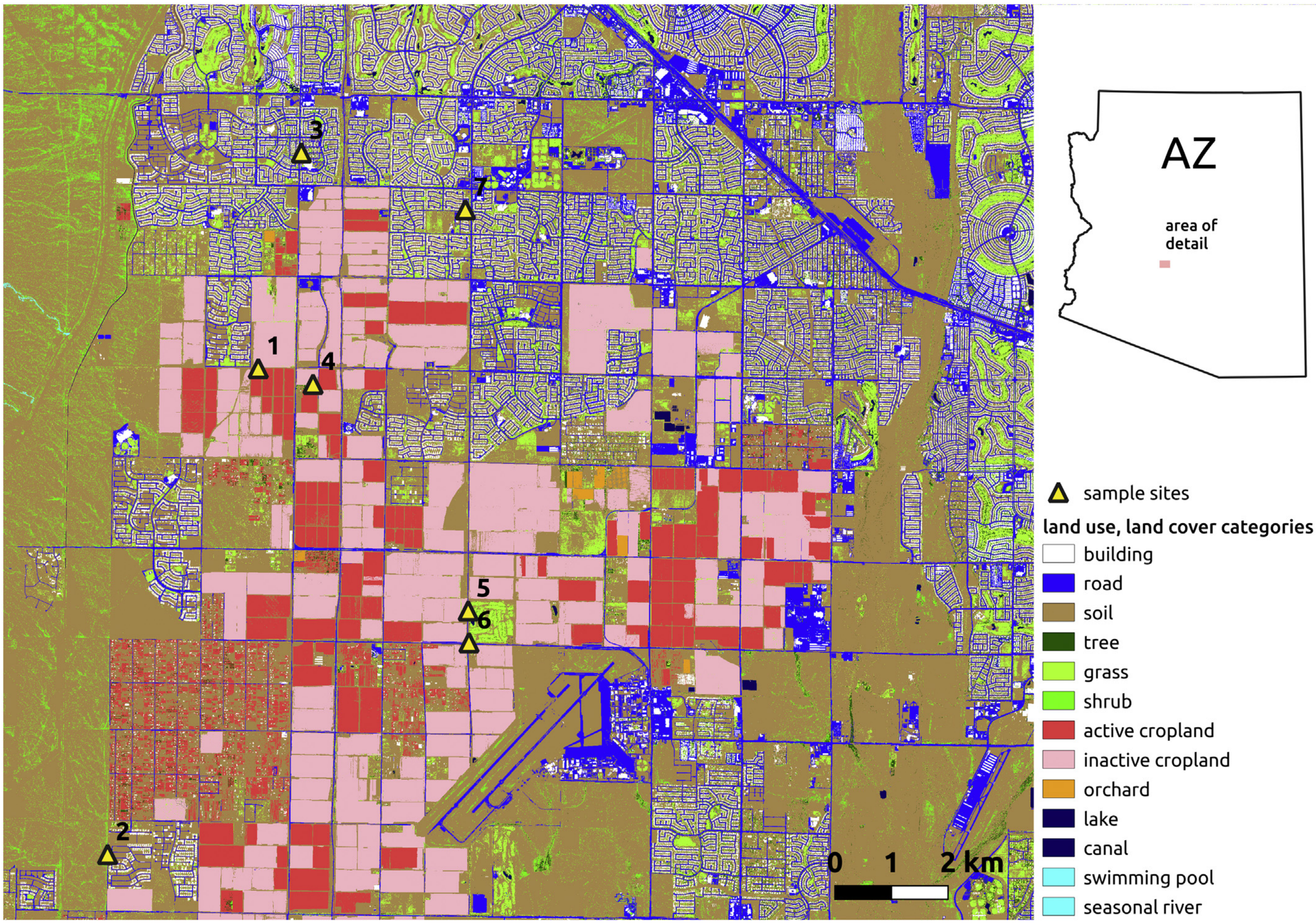

Fig. 1. Map of the study area with land use and land cover categories denoted.

herbivorous insect pest abundance in urban than non-urban environments (Dale and Frank, 2014; Meineke et al., 2013). Gambel's Quail residing in urban areas may, therefore, have greater access to water, fats, and proteins (insects), as well as novel plants, than rural quail, and thus differ from these birds physiologically and morphologically. We hypothesized that urban Gambel's Quail are larger and have higher plasma triglyceride and glucose concentrations, as well as lower free glycerol and protein concentrations, than rural birds.

2. Methods

2.1. Animal capture and sampling

Adult, male Gambel's Quail were captured at 7 locations around Weddell and Surprise, Maricopa, Arizona, USA (Fig. 1). The following number of birds were captured at each site: (1): $n = 1$; (2): n = 1, (3): $n = 7$, (4): n = 1, (5): n = 1, (6): $n = 6$, (7): $n = 5$. Birds were attracted using recordings of conspecific contact calls and captured using Potter traps baited with seeds and grains. Birds were captured 6:10–8:02 am from one location on each capture date between July and September 2015. They received uniquely numbered tarsal bands for individual identification and were released at the site of capture immediately after sample collection and body measurements. Scientific collecting and banding permits were obtained from the Arizona Game and Fish Department, and experimental procedures were approved by the Arizona State University Institutional Animal Care and Use Committee (IACUC).

2.2. Environmental variables

Ambient air and ground temperature at the time of sampling were measured to the nearest 1 °C using an infrared thermometer (Supplemental Table 2). Because conditions at the times of capture may not reflect the environmental conditions generally, we also calculated average Land Surface Temperature (LST, °C) from remotely-sensed data collected during summer months of 2015 (Stuhlmacher and Watkins, 2019) within a 1-km radius of the sampling locations.

To assess relationships among morphological and physiological features, and resources associated with urban and rural environments, we characterized the land use and land cover (LULC) within a 1-km radius around the sampling locations (Supplemental Table 3). We quantified the number of pixels for twelve LULC types (Building, Road, Soil (i.e., bare ground), Tree, Grass, Shrub, Active Cropland, Inactive Cropland, Orchard, Lake, Canal, Swimming Pool) around each sampling location using a land cover classification based on 1-m resolution satellite imagery (Supplemental Table 3; Li, 2015). As the range of a quail covey is approximately 2 km (Brown et al., 1998), a 1-km radius is appropriate for assessing environmental conditions around the sampling locations.

2.3. Blood collection

Traps were continuously monitored, and a small sample of blood (< 200 μL) was collected from the jugular vein using a 27-gauge heparin-coated needle immediately upon capture to avoid stress-induced alterations to plasma metabolites. Lidocaine-containing cream was applied topically prior to blood collection as an analgesic. Blood was transferred to microcentrifuge tubes and samples were placed on ice until transport to the laboratory, where they were centrifuged at 14,000 × g to separate formed elements from plasma. Plasma was stored at −80 °C until the time of analysis.

2.4. Morphometrics

After blood collection, skin temperature under the wing was measured to the nearest 0.1 °C using a digital infrared thermometer according to the methods of McCafferty et al. (2015). Body mass was measured to the nearest gram using a portable balance. Chest circumference including folded wings was measured to the nearest cm using flexible tension tape.

2.5. Blood analyses

Plasma triglycerides and free glycerol were measured using a commercial kit (TR0100; Sigma Aldrich, St. Louis, MO). Plasma total protein concentrations were measured according to the Bradford method (BioRad, Hercules, CA). Plasma glucose concentrations were measured using the glucose oxidase method (kit 10,009,582; Cayman Chemical, Ann Arbor, MI).

2.6. Statistical analyses

We used principal component analysis (PCA; Vegan package, Oksanan et al., 2019, in R; R Core Team, 2019) to derive two principal components that explained > 81% (PC1 = 52.4%, PC2 = 28.7%) of the variation in LULC surrounding the sampling locations. PCA loadings are presented in Supplemental Table 1. PC1 generally reflected a gradient from urban to rural, loading positively with features such as buildings, roads, and swimming pools, and negatively with cropland, particularly inactive cropland. PC2 also reflected an urbanization gradient but from other urban features, loading positively with grass and lakes (urban features in central Arizona), and negatively with shrubs and soil. We used PC1 and PC2 values (Supplemental Table 1) to create an urbanization index that served as the basis to determine correlations with morphological and biochemical data (Spearman correlation coefficient; GraphPad Prism 5.0; GraphPad Software, San Diego, CA, USA). As birds were captured from only one location on each capture date, the dates of capture reflect LULC data and were not included as confounding variables in the analyses.

3. Results

The sampling locations spanned a range of habitat types from highly urbanized (predominately residential) to rural, the latter being characterized by agriculture or open Sonoran desert, though two rural locations (sites 5 & 6) were situated in close proximity to a golf course and agriculture. Mean Land Surface Temperature (LST), as well as other temperature measurements (air temperature, substrate temperature, and animal temperature) collected at the time of sampling, were highest at sites characterized predominately by agriculture and lowest at sites located near the golf course.

Spearman correlations between PC1 and PC2 and morphological and nutritional physiology of quail revealed several significant relationships (Table 1). In particular, air temperature, chest circumference, and plasma triglycerides were positively correlated with PC1. In contrast, air temperature, and plasma free glycerol were negatively associated with PC2. Thus, birds living in more urbanized areas had larger chest circumference and higher plasma lipid concentrations than those living in less urbanized environments.

Spearman correlations between specific land use and land cover types and morphological as well as nutritional physiology variables revealed several other relationships. Anthropogenic alterations to the environment (buildings, roads, swimming pools, trees, shrubs and grass) were positively correlated with chest circumference, with the exception of shrubs (Supplemental Table 4).

With respect to nutritional physiology, the presence of grass was positively associated with plasma total protein concentrations and negatively with plasma free glycerol concentrations (Supplemental Table 4). Plasma triglyceride concentrations were lower in birds captured near croplands and lakes whereas birds captured near swimming pools and roads had higher circulating triglyceride levels (Supplemental Table 4).

4. Discussion and conclusions

We found in Gambel's Quail that land use and cover are associated with morphological and metabolic differences. Birds captured at more developed locations had larger chest circumferences and had higher circulating triglycerides than birds captured in less developed locations. In addition, birds captured at locations with more grass (i.e., an index of urbanization in a desert city) had lower free glycerol concentrations, suggesting that these birds consumed a diet that was lower in fat than birds in less grassy areas. The hypothesis that urbanization is associated with higher circulating glucose concentrations was not supported as there was no correlation between plasma glucose and land use/cover types.

The observation that body mass was not associated with degree of urbanization in quail is not consistent with results obtained in other avian species. For example, House Sparrows, *Passer domesticus*, living in urban areas are smaller than rural conspecifics (Dulisz et al., 2016; Hudin et al., 2016; Meillere et al., 2015). Similarly, Great Tits, *Parus major*, sampled in urban areas are smaller than birds residing in forested locations (Caizergues et al., 2018) or other rural locations (Biard et al., 2017). However, a study examining 463 avian species observed that birds commonly found in urban areas are generally larger than those that avoid urban environments (Palacio, 2020).

The source of proteins consumed by quail in the present study is unknown. However, during summer, when the present study was conducted, Gambel's Quail consume more insects than at other times of the year (Hungerford, 1962). While elevated protein levels in urban compared to non-urban birds has been reported in other species, it should be noted there were no significant relationships between plasma protein concentrations and PC1 or PC2. In fact, birds visiting feeders with higher protein-containing foods have been observed competing for this resource (Machovsky-Capuska et al., 2016). Thus, protein availability may be limited in some urban environments, a conclusion that may contribute to urban House Sparrows and Great Tits being smaller than rural conspecifics (Biard et al., 2017; Caizergues et al., 2018; Dulisz et al., 2016; Hudin et al., 2016; Meillere et al., 2015).

Consistent with greater nutrient availability in urban areas, Gambel's Quail captured near urbanized areas had higher plasma triglycerides than birds captured near croplands. Likewise, House Sparrows captured in urban locations have higher plasma cholesterol and blood urea (a byproduct of protein metabolism) than rural birds (Gavett and Wakeley, 1986). In a recent study of Blue Tits, researchers likewise found that circulating triglycerides may be a useful index of physiological condition when comparing variations in the trophic richness of habitats (Kalinski et al., 2017). The authors found that Blue Tits had higher circulating triglycerides in areas that were trophically rich compared to areas that were trophically poor (Kalinski et al., 2017). These findings suggest that more developed areas may have higher trophic richness resulting in quail captured from these areas having higher circulating triglyceride concentrations.

In conclusion, in the Gambel's Quail, urbanization is associated with morphological and metabolic adjustments that may reflect higher trophic richness. Additional research on this subject is warranted for several reasons. First, the present study used relatively small sample sizes and so work based on larger sample sizes collected from more locations is necessary to confirm the findings. Second, we investigated

Table 1
Spearman's Correlation coefficient (r) and corresponding probabilities showing associations between ambient, morphological, and physiological parameters and principle components PC1 and PC2.

Variable	PC1		PC2	
	r (95% confidence interval)	*p*-value	r (95% confidence interval)	p-value
Air temperature (n = 7)	0.441 (0.010 to 0.734)	**0.0396**	−0.682 (−0.861 to −0.353)	**0.0004**
Animal temperature (*n* = 22)	0.232 (−0.223 to 0.604)	0.2940	−0.437 (−0.732 to −0.006)	**0.0413**
Body mass (n = 22)	−0.306 (−0.652 to 0.146)	0.1620	0.337 (−0.112 to 0.671)	0.1240
Chest circumference (n = 22)	0.510 (0.100 to 0.772)	**0.0155**	−0.193 (−0.578 to 0.261)	0.3830
Plasma free glycerol (n = 22)	0.129 (−0.322 to 0.532)	0.5610	−0.460 (−0.744 to −0.034)	**0.0310**
Plasma triglycerides (n = 22)	0.456 (0.029 to 0.742)	**0.0329**	0.124 (−0.529 to 0.326)	0.5750
Plasma protein (n = 22)	−0.241 (−0.610 to 0.214)	0.2750	0.388 (−0.054 to 0.703)	0.0733
Plasma glucose (n = 22)	0.086 (−0.360 to 0.500)	0.7020	0.110 (−0.339 to 0.518)	0.6210

Bold numbers indicate a statistically significant correlation ($p < .05$).

quail in a single urbanized environment - the Phoenix metropolitan area - which differs from other many other urban centers with regard to climate and vegetation types and cover. Thus, research such as reported here and done in different urban settings, is necessary before findings can be generalized. Future work is needed also to elucidate whether nutritional differences between urban and rural quail are indicative of dietary and/or metabolic differences between populations.

Author's contributions

AF was responsible for trapping and collecting blood samples from quail, assisting with laboratory analyses and writing the first draft of the manuscript. KS was responsible for data collection, analyses, interpretation and revising the initial draft as well as the final manuscript. PH contributed to data interpretation and critically reviewing the final manuscript. SE addressed the assessment of LULC and LST around sampling location, and critically reviewed the final manuscript. PD was responsible for project oversight and contributed to data analyses, interpretation and editing the final manuscript.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cbpa.2020.110730.

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