Estimating bird densities in montane deserts: A methodological comparison in South Sinai, Egypt

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ABSTRACT

Montane desert birds are particularly vulnerable to population declines driven by global climate change that is accelerated at higher elevations. Providing reliable and accurate information about their populations is essential for effective conservation management plans. However, few studies have compared the effectiveness of different survey methods for birds in high altitude arid environments, particularly in the Middle East. Here, we compare the reliability and precision of two sampling methods to estimate densities for two resident bird species in Egypt’s Sinai mountains, the white-crowned wheatear (Oenanthe leucopyga) and desert lark (Ammomanes deserti).

We conducted surveys for both species in vegetated and unvegetated desert using fixed-width strip transects and line transects using the distance sampling approach, and employed several statistical approaches to compare density estimates. While both methods provided reliable density estimates given sufficient detections of target species, strip transects exhibited more flexibility overall for estimating cryptic and rare species, which comprise a large proportion of this and other montane desert bird communities. Strip transects also entail lower effort and costs, an important consideration given research funding constraints. We therefore recommend strip transects over distance sampling for estimating bird densities in this and other arid montane regions.

1. Introduction

Climate change is among the most important global threats to biodiversity and recent modeling studies predict that montane species will undergo substantial future range contractions accompanied by declines and increased extinction risks (Flousek et al., 2015). Montane bird communities tend to be poorly known due to their relative inaccessibility, but a number of studies demonstrate that montane bird species are vulnerable to declines and extirpations driven by global warming and anthropogenic habitat change, even in protected areas (Lehikoinen et al., 2019). In Europe, Flousek et al. (2015) found that higher altitude montane breeding bird species had more negative population trends than lower altitude species, that lower altitude species shifted upwards as a response to global warming, and that these altitudinal range shifts were associated with more negative population trends at higher altitudes; they further found that high altitude species have started to undergo serious climatically induced range contractions due to global warming. In Fennoscandia, a study of 14 common montane bird species over a 10-year period found that nearly two-thirds of these species (9/14) declined significantly with higher summer temperatures and precipitation during this period compared to the preceding 40 years (Lehikoinen et al., 2014). In California, Tingley and Beissinger (2013) showed that montane bird species richness has declined over the past century. Likewise, in the Arctic, Scridel et al. (2018) found evidence of montane bird population responses to climate (extreme weather events, temperature, rainfall and snow) and environmental (i.e. land use) change, but we know little about either the underlying mechanisms driving these responses or the synergistic effects of climate and land use.

Deserts are warming and drying disproportionately rapidly in response to global climate change, increasing the vulnerability of birds and other wildlife already living near the edge of their physiological limits (Inkayan and Beissinger, 2018; Conradie et al., 2019). Due to their sensitivity to environmental change, and their various roles as predators, prey, pollinators, seed dispersers, scavengers, and ecosystem engineers, birds may serve as excellent indicators of ecosystem health and offer numerous advantages as research subjects, including the potential...
Acquiring robust and reliable information on birds in arid mountains is often limited by the relative inaccessibility of many such regions as well as the availability of resources for fieldwork (Ganey et al., 2017). Different survey methods for studying wildlife population parameters vary with study objectives, species’ ecology and behavior, and location (Southwood and Henderson, 2000). Conspicuous and charismatic, birds have been the subjects of numerous studies comparing the effectiveness of different survey methods to quantify population parameters in different species, habitats, and factors (Gottschalk and Huettmann, 2011; Jarvinen 1978). However, few such studies have taken place in arid environments in lower income countries where obtaining funding may pose particular limitations, and fewer still have taken place in arid montane habitats where harsh environmental conditions pose logistical challenges to survey teams (White et al., 2007, 2008; Kent et al., 2013). In such areas, it is particularly important that protected area managers use cost-effective methods to estimate population parameters and use them in conservation and monitoring strategies (Azhar et al., 2008).

Direct counts through fixed-width strip transects (hereafter referred to as “strip transects”) and distance sampling through line transects (hereafter referred to as “distance sampling”) are two of the most common methods used as a basis for estimating wildlife population parameters (Ogutu et al., 2006). In strip transects, the observer travels along a line and records all individuals within a fixed width on both sides (Buckland et al., 2001). In distance sampling, the observer travels along a straight line and measures the perpendicular distance to the target species (Sutherland 2006). Both strip transects and distance sampling make assumptions; strip transects assume that all individuals within a given sampling area are detected, and distance sampling assumes that all individuals on the line (at distance zero) should be detected (Buckland et al., 1993, 2001). In practice, however, many of these assumptions may not be met, challenging our capacity to accurately estimate densities (MacKenzie et al., 2006; Thomas et al., 2010; Hutto, 2016). Despite the popularity of both strip transects and distance sampling, few studies have compared their effectiveness in estimating bird abundance in species with different expected levels of detectability and/or in habitats that have different expected influences on bird detectability. Previous studies comparing sampling methods for birds have often focused on forest and adjacent habitats, and montane deserts in particular appear to be absent from such studies.

Overestimation is a bias commonly associated with distance sampling, particularly when applied to bird studies (Buckland, 2006). The principal notion of distance sampling assumes an ‘instantaneous’ count (i.e., the bird-transect distance should be measured from the initial location/location of detection), and violating this assumption results in density overestimation (Cassey et al., 2007). However, the process of measuring the perpendicular bird-transect distance is time-consuming; during this time, birds may change their initial location, which increases the probability of density overestimation (Cassey et al., 2007). The degree of any overestimation depends on observer skills and qualifications (Hiby, 1986; Cassey et al., 2007). Hence, overestimation can be minimalized when highly skilled observers manage to identify the detected bird and measure bird-transect distance efficiently in a short time (Hiby, 1986; Cassey et al., 2007), as we attempted to do in this study.

Assessing the population status of species inhabiting montane habitats, particularly in hyper-arid regions, is prone to a high degree of overestimation due to many species’ relatively low population densities and the presence of harsh conditions and dramatic topographical features. However, few studies to date have addressed the problem of overestimation in distance sampling in arid montane environments (Kent et al., 2013). Distance sampling is more time-consuming than strip transects, but can provide more details on population trends and the influence of associated environmental conditions (Isaac et al., 2011). However, distance sampling relies on three key assumptions that cannot be relaxed (Thomas et al., 2010). Violating these assumptions limits the application of distance sampling in arid regions (Hutto, 2016). For instance, the observer might not be able to accurately measure the distance to the bird due to topographical obstacles, a typical situation in mountain habitats. Another assumption that is always difficult to meet is perfect detectability (i.e., the subject at zero distance from observers has a detection probability of “1”) (Buckland, 2006). This assumption is particularly difficult to meet for cryptic species with high camouflage ability that move after the observer’s arrival but before detection (Hutto, 2016). For more conspicuous species, on the other hand, the assumption of perfect detectability can be met.

Although previous studies have compared strip transects with distance sampling approaches in other habitats (Kulbicki and Sarramegna, 1999; Azhar et al., 2008; Spurr et al., 2012), no such study to our knowledge has been carried out in hyper-arid montane regions.

Fig. 1. The distribution of vegetated (green points) and unvegetated (black points) desert wadis where surveys were carried out within the high mountains of South Sinai, Egypt. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)
knowledge has been conducted in arid montane regions until now. The accuracy and precision of strip transect counts and distance sampling have been explored in previous works (Burnham et al., 1980; Verner, 1985; Azhar et al., 2008) with varying results depending on habitat type. In tropical forests, Gale et al. (2009) compared density estimates of breeding birds obtained through color-bandng, nest finding, and territory mapping with those derived from distance sampling; they found that abundance estimates from territory mapping and distance sampling were highly correlated and similarly accurate. In temperate forests, however, Taulman (2013) compared strip transects and point count survey methods and concluded that counts effectively sample a larger area than transects, possibly resulting in significantly different parameter estimations from each approach. In temperate grasslands, Golding and Dreitz (2016) compared and assessed the efficiency of point counts and transects based on bird detection probabilities and abundance estimates and concluded that transects resulted in more precise detection and abundance estimates. Likewise, Camponizzi et al. (2020) assessed the efficacy of distance sampling analyses of transect and point count surveys to estimate temperate grassland bird abundance and found that distance sampling analyses of transect surveys provided more accurate abundance estimates. In tropical grasslands, Fontana et al. (2018) compared point counts and transects for bird sampling and found that total abundance of birds estimated by the two methods did not differ. The present study is to our knowledge the first comparison of the performance of these methods in a montane desert environment.

Studies assessing the accuracy, precision, and biases of sampling and population estimation approaches (Gottschalk and Huetmann, 2011) are an important component of designing efficient and cost-effective monitoring programs. Here, we compare the performances of strip transects and distance sampling in estimating densities of two bird species with different detectability levels (conspicuous versus cryptic) in two habitat types with different detectability influences (unvegetated versus vegetated desert) in the St. Katherine Protectorate, Egypt. We selected birds with varied morphological and behavioural traits in order to test if such variation can influence the precision, reliability and agreement of these two different sampling methods in their ability to estimate bird densities in this montane desert protected area. Finally, we considered the costs inherent in conducting field surveys using both methods in order to determine the more cost-effective strategy for long-term biodiversity monitoring efforts in arid montane regions.

2. Methods

2.1. Site description

We carried out this study in a high altitude region (1500m asl) in a 435,000 ha protected area, Egypt’s St. Katherine Protectorate (Fig. 1), which was declared in 1988 by the Egyptian Environmental Affairs Agency in order to conserve the unique ecosystem in South Sinai. As a land bridge between the Eurasian and African continents, this area has exceptional biodiversity (Zalat et al., 2001) and was recognized as an Important Bird Area by BirdLife International in 2001 (Bird Life International 2020) and an Important Plant Area by the IUCN in 2011 (Radford et al., 2011). An arid region, the St. Katherine Protectorate has a mean annual rainfall of 60 mm with temperature as low as 8 °C in February and as high as 35 °C in August (Grainger, 2003). The high mountain region of South Sinai is host to nearly 40% of Egypt’s total flora species as well as characteristic and range-restricted fauna (Goodman et al., 1989; Zalat et al., 2001; Hoyle and James 2005). Few systematic surveys of birds and other wildlife have been carried out in the St. Katherine Protectorate (White et al., 2008; Arcilla et al., 2015), yet systematic monitoring is recommended to form the basis of conservation monitoring. Birds in the St. Katherine Protectorate are threatened by global warming and direct anthropogenic stressors including over-grazing, illegal hunting, increasing settlement, and dwindling water resources (Hoyle and James, 2005; White et al., 2007, 2008; Arcilla et al., 2015). A number of bird species previously recognized as common (Goodman et al., 1989) were uncommon, rare, or absent in surveys conducted between 2005 and 2007 (White et al., 2008).

An ideal approach to compare different survey approaches would include a reference population whose true size is known through a census, or complete count; however, in practice, complete count data are rarely available except in the case of confined populations (e.g., Williams et al., 2002) or in studies that use simulated data (e.g., Aldredge et al., 2007). Because true population size cannot be known with certainty, almost all wildlife population estimates are based on sample surveys, such as the widely-used North American Breeding Bird Survey (Sauer et al., 2017). Such surveys can be inexpensive compared to estimates of absolute abundance, and should ideally incorporate estimates of detection probability to account for differences in visibility or conspicuousness between species (Pollock et al., 2002). Williams et al. (2002), Thompson (2004), and others provide extensive examples and discussion of approaches to estimate wildlife populations using sample surveys and other methods.

Most survey approaches focus on estimating population parameter estimates with confidence intervals to assess precision and accuracy (Gaidet et al., 2003). For instance, Pfeffer et al. (2018) compared density estimates from different approaches (dung counts, camera traps, and DNA) without prior information about the actual ungulate population size, and determined the level of uncertainty associated with estimated ungulate population density. In another example, Weller (2012) compared density estimates of four bird species common in New Zealand farmlands using a large-scale monitoring scheme and more intensive survey; she found that density estimates from raw count data correlated with absolute density estimates for two of the four species, while detectability correction was necessary in the third, and the fourth proved unreliable, showing that individual species’ traits and behaviors may influence estimates, depending on the methods used.

Previous empirical studies showed that survey approaches, particularly the distance sampling that we used in our study, can estimate species density with a high level of precision and accuracy (Buckland et al., 2005; Parmenter et al., 2003; Somersho et al., 2006). Therefore, it has been widely and successfully used with different taxa, and has also been used in our study area (Alqamy, 2002; Arcilla et al., 2015; White et al., 2008). Our study design and analysis approach are thus consistent with previous studies comparing survey approaches in the field using statistical tools and empirical data rather than simulated data or a captive population.

2.2. Study species

We focused on two native bird species in the Sinai desert, the white-crowned wheatear (Oenanthe leucopyga) and desert lark (Ammomanes deserti). Both species are year-round residents that inhabit both vegetated and unvegetated desert sites from low to high altitudes; due to the general paucity of ecological studies of desert birds, both species remain relatively poorly known ecologically. The white-crowned wheatear occupies foothills and mountains of elevations up to 3000 m asl, especially areas of sparse vegetation and rocky deserts with boulders, dry riverbeds, outcrops, and ravines (Collar, 2020). The desert lark occupies lowlands and mountains up to 2250m, especially rocky slopes, escarpments, and undulating terrain with rocks and boulders (de Juana and Suárez, 2020). Species names here follow del Hoyo et al. (2020).

While these two species tend to inhabit the same habitats, they vary in their detectability. The white-crowned wheatear is a curious species with a distinctive color pattern that tends to make individuals easily detectable. By contrast, the desert lark’s cryptic plumage renders this species much more difficult to distinguish from the surrounding landscape (Shkedy and Safriel, 1992). Differences in species’ plumage and behavior are important factors in their detectability (Isaac et al., 2011). In contrast to the desert lark, for example, white-crowned wheatears display tame behavior and are reported to be traditionally revered by...
2.3. Sampling methods

We conducted fieldwork from April to September 2013, in wadis (river valleys) characterized by two different habitats: unvegetated desert and vegetated desert (Fig. 1). We defined unvegetated desert as devoid of wild or cultivated vegetation, and vegetated desert as having either patchy wild or cultivated herbaceous and woody plants (e.g., traditional Bedouin gardens). Unvegetated desert habitat was represented by the following sites: Wadi Rahba, Wadi No’amana, Wadi Gharba, Wadi Rayan and Wadi Gebal, and vegetated habitat was represented by the following sites: Wadi Itlah, Wadi Sheikh Awad, Wadi El-Arbaien, Wadi El-Dir, Wadi Nasab and Wadi Gebal (Fig. 1). We conducted the surveys after dawn between 06:00 to 09:00 and again before dusk between 16:00 to 18:00. At each site, we conducted two transects at a fixed length of 3000m, and a width that varied with the area of the wadi from a minimum of 40 m and a maximum of 100 m on both sides of the transect.

We carried out transects by foot and measured the perpendicular distance from the line transect to observed species using a Bushnell laser range finder. In addition to the perpendicular distance, we recorded the following parameters for each observation: number of individuals, time of the sighting, and whether they were flying, perching or foraging. We also documented other bird species encountered during surveys but did not include these in this analysis. We conducted a total of 22 transects, including 10 (for a total of 3.78 km$^2$) in unvegetated desert habitats and 12 (for a total of 3.96 km$^2$) in vegetated habitats. We calculated the differences in detectability using distance software and incorporated this calculation to estimate species density.

2.4. Data analysis

To estimate species densities, we analyzed field data using two different approaches, distance sampling and strip transects. For distance sampling data analysis, we used Windows software Distance Version 6.0 Release 2 to generate density estimates using our estimates of perpendicular distance (Thomas et al., 2009). To model the detection functions for our focal species, we constructed three different key functions (uniform, half-normal, and hazard rate), as well as three series expansions (cosine, simple polynomial, and hermite polynomial) using the conventional distance sampling (CDS) engine (Buckland et al., 1993, 2001, 2004). We selected the best-fitted model based on the minimum Akaike’s Information Criterion (AIC) (Buckland et al., 1993). For strip transect data analysis, we used Microsoft Excel to estimate species density using the equation presented by Greenwood and Robinson (2006): $D = \frac{n}{2wl}$ where “$D$” is estimated population density, “$n$” is the total number of observed animals in the transect, “$2w$” is the width of the transect, and “$L$” is the total length of the transect.

2.5. Comparison between the two methods

Using Predictive Analytics SoftWare (PASW) v.18, we conducted t-tests with 95% confidence intervals to test for any significant differences between the means of the two field methods we employed, with the null hypothesis assuming there was no difference. We then calculated a Coefficient of Variation (CV) to measure the precision of these two methods, where a lower CV indicates greater precision. Additionally, we assessed the level of agreement between these two methods using a Bland & Altman plot (Lee et al., 1989; Ryan and Woodhall, 2005) to plot the densities estimated by each method against their respective means. A high level of agreement between two methods is indicated when 95% of the differences are scattered around the mean of the differences and plotted within the upper and lower limits of the agreement (Indrayan, 2013). As an additional test for agreement, we calculated the regression coefficient for the means, in which the absence of a significant difference infers agreement between the two methods.
Fig. 3. The detection function of the best candidate model for desert lark in the unvegetated (left) and vegetated (right) desert wadis.

Fig. 4. The estimated densities and coefficients of variation by distance sampling and strip transects in unvegetated desert wadis for white-crowned wheatear (left) and desert lark (right).
3. Results

3.1. White-crowned wheatear

We recorded a total of 105 white-crowned wheatear observations during this study, of which 28 were in unvegetated desert and 77 were in vegetated desert. Estimating density from strip transects, white-crowned wheatear density in unvegetated desert using the Greenwood and Robinson (2006) equation was $D = 8.25$ individuals/km$^2$ (SE = 1.01, CV = 12.27%; 95% CI, 5.95–10.54). By contrast, the estimated density for white-crowned wheatear in vegetated desert was $D = 29.79$ individuals/km$^2$ (SE = 4.57, CV = 15.36%; 95% CI, 19.71–39.86). Estimating density from distance sampling, we selected a uniform model based on the minimum Akaike’s Information Criterion at AIC = 820.50. According to the uniform model (Fig. 2), wheatear density in unvegetated desert was $D = 12.68$ birds/km$^2$ (SE = 1.78, CV = 18.78%; 95% CI, 8.68–16.71), while its density in vegetated desert was $D = 40.97$ birds/km$^2$ (SE = 6.38, CV = 17.96%; 95% CI, 26.93–55.01).

3.2. Desert lark

We recorded a total of 42 desert lark observations during this study, of which eight were in unvegetated desert, and 34 were in vegetated desert. Estimating density from strip transects, desert lark density in unvegetated desert using the Greenwood and Robinson (2006) equation was $D = 3.1$ birds/km$^2$ (SE = 1.23, CV = 39.68%; 95% CI, 0.27–5.84). However, estimated density in vegetated desert was $D = 19.75$ birds/km$^2$ (SE = 3.37, CV = 17.06%; 95% CI, 12.33–27.16). Estimating density from distance sampling, our analysis showed that the uniform model with a truncation at 30m was the best candidate model, based on its minimum value for Akaike’s Information Criterion (AIC = 271.77).

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3.3. Comparison between strip transect and distance sampling methods

In unvegetated desert, there was a significant difference between birds’ density estimated using distance sampling and using strip transects. A paired-sample t-test result shows that white-crowned wheatear density estimated using strip transects was significantly lower ($D = 8.25$, SE = 1.01) than the density estimated by distance sampling ($D = 12.68$, SE = 1.78, t(9) = −3.01, p = 0.015, r = 0.56); the difference in density was −4.43. By contrast, there was no statistical difference between desert lark density in unvegetated desert estimated using strip transects ($D = 8.25$, SE = 1.78, t(9) = −3.01, p = 0.015, r = 0.56); the difference in density was 0.00.

In vegetated desert, on the other hand, we conducted a paired-sample t-test to compare density estimated by distance sampling using distance sampling and strip transects for both white-crowned wheatears and desert larks. White-crowned wheatear density estimation using strip transects was significantly lower ($D = 29.79$ birds/km, SE = 4.58) than density estimation using strip transects ($D = 31.48$ desert lark/km$^2$ (SE = 5.65, CV = 17.96%; 95% CI, 26.93–55.01)).

Similarly, the desert lark density estimation using strip transects was significantly lower ($D = 19.75$, SE = 3.37) than density estimation using distance sampling ($D = 31.48$, SE = 5.65), t(11) = −3.69, p = 0.004, r = 0.87; the difference in density was 11.73 (Fig. 5).
3.4. Precision, reliability and agreement of strip transect and distance sampling methods

The coefficient of variation values indicate that the strip transect method showed a higher level of precision compared with distance sampling, regardless of habitat types or species (Table 1). Both methods of density estimation, strip transects and distance sampling, showed a high level of agreement for estimating white-crowned wheatear densities in vegetated desert, as the Bland & Altman plot showed that all differences were scattered around the mean (Fig. 6). According to our linear regression, we detected no statistically significant difference between the means and their difference, indicating a high level of agreement between these two methods in vegetated desert. Similarly, in unvegetated desert, the Bland & Altman plot indicated moderate level of agreement between these two methods, which was supported by a non-significant t value of the linear regression test (Fig. 5). In contrast with our findings for the white-crowned wheatear, the two methods we used to estimate desert lark density showed disagreement between the two different habitats sampled. This could be due to the low sample size of the desert lark compared to the white-crowned wheatear. As already mentioned, the variabilities in the number of observations between the focal species are likely biased by differences in species’ plumage, behavior, and other traits (Isaac et al., 2011). As white-crowned wheatears are very curious and highly adapted to human presence, many of the recorded observations for this species were very close to the observers. Moreover, their conspicuous color pattern increases their detectability by observers, whereas desert larks may blend perfectly with their surroundings, making them markedly less detectable due to their cryptic plumage, even at very close range. In distance sampling, the peak of both white-crowned wheatear and desert lark detections was on or close to the transect line, implying that all birds on and close to the line were detected (Brunton and Stamp, 2007). However, this may indicate that distance sampling overestimated birds’ density, particularly for white-crowned wheatears, which often approached observers during the pre-counting period (Cassey et al., 2007). Our results thus corroborate findings by Westbrooke et al. (2003) and Spurr et al. (2012), who also found greater precision for strip transects compared with distance sampling of birds.

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4. Discussion

Both strip transects and distance sampling showed high agreement for estimating white-crowned wheatear densities in vegetated desert, while in unvegetated desert we found a moderate level of agreement. By contrast, the two methods that we used to estimate desert lark density showed disagreement between the two different habitats sampled. This could be due to the low sample size of the desert lark compared to the white-crowned wheatear. As already mentioned, the variabilities in the number of observations between the focal species are likely biased by differences in species’ plumage, behavior, and other traits (Isaac et al., 2011). As white-crowned wheatears are very curious and highly adapted to human presence, many of the recorded observations for this species were very close to the observers. Moreover, their conspicuous color pattern increases their detectability by observers, whereas desert larks may blend perfectly with their surroundings, making them markedly less detectable due to their cryptic plumage, even at very close range. In distance sampling, the peak of both white-crowned wheatear and desert lark detections was on or close to the transect line, implying that all birds on and close to the line were detected (Brunton and Stamp, 2007). However, this may indicate that distance sampling overestimated birds’ density, particularly for white-crowned wheatears, which often approached observers during the pre-counting period (Cassey et al., 2007). Our results thus corroborate findings by Westbrooke et al. (2003) and Spurr et al. (2012), who also found greater precision for strip transects compared with distance sampling of birds.

Table 1

Coefficient of variation values (%) for each method and habitat for desert lark and white-crowned wheatear.

![Fig. 6. Scatter plot showing the distribution of differences between fixed strip transect and distance sampling transect that were used to estimate densities for the white-crowned wheatear in unvegetated (right) and vegetated desert wadis (left). The black circle indicates the mean. The black line represents the mean of the differences, and the red lines are the upper and lower limits of agreement. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)](image-url)
Arid regions and desert habitats host many species with small population sizes, which limits the application of distance sampling in these regions (Seddon et al., 2003). The distance sampling approach relies on sophisticated analysis algorithms (Thomas et al., 2010), which require a minimum of 50 detections for a given species in order to estimate species abundance/density (Buckland et al., 1993; Buckland, 2006; Hutto, 2016). The number of observed desert larks we detected was lower than the recommended number (50) of observations to precisely estimate species density using the distance sampling approach, implying that our density estimate was imprecise and leading to inaccurate estimations for the detection probabilities. These estimates in turn were used to estimate species densities, contributing to differences between the density estimates from distance sampling and strip transect in unvegetated desert. As the majority of bird species in the St. Katherine Protectorate appear to be less abundant than either the white-crowned wheatear or desert lark (White et al., 2008), distance sampling does not appear to be an appropriate method for generating density estimates for most birds in this region.

Point counts and other standard methods used to estimate abundance rely on the assumption that the numbers of individuals detected remain constant across space and time; distance sampling and other recent approaches can adjust for birds present but not detected and therefore may present an advantage in many environments (Pollock et al., 2002). On the other hand, distance sampling relies on a number of assumptions that may not always be met, and were sometimes not met in this case. Due to the topographical features in montane desert regions, field surveys require intensive work with many observers, and thus substantial funding. However, protected area budget constraints in many countries, and particularly in less economically developed countries, mean that resources to support monitoring programs are frequently extremely limited. Therefore, choosing the most cost-effective survey method that produces reliable assessments with minimum effort is a main concern of conservationists and park managers. While both strip transect and distance sampling approaches provided reliable density estimates, strip transects entailed less effort and therefore lower costs. We therefore recommend strip transects over distance sampling in this system because any potential advantages presented by distance sampling are undermined by additional costs and assumptions that may not be met.

Our results add to a growing collection of studies comparing methods to estimate bird abundance and density, in which desert environments are typically poorly represented if they are represented at all. These methods will take increasing importance as desert ecosystems are changing rapidly in response to climate change, driving severe declines in some desert bird communities (Iknayan and Bessinger, 2018). The combination of human impacts and climate change, specifically increasing heat and evapotranspiration, have important, often negative, impacts on birds (Albright et al., 2017). Montane desert birds are confined to these areas and cannot escape by moving to other areas, as lowland desert birds have been shown to do (Carrillo et al., 2007). Egypt’s deserts in particular have shown increasing aridity over time (Goodman et al., 1989), and populations of resident bird species may be declining (White et al., 2008). Systematic monitoring of montane desert bird species in this and other regions will elucidate whether and to what degree this is the case, providing a much-needed basis for conservation planning. The local Bedouin people who are the indigenous inhabitants of this region also have a history of traditional conservation strategies that should inform management programs (Goodman et al., 1989).

Our findings highlight the importance of taking into account both landscape features (such as vegetation cover) and species characteristics (conspicuousness versus crypticness) in choosing an accurate sampling method to survey desert bird communities. Most of our bird
observations were in vegetated areas, which tend to be more hospitable to birds than unvegetated desert as they feature greater water and food availability and less heat. These differences in bird abundance between unvegetated and vegetated desert have been observed in other studies concerning desert habitats (Zarco and Jakle, 1985). Future studies that address the specific roles of parameters such as water and food resources as well as shade and other habitat features may benefit from applying strip transects for general use, and distance sampling in special cases, to estimate montane desert bird densities.

The effects of the landscape on desert birds may interact with the effects of climate change and other factors to influence desert bird communities (Gutierrez and Barrow, 2001). Just as habitat type and sampling method can affect population parameter estimation outcomes (Rodrigues and Prado 2018), landscape variation can affect desert birds differently during the breeding and nonbreeding seasons (Marone, 1991) and has been shown to be a key factor affecting winter survival of desert bird species (Macias-Duarte and Panjavi, 2013). In addition, other studies have suggested that anthropogenic communities and seed supplies are key factors influencing desert bird populations (Macias-Duarte et al., 2007; Blendiger and Ojeda, 2001). We recommend that future studies comparing bird sampling and population estimation approaches for montane desert birds therefore consider additional species, habitats, food resources, and seasonality to continue to advance our knowledge of quantitative methods for studying the ecology and population responses of montane desert birds.

Authorship contribution statement

Mohamed Kadry: Formal analysis, conceived and designed the study, acquired and analyzed the data, and produced the table. Nico Arcilla: Writing – original draft, worked with other authors to interpret the results and draft the manuscript. Sandra Goded: Writing – review and editing, conducted supplemental research, including a review of relevant literature to contribute to the manuscript. Alaaeldin Soltan: Formal analysis, conceived and designed the study, acquired and analyzed the data, and produced figures. All authors contributed to revising the manuscript and approved the submitted version.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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