United Arab Emirates University

Scholarworks@UAEU

Civil and Environmental Theses | Civil and Environmental Engineering

6-2020

# THE ECOLOGICAL IMPACTS OF CHANGING RAINFALL ON THE ARABIAN PENINSULA

Zahra Ahmed M Alsomali

Follow this and additional works at: https://scholarworks.uaeu.ac.ae/civil_enviro_theses

Part of the Environmental Sciences Commons

## Recommended Citation

M Alsomali, Zahra Ahmed, "THE ECOLOGICAL IMPACTS OF CHANGING RAINFALL ON THE ARABIAN PENINSULA" (2020). *Civil and Environmental Theses*. 12.
https://scholarworks.uaeu.ac.ae/civil_enviro_theses/12

This Thesis is brought to you for free and open access by the Civil and Environmental Engineering at Scholarworks@UAEU. It has been accepted for inclusion in Civil and Environmental Theses by an authorized administrator of Scholarworks@UAEU. For more information, please contact fadl.musa@uaeu.ac.ae.

United Arab Emirates University

College of Engineering

Department of Civil and Environmental Engineering

# THE ECOLOGICAL IMPACTS OF CHANGING RAINFALL ON THE ARABIAN PENINSULA

Zahra Ahmed M Alsomali

This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science in Water Resources

Under the Supervision of Dr. David L Thomson

June 2020

## Declaration of Original Work

I, Zahra Ahmed M Alsomali, the undersigned, a graduate student at the United Arab Emirates University (UAEU), and the author of this thesis entitled "*The Ecological Impacts of Changing Rainfall on the Arabian Peninsula*", hereby, solemnly declare that this thesis is my own original research work that has been done and prepared by me under the supervision of Dr. David L Thomson, in the College of Engineering at UAEU. This work has not previously been presented or published or formed the basis for the award of any academic degree, diploma or a similar title at this or any other university. Any materials borrowed from other sources (whether published or unpublished) and relied upon or included in my thesis have been properly cited and acknowledged in accordance with appropriate academic conventions. I further declare that there is no potential conflict of interest with respect to the research, data collection, authorship, presentation and/or publication of this thesis.

Student's Signature: Z.Alsomali Date: 10th July, 2020

Copyright © 2020 Zahra Ahmed M Alsomali
All Rights Reserved

# Approval of the Master Thesis

This Master Thesis is approved by the following Examining Committee Members:

1) Advisor (Committee Chair): David L. Thomson
   Title: Associate Professor
   Department of Biology
   College of Science

   Signature ______________________________ Date 15th June, 2020

2) Member (Internal Examiner): Dr. Aaron Henderson
   Title: Associate Professor
   Department of Biology
   College of Science

   Signature ______________________________ Date 15th June, 2020

3) Member (External Examiner): Professor Les Underhill
   Title: Animal Demography Unit (ADU) Director
   Department of Biological Sciences
   Institution: University of Cape Town, South Africa
   *Signed by Dr. David Thomson on behalf of Prof. Les Underhill*

   Signature ______________________________ Date 15th June, 2020

This Master Thesis is accepted by:

Dean of the College of Engineering: Professor Sabah Alkass

Type text here

Signature ____________________ Date 14/7/2020____________

Dean of the College of Graduate Studies: Professor Ali Al-Marzouqi

Signature ____________________ Date July 14, 2020__________

Copy ____ of ____

# Abstract

The Arabian Peninsula is one of the hottest and driest regions in the world, and with climate change, not only is it getting hotter, it is also getting drier. It may be that the desert species here are well-adapted to dry conditions, in which case they may be able to withstand the changes, but it may be that desert species are already challenged by the extremely dry conditions. Here, data from 167 published studies were used to look at whether desert species were living below their optimum rainfall, and to compare the findings with species in other biomes. In all cases, the performance of desert species had a positive relationship with rainfall indicating that they were living below their optima. Across the other biomes studied, it was also found that conditions were more commonly too dry than too wet, suggesting that organisms commonly face water shortage even in quite wet biomes. With deserts being the driest biome of all, species here could be especially vulnerable to climate change, but the vulnerability of species is determined not only by whether they are living below their optimum but also by whether the rainfall trend is taking them further from this optimum. In order to compare the vulnerability of species on the Arabian Peninsula with those in other regions, the findings were combined with information on the relevant rainfall trends in different parts of the world. Even within biomes, it was found that regional heterogeneity in rainfall trends, with some regions getting wetter and some getting drier. The Middle East and North Africa hold the largest single patch of desert in the world, and unlike some of the other desert regions, rainfall is decreasing across this region. Given that desert species appear to be living far below their optimum, this declining rainfall may mean the biodiversity of the Arabian Peninsula and the wider MENA region is particularly vulnerable to changing climate.

**Keywords**: Climate change, Rainfall, Ecological impact, Desert, Arabian Peninsula

## Title and Abstract (in Arabic)

# التأثيرات البيئية لتغير الأمطار على شبه الجزيرة العربية

***الملخص***

تعد شبه الجزيرة العربية واحدة من أكثر المناطق حرارة في العالم وأكثرها جفافاً، ومع تغير المناخ، لا يزداد سخونة فحسب، بل يزداد جفافًا أيضًا. قد يكون أن الأنواع الصحراوية هنا تكيفت بشكل جيد مع الظروف الجافة، وفي هذه الحالة قد تكون قادرة على الصمود أمام التغييرات، ولكن قد يكون أن الأنواع الصحراوية تواجه بالفعل ظروف جافة للغاية. هنا، استخدمت بيانات من 167 دراسة منشورة لمعرفة ما إذا كانت الأنواع الصحراوية تعيش تحت درجات أمطارها المثلى، ولمقارنة النتائج مع الأنواع في المناطق الأحيائية الأخرى. في جميع الحالات، كان لأداء الأنواع الصحراوية علاقة إيجابية مع هطول الأمطار مما يدل على أنهم كانوا يعيشون تحت نطاقهم الأمثل. في جميع المناطق الأحيائية الأخرى التي تمت دراستها، وجدت أيضًا أن الظروف كانت جافة جدًا أكثر من كونها رطبة جدًا، مما يشير إلى أن الكائنات الحية تواجه عادة نقصًا في المياه حتى في المناطق الأحيائية الرطبة تمامًا. نظرًا لأن الصحاري هي أكثر المناطق الأحيائية جفافًا، يمكن أن تكون الأنواع هنا معرضة بشكل خاص لتغير المناخ، ولكن يتم تحديد مدى تأثر الأنواع ليس فقط بما إذا كانت تعيش دون المستوى الأمثل لها، ولكن أيضًا بما إذا كان اتجاه هطول الأمطار يأخذها أبعد من هذا المستوى الأمثل. من أجل مقارنة مدى تعرض الأنواع في شبه الجزيرة العربية لتلك الموجودة في مناطق أخرى، قمت بدمج نتائجي مع معلومات عن اتجاهات هطول الأمطار ذات الصلة في أنحاء مختلفة من العالم. وجدت ان حتى في داخل المناطق الأحيائية، هنالك عدم تجانس إقليمي في اتجاهات هطول الأمطار، حيث تصبح بعض المناطق أكثر رطبا وبعضها أكثر جفافًا. يعد الشرق الأوسط وشمال إفريقيا أكبر بقعة من الصحراء في العالم، وعلى عكس بعض المناطق الصحراوية الأخرى، يتناقص هطول الأمطار في جميع أنحاء هذه المنطقة. ونظرا إلى أن الأنواع الصحراوية تعيش أقل بكثير من المستوى الأمثل لها، فإن انخفاض معدل هطول الأمطار قد يعني أن التنوع البيولوجي في شبه الجزيرة العربية ومنطقة الشرق الأوسط وشمال إفريقيا الأوسع معرضة بشكل خاص لتغير المناخ.

**مفاهيم البحث الرئيسية:** تغير المناخ، هطول الأمطار، التأثير البيئي، الصحراء، شبه الجزيرة العربية

## Acknowledgements

I would like to give my appreciation to my supervisor Dr. David Thomson for his consistent support and constructive suggestions for the development of this project as well as providing his time generously. I am especially grateful for his guidance and enthusiasm throughout this process.

I thank the Coordinators of the Water Resources Master Program, Prof. Mohamed Mohamed and Prof. Munjed Maraqa, for their help and guidance with my studies. I appreciate the unlimited resources provided by the university and more specifically the library department. I thank my friends and colleagues who have supported and encouraged me till the completion of this project.

I would like to thank my Examiners, Dr. Aaron Henderson and Prof. Les Underhill, for their valuable and insightful comments which helped me to improve the thesis.

Finally, I give a huge thanks to my parents who have motivated me throughout this time, and I am grateful to them to have shown me unlimited support and encouragement.

# Dedication

*To my beloved parents and family*

# Table of Contents

# List of Tables

# List of Figures

## List of Abbreviations

| | |
|---|---|
| IUCN | International Union for Conservation of Nature |
| IPCC | Intergovernmental Panel on Climate Change |
| NASA | National Aeronautics and Space Administration |
| NOAA | National Oceanic and Atmospheric Administration |
| UNEP | United Nations Environment Programme |
| USGCRP | US Global Climate Research Program |
| WMO | World Meteorological Organization |
| WWF | World Wide Fund for Nature |

# Chapter 1: Introduction

## 1.1 Overview

In recent decades, increasing concern about climate change has resulted in large numbers of studies into the potential impacts on ecological systems (Scocco et al., 2016; Bretschger, 2017). These studies have so far focused mainly on the higher northern latitudes where the pace of warming has been most rapid (Roots, 1989). It has often been assumed that the impacts of climate change are primarily driven by temperature, and that the regions with the largest temperature changes will be the regions with the largest ecological impacts (Beaumont et al., 2011; Walther et al., 2002; Moritz et al., 2008). Less than 1% of studies on the ecological impacts of climate change have been conducted in the lower latitudes and it has often been assumed that impacts in these regions will be small (Deutsch et al., 2008; Sheldon et al., 2011). The lower latitudes are however characterized by extreme conditions, not just in terms of temperature but also in terms of rainfall. Some interest has been emerging in the possibility that biodiversity in these lower latitudes could actually be very vulnerable, even to quite modest temperature increases (Vinagre et al., 2016), but this remains a minority view and these emerging interests in temperature have not been matched by comparable interest in the potential impacts of changing rainfall (Intergovernmental Panel on Climate Change IPCC, 2014; Beier et al., 2012).

Although most studies so far have focused on the impacts of temperature rather than precipitation (Bachelet et al., 2016), the effects of precipitation on the ecosystems could be just as important as the effects of temperature (Hewitson et al., 2014). The changes in precipitation are more complex and heterogeneous making it harder to develop accurate long-term predictions (Flato et al., 2013). This, combined with the relative lack of research on rainfall, has led to limitations in the current understanding of how organisms and ecological systems respond as it changes (Weltzin et al., 2003). The fact that temperature is changing in ways which are more homogenous, better understood, and more accurately predicted, does not mean that it is the only component of climate change that can impact the Arabian Peninsula biodiversity resources. Rainfall is much more challenging than temperature, but that most certainly does not mean it is less important.

The deserts of the Arabian Peninsula are one of the hottest and driest regions of the world. Rainfall in some parts of the Arabian Peninsula can average about 10 centimeters per year (Sherif et al., 2014; Almazroui et al., 2012), and there is evidence particularly from Saudi Arabia and the United Arab Emirates that rainfall has decreased in recent decades (Ouarda et al., 2014; Merabtene et al., 2016). As in other regions of the world, there is of course spatial heterogeneity in rainfall across the Arabian Peninsula. The southwestern regions are wetter than other parts of the peninsula, but overall, it is extremely dry, and conditions are getting even drier (Al Sarmi & Washington, 2011).

Conditions for life may seem harsh, but this region does have a very unique biodiversity (Tourenq & Launay., 2008; Patzelt et al., 2014). Of the 476 species examined so far, 21.6% are classed as ‘endemic’, with many fish and amphibians found only in this region (Mallon, 2011). The IUCN (International Union for Conservation of Nature) has examined the conservation status of the reptile species, and while some have been graded ‘least concern’, others have been classed as ‘vulnerable' (IUCN et al., 2012).

This unique biodiversity could be impacted as climate changes and conditions become drier, and the severity of these impacts may depend on the extent to which desert species are ‘adapted’ to dry conditions. If they are ‘adapted’ in the sense that they thrive and perform best under hyper-arid conditions, then they may be able to cope well in drier conditions, and the threat posed by declining rainfall may be quite modest. However, if they are ‘adapted’ only in the sense that they have unique features which allow them to withstand extreme conditions beyond the limits of most other species, then they may be close to their own limits and even quite slight changes in rainfall could have substantial effects.

The impacts of changing temperatures have been understood within the conceptual framework of thermal performance curves, where performance increases with temperature when it is too cold, peaks at an optimum, and then decreases with temperature when it is too hot (Angilletta, 2009). Temperature influences many aspects of biological performance, including physiology, behavior, growth, survival and reproduction, so a wide range of different metrics has been used in the construction of thermal performance curves and these have allowed to understand the biological impacts of changing temperatures (Angilletta, 2009). There is no reason why the concept of thermal performance curves cannot be translated and adapted to understand the impacts of changing precipitation – if it is too dry then performance will increase with increasing rainfall, but if it is too wet then it will decrease. Organisms which are ‘adapted’ to dry conditions in the sense that they perform best under dry conditions will be at the peak of the curve where conditions are optimal. Organisms which are ‘adapted’ only in the sense that they can withstand extreme drought will be lower down on the left of their curve, in sub-optimal conditions, and performance will show a positive relationship with rainfall. Organisms living in conditions which are too wet will be on the right-hand side of their curve and performance will show a negative relationship with rainfall. The impacts in different parts of the world could be quite diverse and organisms may respond in quite different ways; not just because rainfall and the changes in rainfall differ markedly between regions (Hijioka et al., 2014) but also because the organisms themselves may be on quite different parts of their performance curves and be adapted to quite different levels of rainfall.

If it can be worked out where desert organisms are on their rainfall performance curves by establishing whether performance increases or decreases with rainfall, then it can determined to what extent they are adapted to dry conditions and to what extent they are vulnerable to decreasing rainfall trends. If it can be repeated for species from other biomes around the world, and combining the findings with information on how rainfall is changing in different regions, then the relative vulnerability of Arabian Peninsula desert biodiversity can be examined in a wider global context.

## 1.2 Statement of the Problem

The objective of this study is to examine the vulnerability of the Arabian Peninsula biodiversity to changing rainfall on the Arabian Peninsula. The aim is to establish whether desert species perform best under dry conditions or whether they are living below their optimal rainfall conditions. Then, to set this into context through comparison with species from other biomes around the globe. Some parts of the globe are getting wetter and some parts are getting drier, so to compare the vulnerability of the Arabian Peninsula biodiversity with that in other desert regions and other biomes around the world, the findings are combined with information on rainfall trends in these different regions.

**1.3 Relevant Literature**

Throughout geological time, there has been some degree of natural climate change, with phases of gradual warming together with phases of cooling and ice ages (Zalasiewicz & Williams, 2016). However, the changes that have been seen in the last 50-100 years have been unusually rapid, as levels of atmospheric greenhouse gases have spiked upwards trapping record levels of heat in the atmosphere, and it is now widely accepted that this recent rapid climate change is not a natural phenomenon (Shaftel, 2018).

Although the idea of anthropogenic climate change is not new, it has not always been the focus of so much attention, and it is only in recent decades that it has become widely accepted. There were long periods when the issue was not much discussed and few papers on it were being published, but by the 1980s, the issue was generating such extensive debate that the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) set up the Intergovernmental Panel on Climate Change (IPCC), to review the evidence and prepare authoritative synthesis reports on the current state of understanding. Thousands of scientists from around the world now contribute to the work of the IPCC and their reports are providing regular authoritative assessments of evidence collated from the hundreds of thousands of papers which have now been published on climate change (IPCC, 2001; 2007; 2014). The findings are in accord with those of established national institutions such as the US Global Climate Research Program (USGCRP), National Oceanic and Atmospheric Administration (NOAA) as well as National Aeronautics and Space Administration (NASA), (USGCRP, 2017). Broad scientific consensus has now emerged on the existence and magnitude of climate change, and on the role which human beings are playing. According to the latest IPCC report (IPCC, 2013), while some natural climate change may have occurred, human beings have played a significant role in the rapid changes that have been seen over the last century, particularly through the high anthropogenic emissions of greenhouse gases. These physical changes are of course having important and extensive impacts, whether societal (Frederick & Schwarz, 1999), economical (Dogru et al., 2019; Bretschger, 2017) or ecological (Schmitz & Barton, 2014).

In recent decades, climate change and its impacts have become topics of intense interest (Lemieux et al., 2011; Singh et al., 2011), and while the volume of research has become huge, the coverage has been uneven, with less than 1% of climate-impact studies being done in lower latitudes, and relatively little has focused on precipitation (IPCC, 2013; Wang et al., 2017; El Kenawy et al., 2019). Most climate impact studies have focused on temperature, and they have been heavily concentrated in the higher northern latitudes where the pace of temperature change is rapid (Roots, 1989; Groisman & Soja, 2007). So far it has been widely assumed the ecological impacts of climate change in lower latitudes will be small and the great majority of research effort continues to focus on higher latitudes (Wang & Zhou, 2019; Groisman & Soja, 2007). Although the number of studies in lower latitudes remains relatively small, some interest has been emerging, and it has been suggested that species in these regions might actually most at risk (Dillon et al., 2010), but even among those studies, the ideas explored so far have primarily been to do with the impacts of changing temperature rather than changing rainfall (Şekercioğlu et al., 2012, IPCC, 2013). Of the studies conducted in lower latitudes, relatively few have focused on the drier desert regions, and the ecological impacts of changing rainfall in the deserts of the Middle East have often been neglected (IPCC, 2013).

While temperatures are rising across the globe, the changes in rainfall are much more heterogeneous - some places are getting wetter while some places getting drier, and a combination of both extreme droughts and extreme floods are being experienced (Ren et al., 2013). Deserts present some of the driest conditions in the world, and while some deserts have been getting wetter, conditions have been getting drier across nearly all of the Middle East and North Africa which represents the largest desert region on Earth (Tierney et al., 2017). Rainfall has been decreasing on most of the Arabian Peninsula (Almazroui et al., 2012), though the eastern tip of Oman and the southwestern regions of Yemen and Saudi Arabia have actually seen slight increases in rainfall (USGCRP, 2017). Overall, rainfall is scarce in these deserts and may occur in small bursts during the winter months (Brown et al., 1989). Rates of evaporation far exceed rates of precipitation, so any water which does fall does not remain available on the surface for long. Conditions are harsh, and studies have been relatively few, but this region has distinctive ecological features and a unique biodiversity warranting much greater attention (Alsharhan et al., 2001; Bachelet et al., 2016).

It has often been assumed that the ecological impacts of climate change are driven primarily by temperature, and because temperatures are increasing more slowly in lower latitudes than in higher norther latitudes, it has often been assumed the ecological impacts in deserts and other low latitude regions will be relatively small. Conditions in deserts are however already harsh with not only extremely high temperatures but also extremely low rainfall, and while desert species might be adapted to these conditions and well able to cope, it is also possible that they are near their limits and small changes in climate might have serious consequences (Crawford & Gosz, 1982). Even if they can withstand the changes in temperature, desert species in the Middle East and North Africa face decreasing rainfall and it may be that this is more important. If rather than being adapted and performing best under dry conditions, desert species are actually using their unique adaptations to cling on in conditions which are too arid for most other species, then slight decreases in rainfall could have considerable impacts.

In order to work out if desert species are particularly vulnerable, one must work out if these species are living below their optimal rainfall i.e. whether they find current conditions ‘too dry’. If they are adapted to dry conditions in the sense that they find current conditions optimal, then they may be able to cope as rainfall decreases. On the other hand, if they find the current arid conditions sub-optimal and are adapted only in the sense of being able to survive in conditions where most other species cannot, then they could be vulnerable to decreasing rainfall. These concepts are similar to those of Thermal Performance Curves which have been used to understand the impacts of changing temperature (Nilsson-Örtman et al., 2013). Thermal performance curves share a basic format where performance increases with temperature when conditions are too cold and then decreases with temperature when it is too hot (Angilletta, 2006). Performance increases up to the optimum temperature and then decreases beyond that. If species find current conditions too cold, and are still living below their optimal temperature, they may actually benefit from climatic warming. Species are much more vulnerable to rising temperatures if they are living above their thermal optima where current conditions are already too hot for them (Angilletta, 2009).

The concept of Thermal Performance Curves is readily adapted and applied to rainfall, and these ideas can be used to work out whether desert species are vulnerable to falling rainfall. It can be established where desert species currently lie on their rainfall performance curves and see whether they already find it too dry or whether they are well-adapted to dry conditions. In practice, rainfall performance curves may be slightly more difficult to implement than Thermal Performance Curves because rainfall has a multitude of impacts, many of which are indirect, and many of the physiological metrics such as metabolic rate which can be used to measure the direct effects of temperature are less meaningful when constructing rainfall performance curves (Bonebrake & Mastrandrea, 2010). The analysis of rainfall performance curves is also more complicated because rainfall itself is changing not only by different amounts but also in different directions in different parts of the world. Some regions are getting wetter and some regions are getting drier. As climate changes, the change in performance depends not only on where a species lies on its curve, but also on the direction in which rainfall is changing.

The ecological impacts of changing temperature have received much more attention than the ecological impacts of changing rainfall, and although there is extensive evidence that temperature can indeed have profound effects on the performance of species (Deutsch et al., 2008; Corlett, 2011), there are also numerous indications that performance depends on rainfall too. There is evidence that rainfall influences initiation of breeding (Pelaez et al., 2017), survival rate of certain species (Dugger et al., 2004), and timing /route of migration (Urrego et al., 2016). Some studies have also found effects of rainfall on habitat structure, food supply and resource availability (Demongin et al., 2010; Ganendran et al., 2016). If rainfall can have profound effects on the performance of organisms, and if rainfall is declining in some of the largest and most arid desert regions in the world, then it does not seem reasonable to assume that impacts of climate change in these regions will be relatively small. It is possible that desert species might be resilient, but it is also possible they might in fact be highly vulnerable, and research is needed to establish the extent to which they could be affected.

So far, the primary focus of the climate impact literature has been on the higher northern latitudes and on the role of changing temperature. Temperature changes at lower latitudes are less rapid and it has often been assumed the impacts of climate change in these regions will be smaller. These lower latitudes include some of the wettest biomes on Earth, but they also contain some of the driest. With rainfall declining on the Arabian Peninsula and across the deserts of the Middle East and North Africa, there is a great need to establish the extent to which the biodiversity of this region may be vulnerable. It is not yet clear whether species in these extremely arid regions perform best under dry conditions or whether they may be near to their limits; holding on in extreme conditions which are beyond the limits which most species can sustain.

# Chapter 2: Methods

## 2.1 Research Design

In order to determine the vulnerability of desert species on the Arabian Peninsula and to compare them with other species around the world, an analysis was conducted where published information was assembled from a wide range of studies on a diversity of species in various biomes, and the relationship between performance and rainfall was examined. Published data was synthesized from studies which had analyzed various measures of performance – especially vital rates such as survival and breeding success, but also other metrics such as growth rates and phenology. Then it was noted whether studies had found positive relationships (i.e. where performance increases with rainfall, and where current conditions are therefore too dry), or negative relationships (i.e. where performance decreases with rainfall, and where current conditions are therefore too wet). In this way, working out whether species in deserts and in other biomes are living below their optimal rainfall on the left-hand side of their performance curve ('too dry') or above their optimal rainfall on the right-hand side of their performance curve ('too wet') was enabled. Thus, allowing to assess the vulnerability of desert species and compare them with other biomes. Deserts may be dry, but if desert species attain peak performance under dry conditions then they might not be vulnerable to decreasing rainfall. If on the other hand desert conditions are already too dry for desert species and they are living below their rainfall optima, then they could be vulnerable as rainfall decreases even further.

The results were then combined with published information on rainfall trends in different regions throughout the world. By comparing the extent to which species in different biomes experience sub-optimal rainfall conditions, and the extent to which rainfall trends in different regions are making these conditions better or worse, the aim was to compare the vulnerability of the Arabian Peninsula biodiversity with that of other regions.

**2.2 Data Collection**

Using bibliographic research databases, it enabled to search the scientific literature and gather the information needed to conduct the analysis. Finding every single paper which had ever studied the relationship between performance and rainfall was not attempted but rather it approached the search as a sampling process deployed to gather enough data to answer the question. By taking this approach, it enabled to create a clearly defined and replicable methodology for the data collection process. The three bibliographic databases focused on were Web of Science, ProQuest Central and Wiley Online Library. Within each of these databases, papers which appeared to be both about precipitation and about the performance of organisms was searched, and by selecting specific key words it enabled to maximize the efficiency of the search. To identify publications about precipitation, on the 'TOPIC' field it was searched for either 'rain*' OR 'precipit*'. The '*' allowed to find all words beginning with 'rain', e.g. rain, rainfall, rains, raining, rainy, etc. To focus in on papers which were not just about precipitation but also about the performance of organisms terms were added which searched on the TOPIC field for any of following words: 'surviv*', 'breed*', 'phenolog*', 'reproduc*', 'clutch*', 'litter*', or 'offspring*'. In selecting these terms, striking a workable balance between finding as many relevant papers as possible while not finding too many papers which were not relevant, and which did not contain the necessary data was sought. Each of these papers were read in more detail to determine whether they were indeed relevant and whether they contained the required data. The papers which were relevant were then collated and archived.

For each study, as well as noting the bibliographic details and whether performance increases or decreases with precipitation, information was extracted on the location, the biome, the species studied, and the metrics used to quantify performance. In order to have a consistent standardized categorization of biomes, the location of each study was matched with the biomes of the World Wide Fund for Nature 2017 Ecoregions map (Appendix A). The vast majority of studies were conducted in a single biome but there were a few studies that spanned different biomes, and these were counted as such in the analysis. In studies of rainfall, because wetlands are not representative of the wider biome within which they are found, and because they are found across many different biomes, it was decided to analyze them as a separate category. All studies conducted in a wetland were amalgamated into the single category ‘Wetland’, regardless of the biome in which they were found.

Because the question can be answered using data on the sign of the relationship between performance and rainfall, the data needed to extract from each individual study was actually quite concise. There was no need to process the original raw data nor analyze primary rainfall data. As long as studies presented analyses on the relationship between performance and rainfall, that provided sufficient data for the analysis. These published studies each had their own different objectives behind analyzing the relationship between performance and rainfall - the authors were not necessarily interested in the question being addressed here – but provided, their study had examined the relationship between performance and rainfall, that was sufficient and it then allowed to synthesize the data and answer the question.

The aim was to concentrate primarily on recent studies which had used modern up to date techniques and methods and which were published in peer reviewed, scientific journals. With this in mind, and in order to build a sample size that could answer the question with sufficient certainty, the process started with papers from the current year and continued the search backward in time until an adequate sample size was reached.

Overall, this approach yielded data from 167 studies (Appendix B) which have analyzed the relationship been performance and rainfall. With very few exceptions, each study focused on a single biome, and between them they covered 8 biome/habitat categories (Desert- 15; Savannah- 32; Montane Grassland- 5; Mediterranean- 7; Temperate Grassland- 14; Temperate Forest- 37; Tropical Forest- 48; Wetland- 11). The studies found were done across a range of taxonomic groups (Birds- 87; Mammals- 42; Plants- 20; Amphibians- 9; Reptiles- 5; Invertebrates- 4) using a range of different performance metrics (Phenology- 47; Reproductive rate- 46; Survival rate- 33; Rate of increase/abundance- 26; Growth rate- 15). Appendices C, D, and E provide supplementary information on how the data are distributed across these different taxonomic groups, biomes and performance metrics.

The individual papers all reported the statistical significance of the relationships they observed between performance and rainfall, and in analyzing the data it enabled to collate the numbers of significant and non-significant results for both positive and negative relationships between performance and rainfall. As well as this, the total numbers of positive and negative relationships (including both significant and non-significant relationships) were added up and used Chi-square analysis as an additional test. Firstly, one overall Chi-square test was conducted on the numbers of positive and negative relationships across those various biomes where numbers were sufficient. Then each biome was tested individually, and lastly, all data from all biomes were amalgamated and a single Chi-square test conducted on the total number of positive v negative relationships in all biomes combined.

Of course, the actual vulnerability of a species to changing precipitation depends not just on whether it is currently living in sub-optimal conditions but also on the direction in which precipitation is changing. A species living below its optimal rainfall on the left-hand side of its rainfall performance would suffer if conditions get drier, but it would benefit if conditions get wetter. For most of the Arabian Peninsula, it is known that precipitation is decreasing, but these trends are highly heterogeneous in different parts of the globe with some regions getting wetter and some getting drier. To set the Arabian Peninsula into context, it was important to look not just at whether species are above or below their optimum rainfall, but at whether climate change is moving them toward or away from their optima. For each biome, it was looked not just at whether species find it too dry, but at whether conditions are actually getting drier. In addition, whether there were biomes where species currently find it too wet was looked at, and at whether rainfall is increasing. In other words, the frequencies of species living in sub-optimal conditions on the ‘wrong’ side of the performance curve where they will suffer even further if the local rainfall trends continue further in the same direction was looked at.

In analyzing the frequencies of species living below or above their rainfall optima, it worked at the level of biomes, but the trends in rainfall are not of course homogeneous across the whole biome. Therefore, regions were identified within biomes where rainfall trends were comparable and examined the vulnerability of species in those regions. For example, the Arabian Peninsula itself can be considered a region, within the desert biome, and it is a region where rainfall is decreasing. Note that the studies conducted within each biome are not evenly distributed across regions. Indeed, relatively few of the studies on desert species were done on the Arabian Peninsula itself, but it was sought to draw inference and examine the vulnerability of species there by combining them with data from other desert regions, and interpreting the findings in the context of rainfall trends in this region.

Overall to summarize the objectives were addressed in 6 steps;

- Identified published studies which contained the necessary information on the sign of the relationship between performance and rainfall.
- Extracted the relevant information by processing and evaluating these papers.
- Constructed a database containing information on the sign of the relationship between performance and rainfall together with details of species, location and biome.
- Analyzed this database and quantified the number desert species which showed positive relationships and negative relationships between performance and rainfall.
- Compared these results with species from other biomes.
- Combined this with information on the direction of trends in rainfall using publicly available climate data from well-known reputable sources (NOAA, NCEI, UNEP, IPCC)

# Chapter 3: Results

In every single one of the 15 desert species studied, a positive relationship was observed between performance and rainfall, and in 10 of these studies the relationship was statistically significant (Figure 1). None of these desert species showed a negative relationship between performance and rainfall. These data suggest that desert species are currently living below their optimal rainfall, and performance improves when conditions are wetter. It would appear that desert species do not reach peak performance under dry conditions and are not adapted to dry conditions in that sense; they may be able to survive in dry conditions but they are living below their optima and performance is likely to decrease further if conditions become even drier.

The studies from other biomes also suggest that conditions are often too dry, and for many species' performance increases with rainfall (Figure 1). Most species are living below their optimal rainfall conditions, even in the wetter biomes, and species more often find it too dry than too wet. The dark red and dark blue bars on Figure 1 show the numbers of studies in each biome where the relationships between performance and rainfall are statistically significant. As well as the significance tests conducted within each individual study, also the frequencies of positive and negative relationships was examined, including those which were not significant in each study on its own. Data are not evenly spread across biomes, and for some biomes the numbers are quite sparse, but conducting a chi square test across the 6 biomes with sufficient data, there is a significant deviation of the observed from the expected frequencies ($\chi_5^2 = 25.328$, P = 0.00012). When the analysis is then broken down into individual biomes, there are significantly more species with positive than negative relationships in deserts, in savannahs, and in tropical rainforests (Figure 1). Montane grassland and Mediterranean could not be included in this analysis because the numbers of studies were too low, but when all studies from all biomes are pooled together, there are significantly more positive relationships than negative relationships ($\chi^2_1$ = 46.87, P < 0.001). The results show that many organisms are living below their optimal rainfall, and although this may be particularly acute in deserts, it is true in other biomes as well.

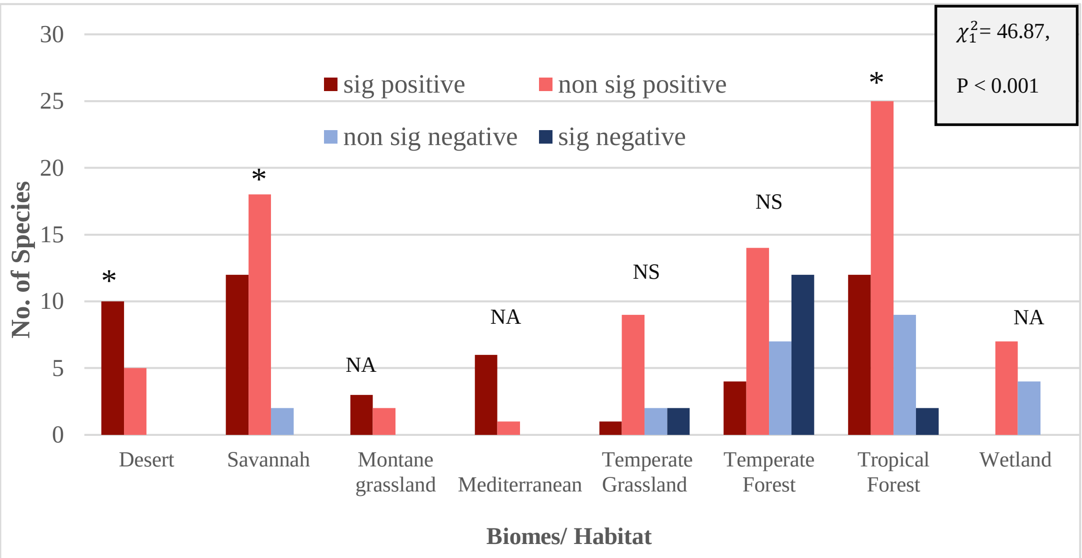



Figure 1: Relationships between performance and rainfall across biomes - Red bars show the number of studies observing positive relationships (too dry), and blue bars show the number observing negative relationships (too wet) – dark red and dark blue indicate studies where the relationships were statistically significant. Across those biomes with sufficient studies to test, there are significant differences in the frequencies of positive and negative relationships ($\chi^2_5$ = 25.328, P < 0.001). When broken down into individual biomes, deserts, savannahs and tropical forests appear too dry: asterisks indicate significantly (P < 0.01) more positive than negative relationships in a biome – 'NS' means 'not significant' (P > 0.05), and 'NA' is 'not applicable' i.e. too few studies to test frequencies in that particular biome on its own. When frequencies are pooled across all biomes, significantly more species find it too dry than too wet ($\chi^2_1$ = 46.87, P < 0.001).

The biomes shown on Figure 1 are arranged left to right from the driest to the wettest. In the drier biomes such as desert, savannah, montane grassland, and Mediterranean, the relationships between performance and rainfall are nearly always positive and many of these are significant. Species in these dry biomes do not seem adapted in the sense of performing best when it is dry; in nearly all cases, they are living below their optimal rainfall and perform better when it is wetter. In the savannah biomes, 30 of the 32 studies observed positive relationships between performance and rainfall, while only 2 studies observed negative relationships; neither of which was statistically significant. Although the numbers of studies in montane grassland and Mediterranean biomes were quite small, all of them observed positive relationships between performance and rainfall and most of these relationships were significant.

Among the wetter biomes and the wetland habitats, there were some studies that observed negative relationships between performance and rainfall, and some of these relationships were statistically significant. In these biomes (temperate grassland, temperate forest, and tropical forest) there are some species which are living above their optimal rainfall. In temperate forests, the number of species living above their rainfall optima was similar to the number living below, but apart from that, even among these wetter biomes, there were actually more species with positive than with negative relationships between performance and rainfall. These biomes may be wetter, but many species still appear to be living below their optimal rainfall there, in conditions which they find too dry. Even in tropical forests which are among the wettest regions on Earth, there were significantly more species that found conditions too dry than too wet. Rainfall in tropical forests generally exceeds two meters per year on average, but even then, most species are still living below their rainfall optima and performance is actually better when rainfall is higher.

In other words, it is not only desert species that are living below their optimum - it would seem that the majority of species in other biomes currently find it too dry as well. It would seem that water is in short supply generally, even in quite wet biomes, and with deserts being one of the driest biomes on Earth, desert species may be especially vulnerable to decreasing rainfall.

# Chapter 4: Discussion

In this study, by examining relationships between performance and rainfall, it abled to look at whether species in deserts and in other biomes are living above or below their optimum rainfall. In most cases, it was found that performance increases with rainfall, suggesting that most species across most biomes actually find conditions too dry.

It might have been assumed that desert species would be adapted to arid conditions and perform best when it is dry, but the data show that they find desert conditions too dry, and performance is actually better when rainfall is higher. Every single desert species studied here showed a positive relationship between performance and rainfall. Desert species appear be living below their rainfall optima, so performance may decrease even further if climate changes and conditions become even drier. These findings were echoed across savannah, montane grassland, and Mediterranean biomes, where almost all species were also living below their optima. These four biomes are all dry and species there are living below their optimal rainfall, so performance would decrease further if conditions were to become drier.

What is perhaps more surprising is that even among the wetter biomes like tropical rainforests, it was found that many species which are still living below their optimal rainfall. Although some species showed negative relationships between performance and rainfall, positive relationships continue to predominate and most species find conditions too dry, even in very wet biomes. If even wetlands, and tropical rainforests, and temperate grasslands are too dry, then it may be that species living in dry biomes like deserts really are especially vulnerable if rainfall declines and conditions become drier.

However, the vulnerability of a species depends not just on whether it is living below its optimal rainfall, but also on whether rainfall is actually decreasing. Unlike temperatures which are rising throughout the globe, rainfall changes are heterogeneous with some regions getting drier and some regions getting wetter. These trends can be seen in Figures 2-3, and it is clear that heterogeneity exists not just between large-scale ecoregions but even within biomes and sometimes on quite fine-grained spatial scales. It cannot be said that any particular biome is getting wetter or drier, because some regions with that biome may be getting wetter and some regions may be getting drier. Figure 2 shows how average annual rainfall in the period 1986-2015 compares with average annual rainfall in the period 1901-1960 (Wuebbles et al., 2017). Figure 3 shows the overall change in precipitation between 1900 and 1994 (Rekacewicz & UNEP/GRID-Arendal, 2005).

These maps highlight the declining rainfall which has taken place across most of the Arabian Peninsula and the Sahara Desert. This is one of the largest patches of desert in the World and rainfall here has been decreasing. This same band of desert then extends beyond the Middle East through Central Asia and into China, but the rainfall trends have been less consistent through these regions, with parts of the desert getting wetter and some parts getting drier. Australia also has a large patch of desert, and conditions there have mostly been getting wetter. Rainfall trends in the deserts of Southern Africa and North America have been more heterogeneous. The remaining desert regions are smaller, and the rainfall trends are less clear.

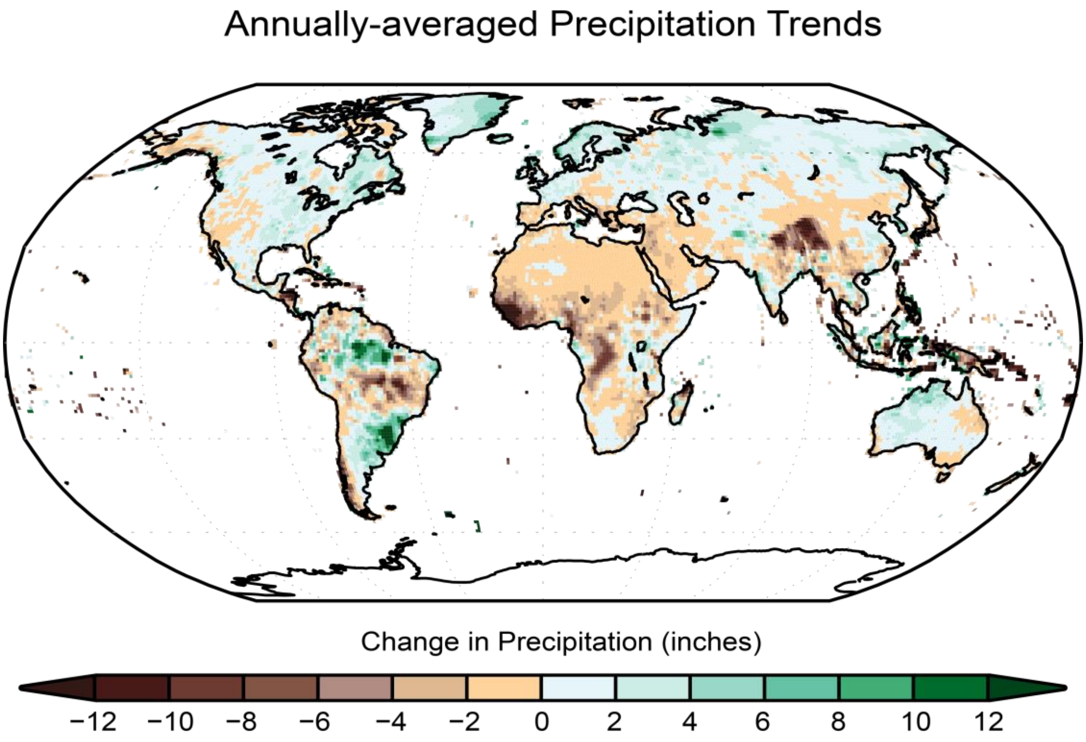



Figure 2: Change in average annual precipitation between the period 1901-1960 and the period 1986–2015 (Figure source: Wuebbles et al., 2017)

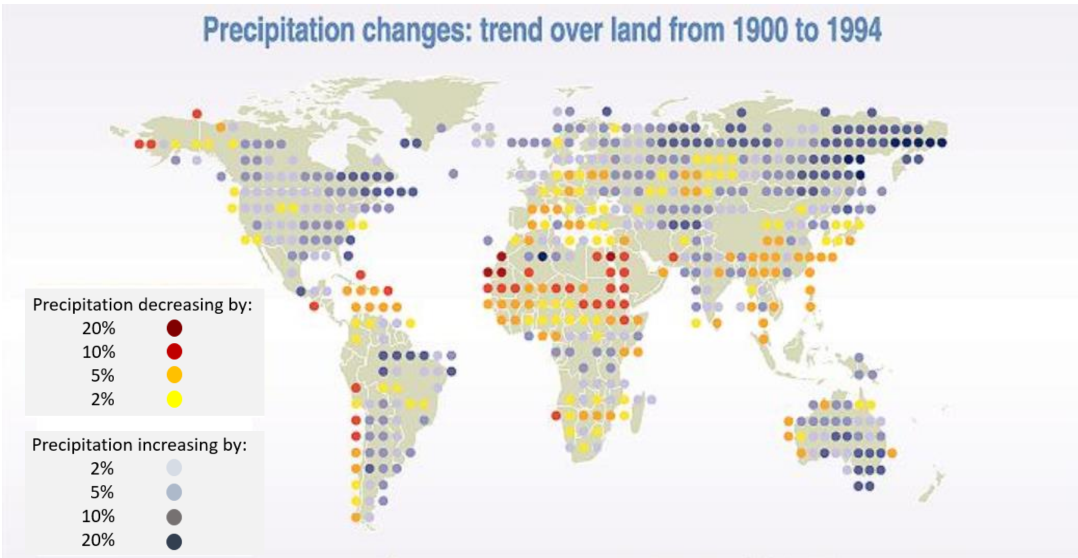



Figure 3: Observed changes in precipitation between 1900 and 1994 (Figure Source: Rekacewicz & UNEP/GRID-Arendal, 2005)

Similarly, rainfall trends in the savannah biome are complex and heterogeneous. The maps show that the savannah regions of South America are mostly getting drier. The largest expanses of savannah are however found in Africa and the rainfall trends there are far from consistent. There is a patch of savannah in North Africa, above the Equator, and like in South America, rainfall there is decreasing. However, the savannahs further south in Africa show more heterogeneity, with some patches in East Africa getting wetter and some patches in West Africa getting drier. In some cases, there are patches of several different biomes in close proximity, and the heterogeneity of biomes is sometimes matched by heterogeneity in rainfall trends, as well as heterogeneity in rainfall itself. Like in the desert species, the results suggest that most savannah species are living below their optimal rainfall. Savannahs have rainy seasons and may not be quite as arid as deserts. The species there may be slightly less vulnerable than those in deserts, but performance is likely to decline in those parts of South America, North Africa, and West Africa where rainfall is decreasing.

The montane grassland biome is a biome found in almost all continents but mostly occurs in small patches. The largest patch is in China, and this is also where all the studies collated here were conducted. The number of studies done in montane grassland was small, but all species were living below their optimal rainfall. With the exception of Australia's montane grasslands, where rainfall has been increasing, montane grasslands in other parts of the World have been getting drier, and there have been quite marked decreases in rainfall in the montane grasslands of China. It would be good to increase the number of studies and examine montane grasslands in more detail but based on the results so far it would seem that species in most montane grasslands might be vulnerable, especially in China.

Mediterranean biomes are found on almost every continent, with the largest patch concentrated around the Mediterranean Sea. Rainfall throughout all of these regions has been decreasing. Like for montane grasslands, it would be good to have more studies on the relationships between performance and rainfall, but the studies synthesized here all suggest that species in this biome are living below their optimal rainfall. Mediterranean biomes are not as dry as deserts, but the species here still seem to find conditions too dry, and with rainfall decreasing throughout, it would seem that species in this biome might be vulnerable.

The desert, savannah, montane grassland, and Mediterranean biomes are all dry, and large expanses of these biomes are experiencing declines in rainfall. The species here are not adapted to dry conditions – they may be able to survive, but they are living below their optimal rainfall, and in those regions where rainfall is indeed decreasing, performance can be expected to decline, and species may be vulnerable.

While rainfall is often decreasing in these drier biomes, there are quite large areas of the wetter biomes where rainfall has been increasing, though here too the patterns are heterogeneous and there are patches where rainfall has also been decreasing. Much of the temperate grassland and temperate forest biomes have been experiencing increases in rainfall. The increases are not universal or uniform, and there are some expanses of both temperate grassland and temperate forest where conditions are getting drier. Around fringes and boundaries, where climate gradients create transitions from one biome to another, there are notable cases where the trends in rainfall deviate from those seen in other parts of that biome. The data that was synthesized here suggest that species in temperate grassland are mostly living below their optimal rainfall, so if this biome is mostly getting wetter the impacts might be positive and species here may be less vulnerable than those in the drier biomes. The findings suggest that species in temperate forests are sometimes living below their optimal rainfall and sometimes living above it. Those species living below their optimum may benefit from wetter conditions, but those living above their optimum might actually suffer. Species in these biomes would appear to be less vulnerable than those in the drier biomes, but there are species in temperate forests where the changes in rainfall could have negative effects.

The tropical rainforests of South America have mostly been getting wetter, while the tropical rainforests of West Africa have mostly been getting drier. Rainfall trends in the tropical rainforests of Southern Asia have been very heterogeneous, and even over quite small spatial scales there have been marked differences with some patches getting wetter and some patches getting drier. Given just how wet the tropical rainforests can be, it is remarkable that so many species there seem to be living below their optimal rainfall. Those species would not appear to be vulnerable in those regions where rainfall is increasing, but they may experience negative impacts in those regions where it is decreasing. It was also found that some species are living above their optimal rainfall, and for them the situation is the other way around – their performance may increase in regions where it is getting drier, and performance may decrease in regions where it is getting wetter. Overall, tropical rainforests appear less vulnerable then the drier biomes, given the heterogeneity both between species and between regions.

Table 1 brings together all the information that have been synthesized on rainfall trends and on relationships between performance and rainfall. Comparing all the information assembled here, it is suggested that species in the deserts of the MENA region may be particularly vulnerable. Desert species are not adapted to dry conditions – they are living below their optimal rainfall. Indeed, beyond deserts, the studies from across a diversity of biomes suggest that conditions on the planet are commonly too dry and only occasionally too wet. With deserts being the driest biome of all, and with rainfall decreasing across the deserts of North Africa and the Middle East, here it is suggested to focus attention on the risks to biodiversity in this region. More research on dry biomes generally would be valuable, and there is a need for more studies from montane grassland and Mediterranean regions.

Table 1: Vulnerability of species to changing rainfall in different biomes and regions

| Biome | Below or above rainfall optimum | Region | Rainfall trend |
|---|---|---|---|
| Desert | Below<br><br>(15 below: 0 above)<br><br>$\chi_1^2 = 15$,<br>$p = 0.00010$ | Sahara Desert | Drier |
| | | Arabian Peninsula | Drier |
| | | North America | Heterogeneous |
| | | Asia | Heterogeneous |
| | | Southern Africa | Heterogeneous |
| | | Australia | Wetter |

Table 1: Vulnerability of species to changing rainfall in different biomes and regions (cont'd)

| Biome | Below or above rainfall optimum | Region | Rainfall trend |
|---|---|---|---|
| Savanah | Below<br><br>(30 below: 2 above)<br><br>$\chi_1^2 = 24.5$,<br>$p = 0.00000074$ | Australia | Heterogeneous |
| | | Tanzania | Wetter |
| | | Mozambique | Wetter |
| | | Kenya- west | Wetter |
| | | Remaining regions | Drier |
| Montane Grassland | Below<br><br>(5 below: 0 above) | China | Drier |
| Mediterranean | Below<br><br>(7 below: 0 above) | All regions | Drier |
| Temperate Grassland | Mostly Below<br><br>(10 below: 4 above)<br><br>$\chi_1^2 = 2.571$,<br><br>$\mathrm{p} = 0.1088$ | All regions | Wetter |

Table 1: Vulnerability of species to changing rainfall in different biomes and regions (cont'd)

| Biome | Below or above rainfall optimum | Region | Rainfall trend |
|---|---|---|---|
| Temperate Forest | Some above and some below<br>(18 below: 19 above)<br>$\chi_1^2 = 0.0027027$,<br>$p = 0.8694$ | All regions | Wetter |
| Tropical Forest | Mostly below<br>(37 below: 11 above)<br>$\chi_1^2 = 14.0833$,<br>$p = 0.00017$ | South America | Wetter |
| | | West Africa | Drier |
| | | South Asia | Heterogeneous |
| Wetlands | Mostly below<br>(7 below: 4 above) | - | Not applicable |

Note: For each biome, the frequencies of studies observing species below v above their optimum rainfall is shown (N below: N above). For those biomes where numbers are sufficient to conduct an individual chi-square test, these are presented. Historical rainfall trends for each region within these biomes are also shown – the most vulnerable regions are those where species are living below their optimum rainfall and where the climate is getting drier. Studies conducted in wetlands were treated separately and combined across biomes.

Figures 2-3, and their rainfall trends as summarized in Table 1, tell about how rainfall has changed in the past, but the vulnerability of species in deserts and other biomes will of course depend on how rainfall changes in the future. Rainfall trends are much more heterogeneous and much more difficult to predict than trends in temperature, so what can be said is inevitably more limited. The predictions set out in the 2013 IPCC report (Figure 4) show some consistency between models and scenarios, and they also show some consistency with the historical changes shown in Figure 2 and 3, but there are also some inconsistencies. Figure 4 shows predictions for two Representative Concentration Pathways, RCP 2.6 (on the left) at the lower end of expectations for future greenhouse gas concentrations, and RCP 8.5 (on the right) at the upper end. The predictions shown on these two maps are averaged across 32 and 39 different climate models respectively. As might be expected, the changes predicted under RCP 8.5 are more intense than those predicted under RCP 2.6, but the qualitative predictions show some similarity in terms of which regions get wetter and which regions get drier. Like the historical trends, much of the Middle East and North Africa will get drier, but the southern parts of this whole region might actually get wetter. The deserts of Central Asia and China are mostly predicted to get wetter, and while the deserts of Australia have historically been getting wetter, the predictions are not suggesting this trend will continue, indeed these deserts may also become drier, as will the deserts of Southern Africa. Compared to historical trends, the future predictions for savannahs show some qualitative consistency, with South America getting drier while the changes in Africa are more heterogeneous and less clear. Historically, the montane grasslands of China have been getting much drier, but predictions suggest the future may actually be wetter. Like the historical trends, the Mediterranean biome around the Mediterranean Sea is predicted to get drier, and the temperate grasslands and forests of northern Asia and North America will mostly continue to get wetter. In sharp contrast to the historical trends, tropical rainforests in the Amazon are predicted to get drier, while the changes predicted in the tropical forests of Africa are more heterogeneous than the historical trends.

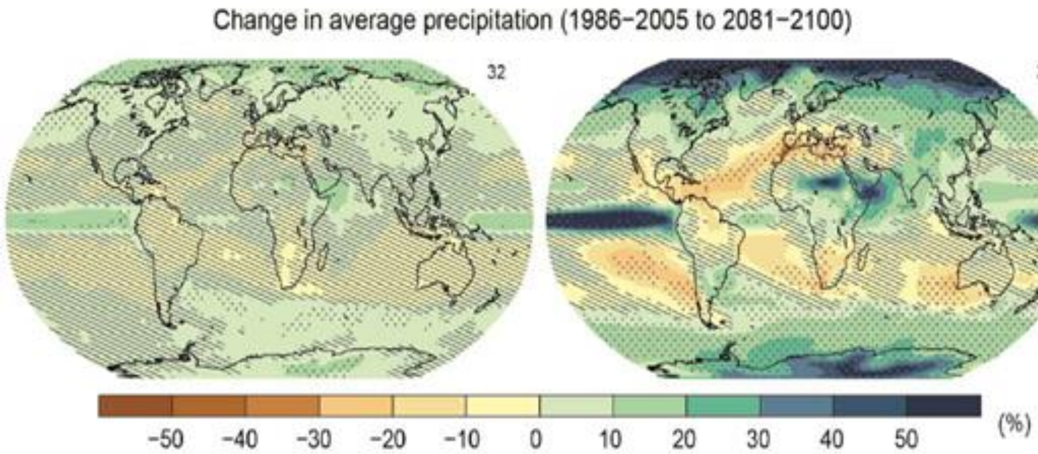



Figure 4: Projected precipitation change (IPCC, 2013) - Left: RCP 2.6. Right: RCP 8.5

In many cases, the predictions suggest the historical trends in rainfall may continue into the future, but there are several regions where they might not, and in some cases they may be reversed. Based on historical trends in rainfall, it have been suggested that species in the deserts of North Africa and the Middle East may be especially vulnerable. Based on the future predictions, this may remain true for much of this region, particularly in the North, but rainfall is expected to increase in some of the more southerly parts of this region and species there may be less vulnerable. In the future, species in the deserts of Australia and Southern Africa may experience drier conditions, and it may then be in these desert regions that species become especially vulnerable. Overall, the future predictions do not contradict the broader suggestion that species in dry biomes are more likely to be vulnerable than those in wetter biomes, but some of the details are different because the regions predicted to experience declining rainfall in the future are not always the same as those which have experienced it in the past. Some dry regions like the Mediterranean Sea will continue to experience declining rainfall, so species there will continue to be vulnerable, but the montane grasslands of China for example are predicted to get wetter so species in this region may become less vulnerable.

Although this project has drawn together data from across the globe, the focus has been on the Arabian Peninsula and particularly on the United Arab Emirates. As climate changes and rainfall in this region declines, assessing the vulnerability of the Arabian Peninsula biodiversity as compared with other parts of the World was sought. In practice, given the lack of primary research in this region, drawing inference by assembling data from other desert regions was pursued. As well as the formal literature searching/sampling process in which most published studies came from outside the Arabian Peninsula, and none came specifically from the United Arab Emirates, also extensive literature searching was conducted targeted at uncovering other relevant studies conducted explicitly in this region, and have managed to find two additional studies covering a number of species. These have not been included in the wider data set because they were not sampled using the standardized literature searching protocol, but it will be discussed here in the context of the conclusions drawn by inference from the wider data set. They are consistent with the finding that desert species show positive relationships between performance and rainfall. Sarli et al. (2016) found that rainfall triggers reproduction in the Arabian Spiny mouse (*A. dimidiatus)*. Sakkir et al. (2015) found that the growth and flowering of desert plants in the UAE is positively correlated with rainfall. More primary research is needed in this region, but these studies are in line with the conclusion drawn from the wider results of this study. Desert species are not adapted to dry conditions – they are living below their optimal rainfall and they are likely to suffer reduced performance if conditions become drier. This is what have been found from desert studies throughout the World, and the information that have been managed to be assembled more specifically from the Arabian Peninsula is so far consistent with these findings.

So what are the implications for the United Arab Emirates? Although climate change is a global phenomenon, it is not evenly distributed across the globe. So far, more attention has been focused on temperature than on rainfall, and the most rapid temperature changes have been happening in the higher northern latitudes rather than in lower latitude regions like the United Arab Emirates. That, coupled with the concentration of universities and institutes in temperate Europe and North America, has led to a disproportionate focus of climate-impact research in these higher latitudes. By some estimates, over 99% of studies have been conducted in cooler regions, with less than 1% in hot/tropical regions (Roots, 1989; Saraux et al., 2011). The rapid proliferation of research-intensive universities is a relatively recent phenomenon on the Arabian Peninsula, and this may partly explain the scarcity of studies found here, but given the global preoccupation with rapid temperature changes in higher northern latitudes, it has often simply been assumed that the ecological impacts of climate change in this region will be relatively small. The findings suggest that far from being minor, the impacts could be substantial, and the Arabian Peninsula, together with North Africa, could actually be one of the most vulnerable regions in the World. While many studies have focused on temperature, the findings suggest that the changing rainfall could be a key issue in this region. Desert species are not adapted to dry conditions – they are already living far below their optimal rainfall, and as rainfall declines further in a region which is already water-stressed (Almazroui et al., 2012), the ecological impacts could be substantial.

What are the limitations of this study? Although the results of this study provide a broad conclusion which is clear, there are limitations in terms of some specific details. In particular, although workable sample sizes for deserts and also for savannahs were able to be assembled, the amount of data that was found on dry biomes generally was substantially less than the amount of data available from wetter biomes such as temperate or tropical forest, and there were very few studies which were conducted specifically on the Arabian Peninsula; the region upon which the primary interest was focused. In this project, montane grassland and Mediterranean biomes were not the focus of interest – they were studied to provide context – but the number of studies that was collated from these biomes was relatively small. And throughout the many different biomes, the studies assembled were concentrated disproportionately on certain specific taxonomic groups so the inference cannot necessarily be extended to the full spectrum of species. In particular, many of the studies focused on birds and mammals, and relatively few studies focused on plants or invertebrates.

Future directions? This project has underlined the need for much more research on the impacts of climate change in the United Arab Emirates and the wider region. It cannot simply be assumed that the ecological impacts of climate change here will be small. The pace of temperature change may be lower, but the earth is already facing extremes of both heat and drought, and as rainfall declines, the impacts of climate change in this region could be substantial. More generally, this project highlights the need for more research in lower latitude regions, in dry biomes, and on the ecological impacts of changing rainfall. Globally, research so far has focused disproportionately on the impacts of temperature in higher latitudes and in wetter biomes. Furthermore, it is recommended to broaden the taxonomic focus and studying those groups which have so far received relatively little attention.

# Chapter 5: Conclusion

As climate changes, and as conditions on the Arabian Peninsula become drier, it has been sought to understand the relative vulnerability of the Arabian Peninsula desert biodiversity. It has been looked at whether desert species are adapted to arid conditions or whether they are living below their optimal rainfall. By compiling data from published studies, it was found that without exception, desert species show positive relationships between performance and rainfall, that they do not perform best under dry conditions, that they appear to be living below their optimal rainfall, and that they will therefore suffer if conditions become even drier. To set these findings in context, the results were compared with studies conducted in other biomes. Throughout the drier biomes – deserts, savannahs, montane grasslands, and the Mediterranean biome – almost all studies observed positive relationships between performance and rainfall suggesting that species in these dry biomes are quite consistently living below their optimal rainfall and will experience negative impacts on performance if rainfall declines further. Even in the wetter biomes and in wetlands, many species which are living below their optimal rainfall were found. Across the spectrum, the challenges of conditions being too dry are much more prevalent than the occasional challenges of conditions being too wet. These findings were combined with historical data on rainfall trends in different regions throughout the World. The risks to species in wet biomes are much smaller than the risks to species living in dry biomes. Many species in dry biomes have been experiencing, or are predicted to experience, declines in rainfall and can be expected to suffer declining performance as a result. The deserts of the Middle East and North Africa form the largest expanse of desert in the World. Conditions throughout this MENA region here have been getting drier, and this trend is predicted to continue, at least in the northern part. Species from dry biomes in those regions where rainfall is decreasing are likely to be most vulnerable. With deserts being the driest of them all, and with rainfall declining on the Arabian Peninsula and throughout much of the MENA region, it is suggested that biodiversity in this part of the World is especially vulnerable.

## References

Almazroui, M., Islam, M. N., Athar, H., Jones, P. D., & Rahman, M. A. (2012). Recent climate change in the Arabian Peninsula: annual rainfall and temperature analysis of Saudi Arabia for 1978–2009. *International Journal of Climatology*, *32*(6), 953–966. https://doi.org/10.1002/joc.3446

AlSarmi, S., & Washington, R. (2011). Recent observed climate change over the Arabian Peninsula. *Journal of Geophysical Research: Atmospheres*, *116*(D11), 89–100. https://doi.org/10.1029/2010JD015459

Alsharhan, A. S., Rizk, Z. A., Nairn, A. E. M., Bakhit, D. W., & Alhajari, S. A. (2001). *Hydrogeology of an Arid Region: The Arabian Gulf and Adjoining Areas* (pp. 1-53). Amsterdam: Elsevier.

Angilletta, M. (2009). *Thermal Adaptation: A Theoretical and Empirical Synthesis* (pp. 1-18). England: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198570875.001.1

Angilletta, M. J. (2006). Estimating and comparing thermal performance curves. *Journal of Thermal Biology*, *31*(7), 541–545. https://doi.org/10.1016/j.jtherbio.2006.06.002

Bachelet, D., Ferschweiler, K., Sheehan, T., & Strittholt, J. (2016). Climate change effects on southern California deserts. *Journal of Arid Environments*, *127*(Apr 2016), 17–29. https://doi.org/10.1016/j.jaridenv.2015.10.003

Beaumont, L. J., Pitman, A., Perkins, S., Zimmermann, N. E., Yoccoz, N. G., & Thuiller, W. (2011). Impacts of climate change on the world's most exceptional ecoregions. *Proceedings of the National Academy of Sciences*, *108*(6), 2306–2311. https://doi.org/10.1073/pnas.1007217108

Beier, C., Beierkuhnlein, C., Wohlgemuth, T., Penuelas, J., Emmett, B., Körner, C., Boeck, H. de, Christensen, J. H., Leuzinger, S., Janssens, I. A., & Hansen, K. (2012). Precipitation manipulation experiments – challenges and recommendations for the future. *Ecology Letters*, *15*(8), 899–911. https://doi.org/10.1111/j.1461-0248.2012.01793.x

Bonebrake, T. C., & Mastrandrea, M. D. (2010). Tolerance adaptation and precipitation changes complicate latitudinal patterns of climate change impacts. *Proceedings of the National Academy of Sciences*, *107*(28), 12581–12586. https://doi.org/10.1073/pnas.0911841107

Bretschger, L. (2017). Climate policy and economic growth. *Resource and Energy Economics*, *49* (Aug 2017), 1–15. https://doi.org/10.1016/j.reseneeco.2017.03.002

Brown, G. F., Schmidt, D. L., & Huffman Jr., A. C. (1989). *Geology of the Arabian Peninsula; shield area of western Saudi Arabia.* (Report No. 560-A) U.S. Geological Survey http://pubs.er.usgs.gov/publication/pp560A

Corlett, R. T. (2011). Impacts of warming on tropical lowland rainforests. *Trends in Ecology & Evolution*, *26*(11), 606–613. https://doi.org/10.1016/j.tree.2011.06.015

Crawford, C. S., & Gosz, J. R. (1982). Desert ecosystems: their resources in space and time. *Environmental Conservation*, *9*(3), 181–195. https://doi.org/10.1017/S0376892900020397

Demongin, L., Poisbleau, M., Strange, I. J., & Quillfeldt, P. (2010). Effects of severe rains on the mortality of southern Rockhopper Penguin (Eudyptes chrysocome) chicks and its impact on breeding success. *Ornitologia Neotropical*, *21*(3), 439–443.

Deutsch, C. A., Tewksbury, J. J., Huey, R. B., Sheldon, K. S., Ghalambor, C. K., Haak, D. C., & Martin, P. R. (2008). Impacts of climate warming on terrestrial ectotherms across latitude. *Proceedings of the National Academy of Sciences*, *105*(18), 6668–6672. https://doi.org/10.1073/pnas.0709472105

Dillon, M. E., Wang, G., & Huey, R. B. (2010). Global metabolic impacts of recent climate warming. *Nature*, *467*(7316), 704–706. https://doi.org/10.1038/nature09407

Dinerstein, E., Olson, D., Joshi, A., Vynne, C., Burgess, N. D., Wikramanayake, E., Hahn, N., Palminteri, S., Hedao, P., Noss, R., Hansen, M., Locke, H., Ellis, E. C., Jones, B., Barber, C. V., Hayes, R., Kormos, C., Martin, V., Crist, E., … Saleem, M. (2017). An ecoregion-based approach to protecting half the terrestrial realm. *BioScience*, *67*(6), 534–545. https://doi.org/10.1093/biosci/bix014

Dogru, T., Marchio, E. A., Bulut, U., & Suess, C. (2019). Climate change: Vulnerability and resilience of tourism and the entire economy. *Tourism Management*, *72*(Jun 2019), 292–305. https://doi.org/10.1016/j.tourman.2018.12.010

Dugger, K. M., Faaborg, J., Arendt, W. J., & Hobson, K. A. (2004). Understanding survival and abundance of overwintering warblers: does rainfall matter? *The Condor; Waco*, *106*(4), 744–760.

El Kenawy, A. M., Lopez-Moreno, J. I., McCabe, M. F., Robaa, S. M., Domínguez-Castro, F., Peña-Gallardo, M., Trigo, R. M., Hereher, M. E., Al-Awadhi, T., & Vicente-Serrano, S. M. (2019). Daily temperature extremes over Egypt: Spatial patterns, temporal trends, and driving forces. *Atmospheric Research, 226*(Sept 2019), 219–239. https://doi.org/10.1016/j.atmosres.2019.04.030

Flato, G., Marotzke, J., Abiodun, B., Braconnot, P., Chou, S.C., Collins, W., Cox, P., Driouech, F., Emori, S., Eyring, V., Forest, C., Gleckler, P., Guilyardi, E., Jakob, C., Kattsov, V., Reason, C. and Rummukainen, M. (2013). Evaluation of climate models. In: Climate change 2013: The physical science basis. *Contribution of working group I to the fifth assessment report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)], pp. 741-866 Retrieved from Intergovernmental Panel on Climate Change (IPCC) website: http://www.climatechange2013.org/images/report/WG1AR5_Chapter09_FINAL.pdf

Frederick, K. D., & Schwarz, G. E. (1999). Socioeconomic impacts of climate change on U.S. water supplies. *Journal of the American Water Resources Association*, *35*(6), 1563–1583. https://doi.org/10.1111/j.1752-1688.1999.tb04238.x

Ganendran, L. B., Sidhu, L. A., Catchpole, E. A., Chambers, L. E., & Dann, P. (2016). Effects of ambient air temperature, humidity and rainfall on annual survival of adult little penguins Eudyptula minor in southeastern Australia. *International Journal of Biometeorology; Heidelberg*, *60*(8), 1237–1245. https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1007/s00484-015-1119-2

Groisman, P., & Soja, A. (2007). Northern hemisphere high latitude climate and environmental change. *Environmental Research Letters*, *2*(4), 4468–4486. https://doi.org/10.1088/1748-9326/2/4/045008

Hewitson, B., Janetos, A. C., Carter, T.R., Giorgi, F., Jones, R.G., Kwon, W.-T., Mearns, L.O., Schipper, E.L.F., & van Aalst, M. (2014). Climate change 2014: Impacts, adaptation, and vulnerability. Part B: Regional aspects. *Contribution of working group II to the fifth assessment report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)], pp. 1153-1155. Retrieved from Intergovernmental Panel on Climate Change (IPCC) website:

https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-PartB_FINAL.pdf

Hijioka, Y., Lin, E., Pereira, J.J., Corlett, R.T., Cui, X., Insarov, G.E., Lasco, R.D., Lindgren, E. and Surjan, A. (2014). Climate change 2014: Impacts, adaptation, and vulnerability. Part B: Regional aspects. Asia. *Contribution of working group II to the fifth assessment report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)], pp. 1327-1370. Retrieved from Intergovernmental Panel on Climate Change (IPCC) website: https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap24_FINAL.pdf

Intergovernmental Panel on Climate Change. (2001). Climate change 2001: Impacts, adaptation, and vulnerability. *Contribution of working group II to the third assessment report of the Intergovernmental Panel on Climate Change* [ McCarthy, J.J., O. F. Canziani, N. A. Leary, D. J. Dokken, K. S. White (eds.)], pp.75-967. Cambridge: Cambridge University Press. Retrieved from Intergovernmental Panel on Climate Change (IPCC) website: https://www.ipcc.ch/site/assets/uploads/2018/03/WGII_TAR_full_report-2.pdf

Intergovernmental Panel on Climate Change. (2007). Climate change 2007: The physical science basis. *Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)], pp. 93-940. Cambridge: Cambridge University Press. Retrieved from Intergovernmental Panel on Climate Change (IPCC) website: https://www.ipcc.ch/site/assets/uploads/2018/05/ar4_wg1_full_report-1.pdf

Intergovernmental Panel on Climate Change. (2013). Climate change 2013: The physical science basis. *Contribution of working group I to the fifth assessment report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)], pp. 119-1310. Cambridge: Cambridge University Press. Retrieved from Intergovernmental Panel on Climate Change (IPCC) website: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_all_final.pdf

Intergovernmental Panel on Climate Change. (2014). Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects.

*Contribution of working group II to the fifth assessment report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)], pp. 169-1132. Cambridge: Cambridge University Press. Retrieved from Intergovernmental Panel on Climate Change (IPCC) website: https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-PartA_FINAL.pdf

International Union for Conservation of Nature (IUCN). (2012). The conservation status and distribution of reptiles of the Arabian Peninsula. [Cox, N.A., Mallon, D., Bowles, P., Els, J. and Tognelli, M.F. (compilers)], pp. 9-18. Cambridge, UK and Gland, Switzerland: IUCN, and Sharjah, UAE: Environment and Protected Areas Authority. Retrieved from International Union for Conservation of Nature (IUCN) website: https://portals.iucn.org/library/sites/library/files/documents/RL-53-002.pdf

Lemieux, C. J., Beechey, T. J., Scott, D. J., & Gray, P. A. (2011). The state of climate change adaptation in Canada’s protected areas sector. *The Canadian Geographer / Le Géographe canadien*, *55*(3), 301–317. https://doi.org/10.1111/j.1541-0064.2010.00336.x

Mallon, D.P. (2011). Global hotspots in the Arabian Peninsula. *Zoology in the Middle East*, *54*(Sup3), 13-20. https://doi: 10.1080/09397140.2011.10648896

Merabtene, T., Siddique, M., & Shanableh, A. (2016). Assessment of seasonal and annual rainfall trends and variability in Sharjah city, UAE. *Advances in Meteorology, 2016*(6206238), 1-13. https://doi.org/https://doi.org/10.1155/2016/6206238

Moritz, C., Patton, J. L., Conroy, C. J., Parra, J. L., White, G. C., & Beissinger, S. R. (2008). Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA. *Science*, *322*(5899), 261–264. https://doi.org/10.1126/science.1163428

Nilsson-Örtman, V., Stoks, R., Block, M. D., & Johansson, F. (2013). Latitudinal patterns of phenology and age-specific thermal performance across six Coenagrion damselfly species. *Ecological Monographs*, *83*(4), 491–510. https://doi.org/10.1890/12-1383.1

Ouarda, T. B. M. J., Charron, C., Niranjan Kumar, K., Marpu, P. R., Ghedira, H., Molini, A., & Khayal, I. (2014). Evolution of the rainfall regime in the United Arab Emirates. *Journal of Hydrology*, *514*(Jun 2014), 258–270. https://doi.org/10.1016/j.jhydrol.2014.04.032

Patzelt, A., Harrison, T., Knees, S. G., & Al Harthy, L. (2014). Studies in the flora of Arabia: Xxxi. New records from the Sultanate of Oman. *Edinburgh Journal of Botany; Cambridge*, *71*(2), 161–180. https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1017/S0960428614000067

Pelaez, M., San Miguel, A., Rodriguez-Vigal, C., & Perea, R. (2017). Climate, female traits and population features as drivers of breeding timing in Mediterranean red deer populations. *Integrative Zoology*, *12*(5), 396–408. https://doi.org/10.1111/1749-4877.12252

Rekacewicz, P., UNEP/GRID-Arendal. (2005). Precipitation changes: Trend over land from 1900 to 1994. *UNEP/GRID-Arendal: Vital Climate Graphics*, 2005.

Ren, L., Arkin, P., Smith, T. M., & Shen, S. S. P. (2013). Global precipitation trends in 1900–2005 from a reconstruction and coupled model simulations. *Journal of Geophysical Research: Atmospheres*, *118*(4), 1679–1689. https://doi.org/10.1002/jgrd.50212

Roots, E. F. (1989). Climate change: High-latitude regions. *Climatic Change*, *15*(1), 223–253. https://doi.org/10.1007/BF00138853

Sakkir, S., Shah, J. N., Cheruth, A. J., & Kabshawi, M. (2015). Phenology of desert plants from an arid gravel plain in eastern United Arab Emirates. *Journal of Arid Land*, *7*(1), 54–62. https://doi.org/10.1007/s40333-014-0036-2

Saraux, C., Le Bohec, C., Durant, J. M., Viblanc, V. A., Gauthier-Clerc, M., Beaune, D., Park, Y.-H., Yoccoz, N. G., Stenseth, N. C., & Le Maho, Y. (2011). Reliability of flipper-banded penguins as indicators of climate change. *Nature*, *469*(7329), 203–206. https://doi.org/10.1038/nature09630

Sarli, J., Lutermann, H., Alagaili, A. N., Mohammed, O. B., & Bennett, N. C. (2016). Seasonal reproduction in the Arabian spiny mouse, Acomys dimidiatus (Rodentia: Muridae) from Saudi Arabia: The role of rainfall and temperature. *Journal of Arid Environments*, *124*(Jan 2016), 352–359. https://doi.org/10.1016/j.jaridenv.2015.09.008

Schmitz, O. J., & Barton, B. T. (2014). Climate change effects on behavioral and physiological ecology of predator–prey interactions: Implications for conservation biological control. *Biological Control*, *75*(Aug 2015), 87–96. https://doi.org/10.1016/j.biocontrol.2013.10.001

Scocco, P., Piermarteri, K., Malfatti, A., Tardella, F. M., & Catorci, A. (2016). Increase of drought stress negatively affects the sustainability of extensive sheep farming in sub-Mediterranean climate. *Journal of Arid Environments*, *128*(May 2016), 50–58. https://doi.org/10.1016/j.jaridenv.2016.01.006

Şekercioğlu, Ç. H., Primack, R. B., & Wormworth, J. (2012). The effects of climate change on tropical birds. *Biological Conservation*, *148*(1), 1–18. https://doi.org/10.1016/j.biocon.2011.10.019

Shaftel, H. (2018). Overview: Weather, global warming and climate change. Retrieved on Jun 30, 2020 from *NASA Global Climate Change*, https://climate.nasa.gov/resources/global-warming-vs-climate-change/

Sheldon, K. S., Yang, S., & Tewksbury, J. J. (2011). Climate change and community disassembly: Impacts of warming on tropical and temperate montane community structure. *Ecology Letters*, *14*(12), 1191–1200. https://doi.org/10.1111/j.1461-0248.2011.01689.x

Sherif, M., Almulla, M., Shetty, A., & Chowdhury, R. K. (2014). Analysis of rainfall, PMP and drought in the United Arab Emirates. *International Journal of Climatology*, *34*(4), 1318–1328. https://doi.org/10.1002/joc.3768

Singh, N. P., Bantilan, M. C. S., Kumar, A. A., Janila, P., & Hassan, A. W. R. (2011). Climate Change Impact in Agriculture: Vulnerability and Adaptation Concerns of Semiarid Tropics in Asia. In Yadav, S. S., Redden, R. J., Hatfield, J. L., Lotze-Campen, H., Hall, A. E. (Eds.), *Crop Adaptation to Climate Change* (pp. 107–130). United States of America: John Wiley & Sons, Ltd. https://doi.org/10.1002/9780470960929.ch9

Tierney, J. E., Pausata, F. S. R., & deMenocal, P. B. (2017). Rainfall regimes of the green Sahara. *Science Advances*, *3*(1), 1-9. https://doi.org/10.1126/sciadv.1601503

Tourenq, C., & Launay, F. (2008). Challenges facing biodiversity in the United Arab Emirates. *Management of Environmental Quality; Bradford*, *19*(3), 283–304. https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1108/14777830810866428

Urrego, L. E., Galeano, A., Peñuela, C., Sánchez, M., & Toro, E. (2016). Climate-related phenology of Mauritia flexuosa in the Colombian Amazon. *Plant Ecology; Dordrecht*, *217*(10), 1207–1218. https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1007/s11258-016-0647-0

U.S. Global Change Research Program. (2017). Climate science special report: *Fourth national climate assessment, volume I.* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)], pp. 35-

470. Retrived from U.S. Global Change Research Program, https://doi.org/10.7930/J0J964J6

Vinagre, C., Leal, I., Mendonca, V., Madeira, D., Narciso, L., Diniz, M. S., & Flores, A. A. V. (2016). Vulnerability to climate warming and acclimation capacity of tropical and temperate coastal organisms. *Ecological Indicators, 62(Mar 2016)*, 317–327. 10.1016/j.ecolind.2015.11.010

Walther, G.-R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T. J. C., Fromentin, J.-M., Hoegh-Guldberg, O., & Bairlein, F. (2002). Ecological responses to recent climate change. *Nature*, *416*(6879), 389–395. https://doi.org/10.1038/416389a

Wang, S.-J., & Zhou, L.-Y. (2019). Integrated impacts of climate change on glacier tourism. *Advances in Climate Change Research*, *10*(2), 71–79. https://doi.org/10.1016/j.accre.2019.06.006

Wang, X., Jiang, D., & Lang, X. (2017). Future extreme climate changes linked to global warming intensity. *Science Bulletin*, *62*(24), 1673–1680. https://doi.org/10.1016/j.scib.2017.11.004

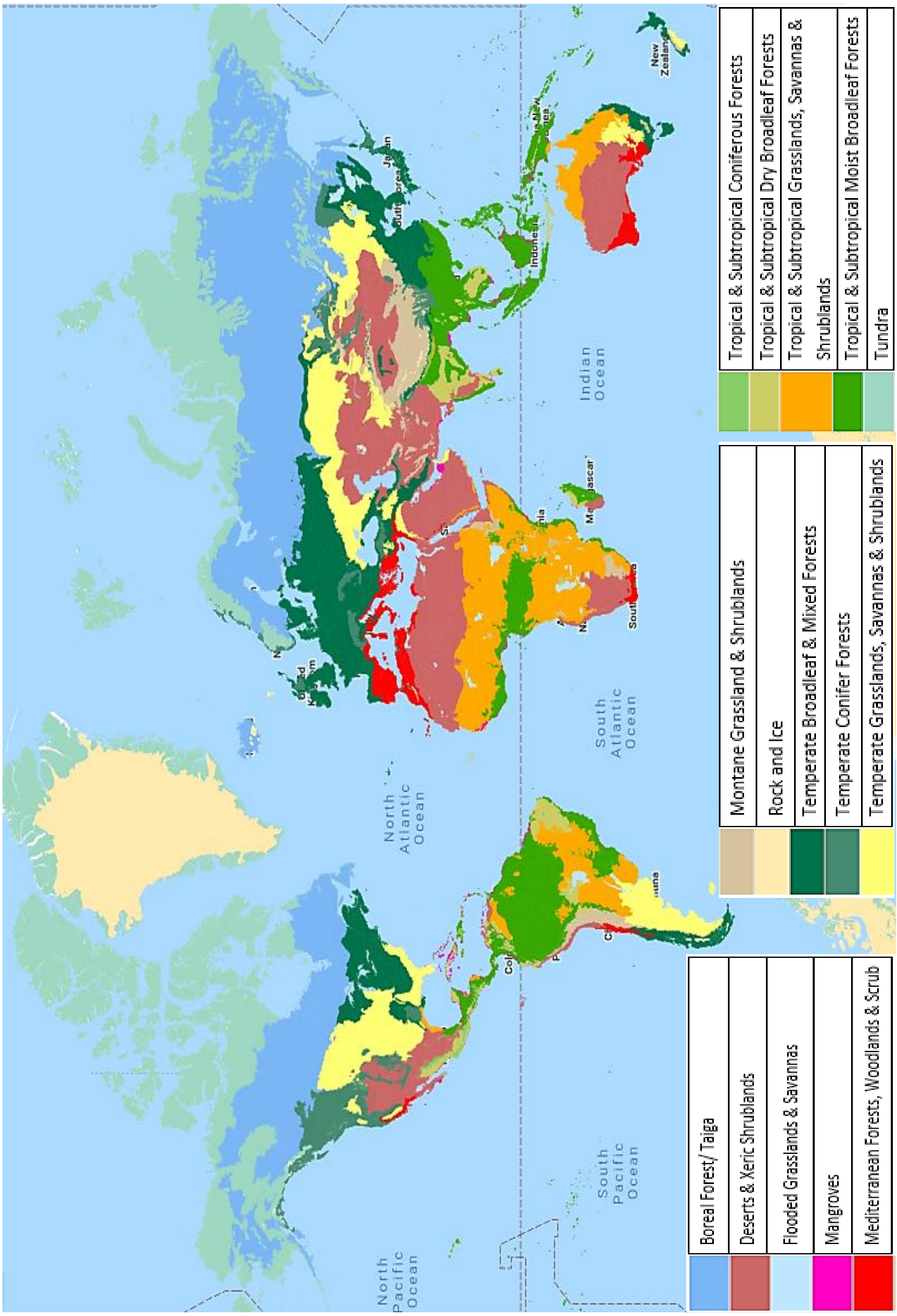
Weltzin, J. F., Loik, M. E., Schwinning, S., Williams, D. G., Fay, P. A., Haddad, B. M., Harte, J., Huxman, T. E., Knapp, A. K., Lin, G., Pockman, W. T., Shaw, R. M., Small, E. E., Smith, M. D., Smith, S. D., Tissue, D. T., & Zak, J. C. (2003). Assessing the response of terrestrial ecosystems to potential changes in precipitation. *BioScience*, *53*(10), 941–952. https://doi.org/10.1641/0006-3568(2003)053[0941:ATROTE]2.0.CO;2

Wuebbles, D. J., Easterling, D. R., Hayhoe, K., Knutson, T., Kopp, R. E., Kossin, J. P., Kunkel, K. E., LeGrande, A. N., Mears, C., Sweet, W. V., Taylor, P. C., Vose, R. S., & Wehner, M. F. (2017). Our globally changing climate. *In climate science special report: Fourth national climate assessment, volume I* [In D. J. Wuebbles, D. W. Fahey, K. A. Hibbard, D. J. Dokken, B. C. Stewart, & T. K. Maycock (Eds.)], (pp. 35–72). Retrieved from U.S. Global Change Research Program, https://doi.org/10.7930/J08S4N35

Zalasiewicz, J., & Williams, M. (2016). Chapter 1 - Climate Change Through Earth’s History. In T. M. Letcher (Ed.), *Climate Change (Second Edition)* (pp. 3–17). Amsterdam: Elsevier. https://doi.org/10.1016/B978-0-444-63524-2.00001-4

# Appendices

**Appendix A:** Map showing categorization of biomes based on the WWF Ecoregions 2017. (Source: Dinerstein et al., 2017)



**Appendix B:** This appendix sets out the full set of data and details of the publications from which they were drawn:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **1** | E. C. Mmassy, R. D. Fyumagwa et al. (2017). African Journal of Ecology 55(3), 298-304 | Kori bustard (Ardeotis kori struthiunculus) occurrence in the Serengeti grass plains, northern Tanzania | Kori Bustard | Ardeotis kori struthiunculus | Southern and Eastern Africa | Tanzania | Population abundance | Sig Positive | Savannah |
| **2** | A. N. Alagaili, N. C. Bennett et al. (2017). Journal of Arid Environment 145, 1-9 | The reproductive biology of the Ethiopian hedgehog, Paraechinus aethiopicus, from central Saudi Arabia: The role of rainfall and temperature | Ethiopian hedgehog | *Paraechinus aethiopicus* | Central Saudi | Saudi Arabia | Breeding rate | Sig Positive | Desert |
| **3** | H. K. Ndithia, K. D Matson et al. (2017). PLoS One 12(4), 1-18 | Year-round breeding equatorial larks from three climatically-distinct populations do not use rainfall, temperature or invertebrate biomass to time reproduction | Red-capped Lark | *Calandrella cinerea* | Kedong | Kenya | Breeding rate | Non Sig Negative | Temperate Grassland |
| **4** | H. K. Ndithia, K. D Matson et al. (2017). PLoS One 12(4), 1-18 | Year-round breeding equatorial larks from three climatically-distinct populations do not use rainfall, temperature or invertebrate biomass to time reproduction | Red-capped Lark | *Calandrella cinerea* | South kedong | Kenya | Breeding rate | Non Sig Negative | Tropical Forest |
| **5** | H. K. Ndithia, K. D Matson et al. (2017). PLoS One 12(4), 1-18 | Year-round breeding equatorial larks from three climatically-distinct populations do not use rainfall, temperature or invertebrate biomass to time reproduction | Red-capped Lark | *Calandrella cinerea* | North kedong | Kenya | Breeding rate | Non Sig Negative | Tropical Forest |
| **6** | P. Crump, J. Houlahan (2017). Freshwater biology 62 (7), 1244-1254 | The impacts of overwintered green frog larvae on wood frog embryo mortality under a wetter climate | Wood frog | *Lithobates sylvaticus* | New Brunswick | Canada | Hatch success | Non Sig Positive | Wetland |
| **7** | N. P. Lemoine, J. D. Dietrich et al. (2017). Functional Ecology 31(10), 1894–1902 | Precipitation and environmental constraints on three aspects of flowering in three dominant tallgrass species | Tallgrass prairies | *Andropogon gerardii* | Kanzas | USA | Growth rate | Non Sig Positive | Temperate Grassland |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **8** | N. P. Lemoine, J. D. Dietrich et al. (2017). Functional Ecology 31(10), 1894–1902 | Precipitation and environmental constraints on three aspects of flowering in three dominant tallgrass species | Tallgrass prairies | *Schizachyrium scoparium* | Kanzas | USA | Growth rate | Non Sig Positive | Temperate Grassland |
| **9** | N. P. Lemoine, J. D. Dietrich et al. (2017). Functional Ecology 31(10), 1894–1902 | Precipitation and environmental constraints on three aspects of flowering in three dominant tallgrass species | Tallgrass prairies | *Sorghastrum nutans* | Kanzas | USA | Growth rate | Non Sig Positive | Temperate Grassland |
| **10** | M. Peláez, A. S. Miguel et al. (2017). Integrative zoology 12(5), 396–408 | Climate, female traits and population features as drivers of breeding timing in Mediterranean red deer populations | Red deer | *Cervus elaphus* | Los Quintos de mora | Spain | Early conception dates | Sig Positive | Mediterranean |
| **11** | C. H. Greenberg, S. J. Zarnoch at al (2017). Ecosphere 8(5), e01789, 1-23 | Weather, hydroregime, and breeding effort influence juvenile recruitment of anurans: implications for climate change | Frog | *Lithobates capito* | Florida | USA | Juvenile Recruitment | Non Sig Positive | Wetland |
| **12** | C. H. Greenberg, S. J. Zarnoch at al (2017). Ecosphere 8(5), e01789, 1-23 | Weather, hydroregime, and breeding effort influence juvenile recruitment of anurans: implications for climate change | Frog | *L. sphenocephalus* | Florida | USA | Juvenile Recruitment | Non Sig Positive | Wetland |
| **13** | C. H. Greenberg, S. J. Zarnoch at al (2017). Ecosphere 8(5), e01789, 1-23 | Weather, hydroregime, and breeding effort influence juvenile recruitment of anurans: implications for climate change | Frog | *Anaxyrus terrestris* | Florida | USA | Juvenile Recruitment | Non Sig Positive | Wetland |
| **14** | C. H. Greenberg, S. J. Zarnoch at al (2017). Ecosphere 8(5), e01789, 1-23 | Weather, hydroregime, and breeding effort influence juvenile recruitment of anurans: implications for climate change | Frog | *A. quercicus* | Florida | USA | Juvenile Recruitment | Non Sig Positive | Wetland |
| **15** | C. H. Greenberg, S. J. Zarnoch at al (2017). Ecosphere 8(5), e01789, 1-23 | Weather, hydroregime, and breeding effort influence juvenile recruitment of anurans: implications for climate change | Frog | *Gastrophryne carolinensis* | Florida | USA | Juvenile Recruitment | Non Sig Positive | Wetland |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **16** | C. H. Greenberg, S. J. Zarnoch at al (2017). Ecosphere 8(5), e01789, 1-23 | Weather, hydroregime, and breeding effort influence juvenile recruitment of anurans: implications for climate change | Frog | *S. holbrookii* | Florida | USA | Juvenile Recruitment | Non Sig Positive | Wetland |
| **17** | S. M. Rockwell, J. M. Wunderle Jr. et al. (2017) Oecologia 183(3), 715–727 | Seasonal survival estimation for a long-distance migratory bird and the influence of winter precipitation | Kirtland's warblers | *Setophaga kirtlandii* | Bahamas | Bahamas | Survival rate | Non Sig Positive | Tropical Forest |
| **18** | J. F. Saracco, P. Radley at al. (2016). PLoS One 11(2), e0148570, 1-18 | Linking vital rates of landbirds on a tropical island to rainfall and vegetation greenness | Rufous fantail | *Rhipidura rufifrons* | Saipan, Northern Mariana Islands | USA | Reproductive rate | Non Sig Negative | Tropical Forest |
| **19** | J. F. Saracco, P. Radley at al. (2016). PLoS One 11(2), e0148570, 1-18 | Linking vital rates of landbirds on a tropical island to rainfall and vegetation greenness | Bridled white-eye | *Zosterops conspicillatus* | Saipan, Northern Mariana Islands | USA | Reproductive rate | Non Sig Negative | Tropical Forest |
| **20** | J. F. Saracco, P. Radley at al. (2016). PLoS One 11(2), e0148570, 1-18 | Linking vital rates of landbirds on a tropical island to rainfall and vegetation greenness | Golden white-eye | *Cleptornis marchei* | Saipan, Northern Mariana Islands | USA | Reproductive rate | Non Sig Negative | Tropical Forest |
| **21** | Y. Wang, Z. Zeng at al. (2016) Oecologia 182(4), 961–971 | Low precipitation aggravates the impact of extreme high temperatures on lizard reproduction | Multi-ocellated racerunner | *Eremias multiocellata* | Inner Mongolia | Mongolia | Reproductive rate | Non Sig Positive | Desert |
| **22** | L. B. Ganendran, L. A. Sidhu et al. (2016). International Journal of Biometeorology 60(8), 1237-1245 | Effects of ambient air temperature, humidity, and rainfall on annual survival of adult little penguins eudyptula minor in southeastern australia | Adult little penguins | *Eudyptula minor* | Phillip Island | Austrailia | Breeding rate/ Moulting | Non Sig Positive | Tropical Forest |
| **23** | L. M. P. Cavalcanti, L. V. de Paiva et al. (2016). Zoologia 33(6), 1-6 | Effects of rainfall on bird reproduction in a semi-arid neotropical region | Birds | *47 species* | Caatinga | South America | Reproduction (Brood Patch/ Nest) | Sig Positive | Tropical Forest |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **24** | R. Y. Conrey, S. K. Skagen et al. (2016). Ibis 158(3), 614-629 | Extremes of heat, drought and precipitation depress reproductive performance in shortgrass prairie passerines | Horned Lark | *Eremophila alpestris* | Colorado | USA | Nest Monitoring/ Survival Rates | Non Sig Positive | Temperate Grassland |
| **25** | R. Y. Conrey, S. K. Skagen et al. (2016). Ibis 158(3), 614-629 | Extremes of heat, drought and precipitation depress reproductive performance in shortgrass prairie passerines | McCown's Longspur | *Rhynchophanes mccownii* | Colorado | USA | Nest Monitoring/ Survival Rates | Non Sig Positive | Temperate Grassland |
| **26** | R. Y. Conrey, S. K. Skagen et al. (2016). Ibis 158(3), 614-629 | Extremes of heat, drought and precipitation depress reproductive performance in shortgrass prairie passerines | Chestnut-collared Longspur | *Calcarius ornatus* | Colorado | USA | Nest Monitoring/ Survival Rates | Non Sig Positive | Temperate Grassland |
| **27** | R. Y. Conrey, S. K. Skagen et al. (2016). Ibis 158(3), 614-629 | Extremes of heat, drought and precipitation depress reproductive performance in shortgrass prairie passerines | Lark Bunting | *Calamospiza melanocorys* | Colorado | USA | Nest Monitoring/ Survival Rates | Non Sig Positive | Temperate Grassland |
| **28** | R. Y. Conrey, S. K. Skagen et al. (2016). Ibis 158(3), 614-629 | Extremes of heat, drought and precipitation depress reproductive performance in shortgrass prairie passerines | Western Meadowlark | *Sturnella neglecta* | Colorado | USA | Nest Monitoring/ Survival Rates | Non Sig Positive | Temperate Grassland |
| **29** | P. Shaw (2016) Journal of Ornithology 158 (1), 263-275 | Rainfall, leafing phenology and sunrise time as potential Zeitgeber for the bimodal, dry season laying pattern of an African rain forest tit (Parus fasciiventer) | Stripe-breasted Tits | *Parus fasciiventer* | Bwindi Impenetrable Forest | Uganda | Breeding rate | Sig Positive | Tropical Forest |
| **30** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | Ruby-throated Hummingbird | *Archilochus colubris* | Pennsylvania | USA | Survival and Breeding rate | Non Sig Negative | Temperate Forest |
| **31** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | Eastern Phoebe | *Sayornis phoebe* | Pennsylvania | USA | Survival and Breeding rate | Sig Negative | Temperate Forest |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **32** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | Red-eyed Vireo | *Vireo olivaceus* | Pennsylvania | USA | Survival and Breeding rate | Non Sig Positive | Temperate Forest |
| **33** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | Black-capped Chickadee | *Poecile atricapillus* | Pennsylvania | USA | Survival and Breeding rate | Non Sig Positive | Temperate Forest |
| **34** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | House Wren | *Troglodytes aedon* | Pennsylvania | USA | Survival and Breeding rate | Sig Negative | Temperate Forest |
| **35** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | Wood Thrush | *Hylocichla mustelina* | Pennsylvania | USA | Survival and Breeding rate | Non Sig Positive | Temperate Forest |
| **36** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | American Robin | *Turdus migratorius* | Pennsylvania | USA | Survival and Breeding rate | Non Sig Positive | Temperate Forest |
| **37** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | Gray Catbird | *Dumetella carolinensis* | Pennsylvania | USA | Survival and Breeding rate | Sig Negative | Temperate Forest |
| **38** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | Cedar Waxwing | *Bombycilla cedrorum* | Pennsylvania | USA | Survival and Breeding rate | Non Sig Positive | Temperate Forest |
| **39** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | Ovenbird | *Seiurus aurocapilla* | Pennsylvania | USA | Survival and Breeding rate | Sig Negative | Temperate Forest |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **40** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | Common Yellowthroat | *Geothlypis trichas* | Pennsylvania | USA | Survival and Breeding rate | Sig Positive | Temperate Forest |
| **41** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | Hooded Warbler | *Setophaga citrina* | Pennsylvania | USA | Survival and Breeding rate | Non Sig Positive | Temperate Forest |
| **42** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | American Redstart | *Setophaga ruticilla* | Pennsylvania | USA | Survival and Breeding rate | Non Sig Positive | Temperate Forest |
| **43** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | Yellow Warbler | *Setophaga petechia* | Pennsylvania | USA | Survival and Breeding rate | Sig Negative | Temperate Forest |
| **44** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | Field Sparrow | *Spizella pusilla* | Pennsylvania | USA | Survival and Breeding rate | Sig Negative | Temperate Forest |
| **45** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | Song Sparrow | *Melospiza melodia* | Pennsylvania | USA | Survival and Breeding rate | Sig Negative | Temperate Forest |
| **46** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | Scarlet Tanager | *Piranga olivacea* | Pennsylvania | USA | Survival and Breeding rate | Sig Positive | Temperate Forest |
| **47** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | Northern Cardinal | *Cardinalis cardinalis* | Pennsylvania | USA | Survival and Breeding rate | Sig Positive | Temperate Forest |

Appendix B:  Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **48** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | Rose-breasted Grosbeak | *Pheucticus ludovicianus* | Pennsylvania | USA | Survival and Breeding rate | Non Sig Negative | Temperate Forest |
| **49** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | Indigo Bunting | *Passerina cyanea* | Pennsylvania | USA | Survival and Breeding rate | Sig Negative | Temperate Forest |
| **50** | M. E. McDermott, L. W. DeGroo (2016). Global Change Biology 22(10), 3304–3319 | Long-term climate impacts on breeding bird phenology in Pennsylvania, USA | American Goldfinch | *Carduelis tristis* | Pennsylvania | USA | Survival and Breeding rate | Non Sig Positive | Temperate Forest |
| **51** | K. K. Cruz-McDonnell, B. O. Wolf (2016). Global Change Biology 22(1), 237-253 | Rapid warming and drought negatively impact population size and reproductive dynamics of an avian predator in the arid southwest | Burrowing Owl | *Athene cunicularia* | Albuquerque, New Mexico | USA | Population size | Sig Positive | Desert |
| **52** | L. E. Urrego, A. Galeano et al. (2016). Plant Ecology 217(10), 1207-1218 | Climate-related phenology of mauritia flexuosa in the colombian amazon | Moriche palm | *Mauritia flexuosa* | Colombian Amazon | Colombia | Reproductive phenology | Non Sig Positive | Tropical Forest |
| **53** | G. Dubost, O. Henry (2017). Zoological Studies 56, 1-9 | Seasonal Reproduction in Neotropical Rainforest Mammals | Small murid | *Hylaeamys megacephalus* | French Guiana | French Guiana | Birth rates | Non Sig Positive | Tropical Forest |
| **54** | G. Dubost, O. Henry (2017). Zoological Studies 56, 1-9 | Seasonal Reproduction in Neotropical Rainforest Mammals | Spiny rat | *Proechimys cuvieri* | French Guiana | French Guiana | Birth rates | Non Sig Positive | Tropical Forest |
| **55** | G. Dubost, O. Henry (2017). Zoological Studies 56, 1-9 | Seasonal Reproduction in Neotropical Rainforest Mammals | Acouchy | *Myoprocta acouchy* | French Guiana | French Guiana | Birth rates | Sig Positive | Tropical Forest |
| **56** | G. Dubost, O. Henry (2017). Zoological Studies 56, 1-9 | Seasonal Reproduction in Neotropical Rainforest Mammals | Agouti | *Dasyprocta leporina* | French Guiana | French Guiana | Birth rates | Sig Positive | Tropical Forest |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **57** | G. Dubost, O. Henry (2017). Zoological Studies 56, 1-9 | Seasonal Reproduction in Neotropical Rainforest Mammals | Paca | *Agouti paca* | French Guiana | French Guiana | Birth rates | Sig Positive | Tropical Forest |
| **58** | G. Dubost, O. Henry (2017). Zoological Studies 56, 1-9 | Seasonal Reproduction in Neotropical Rainforest Mammals | Collared peccary | *Tayassu tajacu* | French Guiana | French Guiana | Birth rates | Non Sig Positive | Tropical Forest |
| **59** | J. Sarli, H. Lutermann (2015). Journal of Arid Environments 113, 87-94 | Reproductive patterns in the Baluchistan gerbil, Gerbillus nanus (Rodentia: Muridae), from western Saudi Arabia: The role of rainfall and temperature | Baluchistan gerbil | *Gerbillus nanus* | Western Saudi | Saudi Arabia | Breeding rate | Non Sig Positive | Desert |
| **60** | J. O. Ogutu, N. Owen-Smith (2015). PLoS One 10(8), e0133744, 1-13 | How rainfall variation influences reproductive patterns of african savanna ungulates in an equatorial region where photoperiod variation is absent | Topi | *Damaliscus lunatus korrigum* | Masai Mara National Reserve | Kenya | Breeding rate | Non Sig Positive | Savannah |
| **61** | J. O. Ogutu, N. Owen-Smith (2015). PLoS One 10(8), e0133744, 1-13 | How rainfall variation influences reproductive patterns of african savanna ungulates in an equatorial region where photoperiod variation is absent. | Warthog | *Phacochoerus africanus* | Masai Mara National Reserve | Kenya | Breeding rate | Non Sig Positive | Savannah |
| **62** | J. O. Ogutu, N. Owen-Smith (2015). PLoS One 10(8), e0133744, 1-13 | How rainfall variation influences reproductive patterns of african savanna ungulates in an equatorial region where photoperiod variation is absent. | Hartebeest | *Alcelaphus busephalus* | Masai Mara National Reserve | Kenya | Breeding rate | Non Sig Positive | Savannah |
| **63** | J. O. Ogutu, N. Owen-Smith (2015). PLoS One 10(8), e0133744, 1-13 | How rainfall variation influences reproductive patterns of african savanna ungulates in an equatorial region where photoperiod variation is absent. | Impala | *Aepycerus melampus* | Masai Mara National Reserve | Kenya | Breeding rate | Non Sig Positive | Savannah |

Appendix B:  Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **64** | A. E. Sieg, M. M. Gambone et al. (2015). Integrative Zoology 10(3), 282–294 | Mojave Desert tortoise (Gopherus agassizii) thermal ecology and reproductive success along a rainfall cline | Mojave Desert tortoise | *Gopherus agassizii* | Ivanpah Valley, California | USA | Reproductive rate | Non Sig Positive | Desert |
| **65** | M. Shen, S. Piao et al. (2015). Global Change Biology 21(10), 3647–3656 | Precipitation impacts on vegetation spring phenology on the Tibetan Plateau | Steppe | *Steppe vegetation* | Tibet Plateau | Tibet | Start of vegetation growth | Sig positive | Montane Grassland |
| **66** | P. M. Magdalita, R. B. Saludes (2015). Science Diliman 27(1), 64-90 | Influence of Changing Rainfall Patterns on the Yield of Rambutan (Nephelium lappaceum L.) and Selection of Genotypes in Known Drought-tolerant Fruit Species for Climate Change Adaptation | Rambutan | *Nephelium lappaceum* | Calauan, Laguna | Philippines | Growth rate | Non Sig Negative | Tropical Forest |
| **67** | M. Shen, S. Piao et al. (2015). Global Change Biology 21(10), 3647–3656 | Precipitation impacts on vegetation spring phenology on the Tibetan Plateau | Meadows | *Meadows vegetation* | Tibet Plateau | Tibet | Start of vegetation growth | Non Sig Positive | Montane Grassland |
| **68** | M. Shen, S. Piao et al. (2015). Global Change Biology 21(10), 3647–3656 | Precipitation impacts on vegetation spring phenology on the Tibetan Plateau | Alpine | *Alpine vegetation* | Tibet Plateau | Tibet | Start of vegetation growth | Non Sig Positive | Montane Grassland |
| **69** | M. Öberg, D. Arlt et al. (2015). Ecology and Evolution 5(20), 345–356 | Rainfall during parental care reduces reproductive and survival components of fitness in a passerine bird | Northern wheatears | *Oenanthe oenanthe* | Uppsala | Sweden | Growth rate | Non Sig Positive | Savannah |
| **70** | Y. Zhu, X. Yang et al. (2014). Plant and Soil 374(1-2), 399-409 | Effects of amount and frequency of precipitation and sand burial on seed germination, seedling emergence and survival of the dune grass leymus secalinus in semiarid china. | Dune grass | *Leymus secalinus* | The Mu-Us Sandland | China | Seed germination | Sig Positive | Montane Grassland |
| **71** | M. G. Sexson, G. H. Farley (2012). The Journal of Wildlife Management 76(8), 1587–1596 | Snowy Plover Nest Survival in Kansas and Effective Management to Counter Negative Effects of Precipitation | Snowy plovers | *Charadrius nivosus* | Kansas | USA | Breeding rate | Sig Negative | Temperate Grassland |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **72** | Y. Zhu, X. Yang et al. (2014). Plant and Soil 374(1-2), 399-409 | Effects of amount and frequency of precipitation and sand burial on seed germination, seedling emergence and survival of the dune grass leymus secalinus in semiarid china. | Dune grass | *Leymus secalinus* | The Mu-Us Sandland | China | Seedling emergence | Sig Positive | Montane Grassland |
| **73** | N. Ockendon, A. Johnston et al. (2014). Journal of Ornithology 155(4), 905–917 | Rainfall on wintering grounds affects population change in many species of Afro-Palaearctic migrants | Yellow Wagtail | *Motacilla flava* | West africa | Several in Africa | Population rate | Non Sig Positive | Savannah |
| **74** | N. Ockendon, A. Johnston et al. (2014). Journal of Ornithology 155(4), 905–917 | Rainfall on wintering grounds affects population change in many species of Afro-Palaearctic migrants | Common Redstart | *Phoenicurus phoenicurus* | West africa | Several in Africa | Population rate | Sig Positive | Savannah |
| **75** | N. Ockendon, A. Johnston et al. (2014). Journal of Ornithology 155(4), 905–917 | Rainfall on wintering grounds affects population change in many species of Afro-Palaearctic migrants | Sedge Warbler | *Acrocephalus schoenobaenus* | West africa | Several in Africa | Population rate | Sig Positive | Savannah |
| **76** | N. Ockendon, A. Johnston et al. (2014). Journal of Ornithology 155(4), 905–917 | Rainfall on wintering grounds affects population change in many species of Afro-Palaearctic migrants | Blackcap | *Sylvia atricapilla* | West africa | Several in Africa | Population rate | Sig Positive | Savannah |
| **77** | N. Ockendon, A. Johnston et al. (2014). Journal of Ornithology 155(4), 905–917 | Rainfall on wintering grounds affects population change in many species of Afro-Palaearctic migrants | Lesser Whitethroat | *Sylvia curruca* | West africa | Several in Africa | Population rate | Non Sig Positive | Savannah |
| **78** | N. Ockendon, A. Johnston et al. (2014). Journal of Ornithology 155(4), 905–917 | Rainfall on wintering grounds affects population change in many species of Afro-Palaearctic migrants | Common Whitethroat | *Sylvia communis* | West africa | Several in Africa | Population rate | Sig Positive | Savannah |
| **79** | N. Ockendon, A. Johnston et al. (2014). Journal of Ornithology 155(4), 905–917 | Rainfall on wintering grounds affects population change in many species of Afro-Palaearctic migrants | Common Chiffchaff | *Phylloscopus collybitac* | West africa | Several in Africa | Population rate | Non Sig Positive | Savannah |

Appendix B:  Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **80** | N. Ockendon, A. Johnston et al. (2014). Journal of Ornithology 155(4), 905–917 | Rainfall on wintering grounds affects population change in many species of Afro-Palaearctic migrants | European Turtle Dove | *Streptopelia turtur* | West africa | Several in Africa | Population rate | Non Sig Positive | Savannah and tropical |
| **81** | N. Ockendon, A. Johnston et al. (2014). Journal of Ornithology 155(4), 905–917 | Rainfall on wintering grounds affects population change in many species of Afro-Palaearctic migrants | Eurasian Reed Warbler | *Acrocephalus scirpaceus* | West africa | Several in Africa | Population rate | Sig Positive | Savannah and tropical |
| **82** | N. Ockendon, A. Johnston et al. (2014). Journal of Ornithology 155(4), 905–917 | Rainfall on wintering grounds affects population change in many species of Afro-Palaearctic migrants | House Martin | *Delichon urbicum* | West africa | Several in Africa | Population rate | Non Sig Positive | Tropical Forest |
| **83** | N. Ockendon, A. Johnston et al. (2014). Journal of Ornithology 155(4), 905–917 | Rainfall on wintering grounds affects population change in many species of Afro-Palaearctic migrants | Tree Pipit | *Anthus trivialis* | West africa | Several in Africa | Population rate | Sig Positive | Tropical Forest |
| **84** | N. Ockendon, A. Johnston et al. (2014). Journal of Ornithology 155(4), 905–917 | Rainfall on wintering grounds affects population change in many species of Afro-Palaearctic migrants | Garden Warbler | *Sylvia borin* | West africa | Several in Africa | Population rate | Non Sig Positive | Tropical Forest |
| **85** | N. Ockendon, A. Johnston et al. (2014). Journal of Ornithology 155(4), 905–917 | Rainfall on wintering grounds affects population change in many species of Afro-Palaearctic migrants | Willow Warbler | *Phylloscopus trochilus* | West africa | Several in Africa | Population rate | Non Sig Positive | Tropical Forest |
| **86** | N. Ockendon, A. Johnston et al. (2014). Journal of Ornithology 155(4), 905–917 | Rainfall on wintering grounds affects population change in many species of Afro-Palaearctic migrants | Spotted Flycatcher | *Muscicapa striata* | West africa | Several in Africa | Population rate | Sig Positive | Tropical Forest |
| **87** | N. Ockendon, A. Johnston et al. (2014). Journal of Ornithology 155(4), 905–917 | Rainfall on wintering grounds affects population change in many species of Afro-Palaearctic migrants | Common Cuckoo | *Cuculus canorus* | Central Africa | Several in Africa | Population rate | Non Sig Positive | Savannah and tropical |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **88** | N. Ockendon, A. Johnston et al. (2014). Journal of Ornithology 155(4), 905–917 | Rainfall on wintering grounds affects population change in many species of Afro-Palaearctic migrants | Barn Swallow | *Hirundo rustica* | Southern Africa | Several in Africa | Population rate | Sig Positive | Desert and savannah |
| **89** | A. N. Facka, G. W. Roemer et al. (2010) Journal of Wildlife Management 74(8), 1752-1762 | Drought Leads to Collapse of Black-Tailed Prairie Dog Populations Reintroduced to the Chihuahuan desert | Black-tailed prairie dog | *Cynomys ludovicianus* | New mexico | USA | Reproductive rate | Sig Positive | Desert |
| **90** | P. Gullett, K. L. Evans et al. Oikos 123(4), 389–400 | Climate change and annual survival in a temperate passerine: partitioning seasonal effects and predicting future patterns | Long-tailed tit | *Aegithalos caudatus* | Sheffield | United Kingdom | Survival rate | Non Sig Negative | Temperate Forest |
| **91** | T. O. Merö, A. Zuljevic et al. (2014). Turk J Zool 38(5), 622-630 | Effect of reed burning and precipitation on the breeding success of Great Reed Warbler, Acrocephalus arundinaceus, on a mining pond | Great Reed Warbler | *Acrocephalus arundinaceus* | Bager Pond | Serbia | Breeding rate | Sig Negative | Temperate Forest |
| **92** | H. Lada, J. R. Thomson et al. (2013). Austral Ecology 38(5), 581-591 | Rainfall in prior breeding seasons influences population size of a small marsupial | Yellow-footed antechinus | *Antechinus flavipes* | Victoria | Austrailia | Population rate | Non Sig Positive | Temperate Forest |
| **93** | D. A. Saunders, B. A.Wintle et al. (2013). Biological Conservation 161, 1-9 | Egg-laying and rainfall synchrony in an endangered bird species: Implications for conservation in a changing climate | Carnaby's Cockatoo | *Calyptorhynchus latirostris* | Southwest Australia | Austrailia | Breeding rate | Sig Positive | Mediterranean |
| **94** | A. E. McKellar, P. P. Marra et al. (2013). Oecologia 172(2), 595–605 | Winter rainfall predicts phenology in widely separated populations of a migrant songbird | American redstart | *Setophaga ruticilla* | (Alberta-mexico)/ (Ontario-Jamaica) | North America | Reproductive phenology | Non Sig Negative | Tropical Forest |
| **95** | J. V. Katandukila, C. G. Faulkes et al. (2013). Journal of Zoology 291(4), 258-268 | Reproduction in the East African root rat (Tachyoryctes splendens; Rodentia: Spalacidae) from Tanzania: the importance of rainfall | The East African root rat | *Tachyoryctes splendens* | Mount Kilimanjaro | Tanzania | Reproductive phenology | Sig Positive | Tropical Forest |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **96** | R. D. Campbell, C. Newman et al. (2013). Global Change Biology 19(4), 1311–1324 | Proximate weather patterns and spring green-up phenology effect Eurasian beaver (Castor fiber) body mass and reproductive success: the implications of climate change and topography | Eurasian beaver | *Castor fiber* | Telemark | Norway | Reproductive phenology | Sig Negative | Temperate Forest |
| **97** | N. L. Cudworth, J. L. Koprowski (2013). Journal of Mammalogy 94(3), 683-690 | Foraging and reproductive behavior of arizona gray squirrels (sciurus arizonensis): Impacts of climatic variation | Arizona gray squirrels | *Sciurus arizonensis* | Arizona | USA | Breeding rate | Sig Positive | Desert |
| **98** | R. D. Campbell, C. Newman et al. (2013). Global Change Biology 19(4), 1311–1324 | Proximate weather patterns and spring green-up phenology effect Eurasian beaver (Castor fiber) body mass and reproductive success: the implications of climate change and topography | Gray alder | *Alnus incana* | Telemark | Norway | Growth rate | Sig Negative | Temperate Forest |
| **99** | A. K. Shaw, K. A. Kelly (2013). Global Change Biology 19(11), 3283–3290 | Linking El Niño, local rainfall, and migration timing in a tropical migratory species | Christmas island red crab | *G ecarcoidea natalis* | Christmas Island in the Indian Ocean | Austrailia | Migration period | Non Sig Positive | Tropical Forest |
| **100** | K. Medger, C. T. Chimimba et al. (2012). Journal of Zoology 288(4), 283–293 | Seasonal reproduction in the eastern rock elephant-shrew: influenced by rainfall and ambient temperature? | Eastern rock elephant-shrew | *Elephantulus myurus* | Limpopo | South Africa | Reproductive rate | Non Sig Positive | Savannah |
| **101** | X.Xiao, K. Liu et al. (2012). PLoS One 7(1), e29718, 1-8 | Predicted Disappearance of Cephalantheropsis obcordata in Luofu Mountain Due to Changes in Rainfall Patterns | Orchids | *Cephalantheropsis obcordata* | Luofo Mountain, Guangdong | China | Survival rate | Non Sig Positive | Tropical Forest |
| **102** | L. C. Rubio-rocha, B. C. Bock et al. (2011). Caldasia 33(1), 91-104 | Continuous Reproduction Under a Bimodal Precipitation Regime in a High Elevation Anole (anolis Mariarum) from Antioquia, Colombia | Blemished Anole | *Anolis mariarum* | Antioquia | Colombia | Breeding rate | Non Sig Positive | Tropical Forest |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **103** | G. W. Schuett, R. A.Repp et al. (2011). Journal of Zoology 284(2), 105-113 | Frequency of reproduction in female western diamond-backed rattlesnakes from the sonoran desert of arizona is variable in individuals: Potential role of rainfall and prey densities | Female western diamond-backed rattlesnakes | *Crotalus atrox* | Sonoran Desert, Arizona | USA | Reproductive rate | Sig Positive | Desert |
| **104** | O. Keynan, R. Yosef (2010). The Wilson Journal of Ornithology 122(2), 334-339 | Annual Precipitation Affects Reproduction of the Southern Grey Shrike (lanius Meridionalis) | Southern Grey Shrike | *Lanius meridionalis* | Shezaf Nature Reserve, Arava Valley | Israel | Breeding rate | Non Sig Positive | Desert |
| **105** | A. M. Shrader, S. L. Pimm et al. (2010). Biodiversity & Conservation 19(8), 2235-2245 | Elephant survival, rainfall and the confounding effects of water provision and fences | Elephant | *Loxodonta africana* | Etosha national park | Namibia | Survival rate | Sig Positive | Savannah |
| **106** | A. M. Shrader, S. L. Pimm et al. (2010). Biodiversity & Conservation 19(8), 2235-2245 | Elephant survival, rainfall and the confounding effects of water provision and fences. | Elephant | *Loxodonta africana* | Chobe national park | Botswana | Survival rate | Non Sig Positive | Savannah |
| **107** | A. M. Shrader, S. L. Pimm et al. (2010). Biodiversity & Conservation 19(8), 2235-2245 | Elephant survival, rainfall and the confounding effects of water provision and fences. | Elephant | *Loxodonta africana* | Moremi wildlife reserve | Botswana | Survival rate | Non Sig Negative | Savannah |
| **108** | A. M. Shrader, S. L. Pimm et al. (2010). Biodiversity & Conservation 19(8), 2235-2245 | Elephant survival, rainfall and the confounding effects of water provision and fences. | Elephant | *Loxodonta africana* | Ngamiland 11 | Botswana | Survival rate | Non Sig Positive | Savannah |
| **109** | A. M. Shrader, S. L. Pimm et al. (2010). Biodiversity & Conservation 19(8), 2235-2245 | Elephant survival, rainfall and the confounding effects of water provision and fences. | Elephant | *Loxodonta africana* | Kruger national park | South Africa | Survival rate | Sig Positive | Savannah |
| **110** | A. M. Shrader, S. L. Pimm et al. (2010). Biodiversity & Conservation 19(8), 2235-2245 | Elephant survival, rainfall and the confounding effects of water provision and fences. | Elephant | *Loxodonta africana* | Zambezi National Park | Zambia | Survival rate | Non Sig Positive | Savannah |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **111** | A. M. Shrader, S. L. Pimm et al. (2010). Biodiversity & Conservation 19(8), 2235-2245 | Elephant survival, rainfall and the confounding effects of water provision and fences. | Elephant | *Loxodonta africana* | Kafue National Park | Zambia | Survival rate | Non Sig Positive | Savannah |
| **112** | A. M. Shrader, S. L. Pimm et al. (2010). Biodiversity & Conservation 19(8), 2235-2245 | Elephant survival, rainfall and the confounding effects of water provision and fences. | Elephant | *Loxodonta africana* | South luangwa National park | Zambia | Survival rate | Non Sig Negative | Savannah |
| **113** | S. R. dos Santos, A. Specht et al. (2017). Revista Brasileira de Entomologia 61(4), 294-299 | Interseasonal variation of Chrysodeixis includens (Walker, [1858]) (Lepidoptera: Noctuidae) populations in the Brazilian Savanna | The soybean looper | *Chrysodeixis includens* | Planatina | Brazil | Phenology | Sig Positive | Savannah |
| **114** | F. A. Campos, W. F. Morris et al. (2017), Global Change Biology 23(11), 4907-4921 | Does climate variability influence the demography of wild primates? Evidence from long-term life-history data in seven species | Verreaux's sifaka | *Propithecus verreauxi* | Beza Mahalafly | Madagascar | Reproductive rate | Sig Positive | Desert |
| **115** | F. A. Campos, W. F. Morris et al. (2017), Global Change Biology 23(11), 4907-4921 | Does climate variability influence the demography of wild primates? Evidence from long-term life-history data in seven species | White-faced capuchin | *Cebus capucinus imitator* | Santa Rosa | Costa rica | Reproductive rate | Non Sig Positive | Tropical Forest |
| **116** | F. A. Campos, W. F. Morris et al. (2017), Global Change Biology 23(11), 4907-4921 | Does climate variability influence the demography of wild primates? Evidence from long-term life-history data in seven species | Northern muriqui | *Brachyteles hypoxanthus* | Caatinga | Brazil | Reproductive rate | Non Sig Positive | Tropical Forest |
| **117** | F. A. Campos, W. F. Morris et al. (2017), Global Change Biology 23(11), 4907-4921 | Does climate variability influence the demography of wild primates? Evidence from long-term life-history data in seven species | Blue monkey | *Cercopithecus mitis stuhlmanni* | Kakamega | Kenya | Reproductive rate | Non Sig Positive | Tropical Forest |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **118** | F. A. Campos, W. F. Morris et al. (2017), Global Change Biology 23(11), 4907-4921 | Does climate variability influence the demography of wild primates? Evidence from long-term life-history data in seven species | Yellow baboon | *Papio cynocephalus* | Amboseli | Kenya | Reproductive rate | Non Sig Positive | Savannah |
| **119** | F. A. Campos, W. F. Morris et al. (2017), Global Change Biology 23(11), 4907-4921 | Does climate variability influence the demography of wild primates? Evidence from long-term life-history data in seven species | Eastern chimpanzee | *P. troglodytes schweinfurthii* | Gombe | Tanzania | Reproductive rate | Non Sig Positive | Savannah |
| **120** | F. A. Campos, W. F. Morris et al. (2017), Global Change Biology 23(11), 4907-4921 | Does climate variability influence the demography of wild primates? Evidence from long-term life-history data in seven species | Mountain gorilla | *Gorilla beringei beringei* | Karisoke | Rwanda | Reproductive rate | Non Sig Positive | Savannah |
| **121** | J. V. Gedir, J. W. Cain III et al. (2015). Ecosphere 6(10), 1-20 | Effects of climate change on long-term population growth of pronghorn in an arid environment | Pronghorn | *Antilocapra americana* | Southwest US states | USA | Survival / Breeding rate | Sig Positive | Desert |
| **122** | F. Amorim, V. A. Mata et al. (2015). Mammalian Biology 80(3), 228-236 | Effects of a drought episode on the reproductive success of European free-tailed bats (Tadarida teniotis) | European free-tailed bats | *Tadarida teniotis* | North-eastern Portugal | Portugal | Reproductive rate | Sig Positive | Mediterranean |
| **123** | J. N.Styrsky, J. D. Brawn (2011). The Condor 113(1), 194-199 | Annual Fecundity of a Neotropical Bird During Years of High and Low Rainfall | Spotted Antbird | *Hylophylax naevioides* | Parque Nacional Soberanía | Panama | Phenology | Non Sig Positive | Tropical Forest |
| **124** | P. Macario, M. Pichorim et al. (2017). PLoS One 12(10), e0185890 | Apparent survival and cost of reproduction for White-lined Tanager (Tachyphonus rufus, Thraupidae) in the northern Atlantic Rainforest, Brazil | White-lined Tanager | *Tachyphonus rufus* | Parnamirim, Rio Grande do Norte state | Brazil | Survival and Reproduction rate | Non Sig Positive | Tropical Forest |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **125** | R. Mares, C. Doutrelant et al. (2017). R. Soc. open sci. 4(9), 170835, 1-12 | Breeding decisions and output are correlated with both temperature and rainfall in an arid-region passerine, the sociable weaver | The sociable weaver | *Philetairus socius* | Benfontein Nature Reserve | South Africa | Breeding rate | Sig Positive | Desert |
| **126** | A. Aslan, M. Yavuz (2010). Turk J Zool 34(2), 255-266 | Clutch and egg size variation, and productivity of the House Sparrow (Passer domesticus): effects of temperature, rainfall, and humidity | House Sparrow | *Passer domesticus* | Antalya | Turkey | Breeding rate | Sig Positive | Mediterranean |
| **127** | L. Demongin, M. Poisbleau et al. (2010). Ornitologia Neotropical 21(3), 439-443 | Effects of Severe Rains on the Mortality of Southern Rockhopper Penguin (eudyptes Chrysocome) Chicks and Its Impact on Breeding Success | Southern rockhopper penguin | *Eudyptes Chrysocome* | Settlement Colony, New Island | Falkland Islands | Survival rate | Non Sig Negative | Temperate Grassland |
| **128** | H. K. Ndithia, S. N. Bakari et al. (2017). Frontiers in Zoology 14(28), 1-14 | Geographical and temporal variation in environmental conditions affects nestling growth but not immune function in a year-round breeding equatorial lark | Red-capped Lark | *Calandrella cinerea* | North and south Kinangop | Kenya | Growth rate | Non Sig Positive | Tropical Forest |
| **129** | H. K. Ndithia, S. N. Bakari et al. (2017). Frontiers in Zoology 14(28), 1-14 | Geographical and temporal variation in environmental conditions affects nestling growth but not immune function in a year-round breeding equatorial lark | Red-capped Lark | *Calandrella cinerea* | Kedong | Kenya | Growth rate | Sig Positive | Savannah |
| **130** | R. T. Reynolds, J. S. Lambert et. al. (2017). Wildlife Monographs 197(1), 1-40 | Long-term demography of the Northern Goshawk in a variable environment | Northern goshawk | *Accipiter gentilis atricapillis* | Arizona | USA | Breeding rate | Non Sig Positive | Temperate Forest |
| **131** | J. P. Kelly, T. E. Condeso (2014). Wetlands 34(5), 893–900 | Rainfall Effects on Heron and Egret Nest Abundance in the San Francisco Bay Area | Great Egret | *Ardea alba* | San Fransisco | USA | Growth rate of nest abundances | Non Sig Negative | Wetland |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **132** | J. P. Kelly, T. E. Condeso (2014). Wetlands 34(5), 893–900 | Rainfall Effects on Heron and Egret Nest Abundance in the San Francisco Bay Area | Great Blue Heron | *Ardea herodias* | San Fransisco | USA | Growth rate of nest abundances | Non Sig Negative | Wetland |
| **133** | J. P. Kelly, T. E. Condeso (2014). Wetlands 34(5), 893–900 | Rainfall Effects on Heron and Egret Nest Abundance in the San Francisco Bay Area | Snowy Egret | *Egretta thula* | San Fransisco | USA | Growth rate of nest abundances | Non Sig Negative | Wetland |
| **134** | J. P. Kelly, T. E. Condeso (2014). Wetlands 34(5), 893–900 | Rainfall Effects on Heron and Egret Nest Abundance in the San Francisco Bay Area | Black-crowned Night- Heron | *Nycticorax nycticorax* | San Fransisco | USA | Growth rate of nest abundances | Non Sig Negative | Wetland |
| **135** | D. Bordjan, D. Tome (2014). Ardea 102(1), 79-86 | Rain may have more influence than temperature on nest abandonment in the Great Tit Parus major | Great Tit | *Parus major* | Mt. Krim & Mt. Pohorje | Slovenia | Nest Monitoring/ Survival Rates | Non Sig Negative | Temperate Forest |
| **136** | F. Angelier, C. M. Tonra et al. (2011). Journal of Avian Biology 42(4), 335 341 | Short-term changes in body condition in relation to habitat and rainfall abundance in American redstarts Setophaga ruticilla during the non-breeding season | American redstarts | *Setophaga ruticilla* | Font Hill Nature Reserve, St Elizabeth parish | Jamica | Body condition/ Survival rates | Non Sig Positive | Tropical Forest |
| **137** | G. F. Pagoti, R. H. Willemart (2015). Journal of Arachnology 43(2), 207–213 | Strong seasonality and clear choice of resting plant in a Neotropical harvestman (Arachnida: Opiliones) | Neotropical harvestman | *Sclerosomatidae Jussara sp* | Sao paulo, brazil | Brazil | Survival rate | Sig Positive | Tropical Forest |
| **138** | L. Salinas-Peba, V. Parra-Tabla et al. (2014). Journal of Plant Ecology 7(5), 470–479 | Survival and growth of dominant tree seedlings in seasonally tropical dry forests of Yucatan: site and fertilization effects | Gumbo limbo | *Bursera simaruba* | Yucatan | Mexico | Seedling survival | Non Sig Positive | Tropical Forest |
| **139** | L. Salinas-Peba, V. Parra-Tabla et al. (2014). Journal of Plant Ecology 7(5), 470–479 | Survival and growth of dominant tree seedlings in seasonally tropical dry forests of Yucatan: site and fertilization effects | Florida fishpoison tree | *Piscidia piscipula* | Yucatan | Mexico | Seedling survival | Non Sig Positive | Tropical Forest |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **140** | L. Salinas-Peba, V. Parra-Tabla et al. (2014). Journal of Plant Ecology 7(5), 470–479 | Survival and growth of dominant tree seedlings in seasonally tropical dry forests of Yucatan: site and fertilization effects | False tamarind | *Lysiloma latisiliquum* | Yucatan | Mexico | Seedling survival | Sig Positive | Tropical Forest |
| **141** | J. Rojas-Sandoval and E. Meléndez-Ackerman (2011). Botany 89(12), 861–871 | Reproductive phenology of the Caribbean cactus Harrisia portoricensis: rainfall and temperature associations | Cactus | *Harrisia portoricensis* | Caribbean dry forest of Mona Island | Puerto Rico | Budd production | Non Sig Positive | Tropical Forest |
| **142** | J. Rojas-Sandoval and E. Meléndez-Ackerman (2011). Botany 89(12), 861–871 | Reproductive phenology of the Caribbean cactus Harrisia portoricensis: rainfall and temperature associations | Cactus | *Harrisia portoricensis* | Caribbean dry forest of Mona Island | Puerto Rico | Reproductive phenology | Sig Positive | Tropical Forest |
| **143** | W. Zhoua, N. Wu et al. (2010). Russian Journal of Ecology 41(2), 147–152 | Growth and Potential Reproduction of Poa crymophila in Response to Season Precipitation Shortage in the Eastern Tibetan Plateau, China | Alpine meadow plant | *Poa crymophila* | Sichuan Province | China | Reproductive rate | Non Sig Positive | Temperate Forest |
| **144** | J. T. Van Stan II, M. Coenders-Gerrits et al. (2017). Hydrological Processes 31(21), 3719–3728 | Effects of phenology and meteorological disturbance on litter rainfall interception for a Pinus elliottii stand in the Southeastern United States | Tree Stand | *Pinus elliottii* | Southeast Georgia | USA | Reproductive rate | Sig Positive | Temperate Grassland |
| **145** | P. Neuhaus, R. Bennett et al. (1999). Canadian Journal of Zoology 77(6), 879-884 | Effects of a late snowstorm and rain on survival and reproductive success in Columbian ground squirrels | Columbian ground squirrel | *Sermophilis columbianus* | Southern Alberta | Canada | Breeding rate | Sig Negative | Temperate Grassland |
| **146** | M. A. Patten, J. T.Rotenberry (1999). The Condor 101(4), 876 | The proximate effects of rainfall on clutch size of the California Gnatcatcher | California Gnatchers | *P. c. californica* | Southern california | USA | Reproductive rate | Non Sig Positive | Mediterranean |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **147** | K. M. Dugger, J. Faaborg et al. (2004). The Condor 106(4), 744 | Understanding Survival and Abundance of Overwintering Warblers: Does Rainfall Matter? | Black and white warblers | *Mniotilta varia* | Guanica commonwealth forest reserve | Puerto Rico | Survival rate | Non Sig Negative | Tropical Forest |
| **148** | K. M. Dugger, J. Faaborg et al. (2004). The Condor 106(4), 744 | Understanding Survival and Abundance of Overwintering Warblers: Does Rainfall Matter? | Oven birds | *Seiurus aurocapilla* | Guanica commonwealth forest reserve | Puerto Rico | Survival rate | Non Sig Positive | Tropical Forest |
| **149** | K. M. Dugger, J. Faaborg et al. (2004). The Condor 106(4), 744 | Understanding Survival and Abundance of Overwintering Warblers: Does Rainfall Matter? | American redstarts | *Setophaga ruticilla* | Guanica commonwealth forest reserve | Puerto Rico | Survival rate | Non Sig Negative | Tropical Forest |
| **150** | J. C. deVos Jr., W.H. Miller (2005). Wildlife Society Bulletin 33(1), 35-42 | Habitat use and survival of Sonoran pronghorn in years with above-average rainfall | Sonoran pronghorn | *Antelocapra americana sonoriensis* | Arizona | USA | Survival rate | Sig Positive | Desert |
| **151** | P. Fernández-Llario, P. Mateos-Quesada (2005). Folia Zoologica 54(3), 240-248 | Influence of rainfall on the breeding biology of Wild boar (Sus scrofa) in a Mediterranean ecosystem | Wild boar | *Sus Scrofa* | Cáceres province | Spain | Breeding rate | Sig Positive | Mediterranean |
| **152** | A. Monadjem, A. J. Bamford (2009). Ibis 151(2), 344–351 | Influence of rainfall on timing and success of reproduction in Marabou Storks Leptoptilos crumeniferus | Marabou storks | *Leptoptilos crumeniferus* | Hlane National Park | Eswatini | Breeding rate | Sig Negative | Tropical Forest |
| **153** | M. Hirschfeld, M. Rodel (2011). Journal of Tropical Ecology 27(6), 601–609 | Variable reproductive strategies of an African savanna frog, Phrynomantis microps (Amphibia, Anura, Microhylidae) | Microhylid frog | *Phrynomantis microps* | Comoe national park | Ivory Coast | Reproductive rate | Sig Positive | Savannah |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **154** | M. Hirschfeld, M. Rodel (2011). Journal of Tropical Ecology 27(6), 601–609 | Variable reproductive strategies of an African savanna frog, Phrynomantis microps (Amphibia, Anura, Microhylidae) | Microhylid frog | *Phrynomantis microps* | Pendjari national park | Benin | Reproductive rate | Sig Positive | Savannah |
| **155** | I. Pipoly, V. Bókony et al. (2013). PLoS One 8(11), e80033, 1-11 | Effects of Extreme Weather on Reproductive Success in a Temperate-Breeding Songbird | The house sparrow | *Passer domesticus* | Kittenberger Zoological Garden of Veszprém | Hungary | Reproductive rate | Non Sig Negative | Temperate Forest |
| **156** | S. M. Rockwell, C. I. Bocetti et al. (2012). The Auk 129(4), 744−752 | Carry-over effects of winter climate on spring arrival date and reproductive success in an endangered migratory bird, Kirtland's Warbler (Setophaga kirtlandii) | Kirtland's Warbler | *Setophaga kirtlandii* | Northern Michigan | USA | Reproductive rate | Sig Positive | Temperate Forest |
| **157** | V. J. T. Loehr, B. T. Henen et al. (2011). Copeia 2011(2), 278-284 | Reproductive Responses to Rainfall in the Namaqualand Speckled Tortoise | Namaqualand Speckled Tortoise | *Homopus signatus* | Spring bok | South Africa | Egg reproduction | Sig Positive | Desert |
| **158** | L. Seabrook, C. McAlpine et al. (2011). Wildlife Research 38(6), 509-524 | Drought-driven change in wildlife distribution and numbers: a case study of koalas in south west Queensland | Koalas | *Phascolarctos cinereus* | Queensland | Austrailia | Survival rate | Non Sig Positive | Temperate Grassland |
| **159** | W. Hochstedler, D L. Gorchov (2007). The Ohio Journal of Science 107(3), 26-31 | The effects of June Precipitation on Alliaria petiolata (Garlic Mustard) Growth, Density and Survival | Garlic Mustard | *Alliaria petiolata* | Ohio | USA | Growth and Survival rate | Non Sig Positive | Temperate Forest |
| **160** | V. Sidorovich, A. Schnitzler et al. (2017). Mammalian Biology 87, 89-92 | Wolf denning behaviour in response to external disturbances and implications for pup survival | Wolf | *Canis lupus* | Naliboki forest | Belarus | Survival rate | Sig Negative | Temperate Forest |

Appendix B: Dataset of publications continued:

| NO. | BIBLIOGRAPHY | TITLE | SPECIES | *LATIN NAME* | LOCATION | COUNTRY | METRICS | IMPACTS | BIOME |
|---|---|---|---|---|---|---|---|---|---|
| **161** | R. B. Srygley, R. Dudley et al. (2010). Global Change Biology 16(3), 936–945 | El Nino and dry season rainfall influence hostplantphenology and an annual butterfly migration fromNeotropical wet to dry forests | Butterfly | *Aphrissa statira* | Panama Canal | Panama | Migration rate | Sig Negative | Tropical Forest |
| **162** | J. Nadal, C. Ponz et al. (2018). Science of the Total Environment 613–614, 1295–1301 | Synchronizing biological cycles as key to survival under a scenario of global change: The Common quail (Coturnix coturnix) strategy | Common quail | *Coturnix coturnix* | Several areas | Spain | Breeding rate | Sig Positive | Mediterran ean |
| **163** | T. L. Imlay, J. M. Flemming et al. (2018). Ecosphere 9(4), e02166, 1-14 | Breeding phenology and performance for four swallows over 57 years: relationships with temperature and precipitation | Bank Swallow | *Riparia riparia* | Nova Scotia / New Brunswick | Canada | Breeding rate | Non Sig Positive | Temperate Forest |
| **164** | T. L. Imlay, J. M. Flemming et al. (2018). Ecosphere 9(4), e02166, 1-14 | Breeding phenology and performance for four swallows over 57 years: relationships with temperature and precipitation | Tree Swallow | *Tachycineta bicolor* | Nova Scotia / New Brunswick | Canada | Breeding rate | Non Sig Positive | Temperate Forest |
| **165** | T. L. Imlay, J. M. Flemming et al. (2018). Ecosphere 9(4), e02166, 1-14 | Breeding phenology and performance for four swallows over 57 years: relationships with temperature and precipitation | Cliff Swallows | *Petrochelidon pyrrhonota* | Nova Scotia / New Brunswick | Canada | Breeding rate | Non Sig Negative | Temperate Forest |
| **166** | T. L. Imlay, J. M. Flemming et al. (2018). Ecosphere 9(4), e02166, 1-14 | Breeding phenology and performance for four swallows over 57 years: relationships with temperature and precipitation | Barn Swallow | *Hirundo rustica* | Nova Scotia / New Brunswick | Canada | Breeding rate | Non Sig Negative | Temperate Forest |
| **167** | L. J. Heffelfinger, K. M. Stewart et al. (2018). Ecology and Evolution 8(3), 3354-3366 | Timing of precipitation in an arid environment: Effects on population performance of a large herbivore | Mule deer | *Odocoileus hemionus* | Southeastern California | USA | Survival rate | Non Sig Positive | Desert |

This is a list of references for the studies in the dataset shown above.

Alagaili, A. N., Bennett, N. C., Mohammed, O. B., & Hart, D. W. (2017). The reproductive biology of the Ethiopian hedgehog, Paraechinus aethiopicus, from central Saudi Arabia: The role of rainfall and temperature. *Journal of Arid Environments*, *145*(Oct 2017), 1–9. https://doi.org/10.1016/j.jaridenv.2017.03.010

Amorim, F., Mata, V. A., Beja, P., & Rebelo, H. (2015). Effects of a drought episode on the reproductive success of European free-tailed bats (Tadarida teniotis). *Mammalian Biology - Zeitschrift Für Säugetierkunde*, 80(3), 228–236. https://doi.org/10.1016/j.mambio.2015.01.005

Angelier, F., Tonra, C. M., Holberton, R. L., & Marra, P. P. (2011). Short-term changes in body condition in relation to habitat and rainfall abundance in American redstarts Setophaga ruticilla during the non-breeding season. *Journal of Avian Biology*, *42*(4), 335–341. https://doi.org/10.1111/j.1600-048X.2011.05369.x

Aslan, A., & Yavuz, M. (2010). Clutch and egg size variation, and productivity of the House Sparrow (Passer domesticus): effects of temperature, rainfall, and humidity. *Turkish Journal of Zoology*, *34*(2), 255–266. https://doi.org/10.3906/zoo-0811-22

Bordjan, D., & Tome, D. (2014). Rain may have more influence than temperature on nest abandonment in the Great Tit Parus major. *Ardea*, *102*(1), 79–85.

Campbell, R. D., Newman, C., Macdonald, D. W., & Rosell, F. (2013). Proximate weather patterns and spring green-up phenology effect Eurasian beaver (Castor fiber) body mass and reproductive success: the implications of climate change and topography. *Global Change Biology*, *19*(4), 1311–1324. https://doi.org/10.1111/gcb.12114

Campos, F. A., Morris, W. F., Alberts, S. C., Altmann, J., Brockman, D. K., Cords, M., Pusey, A., Stoinski, T. S., Strier, K. B., & Fedigan, L. M. (2017). Does climate variability influence the demography of wild primates? Evidence from long-term life-history data in seven species. *Global Change Biology*, *23*(11), 4907–4921. https://doi.org/10.1111/gcb.13754

Cavalcanti, L. M. P., Paiva, L. V. de, França, L. F., Cavalcanti, L. M. P., Paiva, L. V. de, & França, L. F. (2016). Effects of rainfall on bird reproduction in a semi-arid Neotropical region. *Zoologia (Curitiba)*, *33*(6), 1-6 https://doi.org/10.1590/s1984-4689zool-20160018

Conrey, R. Y., Skagen, S. K., Yackel Adams, A. A., & Panjabi, A. O. (2016). Extremes of heat, drought and precipitation depress reproductive performance in shortgrass prairie passerines. *Ibis*, *158*(3), 614–629. https://doi.org/10.1111/ibi.12373

Crump, P., & Houlahan, J. (2017). The impacts of overwintered green frog larvae on wood frog embryo mortality under a wetter climate. *Freshwater Biology*, *62*(7), 1244–1254. https://doi.org/10.1111/fwb.12941

Cruz-McDonnell, K. K., & Wolf, B. O. (2016). Rapid warming and drought negatively impact population size and reproductive dynamics of an avian predator in the arid southwest. *Global Change Biology*, *22*(1), 237–253. https://doi.org/10.1111/gcb.13092

Cudworth, N. L., & Koprowski, J. L. (2013). Foraging and reproductive behavior of Arizona gray squirrels (Sciurus arizonensis): impacts of climatic variation. *Journal of Mammalogy; Oxford*, *94*(3), 683–690.

Demongin, L., Poisbleau, M., Strange, I. J., & Quillfeldt, P. (2010). Effects of Severe Rains on the Mortality of Southern Rockhopper Penguin (eudyptes Chrysocome) Chicks and Its Impact on Breeding Success. *Ornitologia Neotropical*, *21*(3), 439–443.

deVos, J. C., & Miller, W. H. (2005). Habitat use and survival of Sonoran pronghorn in years with above-average rainfall. *Wildlife Society Bulletin; Bethesda*, *33*(1), 35–42.

dos Santos, S. R., Specht, A., Carneiro, E., de Paula-Moraes, S. V., & Casagrande, M. M. (2017). Interseasonal variation of Chrysodeixis includens (Walker, [1858]) (Lepidoptera: Noctuidae) populations in the Brazilian Savanna. *Revista Brasileira De Entomologia*, *61*(4), 294–299. https://doi.org/10.1016/j.rbe.2017.06.006

Dubost, G., & Henry, O. (2017). Seasonal Reproduction in Neotropical Rainforest Mammals. *Zoological Studies*, *56*(2), 1-9. https://doi.org/10.6620/ZS.2017.56-02

Dugger, K. M., Faaborg, J., Arendt, W. J., & Hobson, K. A. (2004). Understanding Survival and Abundance of Overwintering Warblers: Does Rainfall Matter? *The Condor; Waco*, *106*(4), 744–760.

Facka, A. N., Roemier, G. W., Mathis, V. L., Kam, M., & Geffen, E. (2010). Drought Leads to Collapse of Black-Tailed Prairie Dog Populations Reintroduced to the Chihuahuan Desert. *Journal of Wildlife Management; Bethesda*, *74*(8), 1752–1762.

Fernández-Llario, P., & Mateos-Quesada, P. (2005). Influence of rainfall on the breeding biology of Wild boar (Sus scrofa) in a Mediterranean ecosystem. *Folia Zoologica; Praha*, *54*(3), 240–248.

Ganendran, L. B., Sidhu, L. A., Catchpole, E. A., Chambers, L. E., & Dann, P. (2016). Effects of ambient air temperature, humidity and rainfall on annual survival of adult little penguins Eudyptula minor in southeastern Australia. *International Journal of Biometeorology; Heidelberg*, *60*(8), 1237–1245. https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1007/s00484-015-1119-2

Gedir, J. V., Cain, J. W., Harris, G., & Turnbull, T. T. (2015). Effects of climate change on long-term population growth of pronghorn in an arid environment. *Ecosphere*, *6*(10), 1–20. https://doi.org/10.1890/ES15-00266.1

Greenberg, C. H., Zarnoch, S. J., & Austin, J. D. (2017). Weather, hydroregime, and breeding effort influence juvenile recruitment of anurans: implications for climate change. *Ecosphere*, *8*(5), 1–23. https://doi.org/10.1002/ecs2.1789

Gullett, P., Evans, K. L., Robinson, R. A., & Hatchwell, B. J. (2014). Climate change and annual survival in a temperate passerine: partitioning seasonal effects and predicting future patterns. *Oikos*, *123*(4), 389–400. https://doi.org/10.1111/j.1600-0706.2013.00620.x

Heffelfinger, L. J., Stewart, K. M., Bush, A. P., Sedinger, J. S., Darby, N. W., & Bleich, V. C. (2018). Timing of precipitation in an arid environment: Effects on population performance of a large herbivore. *Ecology and Evolution*, *8*(6), 3354–3366. https://doi.org/10.1002/ece3.3718

Hirschfeld, M., & Rödel, M.-O. (2011). Variable reproductive strategies of an African savanna frog, Phrynomantis microps (Amphibia, Anura, Microhylidae). *Journal of Tropical Ecology; Cambridge*, *27*(6), 601–609. https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1017/S0266467411000320

Hochstedler, W. W., & Gorchov, D. L. (2007). The Effects of June Precipitation on Alliaria petiolata (Garlic Mustard) Growth, Density and Survival. *The Ohio Journal of Science; Columbus*, *107*(3), 26–31.

Imlay, T. L., Flemming, J. M., Saldanha, S., Wheelwright, N. T., & Leonard, M. L. (2018). Breeding phenology and performance for four swallows over 57 years: relationships with temperature and precipitation. *Ecosphere*, *9*(4), 1–15. https://doi.org/10.1002/ecs2.2166

Katandukila, J. V., Faulkes, C. G., Chimimba, C. T., & Bennett, N. C. (2013). Reproduction in the East African root rat (Tachyoryctes splendens; Rodentia: Spalacidae) from Tanzania: the importance of rainfall. *Journal of Zoology*, *291*(4), 258–268. https://doi.org/10.1111/jzo.12067

Kelly, J. P., & Condeso, T. E. (2014). Rainfall Effects on Heron and Egret Nest Abundance in the San Francisco Bay Area. *Wetlands*, *34*(5), 893–903. https://doi.org/10.1007/s13157-014-0551-0

Keynan, O., & Yosef, R. (2010). Annual Precipitation Affects Reproduction of the Southern Grey Shrike (lanius Meridionalis). *The Wilson Journal of Ornithology; Fort Collins*, *122*(2), 334–339.

Lada, H., Thomson, J. R., Cunninghan, S. C., & Mac Nally, R. (2013). Rainfall in prior breeding seasons influences population size of a small marsupial. *Austral Ecology; Richmond*, *38*(5), 581–591. https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1111/aec.12002

Lemoine, N. P., Dietrich, J. D., & Smith, M. D. (2017). Precipitation and environmental constraints on three aspects of flowering in three dominant tallgrass species. *Functional Ecology*, *31*(10), 1894–1902. https://doi.org/10.1111/1365-2435.12904

Loehr, V. J. T., Henen, B. T., & Hofmeyr, M. D. (2011). Reproductive Responses to Rainfall in the Namaqualand Speckled Tortoise. *Copeia; North Miami*, *2011*(2), 278–284.

Macario, P., Pichorim, M., Doherty, P. F., Toledo-Lima, G. S., Oliveira-Júnior, T. M., Câmara, T. P. F., Melo, S. M., Silveira, J. L. S., Araújo, J. C., & França, L. F. (2017). Apparent survival and cost of reproduction for White-lined Tanager (Tachyphonus rufus, Thraupidae) in the northern Atlantic Rainforest, Brazil. *PLoS One; San Francisco*, *12*(10), 1–15. https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1371/journal.pone.0185890

Magdalita, P. M., & Saludes, R. B. (2015). Influence of Changing Rainfall Patterns on the Yield of Rambutan ( Nephelium lappaceum L.) and Selection of Genotypes in Known Drought-tolerant Fruit Species for Climate Change Adaptation. *Science Diliman*, *27*(1), 64–90. https://journals.upd.edu.ph/index.php/sciencediliman/article/view/4610

Mares, R., Doutrelant, C., Paquet, M., Spottiswoode, C. N., & Covas, R. (2017). Breeding decisions and output are correlated with both temperature and rainfall in an arid-region passerine, the sociable weaver. *Royal Society Open Science*, *4*(9), 1–12. https://doi.org/10.1098/rsos.170835

McDermott, M. E., & DeGroote, L. W. (2016). Long-term climate impacts on breeding bird phenology in Pennsylvania, USA. *Global Change Biology*, *22*(10), 3304–3319. https://doi.org/10.1111/gcb.13363

Mckellar, A. E., Marra, P. P., Hannon, S. J., Studds, C. E., & Ratcliffe, L. M. (2013). Winter rainfall predicts phenology in widely separated populations of a migrant songbird. *Oecologia; Heidelberg*, *172*(2), 595–605. https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1007/s00442-012-2520-8

Medger, K., Chimimba, C. T., & Bennett, N. C. (2012). Seasonal reproduction in the eastern rock elephant-shrew: influenced by rainfall and ambient temperature? *Journal of Zoology*, *288*(4), 283–293. https://doi.org/10.1111/j.1469-7998.2012.00954.x

Mero, T. O., Zuljevic, A., Varga, K., Bocz, R., & Lengyel, S. (2014). Effect of reed burning and precipitation on the breeding success of Great Reed Warbler, Acrocephalus arundinaceus, on a mining pond. *Turkish Journal of Zoology*, *38*(5), 622–630. https://doi.org/10.3906/zoo-1311-54

Mmassy, E. C., Fyumagwa, R. D., Jackson, C. R., Bevanger, K., & Røskaft, E. (2017). Kori bustard (Ardeotis kori struthiunculus) occurrence in the Serengeti grass plains, northern Tanzania. *African Journal of Ecology*, *55*(3), 298–304. https://doi.org/10.1111/aje.12351

Monadjem, A., & Bamford, A. J. (2009). Influence of rainfall on timing and success of reproduction in Marabou Storks Leptoptilos crumeniferus. *Ibis*, *151*(2), 344–351. https://doi.org/10.1111/j.1474-919X.2009.00912.x

Nadal, J., Ponz, C., & Margalida, A. (2018). Synchronizing biological cycles as key to survival under a scenario of global change: The Common quail (Coturnix coturnix) strategy. *Science of The Total Environment*, *613–614*(Feb 2018), 1295–1301. https://doi.org/10.1016/j.scitotenv.2017.09.168

Ndithia, H. K., Bakari, S. N., Matson, K. D., Muchai, M., & Tieleman, B. I. (2017). Geographical and temporal variation in environmental conditions affects nestling growth but not immune function in a year-round breeding equatorial lark. *Frontiers in Zoology*, *14*(28), 1–14. https://doi.org/10.1186/s12983-017-0213-1

Ndithia, H. K., Matson, K. D., Versteegh, M. A., Muchai, M., & Tieleman, B. I. (2017). Year-round breeding equatorial Larks from three climatically-distinct populations do not use rainfall, temperature or invertebrate biomass to time reproduction. *PLoS One; San Francisco*, *12*(4), 1–18 https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1371/journal.pone.0175275

Neuhaus, P., Bennett, R., & Hubbs, A. (1999). Effects of a late snowstorm and rain on survival and reproductive success in Columbian ground squirrels (Spermophilus columbianus). *Canadian Journal of Zoology; Ottawa*, *77*(6), 879–884.

Ockendon, N., Johnston, A., & Baillie, S. R. (2014). Rainfall on wintering grounds affects population change in many species of Afro-Palaearctic migrants. Journal of Ornithology, 155(4), 905–917. https://doi.org/10.1007/s10336-014-1073-5

Öberg, M., Arlt, D., Pärt, T., Laugen, A. T., Eggers, S., & Low, M. (2015). Rainfall during parental care reduces reproductive and survival components of fitness in a passerine bird. *Ecology and Evolution*, *5*(2), 345–356. https://doi.org/10.1002/ece3.1345

Ogutu, J. O., Owen-Smith, N., Piepho, H.-P., & Dublin, H. T. (2015). How Rainfall Variation Influences Reproductive Patterns of African Savanna Ungulates in an Equatorial Region Where Photoperiod Variation Is Absent. *PLoS One; San Francisco*, *10*(8), 1–13 https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1371/journal.pone.0133744

Pagoti, G. F., & Willemart, R. H. (2015). Strong seasonality and clear choice of resting plant in a Neotropical harvestman (Arachnida: Opiliones). *Journal of Arachnology*, *43*(2), 207–213.

Patten, M. A., & Rotenberry, J. T. (1999). The proximate effects of rainfall on clutch size of the California Gnatcatcher. *The Condor; Waco*, *101*(4), 876–880.

Pelaez, M., San Miguel, A., Rodriguez-Vigal, C., & Perea, R. (2017). Climate, female traits and population features as drivers of breeding timing in Mediterranean red deer populations. *Integrative Zoology*, *12*(5), 396–408. https://doi.org/10.1111/1749-4877.12252

Pipoly, I., Bókony, V., Seress, G., Szabó, K., & Liker, A. (2013). Effects of Extreme Weather on Reproductive Success in a Temperate-Breeding Songbird. *PLoS One; San Francisco*, *8*(11), 1–11. https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1371/journal.pone.0080033

Reynolds, R. T., Lambert, J. S., Flather, C. H., White, G. C., Bird, B. J., Baggett, L. S., Lambert, C., & Bayard De Volo, S. (2017). Long-term demography of the

Northern Goshawk in a variable environment. *Wildlife Monographs*, *197*(1), 1–40. https://doi.org/10.1002/wmon.1023

Rockwell, S. M., Bocetti, C. I., & Marra, P. P. (2012). Carry-over effects of winter climate on spring arrival date and reproductive success in an endangered migratory bird, Kirtland's Warbler (Setophaga kirtlandii). *The Auk; Waco*, *129*(4), 744–752. https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1525/auk.2012.12003

Rockwell, S. M., Wunderle, J. M., Sillett, T. S., Bocetti, C. I., Ewert, D. N., Currie, D., White, J. D., & Marra, P. P. (2017). Seasonal survival estimation for a long-distance migratory bird and the influence of winter precipitation. *Oecologia*, *183*(3), 715–726. https://doi.org/10.1007/s00442-016-3788-x

Rojas-Sandoval, J., & Meléndez-Ackerman, E. (2011). Reproductive phenology of the Caribbean cactus Harrisia portoricensis: rainfall and temperature associations. *Botany*, *89*(12), 861–871. https://doi.org/10.1139/b11-072

Rubio, L., Bock, B., & Paez, V. (2011). Continuous Reproduction Under a Bimodal Precipitation Regime in a High Elevation Anole (anolis Mariarum) from Antioquia, Colombia. *Caldasia; Bogota*, *33*(1), 91–104. https://search-proquest-com.ezproxy.uaeu.ac.ae/docview/1677410773/abstract/E92EC73236274435PQ/64

Salinas-Peba, L., Parra-Tabla, V., Campo, J., & Munguia-Rosas, M. A. (2014). Survival and growth of dominant tree seedlings in seasonally tropical dry forests of Yucatan: site and fertilization effects. *Journal of Plant Ecology*, *7*(5), 470–479. https://doi.org/10.1093/jpe/rtt055

Saracco, J. F., Radley, P., Pyle, P., Rowan, E., Taylor, R., & Helton, L. (2016). Linking Vital Rates of Landbirds on a Tropical Island to Rainfall and Vegetation Greenness: . *PLoS One; San Francisco*, *11*(2), 1–18 https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1371/journal.pone.0148570

Sarli, J., Lutermann, H., Alagaili, A. N., Mohammed, O. B., & Bennett, N. C. (2015). Reproductive patterns in the Baluchistan gerbil, Gerbillus nanus (Rodentia: Muridae), from western Saudi Arabia: The role of rainfall and temperature. *Journal of Arid Environments*, *113*(Feb 2015), 87–94. https://doi.org/10.1016/j.jaridenv.2014.09.007

Saunders, D. A., Wintle, B. A., Mawson, P. R., & Dawson, R. (2013). Egg-laying and rainfall synchrony in an endangered bird species: Implications for conservation in a changing climate. *Biological Conservation*, *161*(May 2013), 1–9. https://doi.org/10.1016/j.biocon.2013.02.004

Schuett, G. W., Repp, R. A., & Hoss, S. K. (2011). Frequency of reproduction in female western diamond-backed rattlesnakes from the Sonoran Desert of Arizona is variable in individuals: potential role of rainfall and prey densities. *Journal of Zoology; London*, *284*(2), 105–113.

Seabrook, L., McAlpine, C., Baxter, G., Rhodes, J., Bradley, A., & Lunney, D. (2011). Drought-driven change in wildlife distribution and numbers: a case study of koalas in south west Queensland. *Wildlife Research*, *38*(6), 509–524. https://doi.org/10.1071/WR11064

Sexson, M. G., & Farley, G. H. (2012). Snowy plover nest survival in Kansas and effective management to counter negative effects of precipitation. *The Journal of Wildlife Management*, *76*(8), 1587–1596. https://doi.org/10.1002/jwmg.405

Shaw, A. K., & Kelly, K. A. (n.d.). Linking El Niño, local rainfall, and migration timing in a tropical migratory species. *Global Change Biology*, *19*(11), 3283–3290. https://doi.org/10.1111/gcb.12311

Shaw, P. (2017). Rainfall, leafing phenology and sunrise time as potential Zeitgeber for the bimodal, dry season laying pattern of an African rain forest tit (Parus fasciiventer). *Journal of Ornithology*, *158*(1), 263–275. https://doi.org/10.1007/s10336-016-1395-6

Shen, M., Piao, S., Cong, N., Zhang, G., & Jassens, I. A. (n.d.). Precipitation impacts on vegetation spring phenology on the Tibetan Plateau. *Global Change Biology*, *21*(10), 3647–3656. https://doi.org/10.1111/gcb.12961

Shrader, A. M., Pimm, S. L., & van Aarde, R. J. (2010). Elephant survival, rainfall and the confounding effects of water provision and fences. *Biodiversity & Conservation; Dordrecht*, *19*(8), 2235–2245. https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1007/s10531-010-9836-7

Sidorovich, V., Schnitzler, A., Schnitzler, C., & Rotenko, I. (2017). Wolf denning behaviour in response to external disturbances and implications for pup survival. *Mammalian Biology*, *87*(Nov 2017), 89–92. https://doi.org/10.1016/j.mambio.2016.11.011

Sieg, A. E., Gambone, M. M., Wallace, B. P., Clusella-Trullas, S., Spotila, J. R., & Avery, H. W. (n.d.). Mojave desert tortoise (Gopherus agassizii) thermal ecology and reproductive success along a rainfall cline. *Integrative Zoology*, *10*(3), 282–294. https://doi.org/10.1111/1749-4877.12132

Srygley, R. B., Dudley, R., Oliveira, E. G., Aizprua, R., Pelaez, N. Z., & Riveros, A. J. (2010). El Nino and dry season rainfall influence hostplant phenology and an annual butterfly migration from Neotropical wet to dry forests. *Global Change Biology*, *16*(3), 936–945. https://doi.org/10.1111/j.1365-2486.2009.01986.x

Styrsky, J. N., & Brawn, J. D. (2011). Annual Fecundity of a Neotropical Bird During Years of High and Low Rainfall. *The Condor; Waco*, *113*(1), 194–199. https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1525/cond.2011.100051

Urrego, L. E., Galeano, A., Peñuela, C., Sánchez, M., & Toro, E. (2016). Climate-related phenology of Mauritia flexuosa in the Colombian Amazon. *Plant Ecology; Dordrecht*, *217*(10), 1207–1218. https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1007/s11258-016-0647-0

Van Stan, J. T., Coenders-Gerrits, M., Dibble, M., Bogeholz, P., & Norman, Z. (2017). Effects of phenology and meteorological disturbance on litter rainfall interception for a Pinus elliottii stand in the Southeastern United States. *Hydrological Processes*, *31*(21), 3719–3728. https://doi.org/10.1002/hyp.11292

Wang, Y., Zeng, Z.-G., Li, S.-R., Bi, J.-H., & Du, W.-G. (2016). Low precipitation aggravates the impact of extreme high temperatures on lizard reproduction. *Oecologia*, *182*(4), 961–971. https://doi.org/10.1007/s00442-016-3727-x

Xin-Ju, X., Ke-Wei, L., Yu-Yun, Z., Yu-Ting, Z., Tsai, W.-C., Yu-Yun, H., Guo-Qiang, Z., Li-Jun, C., & Zhong-Jian, L. (2012). Predicted Disappearance of Cephalantheropsis obcordata in Luofu Mountain Due to Changes in Rainfall Patterns. *PLoS One; San Francisco*, *7*(1), 1–8. https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1371/journal.pone.0029718

Zhou, W., Wu, N., & Bao, W. (2010). Growth and potential reproduction of Poa crymophila in response to season precipitation shortage in the Eastern Tibetan Plateau, China. *Russian Journal of Ecology; New York*, *41*(2), 147–152. https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1134/S1067413610020062

Zhu, Y., Yang, X., Baskin, C. C., Baskin, J. M., Dong, M., & Huang, Z. (2014). Effects of amount and frequency of precipitation and sand burial on seed germination, seedling emergence and survival of the dune grass Leymus secalinus in semiarid China. *Plant and Soil; Dordrecht*, *374*(1–2), 399–409. https://doi.org/http://dx.doi.org.ezproxy.uaeu.ac.ae/10.1007/s11104-013-1892-9

**Appendix C:** Numbers of studies on each taxonomic group for each of the biomes

| | Mammals | Birds | Reptiles | Amphibians | Invertebrates | Plants |
|---|---|---|---|---|---|---|
| Deserts | 8 | 3 | 4 | - | - | - |
| Savannah | 16 | 13 | - | 2 | 1 | - |
| Montane Grassland | - | - | - | - | - | 5 |
| Mediterranean | 3 | 4 | - | - | - | - |
| Temperate Grassland | 2 | 8 | - | - | - | 4 |
| Temperate Forest | 3 | 31 | - | - | - | 3 |
| Tropical Forest | 10 | 26 | 1 | - | 3 | 8 |
| Wetland | - | 4 | - | 7 | - | - |

**Appendix D:** Numbers of studies using each performance metric on each taxonomic group

| | Growth rate | Phenology | Rate of Increase/ Abundance | Reproductive rate | Survival rate |
|---|---|---|---|---|---|
| Mammals | 1 | 9 | 2 | 19 | 11 |
| Birds | 8 | 28 | 18 | 18 | 15 |
| Reptiles | - | - | - | 5 | - |
| Amphibians | - | - | 6 | 2 | 1 |
| Invertebrates | - | 3 | - | -- | 1 |
| Plants | 6 | 7 | - | 2 | 5 |

**Appendix E:** Numbers of studies using each performance metric in each biome

| | Growth rate | Phenology | Rate of Increase/ Abundance | Reproductive rate | Survival rate |
|---|---|---|---|---|---|
| Deserts | 1 | 2 | 2 | 9 | 1 |
| Savannah | 2 | 5 | 11 | 6 | 8 |
| Montane Grassland | - | 3 | 1 | - | 1 |
| Mediterranean | - | 2 | - | 5 | - |
| Temperate Grassland | 3 | 2 | - | 1 | 8 |
| Temperate Forest | 2 | 22 | 1 | 9 | 3 |
| Tropical Forest | 3 | 11 | 8 | 15 | 11 |
| Wetland | 4 | - | 6 | - | 1 |

جامعة الإمارات العربية المتحدة
United Arab Emirates University
UAEU Libraries
DigitizationDepatment
United Arab Emirates
Digitally signed by Shrieen
DN: cn=Shrieen, o=United Arab Emirates University, ou=UAEU Library Digitizatio, email=shrieen@uaeu.ac.ae, c=AE
Date: 2020.07.26 13:11:52 +04'00'