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An Inventory of Terrestrial Vertebrates in Aldesa Valley and Estimating Factors that affect Avian Species Richness and Occurrence

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An inventory of terrestrial vertebrates in Aldesa Valley and estimating factors that affect avian species richness and occurrence

By

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Conducting species inventories is important to provide baseline information essential for management and conservation. Furthermore, understanding the effects of anthropogenic and environmental factors on species richness and occurrence are crucial to conserve species. Aldesa Valley lies in the Tabuk Region of Saudi Arabia, and because of the presence of permanent water and vegetation, is thought to contain high biodiversity. I estimated avian species richness and occurrence in Aldesa Valley during May 10–August 10 in 2014 and 2015 to detect bird species richness and occurrence. I used generalized linear models and occupancy models for six commonly detected bird species. I recorded 24 bird species, and found that species richness and occupancy was affected by numerous anthropogenic and environmental factors that influenced species detection and presence. I encourage more biological inventories to further document species occurrences and facilitate conservation of the unique species assemblages in Aldesa Valley.

DEDICATION

To my parents, I hope that you are proud of me. Everything I have done so far is because of your support, encourage, efforts, and love. To my wife, I thank you for everything you have done for me. I appreciate your concern, asking, and support of me. When I was worried, and thinking, you were next to me to help, consult, and advise. THANKS, I will never forget what you did for me! I love you forever Maryam! To all my siblings, I love you all and I hope that you are proud of me right now.

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CHAPTER I

GENERAL INTRODUCTION

Understanding species richness is critical because of the current rates loss of biodiversity (Chapin et al. 2000; Pimm et al. 2014; Yoshioka et al. 2014). Conservation of biodiversity is important to insure that ecosystems persist and function properly (Naeem et al. 1999; Chapin et al. 2000; Hector and Bagchi 2007; Pimm et al. 2014). The stability of an ecosystem mainly depends on biodiversity; current losses of biodiversity can directly and adversely alter ecological processes and affect the resilience of ecosystems to environmental changes (Naeem et al. 1999; Chapin et al. 2000; Hector and Bagchi 2007). Species are strongly and fundamentally associated with ecosystems through intrinsic relationships (Groombridge and Jenkins 2002); loss of biodiversity can destabilize ecosystem processes, leading to negative consequences including further species losses (Naeem et al. 1999). Biodiversity losses also can be irreversible; therefore, biodiversity should be monitored and protected because of the numerous benefits provided to species and human society (Pimm et al. 1995; Chapin et al. 2000; Cardinale et al. 2012).

Diversity and richness of terrestrial species in deserts are constrained by many conditions (e.g., low rainfall, high temperature; Tiger and Osborne 1999; AbuZinada et al. 2004; Lawrence 2004). As a result, desert ecosystems often contain the lowest species diversity and productivity (Waide et al. 1999). Furthermore, species richness is also influenced by geographical composition (Motroni et al. 1991; Mittelbach et al. 2001; Brown et al. 2007), with valleys in deserts typically containing greater plant diversity which in turn results in greater animal species richness (Panthi et al. 2007; Qian 2007). Vegetation plays an important role in species richness and distribution, as well as in the interactions among species (Cody 1981; Tews et al. 2004; Draycott et al. 2008; Qian 2007). Moreover, presence of water is a strong influential factor for species richness and distribution (Lawrence 2004; Porter and Aspinall 2010; Korine et al. 2015). These conditions are key-factors for habitat quality in terms of food and shelter for species (Slattery et al. 2003; Korine et al. 2015). Documenting and maintaining biodiversity in ecosystems with low species diversity is important; the study of such ecosystems provides baseline information and important data about species existence and richness which can be used to ensure the persistence of species in these extreme conditions (AbuZinada et al. 2004; Almoutiri 2004).

Human activities around the world are considered the main threat to biodiversity (e.g., agricultural activities, urban development [e.g., roads]; Chapin et al. 2000; Hunter and Gibbs 2007; Ellis 2013). For example, human activities can cause extensive habitat fragmentation, which leads to adverse consequences on biodiversity and species richness (Chapin et al. 2000; Franklin et al. 2002; Pimm et al. 1995; Vitousek et al. 1997). Many ecological issues originate from overexploitation of natural resources, which adversely impacts species' habitats and presence (Chapin et al. 2000; Sala et al. 2000; Vitousek et al. 1997). As a result, many species have been classified as endangered (Kerr and Currie 1995; IUCN 2016). Unfortunately, the priority to preserve species richness from anthropogenic actions varies among regions worldwide (AbuZinada et al. 2004; Brooks 2006).

My overall objectives and goals were to inventory terrestrial vertebrates in Aldesa Valley, determine their conservation status using the IUCN Red List of Threatened Species (IUCN 2016), and record and estimate effects of anthropogenic and ecological factors on avian species richness and occurrence in Aldesa Valley.

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CHAPTER II

AN INVENTORY OF TERRESTRIAL VERTEBRATES IN ALDESA VALLEY, SAUDI ARABIA

Introduction

Global biodiversity is a consequence of evolutionary events that occur over time and space (Jetz et al. 2012). With current rates of biodiversity loss, understanding factors influencing species richness is critical (Sala et al. 2000; Hill et al. 2005; Pimm et al. 2014; Yoshioka et al. 2014). Loss of biodiversity can directly and adversely alter ecosystem processes which in turn can affect the resilience of ecosystems to environmental changes (Naeem et al. 1999; Chapin et al. 2000). For instance, modifications in biodiversity may affect species traits and community composition (e.g. through the introduction of exotic species) (Vitousek et al. 1997; Chapin et al. 2000). Species composition and interactions among these species, as well as abiotic factors, are the fundamental elements underlying any given ecosystem (Groombridge and Jenkins 2002; Pimm et al. 2014), with losses in biodiversity threatening ecosystems and the species communities living therein (Motroni et al. 1991; Balvanera et al. 2006; Hector and Bagchi 2007). Conservation of biodiversity is essential to insure that ecosystems persist and function properly (Chapin et al. 2000; Balvanera et al. 2006; Hector and Bagchi 2007). Moreover, maintaining biodiversity is also important to society because of the numerous economic benefits (e.g., plant pollination, pharmaceutical molecules;

Pimentel et al. 1997; Cardinale et al. 2012); Biodiversity losses can be irreversible; therefore, biodiversity should be monitored and protected (Pimm et al. 1995; Chapin et al. 2000; Brooks et al. 2006), and conducting species inventories are the most common approach to survey species richness (Hill et al. 2005).

Considerable variation in species richness exists depending on ecological factors, with areas receiving higher rainfall (e.g., tropical forests) having greater richness than areas receiving less rainfall (e.g., deserts; Gaston 2000; Guerrero et al. 2011). Desert ecosystems often contain the lowest species abundance and productivity (Waide et al. 1999). Deserts are defined as any ecosystem where limited water affects occurrence of species (Lawrence 2004). Hence, diversity and richness of terrestrial species in deserts are constrained by low rainfall; high temperature also has a strong effect on species occurrence in deserts (Walker, 1992; Tiger and Osborne 1999; AbuZinada et al., 2004; Gillman and Wright 2014). Consequently, desert areas including the Arabian Peninsula, Middle East and the Sahara Desert have the lowest number of mammal and amphibian species relative to other realms of the world (AbuZinada et al. 2004; Almoutiri 2004). However, while the number of endemic terrestrial vertebrate species is low in deserts (e.g., Saudi Arabia, Sahara Desert), the proportion of endemic species relative to overall species richness is intermediate among global biomes (Almoutiri 2004).

Species richness is also influenced by geographical composition (Motroni et al. 1991; Mittelbach et al. 2001; Brown et al. 2007; Gibson and Koler 2012), with valleys in deserts containing typically greater plant diversity, which in turn results in greater animal species richness (Panthi et al. 2007; Qian 2007). Also, water may be more important to species in this extreme weather condition where drought is continuous (Walker 1992;

AbuZinadaet al. 2004). The critical conditions offered by valleys in deserts provide a higher quality habitat in terms of food and shelter for species (Slattery et al. 2003; Korine et al. 2015).

Conservation programs tend to emphasize regions with greater species richness, with most national and international conservation efforts occurring in these areas (Fa and Funk 2007; Micheli et al. 2013). In contrast, comparatively few efforts are conducted in areas of low species richness, such as deserts. Though deserts do not typically support high species diversity (Walker 1992; AbuZinada et al. 2004; Lawrence 2004), documenting and maintaining biodiversity in ecosystems with low diversity is important because it provides important information about species existence and richness which can be used to ensure the long-term persistence of species assemblages in these extreme conditions (AbuZinada et al. 2004).

In 2001, the Kingdom of Saudi Arabia became signatory to the Convention of Conservation on Biological Diversity that seeks to ensure the conservation of species and their habitats for all time (AbuZinada et al. 2004). Seventy-nine species of mammals belonging to 25 families in eight orders have been recorded in Saudi Arabia; five other mammal species became extinct within the last 500 years (AbuZinada et al. 2004; Saudi Wildlife 2015). In addition, at least 432 bird species, 103 reptile species, and 7 amphibian species have been recorded in Saudi Arabia (AbuZinada et al. 2004; Almoutiri 2004). Though the occurrence of many species of terrestrial vertebrate species in Saudi Arabia have been documented, few formal (designed studies) species inventories have been conducted.

The Aldesa valley is a unique ecosystem in the Tabuk Region of Saudi Arabia (Tabuk Nature 2015) as the availability of water and vegetation complexity likely supports diverse terrestrial vertebrate species. Since no formal inventory of terrestrial wildlife has been conducted in the Tabuk region, Aldesa Valley, my objective was to conduct an initial inventory of terrestrial vertebrate species in the Aldesa Valley, and determine their global conservation status using the IUCN Red List of threatened species (an international organization concerns about the global conservation status of species).

Materials and Methods

Study site

The Aldesa Valley (27°38'01" N, 036°31'21" E) is a narrow, 10 km-long valley between 2 minor mountain ranges about 225 km southwest of Tabuk City, Saudi Arabia (Figure 1; Tabuk Municipality 2013). Aldesa Valley contains a permanent spring, known as the blue or eye fountain, which is the headwater of a small stream. People who live near Aldesa Valley depend on this water source for their livelihood and small-scale agricultural production. Livestock raised includes camels, sheep, and chickens. In addition, vegetables (e.g., tomato, eggplant, zucchini) and fruit (e.g., mango, citrus, melon) production is common. Temperatures during winter (December–February) typically range from 2 to 15°C, but are occasionally below 0°C. Temperatures during summer range from 19 to 42°C in May and 24 to 48°C in July. Annual rainfall is about 39 mm (Presidency of Meteorology and Environments 2013).

Survey

I conducted fieldwork from 10 May to 10 August in 2014 and 2015, having received permission from Tabuk Province office, and the University of Tabuk. I divided the valley into 40, 250 m- long segments (Figure 1; see Hill et al. 2005; Shirley et al. 2013). Each segment was surveyed twice in 2014 and three times in 2015. I used time area searches to quantify bird species occurrence, conducting searches from 0630–1000 hr and arriving at the first segment 15 min before sunrise (Volpato et al. 2009). I conducted surveys when winds were <12 km/hr and there was no rain (Ralph et al. 1995). I used a handheld anemometer (EA-3010U Handheld Travel Anemometer) to record wind speed and temperature during surveys. I searched segments for 0.5–2.0 hours, based on segment size and complexity (e.g., presence of vegetation) using a pre-determined schedule. I surveyed four or five segments each day. I used two field guides to facilitate identification (e.g., Porter and Aspinall 2010; Pope and Zogais 2012). For each observation, I recorded the time and the number of individuals by species.

During time area searches I simultaneously recorded all mammals, reptiles, and amphibians (Wilson et al. 1996; Hill et al. 2005) observed to species using field guides. (Leviton et al. 1992; Aulagnier et al. 2009; Amr 2012). When not conducting specific field surveys, I used opportunistic searching and recorded all vertebrates observed. I also visited the valley at night on 15 occasions to search for nocturnal species.

I also established opportunistically five camera stations in segments 1 and 10 because I had access to two farms. I placed cameras 30-40 cm above ground to accommodate medium- and large-sized mammals (O'Connell et al. 2011, Glen et al.

2013). I used an infrared motion-activated camera (Bushnell Trophy Cam), and canned tuna in front of each camera as an attractant.

I used the IUCN Red List of threatened species (IUCN 2015) to determine the global conservation status for each species to provide an indication of the importance of Aldesa Valley for supporting terrestrial vertebrate biodiversity within Saudi Arabia.

Results

I observed 2976 bird occurrences in 2014 and 3995 in 2015 belonging to 24 species, 18 families, and seven orders (Figure 2; Table 1). The most frequently detected species included house sparrow (*Passer domesticus*; 28.8% of all birds detected; Figure 3), Tristram's starling (*Onychognathus tristramii*; 16.1%; Figure 4), laughing dove (*Spilopelia senegalensis*; 15.4%; Figure 5), white-spectacled bulbul (*Pycnonotus xanthopygos*; 8.4%; Figure 6), Sinai rosefinch (*Carpodacus synoicus*; 6.5%; Figure 7), and Palestine sunbird (*Nectarinia osea*; 6.4%; Figure 8), The least frequently recorded bird was the Eurasian collared dove (*Streptopelia decaocto*; <0.1% of all birds detected). All bird species Red List conservation status was Least Concern.

I recorded 69 reptile occurrences in 2014 and 90 in 2015 belonging to seven species, five families, and one order (Table 1). Reptiles observed included common fan-footed gecko (*Ptyodactylus hasselquistii*; 64.8 %; Figure 9), Bosk's fringe-fingered lizard (*Acanthodactylus boskianus*; 15.7 % Figure; 10), Schmidt's fringe-toed lizard (*Acanthodactylus schmidti*; 11.3 %; Figure 11), and starred agama (*Stellagama stellio*; 5.7 %; Figure 12). In addition, Arabian toad-headed agama (*Phrynocephalu arabicus*; 1.3 %), Schneider's skink (*Eumeces schneideri*; 0.6 %), and Forskal sand snake (*Psammophis *schokari*; 0.6 %) were observed. In addition, I detected more than 100 Arabian toads (*Bufo arabicus*; Figure 13), the only amphibian species observed.

I detected 30 wild mammal occurrences of five species, three families, and three orders (Table 1). I recorded red fox (*Vulpes vulpes*; 46.7%; Figures 14 and15) at night using remote cameras operated for 10 days total. Desert hedgehog (*Paraechinus aethiopicus*; 26.7%; Figures 16) was also detected at night. Small mammals detected included the Arabian spiny mouse (*Acomys dimidiatus*; 20.0%), the golden spiny mouse (*Acomys russatus*; 3.3%), and Cheesman's gerbil (*Gerbillus cheesmani*; 3.3%), all detected at night. In addition, free-ranging domestic animals observed included 1154 domestic goats (77.8% of all the domestic animals detected), 118 Arabian camels (8.02%), 105 donkeys (7.1%), 101 domestic dogs (6.9%), and two Arabian horses (0.1%).

Discussion

I detected 24 bird, seven reptile, five wild and five domestic mammal, and one amphibian species in Aldesa Valley. I am unaware of any previous formal inventories or scientific studies of terrestrial vertebrates in this area. Limited knowledge about species abundance and composition makes comparisons of species detected in Aldesa Valley difficult. Habitat heterogeneity typically provides diverse food resources; thus, higher species richness is expected in areas with such characteristics (Tews et al. 2004; Hill and Hill 2006). The lower annual rainfall in deserts results in extreme drought most of the year and lower biodiversity (e.g., Arabian Peninsula; Walker 1992; AbuZinada et al. 2004; Kaeslin et al. 2012). Water, vegetation, and topography are key factors for species persistence in the extreme environmental conditions experienced in hot deserts (Pino et al. 2000; Tews et al. 2004; Qian 2007; Aulagnier et al. 2009; Korine et al. 2015). Perennial streams are rare in extreme desert environments, including Saudi Arabia (AbuZinada et al. 2004), which makes the Aldesa valley unique. I suggest the habitat diversity in Aldesa Valley created by topography, vegetation, and especially permanent water is largely responsible for high species richness observed. Overall, there is a positive and fundamental relationship between habitat heterogeneity and species richness (Gough et al. 1994; Tews et al. 2004; Qian 2007).

The conservation status of most reptile species in Saudi Arabia has not been evaluated by the IUCN (www.redlist.org). Though the documented geographic ranges of species I observed include Saudi Arabia, accurate information on their distribution and abundance remains unknown, as is true for amphibian species (Leviton et al. 1992; www.catalogueoflife.org, ITIS, 2015). This highlights the importance for more intensive inventories to assess species occurrence, distribution, and trends in abundance. Because of potential interactions among species in a given ecosystem, the loss of any species may adversely affect other species. Thus, maintaining vertebrate diversity is important for conservation of such ecosystems (Schipper et al. 2008; Koparde and Shirish 2013).

I observed what I consider high species richness in Aldesa Valley, documenting diverse taxa that accentuate the importance of this valley in the region. Such unique areas will likely benefit long term from increased official attention to help ensure species persistence and ecosystem function. The Ministry of Tourism classified Aldesa Valley as a tourism place in Tabuk region (Saudi Commission for Tourism and Antiquities 2015). However, such a designation carries with it potential adverse consequences for the environment and biodiversity. Through my fieldwork and observations, I suggest that tourism can cause negative effects on this ecosystem, as similarly suggested by Gossling (2002), and Higginbottom (2004).

Because of the uniqueness of the Aldesa Valley, I believe that biodiversity conservation of this area should be a priority. I observed numerous human activities in Aldesa valley that may adversely affect wildlife, including deposition of trash from tourists, occurrence of farms, and burning of trees. In addition, over-hunting has been reported in the region along with overgrazing by livestock that may adversely affect plant diversity (Sala et al. 2000; Almoutirti 2004; Eken et al. 2004). These human activities can influence ecological processes and landscape conditions which can adversely affect species richness and endemism (Pimm et al. 1995; Vitousek et al. 1997; Sala et al. 2000; Hunter and Gibbs 2007; LeMaitre et al. 2014). Potential actions that can be conducted to protect reserves from human activities are to increase the number of patrols and the installment of fences (Almoutirti 2004). There is potential for adversely affecting biodiversity if these disturbances continue. I encourage authorities to consider monitoring human activities in this unique location (Almoutirti 2004) to ensure long-term persistence of species assemblages. I also encourage additional inventories and more detailed studies about vertebrate species and their ecological relationships in Aldesa Valley.

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Authors' Contribution Statement

ASA, FB, and JLB designed the survey. ASA conducted the survey, collected the data, and identified the specimens. ASA, FB, and JLB wrote the text.

Table 2.1 Vertebrate species observed in Aldesa Valley, Saudia Arabia, from 10 May to 10 August in 2014 and 2015.

Taxon	English Name	IUCN Status[1]	No. of Detections 2014	2015	Total
Aves					
Passeriformes					
Passeridae					
Passer domesticus (Linnaeus, 1758)	House sparrow	LC	843	1163	2006
Pycnonotidae					
Pycnonotus xanthopygos (Ehrenberg, 1833)	White-spectacled bulbul	LC	223	365	588
Sturnidae					
Onychognathus tristramii (Sclater, 1858)	Tristram's starling	LC	439	682	1121
Nectariniidae					

Table 2.1 (continued)

Nectarinia osea (Bonaparte, 1856)	Palestine sunbird	LC	116	330	446
Muscicapidae					
Cercomela melanura (Temminck, 1824)	Blackstart	LC	89	76	165
Oenanthe leucopyga (Brehm, 1855)	White-crowned wheatear	LC	18	56	74
Monticola solitaries (Linnaeus, 1758)	Blue rock thrush	LC	65	14	79
Cercotrichas podobe (Müller, 1776)	Black scrub-robin	LC	0	4	4
Cisticolidae					
Scotocerca inquieta (Cretzschmar, 1827)	Streaked scrub-warbler	LC	239	154	393
Corvidae					

Table 2.1 (continued)

Corvus ruficollis (Lesson, 1831)	Brown-necked raven	LC	22	19	41
Hirundinidae					
Hirundo obsolete (Cabanis, 1850)	Pale crag-martin	LC	0	21	21
Fringillidae					
Carpodacus synoicus (Temminck, 1825)	Sinai rosefinch	LC	322	131	453
Timaliidae					
Turdoides squamiceps (Cretzschmar, 1827)	Arabian babbler	LC	57	60	117
Alaudidae					
Ammomanes deserti (Lichtenstein, 1823)	Desert lark	LC	0	90	90
Emberizidae					

Table 2.1 (continued)

Emberiza striolata (Lichtenstein, 1823)	House bunting	LC	66	36	102
Columbiformes					
Columbidae					
Spilopelia senegalensis (Linnaeus, 1766)	Laughing dove	LC	419	657	1076
Streptopelia decaocto (Frivaldszky, 1838)	Eurasian collared-dove	LC	0	2	2
Oena capensis (Linnaeus, 1766)	Namaqua dove	LC	8	5	13
Columba livia (Gmelin, 1789)	Rock dove	LC	15	78	93
Pelecaniformes					
Ardeidae					
Ixobrychus minutus (Linnaeus, 1766)	Little bittern[2]	LC	1	2	3
Coraciiformes					

Table 2.1 (Continued)

Meropidae					
Merops orientalis (Latham, 1802)	Green bee-eater	LC	20	13	33
Bucerotiformes					
Upupidae					
Upupa epops (Linnaeus, 1758)	Common hoopoe	LC	4	3	7
Falconiformes					
Falconidae					
Falco tinnunculus (Linnaeus, 1758)	Common kestrel	LC	1	1	2
Galliformes					
Phasianidae					
Ammoperdix heyi (Temminck, 1825)	Sand partridge	LC	9	33	42
Reptilia					
Squamata					

Table 2.1 (Continued)

Agamidae					
Stellagama stellio (Linnaeus, 1758)	Starred agama	LC	3	6	9
Phrynocephalus arabicus (Anderson, 1894)	Arabian toad-headed agama	LC	2	0	2
Gekkonidae					
Ptyodactylus hasselquistii (Donndorff, 1798)	Common fan-footed gecko	NE	42	61	103
Scincidae					
Eumeces schneideri (Daudin, 1802)	Schneider's skink	NE	1	0	1
Lacertidae					
Acanthodactylus boskianus (Daudin, 1802)	Bosk's fringe-fingered lizard	NE	9	16	25
Acanthodactylus schmidti (Haas, 1957)	Schmidt's fringe-toed lizard	LC	11	7	18

Table 2.1 (Continued)

Colubridae					
Psammophis schokari (Forskal, 1775)	Forskal sand snake	NE	1	0	1
Amphibia					
Anura					
Bufonidae					
Duttaphrynus arabicus (Heyden, 1827)	Arabian toad	LC	41	62	103
Mammalia					
Carnivora					
Canidae					
Vulpes vulpes (Linnaeus, 1758)	Red fox	LC	3	11	14
Eulipotyphla					
Erinaceidae					
Paraechinus aethiopicus (Ehrenberg, 1832)	Desert hedgehog	LC	3	5	8

Table 2.1 (Continued)

Rodentia					
Muridae					
Acomys dimidiatus (Cretzschmar, 1826)	Arabian spiny mouse	LC	2	4	6
Acomys russatus (Wagner, 1840)	Golden spiny mouse	LC	0	1	1
Gerbillus cheesmani (Thomas, 1919)	Cheesman's gerbil	LC	1	0	1

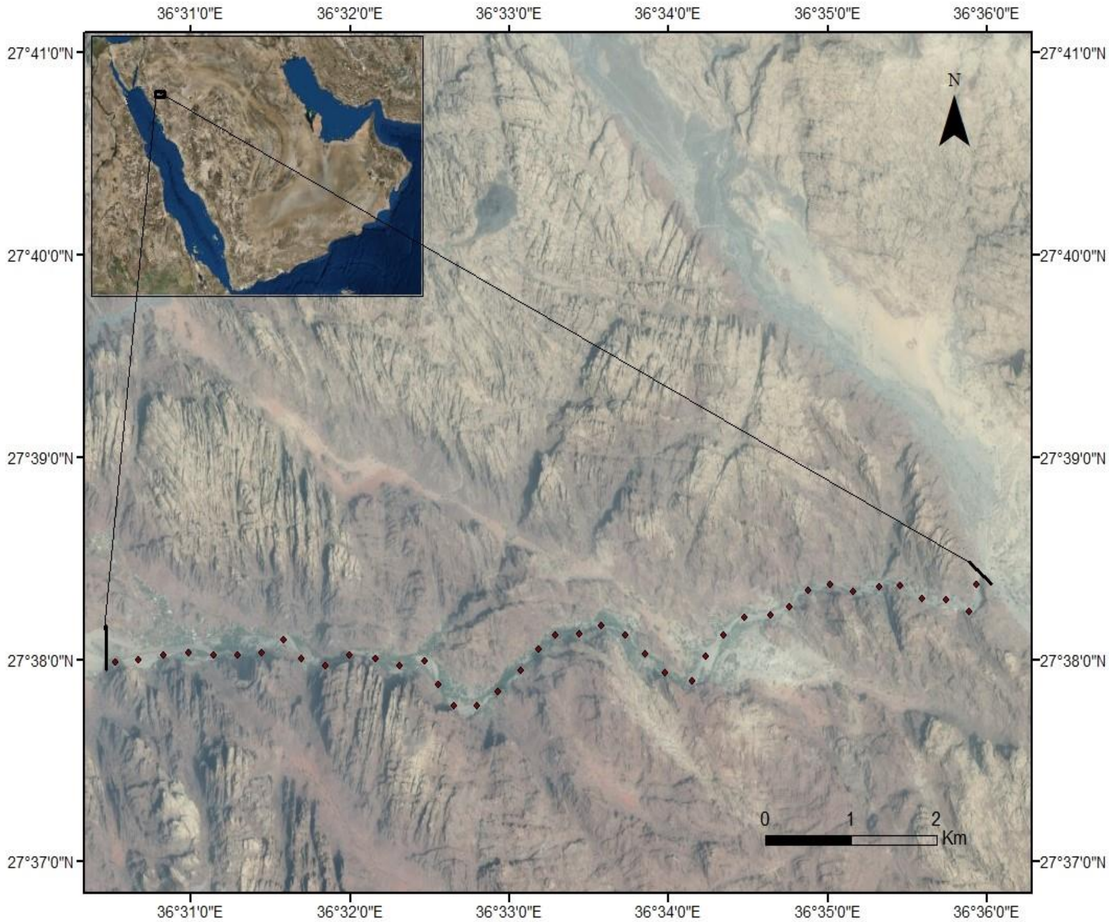

Figure 2.1 Aldesa Valley, Tabuk, Saudia Arabia shown above between the two black lines.

Points inside the Valley represent the 40 segment locations.

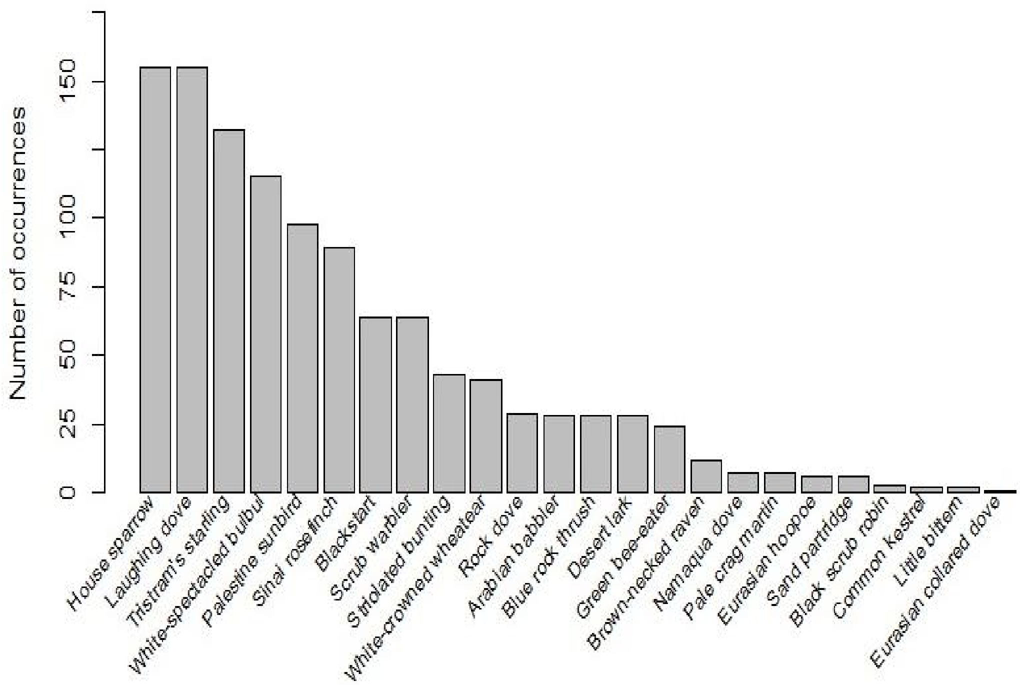

Figure 2.2 Number of occurrences for bird species detected in Aldesa Valley, from 10 May to 10 August in 2014 and 2015.

Figure 2.3 Birds detected during a terrestrial vertebrate inventory in Aldesa Valley, Saudi Arabia, from 10 May to 10 August in 2014 and 2015.

3: house sparrows (*Spilopelia senegalensis*). **4:** Tristram's starling (*Onychognathus tristramii*). **5:** laughing doves (*Spilopelia senegalensis*). **6:** white-spectacled bulbul (*Pycnonotus xanthopygos*). **7:** Sinai rosefinch (*Carpodacus synoicus*). **8:** Palestine sunbird (*Nectarinia osea*). Photos by Abdulaziz Alatawi.

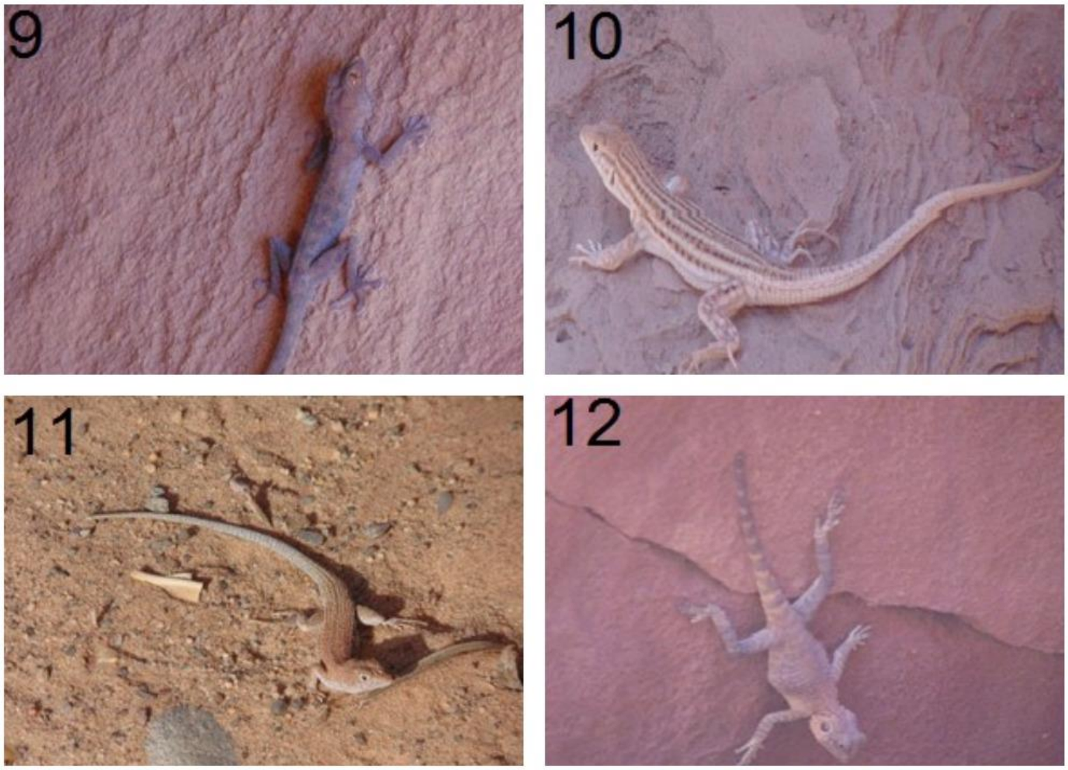

Figure 2.4 Lizards detected during a terrestrial vertebrate inventory in Aldesa Valley, Saudi Arabia, from 10 May to 10 August in 2014 and 2015.

9: common fan-footed gecko (*Ptyodactylus hasselquistii*). **10**: Bosk's fringe-fingered lizard (*Acanthodactylus boskianus*). **11:** Schmidt's fringe-toed lizard (*Acanthodactylus schmidti*). **12:** starred agama (*Stellagama stellio*). Photos by Abdulaziz Alatawi.

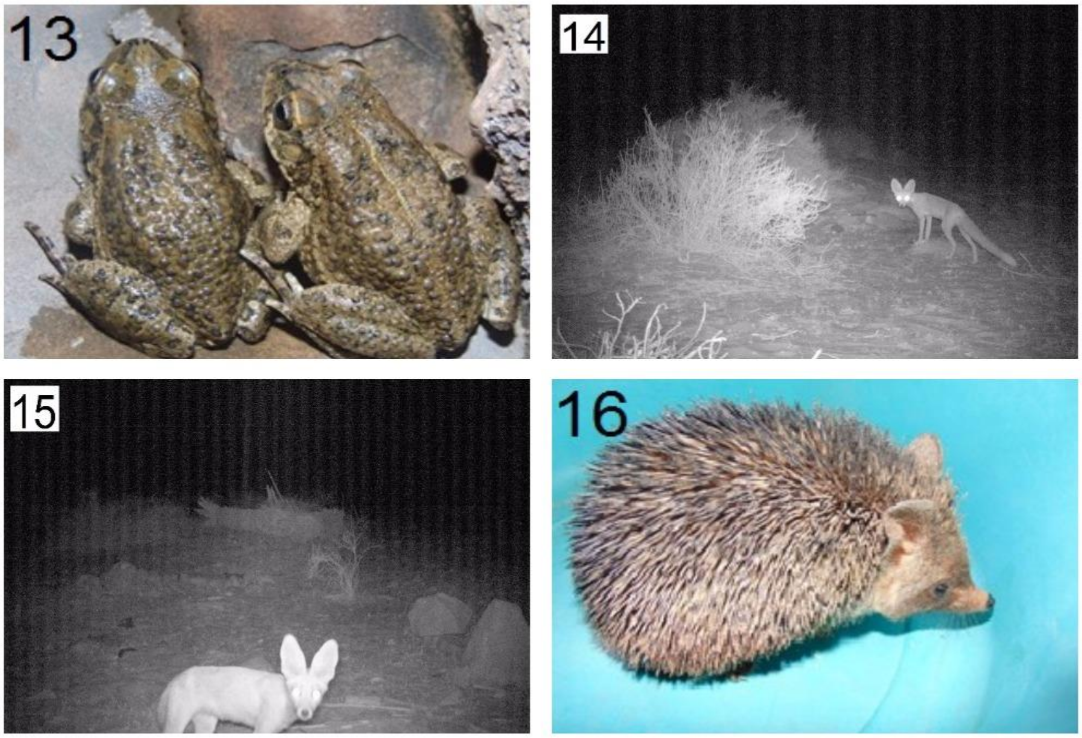

Figure 2.5 Amphibian and mammal species detected during a terrestrial vertebrate inventory in Aldesa Valley. Saudi Arabia, from 10 May to 10 August in 2014 and 2015.

13*:* male and female Arabian toads (*Duttaphrynus arabicus*). **14** and **15:** red fox (*Vulpes vulpes*). **16:** desert hedgehog (*Paraechinus aethiopicus*). Photos by Abdulaziz Alatawi.

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CHAPTER III

ANTHROPOGENIC AND ENVIRONMENTAL EFFECTS ON AVIAN SPECIES RICHNESS AND OCCURRENCE IN ALDESA VALLEY, SAUDI ARABIA

Introduction

With accelerated rates of species extinctions and loss of biodiversity, understanding drivers of species richness is essential (Hill et al., 2005; Pimm et al., 2014; Yoshioka et al., 2014). Conserving biodiversity is important to ensure appropriate ecosystem functions (Chapin et al., 2000; Hector and Bagchi, 2007; Mittelbach et al., 2001; Naeem et al., 1999). Biodiversity losses can lead to severe consequences on ecosystems including increased species extinction rates, increased the concentration of toxic substance, reduced the resistance of ecosystem to environmental perturbations, effect plant and animal productivity, and effect soil nitrogen level. (Cardinale et al., 2012; Chapin et al., 2000; Ehrlich and Ehrlich, 1983; Hector and Bagchi, 2007; Naeem et al., 1999). Maintaining biodiversity is important for ecosystems stability. Society can also benefit economically from biodiversity conservation policies (e.g., ecotourism profits, food production, plant pollination, and pharmaceutical molecules). Other benefits include the protection and continuity of natural resources (Cardinale et al., 2012; Ellis, 2013; Pimentel et al., 1997; Pimmm et al., 1995). A global and multi-disciplinary conservation effort to protect biodiversity has been developed and ranges from measures to improve our understanding of species distributions and the factors affecting it, to reintroduction and management programs to help threatened ecosystems (AbuZinada et al., 2004; Pope and Zogais, 2012).

Several environmental factors can affect species richness and distributions (Hawkins et al., 2003; Qian, 2007). For example; presence, type, and structure of vegetation play an important role in species richness and occurrence (Cody, 1981; Draycott et al., 2008; Qian, 2007). Vegetation structure and communities can also affect interactions between species (e.g., competition for food and shelter; Tews et al., 2004). Variation in vegetation characteristics can lead to modifications of the overall community structure (Anderson et al., 1983; Rotenberry and Wiens, 1980). In addition to vegetation, the presence of water is one of the strongest resources that can directly affect species richness and occurrence (Gillman and Wright, 2014; Korine et al., 2015; Lawrence, 2004). Regions that lack water typically have less biodiversity (e.g., deserts, AbuZinada et al., 2004; Lawrence, 2004; Waide et al., 1999). Factors like vegetation and water in desert are largely responsible for supporting high species richness compared to nearby areas without water and vegetation because of the fundamental relationship between these environmental factors, species richness, and occupancy (Hawkins et al., 2003; Qian 2007; Lawrence 2004).

Human activities are considered the greatest threat for many species (e.g., agricultural activities, urban development, and roads; Chapin et al., 2000; Ellis, 2013; Hunter and Gibbs, 2007; McKinney, 2002). Human activities can negatively impact species richness and occurrence and are considered the main cause of habitat fragmentation (Chapin et al., 2000; Fahrig, 2003; Franklin et al., 2002; Pimm et al., 1995;

Vitousek et al., 1997). Additionally, human activities can reduce habitat heterogeneity that species depend on to forage, resulting in potential reduction of food resources (Chapin et al., 2000; Tews et al., 2004; Vitousek et al., 1997). Consequently, many species have been classified as threatened following changes in their environment due to human activities (Kerr and Currie, 1995; IUCN, 2015), with human activities contributing to increased species extinction rates up to 100 fold relative to background rates (Ceballos et al., 2015).

Anthropogenic factors have transformed many suitable habitats into non-suitable habitats (Mattson, 1990; Vitousek et al., 1997). For example, roads and associated traffic cause habitat loss and/or fragmentation (Baskaran and Boominathan, 2010; Carr and Fahrig, 2001), creating barriers to animal movements (Shepard et al., 2008; Skórka et al., 2013) and concomitant displacement of animals (Smith-Patten and Patten, 2008). In addition to the development of road networks, land conversion to agriculture can strongly affect species richness and distribution through intensive fragmentation, loss of habitat or introduction of invasive species (Jose-Maria et al., 2010; Murphy and Romanuk, 2014; Roschewitz et al., 2005). However, species exhibit ecological plasticity and can adapt to varying degrees of environmental changes (Chevin et al., 2010). Many animals have modified their behavior and habitat use in response to habitat alterations (e.g., shift from diurnal activity to nocturnal activity; Chevin et al., 2010; Kitchen et al., 2000). Such alterations have affected native species in many areas worldwide (Park, 2004). Overall, efforts to preserve species from anthropogenic actions varies among regions worldwide (AbuZinada et al., 2004; Brooks, 2006), and comparatively fewer efforts are conducted in areas of low species richness, such as deserts (AbuZinada et al., 2004).

Deserts are defined as any ecosystem where limited water affects occurrence of species (Lawrence, 2004). Typically, deserts do not support high species diversity due to limitations in food (AbuZinada et al., 2004; Lawrence, 2004; Walker, 1992). Furthermore, deserts are associated with low rainfall, which adversely affect terrestrial species occurrence and richness; aridity and high temperature also constrain species occurrence in hot deserts (AbuZinada et al., 2004; Tiger and Osborne, 1999; Walker, 1992). The Aldesa Valley is a unique ecosystem in the Tabuk Region of Saudi Arabia (Tabuk Nature, 2015) as the availability of water, topographic relief, and vegetation structure supports diverse terrestrial vertebrate species. No formal surveys of the factors affecting terrestrial wildlife have been conducted in Aldesa Valley. My objective was to record and estimate the effects of anthropogenic and environmental factors on bird species richness and occurrence in Aldesa Valley. I expected that vegetation cover and water area would positively affect avian species richness, and local distribution. Also, I expected that number of people would positively affect avian species richness, and detectability, and expected that road area would negatively affect species richness and occupancy. Finally, I expected that water area would affect positively on the detectability of avian species, and temperature would negatively affect the detectability of avian species.

Materials and Methods

Study area

The Aldesa Valley (27° 38'1" N, 36° 31'21" E) is a narrow,10-km valley between 2 minor mountain ranges about 225 km southwest of Tabuk City, Saudi Arabia (Figure 1; Tabuk Municipality, 2013). Aldesa Valley contains a permanent spring, known as the blue or eye fountain, which is the headwater of a small stream. People who live near Aldesa Valley depend on this water source for their livelihood and small-scale agricultural production. Livestock raised includes camels, sheep and chickens. In addition, vegetable (e.g., tomato, eggplant, zucchini) and fruit (e.g., mango, citrus, melon) production is common. Temperatures during winter (Dec–Feb) typically range from 2 to 15 C°, but are occasionally below 0 C°. Temperatures during summer range from 19 to 42 C° in May and 24 to 48C° in July. Rainfall is about 39 mm each year (Presidency of Meteorology and Environments, 2013).

Methods

I conducted fieldwork from 10 May to 10 August in 2014 and 2015, having received permission from Tabuk Province office, and the University of Tabuk. I divided the valley into 40, 250 m- long segments (Figure 1; see Hill et al., 2005; Shirley et al. 2013). Each segment was surveyed twice in 2014 and three times in 2015. I used time area searches to quantify bird species occurrence, conducting searches from 0630–1000 hr and arriving at the first segment 15 min before sunrise (Hill et al., 2005; Volpato et al. 2009). I conducted surveys when winds were <12 km/hr and there was no rain (Ralph et al. 1995). I used a handheld anemometer (EA-3010U Handheld Travel Anemometer) to record wind speed and temperature during surveys. I searched segments for 0.5–2.0 hours, based on segment size and complexity (e.g., presence of vegetation) using a pre-determined schedule. I surveyed four or five segments each day. I used two field guides to facilitate identification (e.g., Porter and Aspinall 2010; Pope and Zogais 2012). For each observation, I recorded the time and the number of individuals by species.

In each segment, I recorded ecological covariates including segment area, road area, number of farms, cover type percentage (perennial herbaceous, herbaceous, tree and shrub, sand, rock, gravel, road, stream), and tree canopy area. I also recorded detection covariates including wind speed, temperature, humidity, stream area, number of domestic animals observed, number of people observed, number of vehicles observed, survey, and search duration as explanatory covariates for avian species richness and targeted bird species occupancy.

For vegetation, I used the point transect method to estimate the percentage of vegetation and other substrates habitat in each segment (Hill et al., 2005). I delineated two parallel transects across the width of each segment at 83-m intervals (Rochefort et al., 2013). Every 20-m, I stopped and recorded within a 3-m radius circle the type of habitat present and its relative coverage (e,g., plants, rock, gravel, etc.; Hill et al., 2005; Rochefort et al., 2013). I grouped plants and substrate habitat into 8 categories: annual herbaceous, shrub and tree, perennial herbaceous, rock, gravel, sand, stream, and road covers (Caratti, 2006; Hill et al., 2005; Rochefort et al., 2013). Additionally, at each point I recorded the percentage of canopy area (Jennings et al., 1999). I then calculated the average percentage of area occupied by each cover type and canopy cover over both lines within each segment. Finally, I measured the area in each segment containing road and stream using a metric tape or handheld GPS (Hill et al., 2005).

Statistical analysis

Species richness

I modeled the relationship between species richness and a set of explanatory covariates using generalized linear models (GLM) (McCullagh and Nelder, 1989). The number of detected species per segment was modeled following a Poisson distribution with a mean expressed as a linear combination of explanatory variables on the log-scale. Considered covariates that were identical among sampling sessions were segment area, road area, number of farms, tree canopy area, and the cover type percentages in each segment. In addition, considered covariates that varied among sampling occasions were temperature, stream area, search duration, start time, wind speed, humidity percentage, number of domestic livestock observed, number of people observed, number of vehicles observed, tree canopy area, and survey.

Occupancy

I used likelihood-based occupancy modeling to determine the factors affecting the distribution of the six most common bird species in the Aldesa valley (house sparrow (*Passer domesticus*), laughing dove (*Spilopelia senegalensis*), Tristram's starling (*Onychognathus tristramii*), white spectacled bulbul (*Pycnonotus xanthopygos*), Palestine sunbird (*Nectarinia osea*), and Sinai rosefinch (*Carpodacus synoicus*)). Based on my time area searches, I built an encounter history with 5 occasions for each segment (MacKenzie et al., 2002a, 2006b).

Occupancy z_i at segment i was modeled following a Bernoulli distribution with mean φ_i, such as:

$$z_i \sim Bern(\varphi_i) \quad (3.1)$$

With φ_i defined as a linear combination of K explanatory variables on the logit scale following.

$$logit(\varphi_i) = \beta_0 + \sum_{k=1}^{K} \beta_k \, x_{i,k} \quad (3.2)$$

Where β_0 is the intercept, β_k are the slopes corresponding to the ecological covariates k in the set of K covariates $\{x_{i,1}, \ldots, x_{i,K}\}$. This set of scaled covariates include the segment area, road area, number of farms, cover type percentages (perennial herbaceous, herbaceous, tree and shrub, sand, rock, gravel, road, stream), and tree canopy area. In this context, z_i is equal to 1 if the species is present and 0 otherwise.

Conditionally on this occupancy z_i, I modeled my observed detection y_{ij} on segment i during occasion j following a Bernoulli distribution with mean μ_{ij} such as:

$$y_{ij} \sim Bern(\mu_{ij} z_i) \tag{3.3}$$

The detection probability μ_{ij} when species is present is then defined as a linear combination of observation covariates $\{x'_{ij,1}, \ldots, x'_{i,K'}\}$ on the logit scale such as:

$$logit(\mu_{ij}) = \beta'_0 + \sum_{k'=1}^{K'} \beta'_{k'} \, x'_{ij,k'} \tag{3.4}$$

Where β'_0 is the intercept, $\beta'_{k'}$ are the slopes corresponding to the observation covariates k in the set of K covariates $\{x_{i,1}, \ldots, x_{i,K}\}$. The set of detection covariates varying across segments and sampling occasions included wind speed, temperature, humidity, stream area, number of domestics observed, number of people observed, number of vehicles observed, survey, and search duration. I also included tree canopy area as a covariate for detection probability.

Model selection

Model selection for analysis of species richness was performed using a backward stepwise algorithm where all covariates were included in the first model, and then removed one at a time to minimize the resulting AIC at each step until no further improvement can be made in the model (Burnham and Anderson, 2002; Venables and

Ripley, 2002). Model selection for occupancy analyses was performed using a forward stepwise selection to build the final models for each birds' species, adding one covariates at a time (Burnham and Anderson, 2002).

Implementation

Statistical analyses were performed in program R (v. 3.1.2.) (R Development Core Team, 2015). Species richness analyses was performed using the 'step' function in the 'stats' package, and model averaging for species richness was done using the package 'MuMIn' (Barton, 2015), with best competing models (i.e., ΔAIC< 2; Burnham and Anderson 2002). I used Akaike's information Criterion (AIC) to measure the relative quality of each model (Burnham and Anderson, 2002). I performed occupancy analyses using the package 'unmarked' (Fiske and Chandler, 201; Royle and Dorazio, 2008) and model averaging using the package 'AICcmodavg' (Mazerolle, 2015). I presented model averaged parameter coefficients for all competing models with mean and 95% confidence intervals or standard errors for each variable with GLM and occupancy models.

Results

Species richness

Bird species richness in Aldesa Valley was best explained by three competing models (Table 1). These models included the explanatory covariates search duration, segment area, extent of sand and rock substrate, road area in each segment, and number of people observed (Table 1). From model-averaged parameter estimates, I found that bird species richness was positively correlated with segment area (0.15 ± 0.06) (mean ± SE) and search duration (0.0018 ± 0.0007) (Table 2). Also, two explanatory covariates were negatively correlated with bird species richness: rock cover (-0.01 ± 0.004), and road area (0.015 ± 0.006). Sand cover (-0.001 ± 0.002) and number of people observed (0.007 ± 0.019) did not influence bird species richness.

Occupancy: ecological covariates

Occupancy of each of the six bird species most commonly detected in Aldesa Valley was associated with a different set of competing models (Table 3). The competing models for each species were composed of different sets of ecological and detection covariates. Collectively, the selected ecological covariates were segment area, the percentage cover of sand, tree and shrub, perennial herbaceous, annual herbaceous, road and gravel in each segment. Tree canopy area was included in most of the final models. In contrast, selected detection covariates included number of vehicles observed, temperature, tree canopy area, search duration, wind speed, and number of people observed in each segment, including a survey effect. Interestingly, all six species showed a general trend of not being correlated with the ecological covariates road cover, stream cover, and number of farms (Table 3).

From model-averaged parameter estimates I found that each species was correlated with a different set of explanatory covariates. The ecological covariates selected for the house sparrow were segment area (8.8 ± 6.2) (mean ± SE), sand cover (-3.4 ± 2.5); Tristram's starling was selected with sand cover (2.8 ± 1.6). Selected ecological covariates for the white spectacled bulbul were segment area (28.8 ± 33.06) and tree and shrub cover (9.88 ± 20.9). For the Palestine sunbird, selected ecological covariates were perennial herbaceous cover (3.5 ± 2.5), annual herbaceous cover (0.85 ± 0.62), tree canopy area (1.01 ± 0.74), gravel cover (0.25 ± 0.64), and road cover (0.7 ±

0.8). Ecological covariates contributing to the selected models for the Sinai rosefinch were segment area (27.14 ± 19.8) and gravel cover (-3.4 ± 2.97) (Table 4).

Occupancy: detection covariates

The detectability of house sparrow was positively correlated with number of vehicles observed (0.8 ± 0.3) (mean ± SE), and negatively correlated with temperature (-0.14 ± 0.06) (Table 4). Laughing dove detectability was positively correlated with number of people observed (0.93 ± 0.39) and, negatively correlated with temperature (0.14 ± 0.05), and varied among surveys. There were no significant covariates correlated with Tristram's starling detectability. White spectacled-bulbul detectability was positively correlated with tree canopy area (0.06 ± 0.02). Also, I found that the detectability of Palestine sunbird was negatively correlated associated with wind speed (-0.15 ± 0.06). Sinai rosefinch detectability was positively correlated with search duration (0.04 ± 0.01) and varied among surveys. The remaining ecological and detection covariates did not strongly influence species detectability (Table 4)

Discussion

Multiple explanatory covariates influenced bird species richness in Aldesa Valley. Increasing rock cover in each segment was negatively correlated with species richness. Most birds observed in Aldesa Valley were near vegetation, water, and farmlands. Higher proportions of rock cover in deserts may affect species richness by reducing food availability (e.g., Walker, 1992). Increasing road area also was negatively correlated with species richness and could cause fragmentation and loss of habitat, thereby reducing potential food availability and abundance (e.g., Fahrig and Rytwinski, 2009; Forman and

Alexander, 1998; Franklin et al., 2002; Hunter and Gibbs, 2007). Additionally, vehicle collisions could cause bird avoidance of roads; large numbers of vertebrate species have exhibited local declines in abundance due to increased mortality from vehicle collision (Baskaran and Boominathan, 2010). The size of the segment area was also positively correlated with species richness (Brown et al., 2007; Gillman and Wright, 2014). Large areas likely support greater number of species by providing a greater variety of habitats and microhabitats, following the species-area relationship (Brown et al., 2007; Gillman and Wright, 2014; MacArthur and Wilson, 1967).

Search duration was positively correlated with bird species richness in Aldesa Valley. Unsurprisingly, an increase in search time in each segment can lead to an increase in the probability of detecting more species (Bibby et al., 1998; Hill et al., 2005). In deserts, search duration and start time may be more important because of extreme temperatures (AbuZinada et al., 2004). Temperature was included as a covariate and high temperature could have an adverse effect by reducing bird activities which would in turn reduce their detectability. Furthermore, high temperatures can affect the observer's concentration and time spent at the field site (Bibby et al., 1998; Hill et al., 2005). As a result, conducting field work early in the morning can help to increase species detections (Bibby et al., 1998; Volpato et al., 2009). I was surprised that the stream area and vegetation cover was not selected as an important covariates for avian species richness contrary to my prediction. However, this may be a consequence of small segment sizes and that birds can move easily among segments to access water. Additionally, these same environmental conditions (i.e., water and vegetation) are represented in the adjacent village. Finally, road area negatively affect avian species richness; however, number of people did not have any significant effect on avian species richness as I predicted.

Each bird species distribution was correlated with a different set of explanatory covariates in Aldesa Valley. Ecological covariates included and selected in the best competing models were segment area, the percentage of tree and shrub cover, perennial herbaceous, herbaceous, gravel, sand, and road and tree canopy area. Greater numbers of species are found with large areas by likely providing a variety of habitats and microhabitats which emphasizes the species-area relationship as previously mentioned (Brown et al., 2007; Gillman and Wright, 2014; MacArthur and Wilson, 1967). Sand cover and gravel cover in each segment were negatively correlated with bird's species occupancy. Typically, increased sand and gravel is associated with less vegetation cover and water which can result in reduced food availability (Walker, 1998). Indeed, each of my 6 common detected birds depend on vegetation directly or indirectly (Pope and Zogais, 2012; Porter and Aspinall, 2010). For example, white spectacled bulbul and Palestine sunbirds select for dense perennial herbaceous and shrubs to nest and forage (Porter and Aspinall, 2010; Tadmor-Melamed et al., 2004). Additionally, the type and structure of tree canopy can create structure that can improve habitat quality which in turn can effect birds' occupancy (Erwin et al., 2013, Nadkarni, 1994; Wood etal., 2012).

Area of road also contributed to the final ecological component of the occupancy model for Palestine sunbirds. Roads usually are associated with direct negative effects on bird's occupancy (Fahrig and Rytwinski, 2009; Forman and Alexandarr, 1998). For instance, Palestine sunbird is a nectarivorous bird that depends on flowers to forage (e.g., Tadmor-Melamed et al., 2004); as a result, any potential increase in the road area will reduce the area available for trees. Increasing road cover could directly reduce other selected habitats, again reducing the availability of food (e.g., Fahrig and Rytwinski, 2009; Forman and Alexandarr, 1998), which supports my prediction about the potential negative effect on avian occupancy due to road area.

Stream area was included in the best model with white spectacled bulbul and Palestine sunbird. As standing water is limited in deserts, water bodies can facilitate detection of birds (Bibby et al., 1998). Also, Palestine sunbird detectability was negatively correlated with wind speed. Higher wind speeds can reduce bird activity and consequently, detectability (Bibby et al., 1998; Carr and Lima, 2010; Hill et al., 2005; Volpato et al., 2009). White spectacled bulbul detectability was positively correlated with tree canopy area and may be related to structural complexity. Structure and type of tree canopy has been documented to influence the habitat quality (Erwin et al., 2013; Nadkarni, 1994), which may affect the detectability of birds.

Laughing dove and house sparrow detectabilities were negatively correlated with temperature. Desert weather typically includes high temperatures during summer (AbuZinada et al., 2004; Bibby et al., 1998; Walker, 1996). I would expect birds to reduce their activities during periods of high temperature, and therefore have lower detectability as temperature increases (Bibby et al., 1998; Hill et al., 2005). I suggest that my early starting time for conduct of surveys reduced the negative effects of high temperature and increased detectability of birds. House sparrow detectability was positively correlated with the number of vehicles observed. House sparrow exhibits considerable behavioral plasticity and is commonly correlated with heavily disturbed areas occupied by humans (Pope and Zogais, 2012; Porter and Aspinall, 2010). As I expected, laughing dove detectability was positively correlated with the number of people observed because laughing doves often forage next to human settlements, villages, and farmlands (Porter and Aspinall, 2010). For the house sparrow and laughing dove, increased human activity could lead to an increase in the species' abundance, and consequently improve detectability.

Sinai rosefinch detectability was positively correlated with search duration. Unquestionably, increasing search duration will increase the ability to detect more species (Bibby et al., 1998; Hill et al., 2005; Volpato et al., 2009). In deserts, start time and search duration may be more important compared to temperate regions because of extreme temperatures (AbuZinada et al., 2004; Bibby et al., 1998). Additionally, there was also a survey effect on laughing dove and Sinai rosefinch. In contrast, the survey effect (time of survey) may be due to variations in weather conditions, the position of the observer, or time of day surveys were conducted (Bibby et al., 1998; Mayhew, 1981). Number of domestics' animals was included in the final best competing models of Tristram's starling. Normally, Tristram's starlings perch on animals, particularly domestic animals (Porter and Aspinall, 2010). More domestic animals would provide more perching locations, increasing the species visibility. Overall, my results support my prediction about the potential relationship between stream area and bird detectability. Additionally, the results confirmed the prediction about the temperature and its negative impact on bird detectability.

Though ecological covariates were included in the best models of targeted species occurrence, they did not have a direct significant influence. Two of the six most common birds I detected (house sparrow, laughing dove) are generalist species adapted to diverse environmental conditions (e.g., Devictor et al., 2008; Porter and Aspinall, 2010), which may explain why ecological covariates in Aldesa Valley did not influence their occupancy (Porter and Aspinall, 2010). The four remaining species (Tristram's starling, Palestine sunbirds, white spectacled bulbul, and Sinai rosefinch) appear more specialized to particular habitats or adapted to a more limited range of environmental conditions (Porter and Aspinall, 2010). Though the Aldesa Valley evidently supports these species (Porter and Aspinall, 2010; and Pope and Zogaris, 2012), I believe that the spatial extent of Aldesa Valley may have an indirect effect on their occurrence. Because the valley is narrow and only 10 km in length, birds can move freely to any habitat among segments.

Knowing which anthropogenic factors, and ecological factors affect bird species richness and their distributions is critical to preserve species. In the Aldesa Valley, bird species richness and the occupancy of our selected species were related to several covariates. Improving our knowledge of the relevant factors affecting species richness and occupancy is important in this low diversity area, and could help guide conservation efforts, particularly important in desert ecosystems. (AbuZinada et al., 2004; Brooks et al., 2006; Brown et al., 2007; MacKenzie et al., 2006; Morris and Doak, 2002).

Conclusion

My study contributes to improve understanding of the intrinsic relationships between avian species and their habitat in Aldesa Valley. Species in deserts are more sensitive to habitat isolation and disturbances because of limited food availability and extreme environmental conditions (AbuZinada et al., 2004; Lawrence, 2004; Walker, 1992). Not only are the food resources in the Aldesa Valley likely limited and potentially vulnerable, they may be important in explaining the local species richness and distribution of several species. I observed numerous human activities that can influence ecological processes and landscape conditions, which can adversely and directly affect species richness and occupancy (Hunter and Gibbs, 2007; Vitousek et al., 1997). The local wildlife authority should consider monitoring human activities in Aldesa Valley (Almoutirti, 2004) to help ensure long-term persistence of species assemblages. I also encourage additional inventories and more detailed studies of vertebrate species and their ecological relationships in Aldesa Valley.

Table 3.1 Best-ranked model selection results for factors influencing bird species richness, Aldesa Valley, Tabuk, Saudi Arabia, from 10 May to 10 August in 2014 and 2015.

Model	K	AIC	ΔAIC	w
Search duration + segment area + rock cover + road area	5	806.80	0.00	0.35
Search duration + segment area + sand cover + rock cover + road area	6	807.38	0.58	0.26
Search duration + no. people + segment area + sand cover + rock cover + road area	7	808.20	1.41	0.17

K = number of parameters, AIC = Akaike Information Criteria, and W = Akaike weight

Table 3.2 Model-averaged parameters estimates from best ranked models for estimating bird species richness, Aldesa Valley, Tabuk, Saudi Arabia, from 10 May to 10 August in 2014 and 2015.

			95% CI	
Covariate	Mean	P	Lower	Upper
Intercept	1.37	<0.001	0.924	1.817
Search duration	0.0018	0.019	0.0003	0.0033
Segment area	0.15	0.009	0.038	0.268
Rock cover	-0.01	0.005	-0.019	-0.003
Road area	-0.015	0.012	-0.027	-0.003
Sand cover	-0.001	0.469	-0.007	0.001
Number of people	0.007	0.703	-0.023	0.090

Table 3.3 Best ranked model selection results for factors influencing bird species occupancy, Aldesa Valley, Tabuk, Saudi Arabia, from 10 May to 10 August in 2014 and 2015.

Species	Model	Covariates	K	AIC	ΔAIC	W
House sparrow	1	~segment area + sand cover	13	158.3	0.00	0.51
		~no. of vehicles + survey + temperature + tree canopy cover				
	2	~segment area + sand cover	12	158.4	0.11	0.49
		~no. of vehicles + survey + temperature + tree canopy cover + no. of domestics				
Laughing dove	1	~no. of people + survey + temperature	10	189.2	0.00	0.32
	2	~no. of people + survey + temperature + no. of vehicles	10	189.4	0.14	0.29
	3	~no. of people + survey + temperature + no. of vehicles + search duration	11	189.6	0.40	0.26

Table 3.3 (continued)

	4	~no. of people + survey + temperature + no. of vehicle + search duration + no. of domestics	12	190.9	1.77	0.13
Tristram's starling	1	~ sand cover ~no. of domestics	5	228.7	0.00	0.66
	2	~ sand cover ~no. of domestics + wind speed	4	230.0	1.36	0.34
White-spectacled bulbul	1	~segment area + tree and shrub cover ~tree canopy cover + no. of vehicles	6	238.6	0.00	0.55
	2	~segment area+ tree and shrub cover ~tree canopy area + no. of vehicles + stream area	7	239.6	0.96	0.34

Table 3.3 (continued)

	3	~segment area+ tree and shrub cover ~tree canopy area+ no. of vehicles + stream area+ survey	12	241.8	3.20	0.11
Palestine sunbird	1	~perennial herbaceous cover + annual herbaceous cover + tree canopy area + gravel cover + road area ~wind speed + humidity percentage + no. of domestics + search duration	11	219.4	0.00	0.65
	2	~perennial herbaceous cover + annual herbaceous cover + tree canopy area +	12	220.1	1.26	1.00
	3	gravel cover + road area ~wind speed + humidity percentage + no. of vehicles + search duration+ stream area				

Table 3.3 (continued)

Sinai rosefinch	1	~segment area + gravel cover	11	203.3	0.00	0.42
		~ search duration + survey				
	2	~segment area + gravel cover	10	203.4	0.06	0.41
		~duration + survey + no. of people				
	3	~segment area + gravel cover	12	205.2	1.893	0.16
		~search duration + survey + no. of people				
		+ tree canopy area				

The first portion of models for each species includes the ecological covariates, and the second portion includes the detection covariates. K = number of parameters, AIC = Akaike Information Criteria, and W = Akaike weight.

Table 3.4 Model-averaged parameters estimates for best ranked models for estimating bird species occupancy, Aldesa Valley, Tabuk, Saudi Arabia, from 10 May to 10 August in 2014 and 2015.

Species	Covariate type	Covariate	Mean	95% CI Lower	95% CI Upper
House sparrow	Ecological	Intercept	11.47	-2.38	25.33
		Segment area	8.8	-3.3	20.9
		Sand cover	-3.4	-8.2	1.4
	Detection	Intercept	5.2	1.4	8.9
		Number of vehicles	0.88	0.37	1.39
		Survey 2	7.7	-42.7	85.1
		Survey 3	-1.3	-3.0	0.5
		Survey 4	0.9	-0.4	2.3
		Survey 5	1.4	-0.1	2.9
		Survey 6	0.73	-0.59	2.04
		Temperature	-0.14	-0.25	-0.03
		Tree canopy area	-0.06	-0.11	0.008
		Number of domestics	-0.03	-0.05	0.04
Laughing dove	Ecological	Intercept	11.01	-100.69	122.71
	Detection	Intercept	5.1	1.7	8.6
		Number of people	0.93	0.17	1.69

Table 3.4 (continued)

		Survey2	0.49	-1.06	2.05
		Survey3	-2.44	-4.12	-0.76
		Survey4	0.79	-0.52	2.11
		Survey5	0.8	-0.5	2.1
		Survey6	0.95	-0.34	2.23
		Temperature	-0.14	-0.24	-0.04
		Number of vehicles	0.3	-0.06	0.7
		Search duration	0.005	-0.002	0.01
		Number of domestics	-0.02	-0.04	0.01
Tristram starling	Ecological	Intercept	4.71	0.66	8.76
		Sand cover	2.8	-0.3	5.9
	Detection	Intercept	0.59	-0.04	1.22
		Number of domestics	0.02	-0.004	0.05
		Wind speed	0.11	-0.02	0.24
White spectacled bulbul	Ecological	Intercept	32.3	-49.4	113.9
		Segment area	28.89	-35.91	93.69
		Tree and shrub cover	9.88	-31.24	51
	Detection	Intercept	-0.27	-0.88	0.34
		Tree canopy area	0.06	0.01	0.11

Table 3.4 (continued)

		Number of vehicles	0.26	-0.02	0.53
		Stream area	0.004	-0.0007	0.01
		Survey2	0.4	-0.8	1.6
		Survey3	-1.07	-2.69	0.55
		Survey4	0.55	-0.56	1.66
		Survey5	-0.57	-1.59	0.45
		Survey6	-0.1	-1.1	0.9
Palestine sunbird	Ecological	Intercept	3.28	0.08	6.48
		Perennial herbaceous cover	3.54	-1.31	8.38
		Annual herbaceous cover	0.85	-0.37	2.06
		Tree canopy area	1.01	-0.44	2.45
		Gravel cover	0.25	-1	1.51
		Road cover	0.7	-0.8	2.2
	Detection	Intercept	-1.76	-4.68	1.16
		Wind speed	-0.15	-0.28	-0.03
		Humidity percentage	0.12	-0.03	0.27
		Number of domestics	-0.02	-0.04	0.01
		search duration	0.01	-0.01	0.02
		Stream area	0.005	-0.0004	0.01

Table 3.4 (continued)

Sinai rosefinch	Ecological	Intercept	27.25	-9.99	64.49
		Segment area	27.14	-11.85	66.12
		Gravel cover	-3.43	-9.24	2.39
	Detection	Intercept	-2.01	-3.39	-0.62
		Duration	0.04	0.02	0.06
		Survey2	2.14	0.42	3.86
		Survey3	-1.21	-3.05	0.63
		Survey4	0.23	-0.86	1.33
		Survey5	-0.2	-1.8	0.4
		Survey6	-1.25	-2.36	-0.14
		Number of people	0.31	-0.16	0.77
		Tree canopy area	0.04	-0.02	0.09

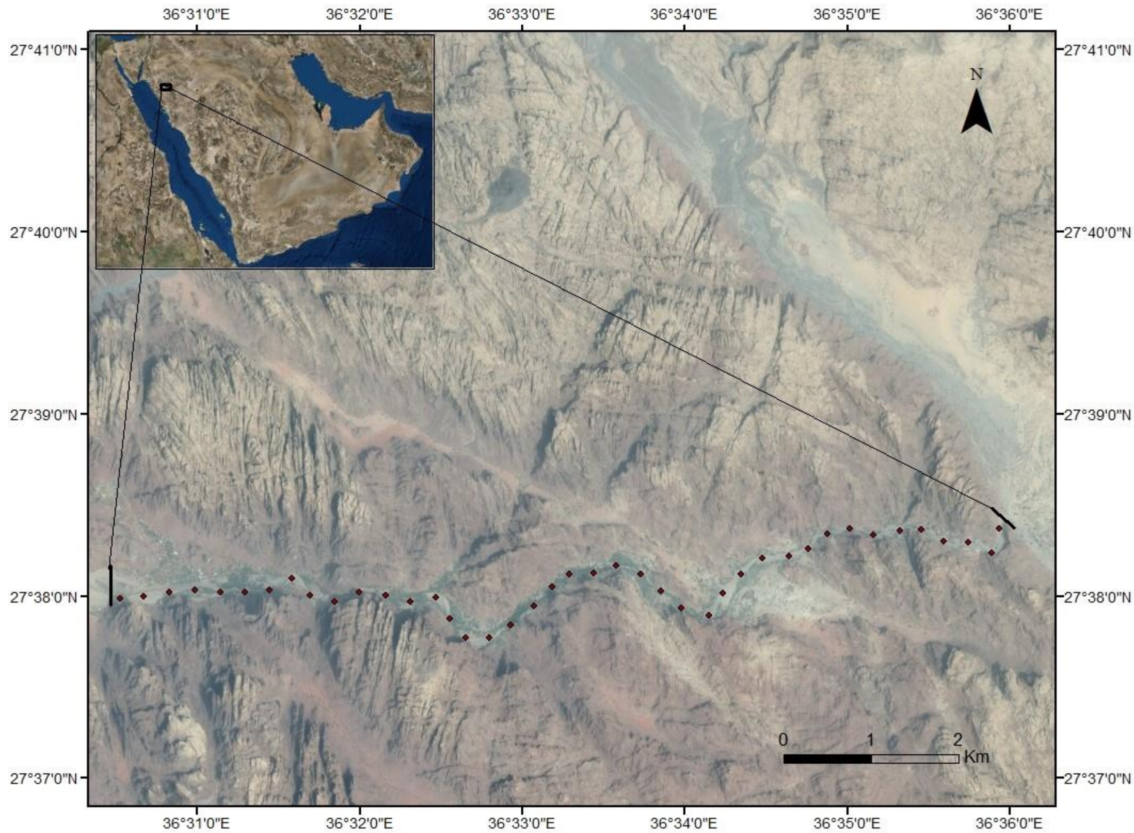

Figure 3.1 Aldesa Valley, Tabuk, Saudia Arabia shown above between the two black lines.

Points inside the Valley represent the 40 segments locations.

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CHAPTER IV

GENERAL CONCLUSION

Protecting biodiversity is crucial to ensure the continuity of natural resources and maintaining healthy ecosystems (Chapin et al., 2000; Naeem et al., 1999). Numerous services are provided by biodiversity (e.g., Cardinale et al., 2012). For instance, biodiversity can enhance ecosystem abilities to function properly and increase productivity (Chapin et al. 2000; Hector and Bagchi 2007; Naeem et al., 1999). Consequently, ecosystems can recover from and counter natural disasters and disturbances (Sudmeier-Rieux et al., 2006). Currently, there are global anthropogenic pressures on biodiversity due to accelerated human activities which cause negative consequences to biodiversity (e.g., increased species extinction; Cardinale et al., 2012; Ceballos 2015; Chapin et al., 2000; Ellis, 2013; Ehrlich and Ehrlich, 1983).

Deserts are a difficult place to live in, even for humans, due to extreme environmental conditions. Predominantly, deserts do not support high species diversity due to limitations in food resources (AbuZinada et al., 2004; Lawrence, 2004; Walker, 1992). Hot deserts usually have less annual rainfall which in turn negatively affect terrestrial species occurrence and richness (AbuZinada et al., 2004; Lawrence, 2004). Additionally, the aridity and high temperatures also constrain species richness and occurrence in deserts (AbuZinada et al., 2004; Tiger and Osborne, 1999; Walker, 1992); thus, biodiversity is especially low in deserts (Waide et al.,1999).

Understanding factors that affect species are fundamental and crucial to increase our knowledge and ability to protect species. In Chapter 2, I conducted the first formal terrestrial inventory in Aldesa Valley, Tabuk region. Aldesa Valley is a unique due to special environmental conditions (e.g., water, dense vegetation, topographic variation) that rarely occurs in hot deserts. These environmental factors may influence the presence of species and attract species from nearby areas due to the potential positive relationships between these environmental conditions and species requisites (Hawkins et al., 2003; Korine et al., 2015; Tews et al., 2004; Qian, 2007). I observed and documented several terrestrial vertebrate taxa in Aldesa Valley which emphasizes the importance of this valley for local biodiversity. In Chapter 3, I estimated anthropogenic and environmental factors that affect avian species richness and local occupancy. There is a strong relationship between environmental factors, topography, and species richness and occupancy (Gillman and Wright, 2014; Hawkins et al. 2003; Tews et al., 2004; Qian, 2007). Our results have identified some explanatory covariates correlated with species richness which can be used to predict what factors should be emphasized to maintain biodiversity. Also, I used occupancy model to investigate which explanatory covariates may affect the six most commonly avian species (house sparrow, laughing dove, Tristram's starling, white spectacled bulbul, Sinai rosefinch, Palestine sunbird) (MacKenzie et al., 2006; Royle and Dorazio, 2008). I identified and found different sets of covariates correlated with the occupancy, and the detectability of these birds. Selected ecological covariates were segment area and the percentage cover of sand, tree and shrub, perennial herbaceous, annual herbaceous, road, and gravel in each segment. Tree canopy area was included in most of the final models. In contrast, selected detection covariates included number of vehicles observed, temperature, tree canopy area, search duration, wind speed, and number of people observed in each segment, including a survey effect. Overall, avian responded differently toward this variety of explanatory covariates which represents an explicit evidence about the need for more detailed studies about avian distribution and their ecological situation.

I observed numerous human activities in Aldesa Valley which can adversely affect ecosystem and species (Chapin et al., 2000; Ellis, 2013; Hunter and Gibbs, 2007; McKinney, 2002). In the last five years, many large fires have been reported in Aldesa Valley, and these fires have destroyed considerable habitats and farmlands (personal observation). Protecting species and this unique ecosystem amidst the larger desert should be a priority for authorities because species are sensitive to habitat isolation and disturbances due to limited food and extreme environmental conditions (AbuZinada et al., 2004; Almoutiri, 2004; Lawrence, 2004). Finally, I encourage authorities to support more biological inventories and monitor human activities in Aldesa Valley.

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