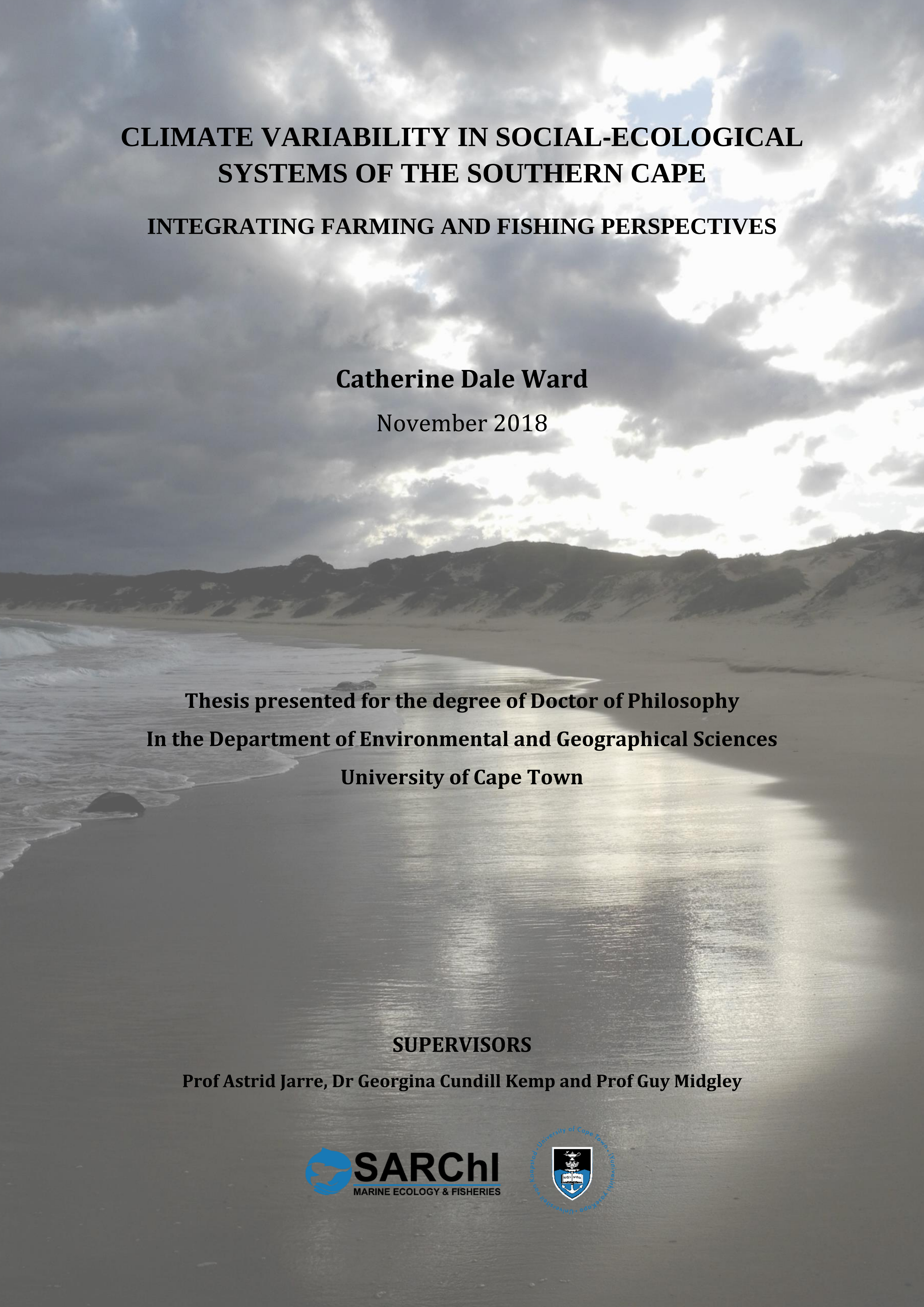


CLIMATE VARIABILITY IN SOCIAL-ECOLOGICAL SYSTEMS OF THE SOUTHERN CAPE

INTEGRATING FARMING AND FISHING PERSPECTIVES

Catherine Dale Ward

November 2018

Thesis presented for the degree of Doctor of Philosophy

In the Department of Environmental and Geographical Sciences

University of Cape Town

SUPERVISORS

Prof Astrid Jarre, Dr Georgina Cundill Kemp and Prof Guy Midgley

SARChI MARINE ECOLOGY & FISHERIES

DECLARATION

I know the meaning of plagiarism and declare that all of the work in this thesis, save for that which is properly acknowledged, is my own. This thesis has not been submitted in whole or in part for a degree at any other university.

Signed: C.D. Ward

Date: July 2018

ACKNOWLEDGEMENT OF FUNDING

Financial support was provided by the South African Research Chairs Initiative of the Department of Science and Technology and the National Research Foundation.

The financial assistance of the National Research Foundation towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at, are those of the author and are not necessarily to be attributed to the National Research Foundation.

ACKNOWLEDGEMENTS

It is with the first and greatest thanks to my supervisors Prof Astrid Jarre, Dr Georgina Cundill Kemp and Prof Guy Midgley for the invaluable support, guidance, motivation, encouragement and time given to me during this thesis. I would like to thank the South African Research Chairs Initiative of the Department of Science and Technology and the National Research Foundation for financial support through the South African Research Chair in Marine Ecology and Fisheries. I would also like to thank the South African Weather Service, Western Cape Department of Agriculture, Riversdale Co-operation, Tarron Lamont and Fabien Desbiolles for data contributions. I am very grateful to Muhammad Jamal for his valuable guidance when assisting me with data analyses. Thank you to the Integration and Application Network for the amazing material available on their online symbol library and to the UCT GIS Laboratory for assisting with map creation.

I am very grateful to the support given to me in the southern Cape and would like to give special thanks to the farming and agricultural community for giving their time and invaluable contributions to this thesis. In particular I would like to thank Douglas Taylor, Ronny de Klerk, Elanore Nel and Hannetjie Ferguson. I am also very grateful to my research assistant, Evangeline Motley, for her dedication and good company for the many hours spent on the road. I am very appreciative for the support from the Southern Cape Interdisciplinary Fisheries project in both the office and in the field, with special thanks to Greg Duggan. In particular, thank you to Louise Gammage for all her invaluable support and sage advice.

Thank you to the staff in the Biological Sciences Department, particularly to the ladies downstairs, for keeping the research running smoothly and fielding all my claims, requests and funding-related needs. I would like to give special thanks to Elizabeth for her daily pearls of wisdom and encouragement shared with the students in the department.

Finally, thank you to my personal support base – family, friends and colleagues. Thanks to Emily McGregor for starting this journey and the many friends who shared a sympathetic ear throughout this process. Thank you to the SARChI lab for the tea support group and whimsical conversations. Thank you to my mother for undertaking the task of being editor-in-chief for this thesis, and thank you to my sister and father for all their encouragement and support. Finally, I would like to thank my better half, Sunny, for making sure this thing got done.

ABSTRACT

Large scale shifts playing out on global climate levels are manifesting locally in the South Africa's terrestrial and marine ecosystems, where it is difficult to predict how different habitats may respond to these changes in natural systems, particularly at local levels. For example, the highly complex nature of climate variability in the southern Cape and on the Agulhas Bank, coupled with the lack of long-term environmental monitoring data, has resulted in knowledge gaps on how climate impacts these local social-ecological systems. This thesis focuses on bringing together knowledge systems from farmers, handline fishers and local scientific weather sources to examine climate variability in terrestrial and marine social-ecological systems of the southern Cape, in order to bring local perspectives into conversation with scientific data outputs. Through examining different knowledge systems in parallel and overlaying different perspectives and observations, this thesis contributes towards a better understanding of complex systems change, linked through the common thread of climate variability under a resilience lens, at the local scale of the southern Cape and Agulhas Bank. This thesis also contextualises responses to change under the theme of climate variability from farmers' and fishers' perspectives, and shows how different theoretical discourses can work in a complementary fashion to address complexity.

The terrestrial component of this thesis examined local agricultural perspectives by surveying southern Cape farmers, and built in terrestrial scientific data through looking at local climate in relation to farming perspectives. Observations on terrestrial rainfall and temperatures were collected through interviews with 50 farmers, along with shared rainfall records from 13 farming families and ten official weather stations in the area. Fisher perspectives in relation to climate variability were then integrated with marine scientific data to examine the marine component of the Agulhas Bank. Fisher observations of climate variability were examined by drawing on existing research conducted through the South Coast Interdisciplinary Research Project. Marine wind data were obtained through model outputs from NCEP-DOE Reanalysis and a recent scatterometer-based product.

Overlaying these different bodies of knowledge reduced the uncertainties associated with any single set of observations and confirmed two environmental regime shifts in the region, in the mid-1990s and end-2000s. Local climate knowledge of farmers and fishers also overlapped and corroborated these environmental regime shifts. Changes in prevailing wind direction, rather than wind speed, were more prominent over time. While no clear trends of change over time were found in rainfall and temperature time series, decadal variability was present and after the mid-2000s, the onset of seasonal autumn rainfall was found to have shifted to a month later. Knowledge disconnects were broadly related to scale mismatches between fisher observations and marine data tendencies; complexities around freshwater availability; and shifting baselines of natural resources concerning present versus past variability observed by farmers and fishers. Responses to climate variability were complex and other stressors associated with economic and political challenges were usually seen as a greater threat to local livelihoods. However, climate stressors can push social-ecological systems into vulnerable states if not well integrated into adaptation strategies, which can have serious implications for future food and job security in the southern Cape. Local-based case studies such as this one increase understanding of local social-ecological systems under global change in an effort to contribute to future adaptation strategies in the southern Cape region.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1. Overview

Large scale global shifts in climate are manifesting locally in South Africa's terrestrial and marine ecosystems, shifting familiar weather patterns and altering valuable food supply chains (Watermeyer et al., 2016; Masipa, 2017). This, compounded with economic uncertainty and political unease, is changing social and ecological systems in South Africa and there is an urgent need for society to respond and adapt accordingly.

The impacts of climate variability on local environments in South Africa, have been demonstrated across many metropolitan and rural areas in the country. In 2015, five provinces (KwaZulu-Natal, Mpumalanga, North West, Limpopo and Free State) were declared drought disaster areas, where country-wide maize production declined by 31 % between 2013 and 2014 due to this drought (Ngoepe, 2015). The Western Cape Province followed suit in 2017 and was also declared a disaster zone in response to one of the most severe droughts experienced since 1904 (Dentlinger, 2017). It is projected by officials that 17 000 jobs could be lost in this province's agricultural sector as a result of the drought, as well as an estimated R3.2 billion loss for the South African economy due to a possible drop in the Western Cape's agricultural outputs (Evans, 2017). Severe multi-year droughts such as the below average rainfall years of 2015-2017 in the Western Cape are rare; however, compounded with a sprawling urban populace, increased demand for (irrigated) agricultural production and difficulty to predict highly variable rainfall patterns, it is expected that this province could run out of water during the course of 2018 (Wolski et al., 2017). It appears that these unfavourable changes in the local climate may persist as the 'new normal' (Wolski, 2017).

Similarly in marine environments, South Africa's fisheries have experienced a suite of challenges over the past two decades, ranging from both anthropogenic and biophysical spheres of this system (van Sittert et al., 2006; Hutchings et al., 2012; Mead et al., 2013).

From the fishery perspective, half of commercial fish stocks for the country are considered to be over-exploited, with over 20 percent of these exploited stocks considered to be depleted or heavily over-fished (DAFF, 2014). For example, in 2000, the Minister of Environmental Affairs and Tourism declared an emergency in the linefish sector in an effort to protect severely depleted stocks (Government Gazette, 2000). Environmental changes in the South African marine environment have also exacerbated rapidly depleting stocks and compromised commercial industry, such as the shift in distribution of various commercially-significant fish stocks (Blamey et al., 2012) and increased variability of wind and temperature in marine systems (Jarre et al., 2015). Some primary threats to South Africa's marine ecosystems include overfishing, pollution, invasive species, habitat destruction and climate change (Blamey et al., 2015; James, 2015). Negative impacts on the fishery sector due to over exploitation and/or environmental variability will be most acutely felt in the Western Cape, as fisheries make an important economic contribution (five percent) towards the local regional economy (DAFF, 2015).

Understanding how important sectors such as agriculture and fisheries respond to climate variability is crucial to build a comprehensive picture of how these systems can respond to change, particularly at local scales where multiple stressors can play different roles depending on 'on the ground' experiences and perceptions. This introduction looks at the changing climate of South Africa, along with the dynamics of the country's agriculture and fishery sectors, to provide an overview before examining the nuanced local example of climate variability as experienced by farmers and fishers in a specific area of South Africa – the southern Cape. Therefore, this introduction of climate variability, which focuses on agriculture and fishery sectors, looks at three nested spatial scales (refer to Figure 1.1):

- **national scale** constituting terrestrial South Africa and the Benguela Current Large Marine Ecosystem;
- **regional scale** constituting the Western Province and the Southern Benguela South Coast subsystem; and
- **local scale** constituting the southern Cape (area between Witsand and Mossel Bay) and the Agulhas Bank.

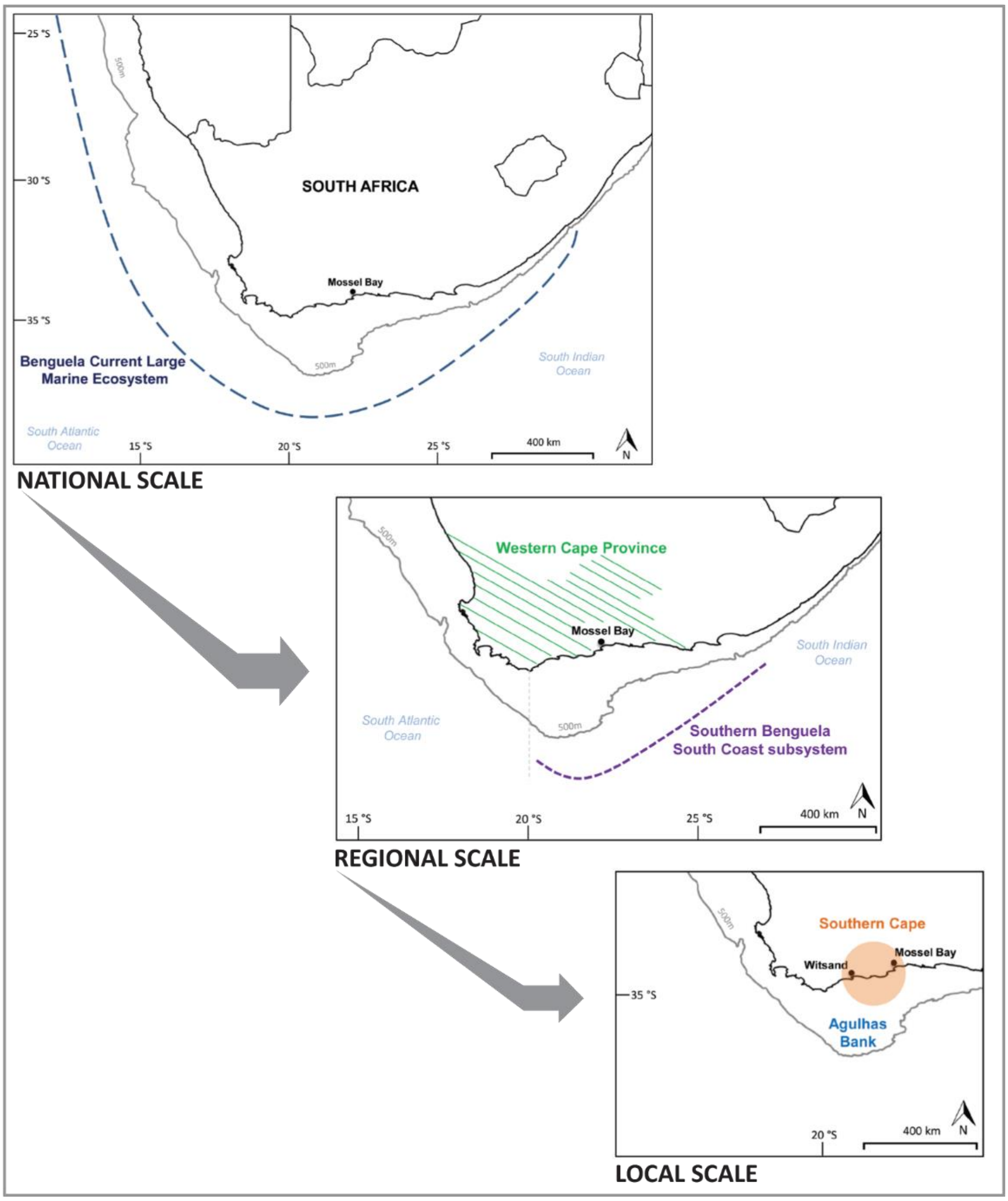


Figure 1.1: Three nested spatial scales, of which the local scale (i.e. southern Cape and Agulhas Bank) is the focus of this thesis

1.2. South Africa's changing climate

South Africa has a subtropical climate moderated by ocean on three sides of the country and, as detailed above, changes in local climate could have significant implications for communities reliant on weather, such as farmers and fishers. Local climate impacts have numerous implications for the future development of South Africa, and require a deeper understanding into the dynamics around such environmental changes within the complex realm of social-ecological systems. This section explores South Africa's changing climate through a terrestrial and marine lens in turn, to gain a better understanding of complexities associated with social-ecological systems from both perspectives.

1.2.1. Climate through a terrestrial lens

For South Africa as a whole, mean annual temperatures have generally increased 1.5 times more than the observed 0.65 degrees Celsius global average over the past five decades and warming trends are likely to be observed predominately in the interior of the country (DEA, 2013; Ziervogel et al., 2014). Generally, minimum and maximum temperatures have displayed significant increases every year, across almost all seasons (DEA, 2013). Rainfall has always shown high inter-annual variability and predictions of precipitation changes are less certain in terms of both direction and magnitude than air temperature (DEA, 2013; MacKellar et al., 2014; Ziervogel et al., 2014). South Africa, like other developing countries, is particularly vulnerable to climate change impacts. With terrestrial temperatures projected to increase even under optimistic scenarios according to the Long Term Adaptation Scenarios (LTAS) programme (DEA, 2013), parts of South Africa are predicted to become much drier with decreased water availability. Extreme environmental events such as fires, storms, floods and droughts are projected to increase in frequency and severity.

The Western Cape is one of the South African regions most likely to be highly vulnerable to projected climate change-induced warming and rainfall change (Midgley et al., 2005; Wiid and Ziervogel, 2012). This region has a highly diverse production environment that supports a diverse local agricultural economy. However, it is prone to warming conditions and stressed water supplies (Midgley et al., 2016). Work carried out by MacKellar et al. (2014) on observed and modelled trends in rainfall and temperature for South Africa from 1960 to 2010 found that maximum temperatures had significantly increased for all seasons in the Western Cape, with strong warming occurring over the last ten years. The study also noted that while trends in rainfall indices were generally not significant and were inconsistent across the Western Cape region, the number of rain days indicated drier conditions along the southern coastal regions. When scaling further down to the southern Cape area within the Western Cape region, model outputs from the LTAS programme indicate a significant increase in flooding risk for the future (DEA,

2013) and Midgley et al. (2016) note that current warming trends are expected to continue in this area.

1.2.2. Climate through a marine lens

The South African coastline, considered one of the most naturally variable in the world, is approximately 3100 km long and incorporates ecoregions ranging from cool-temperate on the west coast, warm-temperate on the south coast to subtropical on the east coast (Mead et al., 2013). The oceans off South Africa hold a prominent position in the global ocean conveyor belt. The Benguela Current Large Marine Ecosystem (BCLME) is a large marine eastern boundary current system dominated by coastal upwelling that is a very productive region in terms of commercially-exploited fisheries (Jarre et al., 2015). The BCLME consists of four alongshore subsystems – the (1) Angolan Subtropical subsystem and the (2) Northern Benguela upwelling off the west coasts of Angola and Namibia; the (3) Southern Benguela West Coast off South Africa with an upwelling subsystem comprised of the west coast and Western Agulhas Bank; and the (4) Southern Benguela South Coast subsystem which consists of the Central and Eastern Agulhas Bank until East London (Jarre et al., 2015). These upwelling systems display substantial variability in both oceanographic and biological components (Hutchings et al., 2009; Hutchings et al., 2012).

On a global scale, environmental drivers of change in marine systems include ocean surface warming, increased wind stress, expanding low-oxygen zones, increased surface stratification and nutrient distribution changes (Jarre et al., 2015). These changes within the BCLME would be compounded by heavy fishing pressure that has been taking place since the 1950s (Hutchings et al., 2009; Jarre et al., 2013; 2015), placing high pressure on this ecosystem in the face of climate changes. The southern Benguela system has seen shifts in climate drivers such as wind patterns, upwelling and ocean temperature (Jarre et al., 2015) and environmental variability has been recorded in the Agulhas Bank subsystem (Blamey et al., 2012). In terms of wind variation in the Agulhas Bank, a decline in easterly (upwelling favourable) winds was observed during the 1980s for over a decade, but then strong south easterly winds dominated most of the 1990s (Blamey et al., 2015).

Understanding changes in the ocean around South Africa is important as ocean currents and water masses have a profound influence on the weather and climate of the continent (Zietsman, 2011). For example, air moving over the Agulhas Current picks up heat and moisture that can enhance rainfall events when this water mass moves over land, which can result in flood events along the southern coast of South Africa (Zietsman, 2011). Understanding how these different terrestrial and marine systems overlap at local scales and how natural resource users, such as farmers and fishers, experience change within these natural systems can reduce uncertainties associated with these complex systems. The role of healthy ecosystems, that can provide productive and sustainable ecosystem services, are advocated as a viable means to respond to risks associated with climate variability through managing anthropogenic activities in natural ecosystems on land and at sea to improve resilience to climate change impacts (Driver et al., 2012; Biggs et al., 2015).

1.3. Farming and fishing in changing environments

Healthy, functioning systems are vital to ensure the sustainability of food production where food security can be provided without compromising ecological integrity, and in turn social well-being and economic stability. Food production systems are fundamental to human survival, particularly in South Africa where approximately 11.5 million people (approximately 20 percent of the population) experience insufficient to severe inadequate access to food (DAFF, 2012). The future of agricultural and fishery sectors in South Africa are strongly influenced by multiple pressures such as climate and environmental variability, population growth, skill gaps, consumer demands, national market performance and global economy shifts. In the case of this thesis, understanding how complex drivers such as climate variability affect these sectors is important, particularly at the local scale of the southern Cape and Agulhas Bank, as mismatches between different scales can result in knowledge gaps and increase uncertainty in these complex systems.

1.3.1. Agriculture

South Africa has a dual agricultural economy that consists of a well-established commercial farming sector, as well as the less formalised subsistence-based production sector. Over the last 20 years, the contribution of the agricultural sector to the country's gross domestic product (GDP) has decreased to approximately 2.8 percent (DAFF, 2015). While primary agriculture does not make a large contribution to the overall South African GDP, the broader agro-food complex contributes up to 14 percent towards the GDP as this sector is one of the most employment-intensive sectors within the South African economy (DAFF, 2015). Since the 1950s, the number of commercial farms involved in primary agriculture have decreased by about 70 percent, in parallel with a commensurate increase in average farm size and change in technology mix on farms (DAFF, 2015). Present challenges, as highlighted by the South African government, associated with the agricultural industry include job losses due to increased capital and industrial inputs, unequal wealth distribution due to former homeland policies, and high input costs that erode the competitiveness of agriculture (DAFF, 2015).

Unsurprisingly, the South African agriculture sector is considered to be one of the more vulnerable sectors to changing natural systems (Midgley et al., 2005). On a national scale, increasing temperatures, uncertainty around water availability due to inter- and intra-seasonal variation and an increase in extreme weather events such as severe droughts or heavy floods are some of the possible challenges farmers will face in the future (Rosin et al., 2012). Climate change may also propagate invasive species, pests and disease that can constrain and impact agricultural productivity (Rosin et al., 2012). There is a need for more research into the complex relationship between temperature, rainfall and water availability for agriculture to better understand the impacts of these multifaceted dynamics within agricultural contexts (Midgley et al., 2005).

In the Western Cape specifically, climate change effects are predicted to have negative impacts on regional agricultural productivity (Midgley et al., 2005; Wiid and Ziervogel, 2012; Midgley et al., 2016). While this province's agricultural sector is well developed, the future development of this sector could be compromised due to changing climatic conditions (Midgley et al., 2016). Although the region is generally regarded as climatically stable, it is prone to extreme climatic events and observed climate trends over the past five decades indicate an increased frequency of hot extremes, and more frequent and intense rainfall events are projected for the Western Cape (DEA, 2013; Midgley et al., 2016). On the local scale, farmers residing in the Little Brak River area, adjacent to Mossel Bay to the east, have noted changes in their natural terrestrial system that are generally in agreement with local scientific weather data (Wiid, 2009). Climate variability observed by participating farmers in this community included decreased winter rainfall and increased summer rainfall from the early 1990s to late 2000s; increased flooding events and frequent drought conditions over the last decade; greater presence of northerly winds between the mid-2000s to late 2000s; and an increase in temperature extremes over the past three decades.

1.3.2. Fisheries

While the national formal fisheries sector makes a comparatively small contribution of 0.1 percent to the South African GDP, it is particularly important for economic development in the Western Cape as the majority (11 out of 13) proclaimed fishing harbours are situated in this province (DAFF, 2015). Here, the importance of local fisheries is demonstrated by the fact that this sector contributes five percent to the gross provincial domestic product. An estimated 27 000 people are employed directly by the fishing industry, while there are an additional 81 000 jobs in industries that are partially dependent on fisheries (DAFF, 2015).

As in the case of agriculture, changes within the natural marine environment of South Africa can compromise the fishing sector and its contribution to the local economy and human well-being. Examples of changes in commercially valuable fish stocks can be drawn from South Africa's small pelagic fishery operating within the southern Benguela system. Anchovy (*Engraulis encrasiolus*) and sardine (*Sardinops sagax*), both economically and ecologically important species, have shifted eastwards in recent years due to environmental changes and anthropogenic forcing through fishing. The changed distribution patterns of these commercially significant species have had far-reaching adverse consequences for both the South African fishery and the ecosystem (Coetzee et al., 2008; Jarre et al., 2013; Watermeyer et al., 2018).

While environmental changes have been documented in the southern Benguela system and specifically the Agulhas Bank subsystem such as increased inter-annual variability (Blamey et al., 2012), shifts in this marine environment, whether due to environmental forcing or fishing pressures or both, remain poorly understood due to scientific data discrepancies (Lamont et al., 2017). Changes in the natural marine environment of the Agulhas Bank have been noted by linefishers in the southern Cape, as reflected by research carried out by Duggan (2012) and Gammage (2015). Observed variability in the natural system was identified as a key stressor for these fishers and was largely described in terms of warmer air and sea temperatures, as well as increased intra-seasonal variability in prevailing wind conditions over the past three decades (Gammage et al., 2017a).

When examining agriculture and fishery sectors, it is very important to understand how these natural systems may be changing, as well as how natural resource users respond to perceived changes, so that human activities can be managed to maintain valuable ecosystem services accordingly, with the aim of avoiding environmental degradation or (fish) stock collapse. Shifts in natural terrestrial or marine environments can have far-reaching consequences for food production if prevailing climate and biotic conditions alter into different states or become progressively unstable through increased variability. It is also important to gain a more holistic understanding of where these local social-ecological systems overlap, as terrestrial and marine systems do not function in isolation.

1.4. Connecting knowledge systems

Climate variability and change can affect local social-ecological on a number of temporal and spatial scales, with complexity arising out of these systems due to possible scale mismatches and problematic translation between different bodies of knowledge, where uncertainty is increased as a result of gaps in understanding. In local social-ecological systems such as the southern Cape and the Agulhas Bank, knowledge gaps are created due to inconsistent or unavailable scientific data, along with limited understanding of interacting climate variables with key resources (as discussed in Section 1.3). Given the high uncertainty in predicting impacts of global environmental change (such as climate variability) on local ecological systems, as well as associated known and unknown shocks in social-ecological systems due to multi-scalar social and ecological changes (Walker et al., 2004), it is important to draw on diverse knowledge systems to better understand complex systems (Tengö et al., 2014).

Comparing local climate experiences of farmers and fishers can be useful in gaining a better understanding of social-ecological systems under change, particularly where uncertainty persists in complex systems due to possible knowledge gaps and scale mismatches. As introduced above, temporal and spatial changes occurring in natural marine and terrestrial systems do not necessarily act in isolation and through overlaying different strands of knowledge, a more comprehensive understanding of local systems can be created. Therefore, this thesis brings together different bodies of knowledge from both terrestrial and marine perspectives to address underlying uncertainties on how climate variability is playing out in the southern Cape and Agulhas Bank, drawing together climate experiences of farming and linefishery communities residing in this local area, as well as relevant scientific weather data for both systems.

Furthermore, it is essential to understand why and how farmers and fishers respond to environmental challenges associated with climate variability. Perceptions of risk that include environmental, social, economic and political drivers are important as that may affect people's perceived or actual ability to respond (Grothmann and Patt, 2005). Generally, adaptive actions within agricultural and fishing sectors are shaped by perceptions of risk, direct climate change effects on productivity, as well as complex changes in markets, policies and government institutions. Opportunities for adaptation are presented within the operating context of decision making, access to effective adaptation options and the capacity of individuals and institutions to adapt within changing climatic conditions (Smit and Wandel, 2006). Structured climate change adaptation management in the Western Cape will require identifying how weather fluctuates, the implications of climate variability and how these impacts may evolve over time (Midgley et al., 2005).

1.5. Situating this thesis

This thesis was initiated to examine links between terrestrial and marine social-ecological systems under the common theme of climate variability, specifically at the local scale of the southern Cape and Agulhas Bank. Currently, knowledge gaps in the marine system have been highlighted at this local scale through research conducted by the South Coast Interdisciplinary Research Project (SCIFR) project, which specifically focuses on the southern Cape fisheries (Jarre et al., 2018). Scientific data sets for the Agulhas Bank have larger discrepancies compared to the rest of the southern Benguela system, resulting in limited understanding on how environmental changes are playing out in this subsystem (Lamont et al., 2017); however, there are warning signals associated with possible shifts on the Agulhas Bank such as increased inter-annual variability and biotic changes (Blamey et al., 2015; Watermeyer et al., 2016). Additionally, limited scientific data are available for climate-related variables at bay scales in which the southern Cape linefishery operates on the Agulhas Bank, resulting in scale mismatches of climate changes observed by local linefishers (Gammage et al., 2017a). Gaps in understanding also persist in local terrestrial systems, such as the southern Cape, largely due to high uncertainty associated with regional climate forecasting models and limited, locally available, long-term weather data (A. Jarre, University of Cape Town, pers. comm.).

The overlay of terrestrial and marine social-ecological systems has not been formally researched in the southern Cape, but initial work carried out by Duggan (2012) and Gammage (2015) on the local linefishery has pointed to the complexity of this marine social-ecological system and its adjacent terrestrial system. For example, one fisher (2014) noted: "*Dit gaan oor die natuur. In 1969 het hulle die meeste kabeljou gevang wat hulle al ooit gevang het. 1969 was die droogste jaar wat hulle ooit op land gehad het. Daai tiepe van ding. Alles speel 'n rol. Jy kyk na die natuur en jy moet kyk*" [It goes along with nature. In 1969 they (fishers) caught the most silver kob that they had ever caught. 1969 was also the driest year they (farmers) had ever had on land. That sort of thing. Everything plays a role. You need to look to nature and you need to look]. Through linking farmer and fisher experiences around climate variability to scientific weather data in the southern Cape, a more comprehensive understanding of how local communities are perceiving and reacting to possible climatic shifts can be established.

1.5.1. Objective

The objective of this thesis is separated into two parts:

Firstly, to examine climate variability over time in terrestrial and marine social-ecological systems of the southern Cape and its associated Agulhas Bank, through overlaying knowledge systems from farmers, linefishers and local scientific weather data; with a focus on bringing local perspectives into conversation with scientific data outputs.

Secondly, to look at responses to changes, with a focus on climate variability, in terrestrial and marine social-ecological systems through farmer and fisher perspectives contextualised through a resilience lens.

1.5.2. Key Questions

Key questions were divided up to examine different components of terrestrial and marine social-ecological systems separately, under the theme of climate variability, before bringing together these components and overlaying the different systems, perceptions and responses to change.

The first component of this thesis explores the relationship between climate variability and local perspectives from southern Cape farming communities. Changes in terrestrial weather systems are examined based on, firstly, the local perceptions of farmers residing in the southern Cape and, secondly, integrating local climate data:

1. How is climate variability perceived by farmers and are they responding to changes in climate (weather)?
2. How have terrestrial climate (weather) patterns changed in the southern Cape?

The second component of this thesis explores the relationship between climate variability and local perspectives from southern Cape linefishery communities. Drawing on previous research conducted under the SCIFR project, with a focus on local fishers' experiences and responses to change, changes in marine weather systems for the near-shore area of the Agulhas Bank are examined based on the perceptions of local fishers:

3. How have marine climate (weather) patterns changed from the perspective of fisher communities located in the southern Cape?

The third component overlays terrestrial and marine components through comparing farmers' and fishers' perceptions of climate variability in relation to change observed from scientific weather data sets, and contrasts how these communities' respond to change in the southern Cape and on the Agulhas Bank:

4. Are local knowledge of climate variability (i.e. weather patterns) by farmers and fishers in agreement and how do these compare to scientific observations, and are there synergies or mismatches across local and scientific knowledge stands examined?
5. How are farmers responding to change within the context of climate variability compared to fishers in the southern Cape?

1.6. Thesis structure

Chapters 1 and 2 provide an introduction to agriculture and fisheries within the context of climate change and variability at national, regional and local scales in South Africa, where key objectives and questions are set. Pressing challenges in the context of the Anthropocene are discussed, followed by conceptual framing of social-ecological systems, resilience and connecting knowledge systems. An overview is then provided on overarching research approaches, design and methods in this thesis.

Chapter 3 addresses Key Question 1 and describes local climate knowledge within southern Cape farming communities. The local study area, methods and results are examined and discussed in detail. This chapter explores local climate knowledge of, and strategies employed by, these communities within the terrestrial climate context of the southern Cape.

Chapter 4 examines terrestrial weather patterns within the southern Cape from the farming perspective, addressing Key Question 2. Coupled with farmer observations, weather analysis has been carried out on terrestrial rainfall and temperature data to examine how weather patterns have changed in the southern Cape.

Chapter 5 addresses Key Question 3 and examines wind patterns on the Agulhas Bank. This chapter incorporates a marine perspective to weather patterns in the southern Cape by drawing on local knowledge from fishing communities and subsequent (near- and off-shore) wind data products to better understand complexities in local marine climate systems.

Chapter 6 addresses Key Questions 4 and 5, integrating different perspectives, responses and data sets from previous chapters. Local knowledge of climate variability by farmers and fishers are brought into dialogue and linked to scientific weather observations across multiple scales. Synergies and mismatches across the different knowledge systems are discussed. Responses to changes within the southern Cape, specifically to climate variability, are also examined from both farming and fishing experiences.

Chapter 7 reflects on broad academic discourses underpinning the Anthropocene in relation to this thesis and further reflects on the social-ecological framing used to examine southern Cape communities within a resilience perspective.

CHAPTER 2

LITERATURE REVIEW AND RESEARCH APPROACH

This chapter provides an overview of relevant literature to address the objectives and key questions of this study, contextualising research within global change in the Anthropocene and unpacking literature on social-ecological systems thinking, resilience framings and connecting knowledge systems.

2.1. Change in the Anthropocene

> People and the natural environment are intricately linked – people and societies form integrated parts of the biosphere, where global environmental changes interplay with rapidly globalising human societies (Folke et al., 2011).

To better situate this thesis, a wider scope in literature is initially explored to contextualise current global changes within local areas, thus placing present day challenges faced by ecological and social systems in this context. The biosphere refers to the sphere of life – it is the global ecological system that includes all living beings as well as their interactions with each other and elements of the lithosphere, hydrosphere, atmosphere and cryosphere (Folke et al., 2011). Humanity is embedded in the biosphere, where people and societies depend on the functioning and life support the biosphere provides. The early existence of *Homo sapiens* had a low impact on the environment as people subsisted largely as hunter-gatherers. However, in the early stages of the Holocene (approximately 10 000 years ago) agriculture developed and subsequently led to the development of complex human civilizations – largely due to climate stability that lasted longer than in the previous three interglacial periods.

Since the 19th century, the industrial era ushered in an age of human-dominated landscapes and activities within natural environments and, coupled with the rapid expansion of the global population, scientists have suggested that the Holocene Epoch has come to an end and moved into the Anthropocene Era (Crutzen, 2002; Steffen et al., 2011). While there is currently no formal consensus amongst scientists for when the Anthropocene began, there is little doubt that recent global environmental changes suggest the onset of a new human-dominated geological epoch (Lewis and Maslin, 2015). Anthropogenic forces are having an increasingly large-scale impact on the earth, such as impacting biogeochemical or element cycles (carbon, nitrogen, phosphorus and sulphur); altering the terrestrial water cycle; and possibly contributing to a major species extinction event (Steffen et al., 2011; Westley et al., 2011).

Worldwide, ecosystem structures have changed more drastically in the second half of the 20th century than any other time recorded in human history and today, human actions have left a significant footprint on almost all of the world's ecosystems (Millennium Ecosystem Assessment, 2005). A pressing 21st century challenge is to ensure that there will be adequate and reliable ecosystem services available to meet the needs of the rapidly expanding population across the globe (Millennium Ecosystem Assessment, 2005), having jumped from 1.6 billion people in 1900 to over 7 billion in 2011. Meeting global food security demands has already resulted in problems such as land degradation and natural resource exploitation, for example the large-scale conversion of natural ecosystems to cropland and intensification of fishing practices (Hutchings and Myers, 1994; Biggs et al., 2012). Extensive anthropogenic alterations to ecosystems have potential impacts of large, non-linear and irreversible changes, which in turn will harm the environment and people alike (Collie et al., 2004; Biggs et al., 2015).

This thesis emphasises the importance of building understanding around how environments are changing from both ecological and social perspectives in terrestrial and marine systems. Some key environmental challenges associated with the Anthropocene include climate variability, ecological regime shifts and changes in land-use – which are examined in detail at the local scale of the southern Cape and Agulhas Bank for this thesis.

2.1.1. Climate variability and change

Variability and change within climate systems, from local to global scales, is arguably one of the most pressing environmental issues today. While climate variability and change have formed an integral part of natural systems and their ability to adapt throughout the earth's history, anthropogenic influences have increasingly exacerbated these changes (Salinger, 2005). Major anthropogenic influences on climate are associated with greenhouse gas emissions such as carbon dioxide, methane and nitrous oxide (Salinger, 2005; IPCC, 2014). Since the pre-industrial era, greenhouse gas emissions have increased and today are at the highest levels in history. As the contributing result of anthropogenic disruptions, inputs and drivers, warming of the climate system has become a clear trend on a global scale and observed changes since the 1950s are unparalleled to previous decades or millennia (IPCC, 2014). To date on this global scale, warming has occurred in the atmosphere and ocean; snow and ice cover have decreased globally; sea levels have risen and global land precipitation has increased – to highlight some major challenges related to climate variability associated with anthropogenic influences (IPCC, 2014).

Over the next century, climate change is projected to directly and indirectly affect all aspects of ecosystem service provision, which may negatively affect human well-being (Millennium Ecosystem Assessment, 2005). Some impacts already reflected in both terrestrial and marine ecosystems as the result of anthropogenic climate variability include changes in species distributions, population sizes, timing of reproduction and migration events, as well as more frequent pest and disease outbreaks (Millennium Ecosystem Assessment, 2005; Cheung et al., 2009; Bellard et al., 2012). By the end of the century, changes in climate and its consequences may be the dominant driver of marine and terrestrial biodiversity loss across the world (Millennium Ecosystem Assessment, 2005; Cheung et al., 2009; Bellard et al., 2012).

Increased population pressures from rapidly expanding societies over the last century have also highlighted the impacts of extreme weather and climate events, due to the large loss of human life and massive economic costs associated with them (Easterling et al., 2000). Since the 1950s, changes in extreme weather and climate events have been observed, particularly those associated with anthropogenic influences (IPCC, 2014). Decreased cold temperature extremes, increased warm temperature extremes, increased heavy precipitation events, and an increase in unusually high sea levels have been observed in several systems, and will continue to evolve out of the presently changing climate (IPCC, 2014). Climate and weather extremes are expected to increase, likely compromising the functionality of human and ecological systems (Salinger, 2005).

2.1.2. Ecological regime shifts

Ecological regime shifts characterise large, sudden changes in ecosystems that last for an extensive period of time (deYoung et al., 2004; Biggs et al., 2009). Regime shifts involve the alteration of internal dynamics and feedbacks of an ecosystem, resulting in the systems to shift to a different state that cannot necessarily be reversed, even when the driver is reduced or removed (Collie et al., 2004; Biggs et al., 2009). Generally, regime shifts are considered as undesirable as they can negatively impact human well-being and may be extremely costly or impossible to reverse. Rising human impacts on the environment are increasing the likelihood of ecological regime shifts from local to global levels and can occur in diverse ecological systems – from oceans, freshwaters, forests, woodlands, drylands, rangelands and agro-ecosystems (Biggs et al., 2009).

Examples where ecological regime shifts are prevalent can be drawn from marine systems. Marine environments are systems in serious decline, largely the result of over-exploitation, pollution and climate change impacts (Jackson et al., 2001; Srinivasan et al., 2010; Poloczanska et al., 2016). For example, the collapse of the cod fishery off Canada's Newfoundland and Labrador coast in 1992, where over-exploitation of this species was a major contributor to the commercial extinction of northern cod (*Gadus morhua*) (Hutchings and Myers, 1994). This collapse of Canada's cod fishery directly impacted the livelihoods of 35 000 fishers and fish-plant workers, resulting in the decline of 200 million dollars per annum in revenue from cod landings, which in turn negatively affected the local economy and society (Ommer, 2007). This collapse was also persistent, as the fishery showed little sign of recovery despite a moratorium placed on the Canadian cod fishery for over 15 years (Schrank and Roy, 2013).

In many marine locations, ecosystem regime shifts have been the consequence of a complex interplay between environmental and anthropogenic drivers. For example, spatial and temporal changes have been documented in the southern Benguela marine ecosystems over the last 40 years (Hutchings et al., 2012; Blamey et al., 2015). In the southern Benguela upwelling system, which supports economically important commercial fishery activities for South Africa, a number of commercially-exploited fish species have undergone distributional shifts (for example Blamey et al., 2012). Two major ecosystem regime shifts in the southern Benguela were identified by Howard et al. (2007) – the first was mainly attributed to overfishing activities with some environmental influence that occurred in the late 1950s. The second regime shift occurred from the 1990s to 2000s and found to be primarily the result of environmental shifts (Howard et al., 2007), but aggravated by fishing activities (Coetzee et al., 2008; Blamey et al., 2012). The implications of commercially important marine species shifting in this system are significant as it has social, economic and ecological ramifications for South African fisheries and other sectors, including livelihoods, which directly or indirectly rely on these productive ecosystem services (Jarre et al., 2015; Watermeyer et al., 2016)

2.1.3. Changing land-use patterns

Land-use activities associated with human use, from converting natural landscapes to changing management practices, have drastically changed the face of the world's physical landscape. Intensifying land use practices ranging from deforestation, farmland expansion to urban sprawl usually have the same outcome – the use of natural resources to meet human demands which results in environmental degradation (Foley et al., 2005). Environmental impacts of land use across the world have been linked to shifts in atmospheric composition and the extensive alteration of ecosystems. Changes in the global carbon cycle have been partly attributed to human activities, for example land use practices have contributed to 35 percent of anthropogenic carbon dioxide emissions since 1850 (Foley et al., 2005). Biodiversity has also been extensively affected by anthropogenic land use through the loss of species; modification and fragmentation of habitats; and degradation and over-exploitation of natural resources (Foley et al., 2005). As such, degraded land can be defined as "the state of land which results from the persistent decline or loss in biodiversity and ecosystem functions and services that cannot fully recover unaided within decadal time scales" (IPBES, 2018: 18).

Desertification and land degradation are concerns that dominate rural communities reliant on agricultural activities and natural resource use; however, issues linked to land degradation such as food security, poverty and urban migration have a wide impact on social systems – affecting both rural and urban areas (Hoffman and Ashwell, 2001). Globally, croplands and pastures combined have become one of the largest terrestrial biomes in an effort of modern agriculture to increase food production (Foley et al., 2005) Agricultural land use occupies approximately 40 percent of the world's land surface and changing land use practices have resulted in the doubling of global grain harvests over the last four decades, largely due to Green Revolution technologies and (to a lesser extent) an increase in cropland area (Foley et al., 2005; Foley et al., 2011).

Modern agricultural activities are responsible for large-scale ecosystem degradation as they disrupt and exploit ecosystem services associated with freshwater resources, habitat biodiversity, regional climate and air quality, and infectious disease management (Foley et al., 2005). "In short, modern agricultural land-use practices may be trading short-term increases in food production for long-term losses in ecosystem services, including many that are important to agriculture" (Foley et al., 2005: 570). Environmental degradation leads to the loss of essential ecosystem services that in turn reduce the resilience of systems to adapt to changing conditions – increasing the likelihood of unpredictable (and often adverse) ecosystem regime shifts (Millennium Ecosystem Assessment, 2005). Environmental degradation also adversely impacts the capacity of both social and ecological systems to buffer against sudden ecological shifts or changes, which as a consequence, can negatively impact these systems (Hoffman and Ashwell, 2001; Millennium Ecosystem Assessment, 2005).

2.2. Responding to 21st century environmental challenges

Consequently, the impact of human activities on the environment from local to global scales is drawing considerable attention. Towards the end of the 20th century, the state of the environment began to attract international interest as people became increasingly aware of risks associated with environmental degradation (United Nations, 1992; Hoffman and Ashwell, 2001). Concepts such as sustainability, defined as the use of environment and resources to meet the needs of the present without compromising the ability of future generations to meet their needs (The World Commission on Environment and Development, 1987), gained traction in the late 1980s and sustainable development gained momentum in the 1990s that resulted in a shift in development thinking and research (Chambers and Conway, 1991; Scoones, 1998; Solesbury, 2003).

In the 2000s, assessments such as the Millennium Ecosystem Assessment were carried out by experts across the globe to evaluate ecosystem services and change within the context of human well-being (Millennium Ecosystem Assessment, 2003, 2005). Global climate change, loss of biodiversity and desertification were identified as three environmental problems with global significance in terrestrial systems, which are interlinked and are perpetuated by anthropogenic activities with vast implications for social systems from food production to human health (Millennium Ecosystem Assessment, 2005). Similarly in ocean environments, international attention has been drawn to destructive fishing activities that have negative social and environmental ramifications from local to global scales (Pinsky et al., 2011). The collapse of large-scale, lucrative fisheries from the 1940s into the 1990s indicated that universal management practices were unsustainable regarding marine food production (Hauge et al., 2009). Stock collapse due to exploitative fishing practices in the world's oceans is further compounded by policy changes, pollution, habitat destruction, invasive species, climate change and highly variable environmental factors, which can lead to widespread consequences as seafood is the most traded food commodity globally (Hauge et al., 2009; Gephart et al., 2017).

With the onset of the Anthropocene, the role and responsibility of society as a driving force of change within the biosphere has been widely recognised (Steffen et al., 2007; Ruddiman et al., 2015), which has sparked the need for new forms of engagement and responses to build towards sustainability (Preiser et al., 2017) in light of the pressing 21st century challenges discussed above.

2.2.1. Different academic discourses

Current academic discourses use different framings when examining the Anthropocene, thus influencing how sustainable human-environment interactions are understood, interpreted and acted upon (Preiser et al., 2017). As examined by Preiser et al. (2017), four mainstream ontological imageries that define current academic perspectives around the Anthropocene include eco-modernism, biosphere stewardship, sustainable pathways and critical post-humanism, as detailed in Table 2.1.

Table 2.1. Different academic perspectives used for framing human-environment responses to the Anthropocene (from Preiser et al., 2017)

Perspective	Underlying worldview and problem framing	Primary Response to Anthropocene challenges	Strategies for achieving sustainability and a 'Good Anthropocene'	Examples	References
Eco-modernism/ post-environmentalism	Enlightenment ideals of progress and instrumental rationality.	Technological innovation needs to address and account for environmental sustainability.	Humans should use their growing social, economic, and technological powers to manage the Earth System, including the climate.	Agricultural intensification, Desalinisation, Nuclear power, Decoupling strategies	Shellenberger and Nordhaus (2015), Asafu-Adjaye et al. (2015), Ellis (2011)
Biosphere stewardship	Humans are intertwined with and dependent on the functioning of the Earth System.	Biosphere stewardship & reconnecting people to nature.	Maintaining resilient social-ecological systems to sustain human wellbeing.	Earth system governance, Sustainable Development Goals, Ecosystem Goods and Services, Natural Capital Accounting	Folke et al. (2011), Folke et al. (2016), Biermann et al. (2009), Brondizio et al. (2016), Galaz et al. (2012), Rockström et al. (2009), Steffen et al. (2015)
Sustainability pathways	The current world reinforces unequal access to natural resources and marginalises the poorest.	Opening up spaces for multiple perspectives to be engaged.	Reducing inequality and domination of powerful perspectives. Allowing space for diverse realizations of human wellbeing.	Participatory deliberation and contestation, Political Ecology, Social Movements	Leach et al. (2012), Stirling (2015)
Critical post-humanism	Nature, culture, subjects, and objects do not exist independently but arise through their relationships with other entities. Agency emerges through webs of relations in which human exceptionalism is denied.	Agency is not just located in human activity but comes about through multiple collective alliances or collaborative socio-material assemblages.	Enable generative capacities constituted through processes of interconnectedness that cut across the agency of all species, other entities, space and time.	Actor-Network theory, Non-human agency, Relational ethics	Braidotti (2006), Harraway (2016), Latour (2014), Lorimer (2012)

These different perspectives propose contrasting ways of understanding and achieving sustainability within the context of present environmental and socially-related challenges of the 21st century. The eco-modernism outlook examines sustainability through the dimension of human development, where modernisation and technological innovation is viewed as primary means to achieve social and environmental stability within the new geological epoch governed by human-directed opportunity (Ellis, 2011). In contrast, the biosphere steward perspective argues that people and the natural environment cannot be treated as separate entities and calls for humanity to 'reconnect to the biosphere' (for example Folke and Gunderson, 2012), where sustainability can be achieved through adaptive governance strategies that place humans within the biosphere (Folke et al., 2016). The sustainable pathways approach moves away from technological or top-down governance innovations and instead advocates multiple pathways that draw on diverse (and often marginalised) perspectives within the realm of human agency to achieve sustainability (Leach et al., 2012). The critical post-humanism paradigm proposes that sustainability under the Anthropocene is the responsibility of both human and non-human entities in order to allow all forms to flourish on Earth (Haraway, 2016).

Within these broad academic discourses, Preiser et al. (2017) propose that a plurality of framings should exist within the Anthropocene to respond to challenges from a diverse range of disciplines and perspectives that can broaden understanding, leading to the possibility of developing "more nuanced, socially considerate and credible responses" (Preiser et al., 2017: 86). While recognising that choosing one academic perspective can be limiting in terms of how sustainability can be interpreted, this thesis primarily borrows from the planetary (or biosphere) stewardship discourse that focuses on how ecological and social systems interact – along with the complexities, uncertainties and multi-scale dynamics inherent to these complex systems – as this framing is best suited for examining local systems across terrestrial and marine perspectives in the southern Cape. Natural systems and social systems are viewed as complex systems, with many present day environmental and resource problems involving complex interactions between natural and social systems (Berkes et al., 2003). Complexity within non-linear and unpredictable systems has created challenges for traditional, compartmentalised disciplinary approaches and so complex systems thinking is used to bridge social and biophysical sciences in order to gain a more holistic picture of these challenges (Burns and Weaver, 2008; Jarre et al., 2013; Rogers et al., 2013).

Additionally, this thesis brings together diverse knowledge systems to better understand uncertainties within complex social-ecological systems as a way to build towards a deeper understanding of different experiences, perspectives and responses held by local natural resources users (i.e. farmers and fishers) to global 21st century challenges, such as climate variability. As proposed by Leach et al. (2013), responses to challenges presented in the Anthropocene require interdisciplinary approaches that are inclusive of both social and natural sciences, which should be further augmented by multiple forms of knowledge.

2.2.2. Interpreting sustainability

To better understand how possible large-scale changes such as climate variability, regime shifts and land-use changes play out in a local area, such as the southern Cape and the Agulhas Bank, this thesis examines ecological and social systems in tandem – through a social-ecological perspective. Many serious and recurrent problems relating to natural resource use and environmental management practices can be attributed to the lack of recognition that ecosystems and social systems are complexly linked (Folke et al., 2010;

2011). The planetary stewardship discourse recognises social-ecological systems as dynamic and connected from local to global scales, forming part of complex webs of interactions which experience both gradual and sudden changes (Folke et al., 2011; Folke and Gunderson, 2012). To maintain the capacity of ecological systems to support, for example, social and economic systems requires understanding the feedbacks and dynamics of interrelations between ecological systems and social systems (Berkes et al., 2003), as sustainability of interlinked social and ecological systems can be dependent on feedback loops between the different components. Therefore, sustainability can be viewed as a dynamic process, that requires people to continuously adapt in order for societies to deal with change, rather than merely an end product (Berkes et al., 2003).

2.3. A social-ecological systems perspective

> "In the globalized world, there are no ecosystems without people and no people who do not depend on ecosystem functioning. They are inextricably intertwined in a new play of interdependent social-ecological systems" (Folke and Gunderson, 2012: 55)

Social-ecological systems encompass both biophysical and social components, where these components interact with diverse internal problems and external disturbances, thus changing over time according to multi-scale feedbacks (Janssen et al., 2007; Biggs et al., 2015). Biggs et al. (2015: 8) describe social-ecological systems as "cohesive systems in themselves that occur at the interface between social and ecological systems, characterized by strong interactions and feedbacks between social and ecological system components that determine the overall dynamics", as illustrated in Figure 2.1. Social systems can comprise of economic systems, organisations, institutional and physical infrastructure, as well as knowledge and perceptions around the environment and resource use (for example Berkes et al., 2003; Janssen et al., 2007). Institutions refer to the set of norms and rules that people use to organise activities (Ostrom, 1990). Ecological systems, or ecosystems (Tansley, 1935), are self-regulating communities of organisms that interact with each other and their surrounding environment. In the Anthropocene, ecosystem services are influenced and generated by social-ecological systems (Folke et al., 2011).

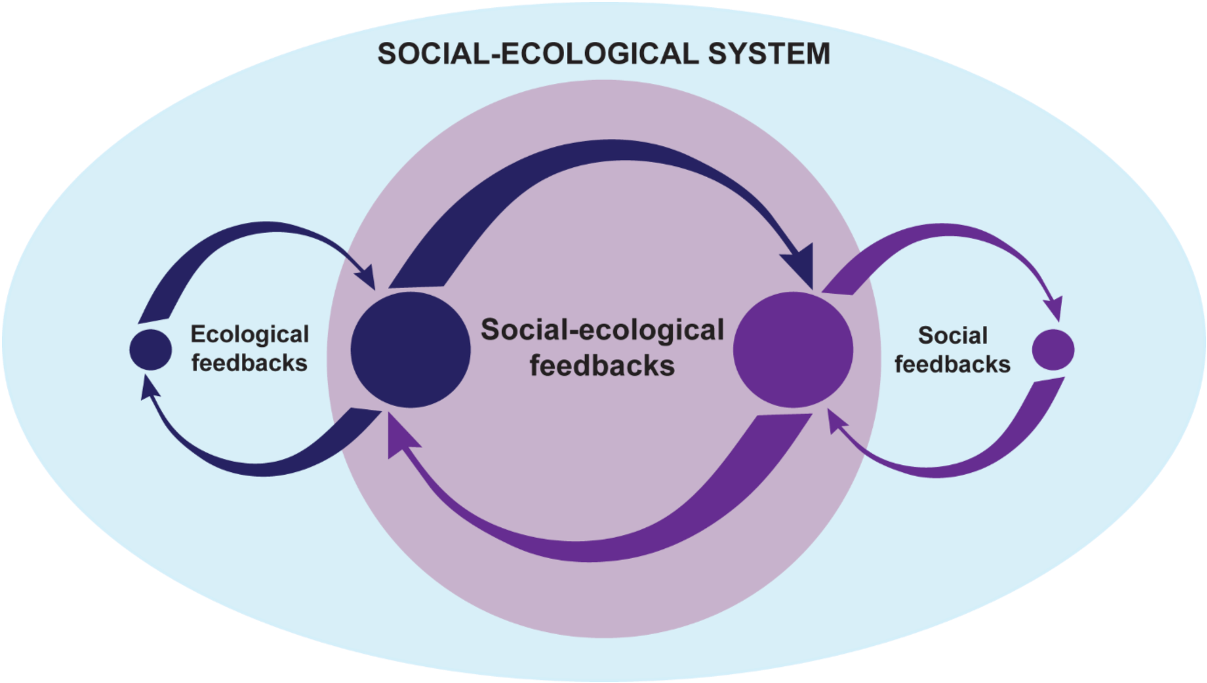


Figure 2.1: Social-ecological systems are viewed as intertwined, complex systems that are linked through feedback loops between social and ecological components (adapted from Biggs et al., 2015)

2.3.1. Ecosystem services

Ecosystem services are described as benefits provided by ecosystems such as provisioning services (food, water, timber), supporting services (soil formation, pollination, nutrient cycling), regulating services (climate, floods, disease) and cultural services (recreation, aesthetics, spiritual) – refer to Box 2.1 for expanded definitions (Millennium Ecosystem Assessment, 2003). Steffen et al. (2011) proposed that this classification of ecosystem services be expanded to take geophysical goods and services into account, so that it may be extended to a planetary scale and be termed 'Earth System goods and services'.

Box 2.1: Ecosystem Definitions (from Millennium Ecosystem Assessment, 2003)

Ecosystem – a dynamic complex of plant, animal and microorganism communities and the non-living environment that interact as a functional unit. People also form an important part of ecosystems and are fully dependent on these systems. Ecosystem sizes can vary from large scale (e.g. ocean basin) to small scale (e.g. small pond in a tree hollow).
Ecosystem services – benefits people obtain from ecosystems. These benefits include provisioning services, supporting services, regulating services and cultural services.
(Human) well-being – includes having access to basic material for a good life, freedom of choice, health, good social relations and security. The components of well-being experienced and perceived by people are situation-dependent and reflected in local geography, culture and ecological circumstances.

Earth System goods and services therefore include materials derived from geological resources (fossil fuels, phosphorus, metals) regulated by market prices under provisioning services. Supporting services would include geophysical processes such as gaining fertile soil through glacial action, obtaining nutrients from upwelling branches of ocean circulation and storing fresh water in (for example) Himalayan glaciers. Regulating services would extend its definition of carbon uptake and storage by ecosystems to include the dissolution of atmospheric carbon dioxide into the ocean; as well as to take account of chemical reactions in the stratosphere that form ozone and the role polar ice sheets play in regulating temperature (Steffen et al., 2011). The concept of social-ecological systems can assist when dealing with sustainability challenges that arise from the complex interaction of people and the environment at local, regional and, more recently, global scales (Steffen et al., 2011).

Human activities have now reached a point where they can be considered as an interacting component of the Earth System, and global-scale social and economic processes are as important to take into consideration in the functioning of this planetary system, as atmospheric and oceanic. The concept of Earth System goods and services is useful in that it can provide a holistic overview of ecosystem services, as people tend to focus on changes that occur on the land or in the atmosphere, and sometimes overlook the role of the ocean (Steffen et al., 2011). An unfortunate example is the fundamental role ocean circulation plays in forming the global distribution patterns of heat and moisture, which in turn influence the patterns of water availability for human societies (Steffen et al., 2011).

2.3.2. Taking scale into consideration

In both ecological and human studies, scale is an important component – thus the concept of ecosystem services is strongly linked to scale due to its combined social and ecological elements (Scholes et al., 2013). Social-ecological systems usually involve groups of resource users that are interlinked to each other, as well as to numerous resources that occur across multiple scales, and therefore are influenced by spatial and temporal changes within these complex systems (Janssen et al., 2007). Scale can refer to extent, duration, resolution, grain and hierarchical level that encompass the physical dimensions of time and space (Scholes et al., 2013).

Ecosystem services can be used, supplied, managed and valued at different spatial and temporal scales – for example, ecosystem service benefits such as climate regulation are produced locally on an annual basis, but are valued over longer periods of time at a global level. Social and ecological structures that determine or influence delivery, usage or value of ecosystem services also function at different scales – for example, food supply relies on multiple scales from local pollination processes to regional water supply to global market trends. Ecosystem services are the result of intricate and complex social-ecological systems, dependent on the interaction and feedback loops from numerous components that function at multiple scales – for example, national or even global policy decisions that change food prices can lead to farmers altering land use practices locally, which in turn impact the functioning of ecosystem services (Scholes et al., 2013).

So why is considering scale important? Perry and Ommer (2003) stress that there is an inadequate understanding of highly complex links between social and environmental restructuring and highlight how scale mismatches aggravated, for example, the ramifications of the Newfoundland cod stock collapse in Canada (Ommer, 2007). Scale effects are viewed as a foundation of complexity science – the study of how interactions between well-studied system components can result in unexpected outcomes when working within systems. Particularly in social-ecological systems, many findings are scale-sensitive where answers obtained depend on the spatial and temporal scale at which the research was conducted. As far as complex systems are concerned, a single scale study is unlikely to give a complete understanding of the study – for example, what appears to be sudden and unexpected variability at one scale, may manifest as a stable and predictable pattern at another scale (Scholes et al., 2013).

Examining how a system changes over time at a particular scale usually requires an understanding of the system's interconnectivity to other systems at multiple scales and how these interact (Scholes et al., 2013). Drawing on case studies from four different marine social-ecological systems, Perry et al. (2011) illustrated how scale can influence responses within marine social-ecological systems to combined impacts of environmental and global socio-economic stressors. Responses that occurred on short time scales and allowed the system to survive relatively unchanged through the stress were considered as 'coping' – where the system returned to previous conditions. However, stressors that occurred on longer time scales usually required more permanent adjustments called 'adaptive' responses as the marine social-ecological systems moved into new states or conditions. For example, human communities can cope with depleted fish stocks by moderating existing behaviours to accommodate reduced catches, whereas adaptation involves greater change when stocks collapse such as political intervention and/or community closure (Perry et al., 2011).

Through a social-ecological framing, different responses to changes in these systems can be described using a range of concepts that detail features of complex systems. When considering ecosystem services and human well-being that are influenced across multiple scales, social-ecological systems can be investigated through concepts such as vulnerability, resilience and adaptive capacity.

2.4. Vulnerability, resilience and adaptive capacity

The terms vulnerability, resilience and adaptive capacity are applicable to both biophysical and social domains (Gallopín, 2006). Previously, studies concerning these terms had focused on either ecological systems or social systems; however, there has been a move towards holistic conceptualisations and models of social-ecological systems (Young et al., 2006). Concepts around these terms have focused on the behaviour and evolution of social-ecological systems in the context of threats or hazards posed by multiple levels of disturbances or stressors (Young et al., 2006). In light of global environmental challenges linked to anthropogenic stressors, vulnerability, resilience and adaptation have gained important status in the study of the human dimensions of global environmental change (Folke, 2006; Janssen and Ostrom, 2006; Folke et al., 2011; Biggs et al., 2012).

2.4.1. Unpacking core definitions

Vulnerability originated from fields concerned with natural hazards and poverty (for example White and Haas, 1975; Chambers, 1989). Vulnerability is traditionally defined as "the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt" (Adger, 2006: 268). From the 1990s, the focus of vulnerability studies shifted to environmental change, particularly climate change (Bohle et al., 1994; Adger, 1999). The Intergovernmental Panel on Climate Change (IPPC) examined vulnerability in relation to how susceptible a system is to cope with (or unable to cope with) the effects of climate change, including climate variability and extremes (IPCC, 2007). Newer views retain the multi-dimensionality but depict vulnerability as more comprehensive and integrated, conceptualised as a function of interactions between exposure, sensitivity and adaptive capacity (Bennett et al., 2014; Cinner et al., 2018). Exposure refers to the presence and intensity of stressors felt by a system; sensitivity is defined as the extent a system is affected through exposure to stressors; and adaptive capacity is the ability of a system to respond to stressors through learning, developing knowledge bases, managing risks and creating new strategies (Marshall et al., 2009).

Resilience emerged initially as a perspective used by ecologists in their analysis of population ecology in plants, animals and the management of human activities in ecosystems (Holling, 1961; Rosenzweig, 1971; May, 1977). Before the 1980s, resilience was seen as a concept to determine the "persistence of relationships within a system and [as] a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist" (Holling, 1973: 17). Subsequently, resilience morphed into a new use in the analysis of human-environment interactions and redefined as the capacity of a social-ecological system to maintain desired ecosystem services in the face of disturbance and change (Berkes et al., 2003; Smit and Wandel, 2006). Resilience thus was viewed as a means to enhance the likelihood of sustainable development within the context of environments characterised by change and uncertainty (Walker et al., 2004; Adger et al., 2005).

Adaptation originated from natural sciences, specifically evolutionary biology (Darwin, 1859), that referred to the development of genetic or behavioural characteristics that allow organisms or systems to adjust under environmental changes (for example Winterhalder, 1980). Since the early 1990s, adaptation to environmental variability has been a focus of anthropological studies and subsequently became popular in the study of the consequences of human-induced climate change (for example Easterling, 1996; Tol et al., 1998; Smit et al., 1999). In the context of social-ecological approaches, "adaptation is generally perceived to include an adjustment in social-ecological systems in response to actual, perceived, or expected environmental changes and their impacts" (Janssen and Ostrom, 2006: 237). Within the context of the current global change field, adaptation is not limited to changes in the natural environment, but can also include responses to political, economic and social changes (and their subsequent impacts) within social-ecological systems.

Until about a decade ago, literature around vulnerability and adaptation tended to focus more on the comparative analysis of case studies (Watts and Bohle, 1993; Bohle et al., 1994; Easterling, 1996; Adger, 1999), whereas resilience literature has a strong history of theoretical and mathematical models stemming from ecological studies (Holling, 1973; Scheffer et al., 2001; Folke et al., 2004). More recently, vulnerability, resilience and adaptation are widely applied in the sphere of global change science, notably in climate change fields (IPCC, 2007), where applications vary according to field of study and scale. While resilience has its roots in ecosystem processes, social sciences have also played an important role in influencing this perspective (for example Scoones, 1999; Abel and Stepp, 2003) and contributing towards integration of this concept within social-ecological systems (Folke, 2006). This thesis analyses social-ecological systems at the local scale (i.e. southern Cape and Agulhas Bank) in relation to the concept of resilience when examining environmental change, specifically climate variability, in context with local perceptions and responses of farmers and fishers to change.

2.4.2. Focusing on resilience as a concept

Resilience as a concept can be useful for analysing adaptive change towards sustainability as it offers insight on how to maintain stability or manage change – specifically unexpected change (Berkes et al., 2003; Biggs et al., 2015). A resilient social-ecological system – one that can buffer against or adapt to numerous disturbances – can result in ecological, economic and social sustainability (Berkes et al., 2003). As proposed by Folke et al. (2010), resilience thinking should also incorporate concepts of adaptability and transformability when considering social-ecological systems' response to feedbacks and thresholds. Adaptability refers to the capacity of actors in a system to influence resilience, whereas transformability is the capacity to transform a system to create a fundamentally new system (Folke et al., 2010). The resilience of the social-ecological systems that are the focus of this thesis can therefore be defined as "the capacity to adapt or transform in the face of change in social-ecological systems, particularly unexpected change, in ways that continue to support human well-being" (Folke et al., 2016: 41).

The importance of understanding and managing for resilience is underpinned by the existence of tipping points and thresholds (Folke et al., 2011). Several applications of the concept of resilience have been developed – ranging from resilience relating to ecological knowledge (Berkes et al., 2003), natural disasters (Adger et al., 2005; Cutter et al., 2008), environmental change (Nelson et al., 2007), cities (Seeliger and Turok, 2013), community (Frankenberger et al., 2013; United Nations Development Programme, 2014), farming systems (Dixon et al., 2014) and climate change (Moench, 2014). Within the context of social-ecological systems, resilience is about dynamic and complex systems that do not necessarily imply that the goal is to return to equilibrium. As a consequence of complexity, numerous states of attraction and multiple equilibria, it is unrealistic to assume ecological stability within social-ecological systems, and therefore resilience cannot be defined as bouncing back to equilibrium as there is no equilibrium to bounce back to (Berkes et al., 2003). Folke (2006) outline the sequence of resilience concepts that move from a narrow interpretation to the broader, social-ecological context (Table 2.2).

Table 2.2: Resilience concepts sequence from a narrow to broad interpretation (from Folke, 2006)

Resilience concepts	Characteristics	Focus on	Context Vicinity
Engineering resilience	Return time, efficiency	Recovery, constancy	Vicinity of a stable equilibrium
Ecological resilience **Social resilience**	Buffer capacity, withstand shock, maintain function	Persistence, robustness	Multiple equilibria, stability landscapes
Social-ecological resilience	Interplay disturbance and reorganization, sustaining and developing	Adaptive capacity, transformability, learning, innovation	Integrated system feedback, cross-scale dynamic interactions

Following the evolution of resilience concepts from a narrower interpretation (refer to engineering resilience and ecological/social resilience in Table 2.2); the conceptualisation of social-ecological resilience recognises that efforts to foster specified resilience, rather coping with uncertainty in all ways, will not necessarily avoid a regime shift (Folke et al., 2010). Specified resilience refers to the “resilience ‘of what, to what’; resilience of some particular part of a system, related to a particular control variable, to one or more identified kinds of shocks” (Folke et al., 2010: 20). This opens up opportunities to re-evaluate the current situation, trigger social mobilisation and reconnect sources of experience and knowledge for learning, which could ultimately spark novelty and innovation, leading to new kinds of adaptability or transformational change. “Resilience thinking is about thresholds and shifts among different pathways of development and provides a lens for capturing the interplay between gradual and abrupt, often surprising changes that now increasingly play out in cascading fashions in a world where everyone is in everyone else's backyard" (Folke et al., 2011: 732).

The resilience lens has been applied around the world in an effort to understand social-ecological dynamics (Folke et al., 2016), from developed to developing regions (for example Berkes et al., 2003; Walker et al., 2006a; Folke et al., 2010). The resilience perspective has also been applied to the outcomes of high impact climate events on rural livelihoods in Central America (McSweeney and Coomes, 2011); influences of environmental and economic change on land-use choices among farmers in Latin America (Eakin and Wehbe, 2009); interactions between society and nature along the United States-Mexico border (Morehouse et al., 2008); and poverty traps of rural drylands in sub-Saharan Africa (Gordon and Enfors, 2008). Folke et al. (2011) highlight the importance of understanding what resilience entails by examining traps and regime shifts within the context of the Maine lobster fishery in the United States and agricultural activities within the Goulburn-Broken catchment in the Murray Darling Basin, Australia.

In South Africa specifically, research carried out by Gammage (2015) in the southern Cape examining fishers and their responses to stressors drew on a resilience-based approach to vulnerability as a theoretical and conceptual framework. When looking at the marine system in which fishers operate in the southern Cape, Gammage (2015) explore multiple inputs and interactions at various spatial and temporal scales which can be examined in parallel, under the framing of resilience, within the objectives of this thesis. When looking at how natural resource users, such as farmers and fishers, are responding to environmental change within their systems, a resilience lens is useful to interpret these responses within the context of multi-scalar interactions. While work carried out by Duggan (2012) and Gammage (2015) has examined how southern Cape fishers perceive and respond to change in the context of multiple stressors of the marine social-ecological system, the terrestrial component of this system has not yet been examined. Using the common thread of resilience, this thesis builds on previous work carried out on southern Cape fishing communities and further explores both marine and terrestrial components of this social-ecological system.

2.4.3. Examining responses through adaptive capacity

While the concept of resilience provides a suitable framing to examine social-ecological systems for this thesis, understanding how people respond to environmental change is complex and a multidimensional approach is required that does not solely focus on one concept (such as either resilience or vulnerability) but rather an integrated understanding of responses within social-ecological systems. When referring back to how sustainability is defined in the context of this thesis (see Section 2.2.2), it is a dynamic process that implies people need to continuously adapt so that social systems can deal with change to build towards resilient social-ecological systems. Four key components of adaptation, identified by Bryant et al. (2000) and described by Bryan et al. (2009), are (1) characteristics of the stress; (2) characteristics of the system; (3) multiple scales and (4) adaptive responses. Stressors, or stimuli to which systems respond, can include climate variability, economic drivers, population growth and political policies. System characteristics influence its response to stressors and can include vulnerability, resilience and adaptive capacity. Stressors and responses change over multiple scales – for example on a spatial scale, adaptation can be classified in terms of being localised to widespread (Smit and Wandel, 2006). Adaptive responses can be classified as anticipatory, concurrent or reactive, depending on the temporal scale over which the actions are carried out (Smit and Wandel, 2006).

Within a resilience framing, the concept of adaptability entails sufficient adaptive capacity to respond within the social domain, as well as to respond to and shape ecosystem dynamics in an cognizant manner (Folke, 2006). Under a vulnerability framing adaptation research focuses on the susceptibility to harm (Eakin and Luers, 2006). In the context of climate variability, adaptation is seen as a way to enhance resilience of individuals and systems in the face of global environmental change (Elum et al., 2017). While both resilience and vulnerability can be used as concepts for understanding specific disturbances, focusing on a specific disturbance can be limiting when dealing with uncertainty associated with climate change (Wardekker et al., 2010). Additionally, resilience also is not always considered desirable when considering economic, ecological or social terms – where some system regimes may be undesirable to one segment – which can in turn hinder change or development (Walker et al., 2006b).

Adaptive capacity, defined as the ability to adapt, is the common thread that links both resilience and vulnerability, and is widely accepted as a necessary feature in a system for simultaneously reducing vulnerability and increasing resilience (Anderies et al., 2004; Engle, 2011; Dixon et al., 2014). This requires looking at what a system has that enables it to adapt, and what this systems does in order to adapt (Dixon et al., 2014). The interplay of gradual and abrupt change needs to be understood in context to variables and processes that structure ecosystem and social dynamics, in order to understand and actively manage sources of social and ecological resilience. Adaptive capacity is understood as a universally positive system property, that can be shaped or manipulated by people, where adaptive capacity affects both social and ecological systems (Engle, 2011). Dixon et al. (2014) highlight the interconnected nature of resilience and vulnerability through adaptive capacity (see Figure 2.2) to better understand past drivers of adaptations and how they influence adaptive capacity of the examined system.

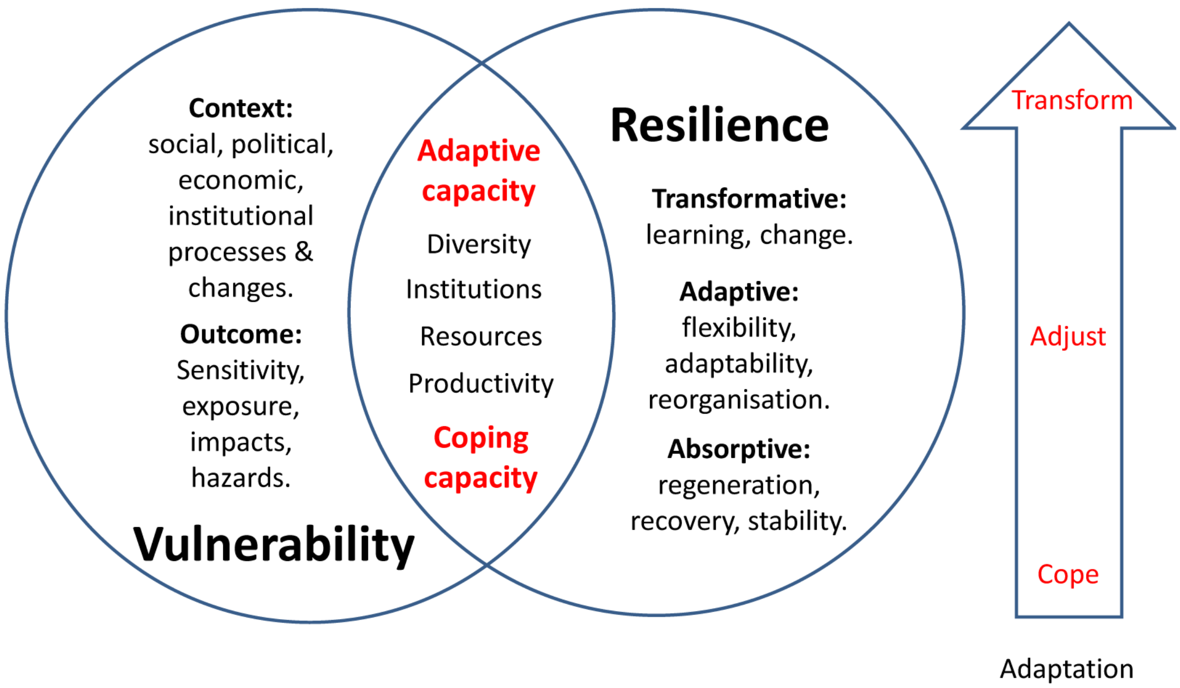


Figure 2.2: Resilience and vulnerability concepts connected through adaptive capacity (from Dixon et al., 2014)

While it is important to understand factors that enhance or diminish adaptive capacity of social systems (for example Adger and Vincent, 2005), limited attention has been given to the role of motivation in the process of adaptation (Frank et al., 2011). Within processes surrounding human decision-making and action, motivation and perceived abilities are central determinants of human action (Grothmann and Patt, 2005). Regardless of external pressures, individuals base their actions on whether they perceive a need, an ability and motivation to act to external pressures such as climate variability (Frank et al., 2011). Perceptions of risk play an important role as this influences people's perceived or actual ability to respond (Grothmann and Patt, 2005). Perceived adaptive capacity is influenced by the communication of risk, which could result in avoidant maladaptive responses (like denial of risk) if not complemented with adaptation options that are doable, effective and low cost (Grothmann and Patt, 2005).

Perceived risk is important to consider as it drives decisions around responses to environmental changes, which is often influenced by past experiences (Wiid and Ziervogel, 2012). The perception of risk depends on how it changes one's prospects and people tend to interpret risks differently, depending on individual circumstances. As noted by Burgman (2005), people tend to be poor judges of risk, and judgements on importance do not necessarily match the estimated magnitude of risk, and are influenced by the social context. Particularly in climate adaptation, the availability of information from scientific data sources could influence local adaptation strategies, which is further complicated as perceptions of climate change may differ from broader scientific understanding (Bryan et al., 2009; Hitayezu et al., 2017).

The requirements for learning and flexibility within social systems confronted with uncertain explanations of ecosystem change are essential to build the capacity of social-ecological systems to adapt to and shape change (Folke, 2006; Cundill et al., 2014). Climate change adaptation studies often neglect historical experiences of climate and other drivers of change; however, this is problematic given that present and future vulnerability is determined by how systems were previously exposed and reacted to stress, or how past experience has implications for resilience based on the assumption that all systems can learn from previous exposures to stress (Dixon et al., 2014). Perception of and response to climate change is largely the result of experience and accumulated knowledge (Wiid and Ziervogel, 2012). Evaluating perception of and response to climate change includes exploring what these perceptions are, how they were formed and how they influence response. These perceptions around climate change and its potential threats are rooted in individual values, trust of public opinions and personal experience. Within the field of climate change adaptation, local climate knowledge within the context of adaptation has the potential to positively impact choices and livelihood outcomes when dealing with weather uncertainty (for example Nyong et al., 2007; King et al., 2008; Wiid and Ziervogel, 2012). However, some studies indicate that climate trends are not necessarily in line with individual perceptions of how climate is changing (for example Osbahr et al., 2011; Muller and Shackleton, 2014; Hitayezu et al., 2017). Consequently, how people perceive global changes like climate change and how they respond is not a straightforward relationship.

Therefore, it is essential to understand why and how farmers and fishers respond to environmental challenges associated with climate variability. Understanding factors that drive decisions around land use practices or fishing methods is important to contextualise in order to understand how farmers or fishers operate in relation to environmental change. It is critically important not to view social-ecological systems in isolation, but rather acknowledge the complexities and risks across multiple facets in to gain a more holistic picture. Hence this thesis examines responses of farming and fishing communities in the southern Cape in relation to climate variability to better understand decision making-processes and associated complexities within these social-ecological systems.

2.5. Responding to uncertainty: Connecting knowledge systems

> "As we know, there are known knowns. There are things we know we know. We also know there are known unknowns. That is to say, we know there are some things we do not know. But there are also unknown unknowns, the ones we don't know we don't know."
>
> Donald Rumsfeld, Former U.S. Secretary of Defence (2002)

From examining how local terrestrial and marine social-ecological systems overlap in the southern Cape, to looking at responses of farmers and fishers within the context of climate variability, different elements of knowledge systems are drawn together in an effort to address gaps in understanding. However, as complexity is embedded in social-ecological systems, which in turn presents uncertainties when examining global environmental changes at localised scales, different systems have numerous of reactions to multiple stressors that play out over varying temporal and spatial scales. In the current context of the Anthropocene and associated complex global environmental challenges, there is a need to develop innovative paths to connect diverse knowledge systems to better understand sustainability in the context of social-ecological systems (Neis and Felt, 2000; Lutz and Neis, 2008; Tengö et al., 2014; Sterling et al., 2017). Many types of knowledge and their systems, ranging from local place-based values to external research or policy information, are important contributors towards understanding and managing systems in a sustainable manner (Sterling et al., 2017). Sterling et al. (2017) suggest three states in which different knowledge systems from external to local scales can occur, namely as separate systems (Figure 2.3a); as disconnected systems (Figure 2.3b); and as synthesized, multi-knowledge systems (Figure 2.3c).

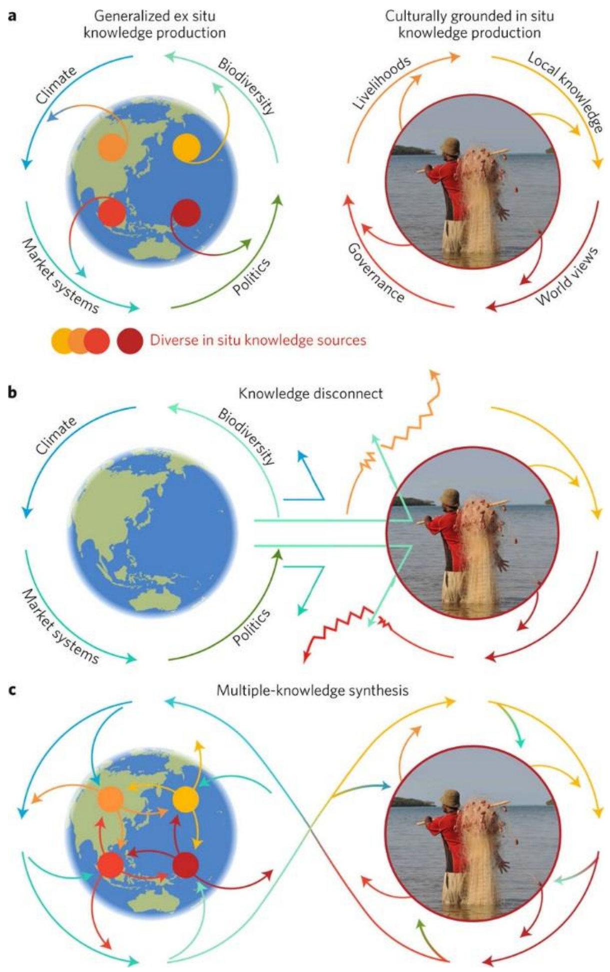


Figure 2.3: Internal and external knowledge production and synthesis in the form of three states: separate (a); disconnected (b); and synthesized (c) (from Sterling et al., 2017)

How information is turned into knowledge and subsequently into wisdom, as well as how to move knowledge and wisdom to people who urgently need it, present some of the most pressing issues of our time (Lutz and Neis, 2008). Non-scientific information can be one of the richest, undervalued sources of information that offers immense potential to improving understanding within social-ecological contexts (Mackinson and Nottestad, 1998; Neis and Felt, 2000). As illustrated in Figure 2.3c, the ability to synthesize across locally grounded and generalised knowledge from multiple sources can strengthen social-ecological resilience and foster human adaptive capacity (Sterling et al., 2017). The complex interconnectedness of people and knowledge production within natural and social paradigms has led to the realisation that we do not know enough about interactions between social and environmental change (Lutz and Neis, 2008). As such, it is necessary to develop new tools and approaches for combining and relating multiple data, both quantitative and qualitative (Tengö et al., 2014).

2.5.1. Examining diverse knowledge systems

Knowledge can be built on information that is obtained through observations or facts – which is considered more than just information; as knowledge is generated through a complex system of learning and understanding with multiple facets of experiences, skills and techniques that are accumulated and remembered (Lutz and Neis, 2008). Knowledge is embodied through perceptions, observations, actions, analyses, conceptual constructs, attitudes and world views; where these components are communicated, acquired and developed. Therefore, knowledge is built on ideas that are embedded in social institutions, structures and cultures, which are subject to perceptions, misperceptions and limitations of a specific society in a prescribed time period (Lutz and Neis, 2008).

Within this thesis, elements of knowledge systems considered and examined come from natural and social sciences, as well as local knowledge bases, therefore borrowing a more interdisciplinary approach. As noted by Lutz and Neis (2008), interdisciplinary work expands inputs to understanding and enhances the complexity of that understanding, thus generating an enriched knowledge of the examined subject. It is, however, important to acknowledge the potential gaps in understanding and uncertainty within and between knowledge systems. Therefore, drawing on parallel knowledge systems to create a fuller understanding of a particular issue can help address mismatches of information and create innovative pathways towards sustainability (Tengö et al., 2014).

From an academic knowledge perspective, science can be defined as "systematic knowledge increasingly acquired in the context of society, culture, and the economy" (Lutz and Neis, 2008: 22). This branch of knowledge can be either applied (i.e. understanding acquired through data analysis applied to real world situations that are reassessed on an ongoing basis) or theoretical (i.e. identifying patterns in observed data, postulating likely explanations and building up a fact base on proven theory). There is science that focuses on social and cultural society (social science), as well as science that looks at physical nature (natural science), both aiming at rational analysis where the methodologies of science further their aims. Science is 'ongoing, bounded, and multi-faceted' and should be mediated within the context of highly dynamic, increasingly complex and interconnected human societies; as well as conducted in the context of highly variable and rapid environmental change (Lutz and Neis, 2008).

A stream of knowledge that differs from such scientific knowledge is held by long-resident communities on their local environments (Lutz and Neis, 2008). There are many forms of diverse local knowledge systems associated with natural or ecological systems, with an array of terms and approaches ranging from Traditional Ecological Knowledge, Indigenous Knowledge, Rural Peoples' Knowledge, Farmer Knowledge and Folk Knowledge (Brook and McLachlan, 2008). For the purpose of this thesis, local knowledge systems concerned with natural resource use that are more closely associated with local ecological knowledge, defined as "knowledge held by a specific group of people about their local ecosystems" (Olsson and Folke, 2001: 87) were specifically examined. Local ecological knowledge can include a mix of scientific and practical knowledge, is locale specific and can involve a belief component. However, local belief components were not examined in this thesis and hence the examined knowledge systems are referred to as 'local knowledge' and deal more with locale specific, mixed scientific and practical knowledge around natural resource use.

Pertinent characteristics of local knowledge include the constant evolution of this knowledge base through generations of local experimentation (usually passed along through social memory); it is used in everyday situations in response to local challenges; and is seldom formally documented (Fabricius et al., 2006). Local knowledge systems that evolve through experimentation and adaptation over long periods of time can provide valuable and practical knowledge, particularly if there is limited scientifically documented information related to past patterns of local ecosystem use or functioning (for example Haggan et al., 2006), which can in turn be used to improve the sustainability of ecosystem use (Fabricius et al., 2006; Tengö et al., 2014).

2.5.2. Examining multiple knowledge systems

As large-scale environmental change is becoming more evident, conventional ecological research is not necessarily conducted at a fast enough pace nor covers a large enough area to fully grasp these complex changes, whereas local knowledge affiliated with nature can provide valuable insights for researchers, managers and policymakers (Brook and McLachlan, 2008). For example, developing historical perspective (drawing on local knowledge) on changes in social-ecological systems can be a useful tool in fisheries management (Haggan et al., 2006), as it can add important historical stock information to counteract shifting baselines, as well as highlight drivers of past social-ecological change in order to facilitate future-oriented discussion (Lutz and Neis, 2008). Particularly in the case of fisheries, where scientific data may be patchy or only have short time series and environmental history may not account for all processes involved in social-ecological change, different sources of information can complement one another in broadening understanding around complex, multi-scalar fisheries and their social-ecological systems (Lutz and Neis, 2008; Ommer et al., 2012).

Knowledge systems are comprised of agents, practices and institutions that facilitate production, transfer and use of knowledge (Tengö et al., 2014). While knowledge systems are typically developed synergistically, usually drawing on different streams to the benefit of each other, it is important to acknowledge potential power inequalities and epistemological differences between knowledge systems as highlighted by Tengö et al. (2014). The integration of knowledge systems, such as using scientific knowledge to validate local knowledge, can be problematic if used to validate one method as superior but can also be empowering if endorsed through a collaborative process. The co-production of knowledge is participatory in nature and engages all actors from the onset of the process (for example Duggan, 2018), resulting in mutual validation of knowledge generation. However, sometimes different bodies of knowledge are incomparable and best examined in parallel as specific strands of knowledge can be conceptualised differently (for example Verran, 2002). Parallel approaches to assessing diverse knowledge systems can be useful as there is acknowledgement that each knowledge stream adds value within an individual context, however can be equally valuable when used in parallel to generate an enhanced understanding of a complexity or issue.

Tengö et al. (2014) propose the multiple evidence base (MEB) approach that parallels different knowledge streams, such as local, indigenous and scientific systems, to generate different angles of useful knowledge that contribute towards an enriched picture (Figure 2.4). Building an enriched picture through examining complementary, contradictory and synergies of diverse knowledge systems can strengthen learning and improve understanding of complex social-ecological systems, particularly when responding to change and novel conditions in order to build up resilience (Tengö et al., 2014). Multiple knowledge systems are complex and face many matches and mismatches through different scales, validation methods or even disciplinary approaches (Ommer, 2007). The MEB approach stresses the importance of bringing diverse knowledge sets together in an equal and transparent manner, "for potential synergies across knowledge systems, processes for validating knowledge need to recognize and respect differences in theoretical and methodological approaches to understanding the biophysical world as well as the underlying worldviews" (Tengö et al., 2014: 584). In the case where different knowledge systems may be incommensurable, examining different framings in parallel can add a richer understanding of complex systems through contrasting perspectives (Verran, 2002).

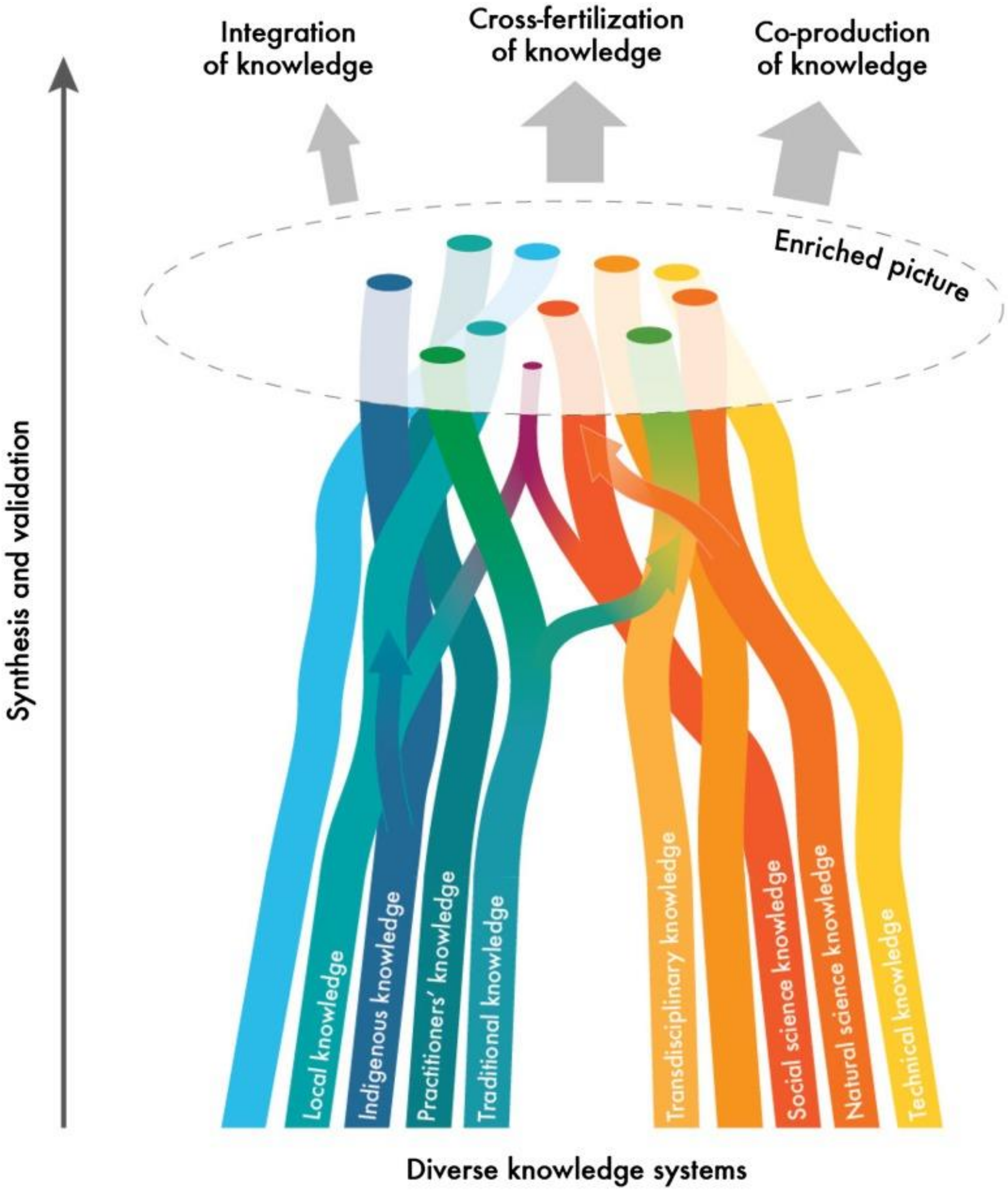


Figure 2.4: Multiple evidence base approach comprised of different knowledge systems that result in an enriched picture of a selected problem (from Tengö et al., 2014)

Tengö et al. (2014: 585) propose that "(e)xamining the enriched picture using a MEB approach can enable triangulation of information across knowledge systems and evaluation of the relevance of knowledge and information at different scales and in different contexts". The triangulation of information is necessary when investigating potential mismatches or disagreements between knowledge streams, particularly when trying to address knowledge gaps at different scales or generate new insights to further improve understanding.

2.6. Over-arching research approach, design and methods

> "Everything should be made as simple as possible, but not simpler"
> Albert Einstein (1933)

Many current environmental issues, such as climate change, cannot be sufficiently addressed through a single disciplinary perspective but rather require an integrated view to address systems problems (Nicolson et al., 2002). Bridging perspectives and disciplines can effectively address systems problems and deal with complex processes over multiple temporal and spatial scales (Nicolson et al., 2002). Therefore, when dealing with complex social-ecological systems, an integrative approach to research is required and thus interdisciplinarity is valuable in that it is a means to solving problems and answering questions that cannot be sufficiently addressed through a single method or approach (Newing, 2011). As noted by Paterson et al. (2010: 782), "(i)ntegrative and transdisciplinary approaches are required to develop new attitudes, methods and solutions" to deal with increasingly complex environmental and social challenges that emulate at multiple scales. This thesis examines local social-ecological systems through an interdisciplinary perspective, which is underpinned by an over-arching research approach and design that bridges individual chapters to create an integrated picture of local systems under climate variability and change.

2.6.1. Approach

The over-arching approach for this thesis is associated with a pragmatist worldview that focuses on "the consequences of research, on the primary importance of the question asked rather than the methods, and on the use of multiple methods of data collection to inform the problems under study" (Creswell and Plano Clark, 2011: 41). Pragmatism is typically affiliated with mixed methods research as it is a well-developed and attractive philosophy for integrating approaches (Johnson et al., 2007). Ontology associated with a pragmatist worldview looks at both singular realities – which tests a hypothesis, and multiple realities – which provides perspectives; where researchers select the most appropriate data collection method to address questions through a practicality epistemology (Creswell and Plano Clark, 2011).

Due to the nature of this study, the research strategy underpinning this project is based on inductive research. In contrast to deductive research where the researcher generates a specific hypothesis and designs data collection accordingly to test this specific theory, inductive research does not have a specific hypothesis (Newing, 2011). Rather, data collection is guided by a broad set of issues and these data are used to generate a theory or better understanding of the issues at hand. As there is limited understanding as well as knowledge gaps associated with how local climate is changing over time in the southern Cape and its possible impacts on natural resource users (such as farmers and fishers), an inductive approach is necessary to start with broad, open-ended research with the aim to build up detailed understanding of complex adaptive systems.

Local knowledge systems, together with natural and social sciences, can improve the understanding of how to care for social-ecological systems, as well as lead innovative or desirable pathways in the face of uncertainty (Tengö et al., 2014). Similar to the MEB approach described by Tengö et al. (2014) (refer to Figure 2.4), this thesis uses a parallel approach to bring together local climate knowledge from multiple sources, namely farmers, fishers and scientists. Drawing on existing work done by the SCIFR team, selected natural resource users are used as knowledgeable experts of their social-ecological systems alongside scientific data sources. This two-fold approach is interdisciplinary in nature in that it examines local knowledge systems in concert with regional climate data with the aim to build up a more comprehensive understanding of complex terrestrial and marine social-ecological systems of the southern Cape.

2.6.2. Design

A case study design, focusing on southern Cape farmers, fishers and local climate systems under the common theme of climate variability, is used to build a detailed description and understanding of this specific situation for the thesis. Case study design involves “detailed data collection about a single ‘case’ or situation” with the aim of contributing to its own understanding, as well as to add to broader theoretical understanding, to generate theories around underlying issues (Newing, 2011). The case study method in the context of this research is a way to better understand a real-life phenomenon, such as climate change, in depth – where this understanding encompasses pertinent contextual conditions, such as the realities of farmers and fishers operating in the southern Cape (Yin, 2009). Through linking different climate knowledge systems, drawing on knowledgeable resource users and local climatic data, the detailed case study undertaken for this thesis aims to better understand the southern Cape social-ecological system.

2.6.3. Methods

Research can be characterised based on various methods employed that are categorised through data collection and analyses. Examples of different research characteristics are determined through methods such as quantitative, semi-quantitative and qualitative tools (refer to Table 2.3), where different data collection and analyses tools are used that best suit the characteristics of what the research is examining. At a basic level, quantitative and qualitative research can take different positions when examining epistemological questions around the nature of knowledge (Newing, 2011): for example quantitative research can focus on statistical significance to validate scientific knowledge; whereas qualitative research can argue that reducing complex problems to numerical values can result in losing knowledge. Different forms of quantitative, semi-quantitative and qualitative research provide can useful perspectives when examining complex problems, as the limitations of one method can be offset by the strengths of the other to work towards solutions of complex problems, such as understanding climate variability.

Table 2.3: Quantitative, semi-quantitative and qualitative characteristics for research (adapted from Newing, 2011)

	Quantitative	Semi-quantitative	Qualitative
Characteristics	Correlations Cause-effect relationships Statistical significance Different factor prevalence	Models Decision makers Stakeholders Scenarios	Overview Disentangle complexity In-depth understanding Social and cultural context
Data collection	Numbers	Indicators Observations	Non-numerical (e.g. words)
Data analysis	Statistical	Synthesize knowledge	Narrative account Critical analysis

Studies that make use of both quantitative and qualitative elements are referred to as mixed methods studies in that they can combine the best of both approaches to gain complementary insights into an over-arching topic (Newing, 2011). In the realm of interdisciplinary research, mixed methods are the typical methodology of choice (for example Ommer, 2007), as it allows for an integrated approach to problems in complex systems (Creswell and Plano Clark, 2011). "Research problems suited for mixed methods are those in which one data source may be insufficient, results need to be explained, exploratory findings need to generalized, a second method is needed to enhance a primary method, a theoretical stance needs to be employed, and an overall research objective can be best addressed with multiple phases" (Creswell and Plano Clark, 2011: 8).

Mixed methods designs include the convergent parallel design, explanatory sequential designs, embedded design, transformative design and multiphase design (for details see Creswell and Plano Clark, 2011: 96). For the purpose of this study, the convergent parallel design is applied within the mixed methods approach. This design is used by researchers who make use of concurrent timing to implement quantitative and qualitative strands during the same phase of the research process where methods are prioritised equally. Each strand is analysed separately and then results are mixed during the overall interpretation (Creswell and Plano Clark, 2011). The convergent design is a practical method to acquire a more comprehensive understanding of the topic at hand and identify possible mismatches between data sets or different knowledge systems, in line with objectives of this thesis.

As detailed in Figure 2.5, each empirical chapter (Chapters Three to Five) in this thesis focuses on a particular set of methods for data collection and analysis, which is then synthesised in the final chapters (Chapters Six and Seven) – drawing on the convergent parallel design. Through the framing of a pragmatist worldview, data collection and analysis of this thesis are directed through a mixed methods approach that is interdisciplinary by nature. Data collection for this project was guided by a set of broad issues with the aim to generate a theory once sufficient evidence has been collected. For this particular research strategy it is important to find a balance between "defining a precise focus for the research and keeping an open mind so that you don't predetermine the results" (Newing, 2011: 6). This thesis therefore examines climate variability in local terrestrial and marine social-ecological systems through the perspective of local farming and fishing communities of the southern Cape.

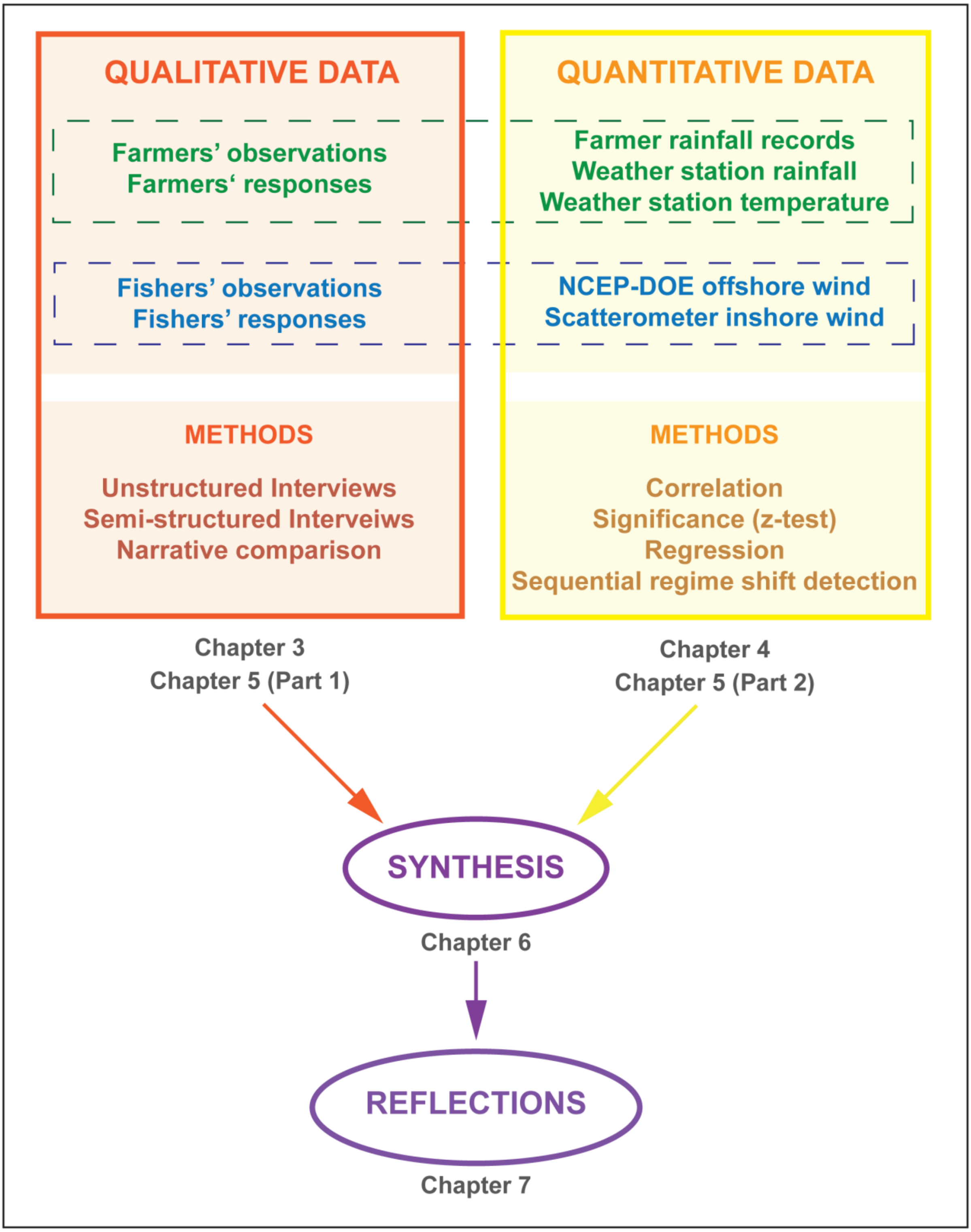


Figure 2.5: Thesis layout based on the convergent parallel design for mixed methods (adapted from Creswell and Plano Clark, 2011)

CHAPTER 3

THE CLIMATE PERSPECTIVE: SOUTHERN CAPE FARMING COMMUNITIES

3.1. Introduction

The Western Cape has been highlighted as a South African region likely to be highly vulnerable to projected warming and rainfall change induced through climate change, thus significant impacts on agricultural practices are expected in this province (Midgley et al., 2005; Wiid and Ziervogel, 2012). Shifts in weather conditions can drive farmers' efforts to adapt, thus influencing the type of agricultural activities that take place. Climate variability can also push farmers into vulnerable states (Leichenko and O'Brien, 2002; Thomas et al., 2007), which would have negative repercussions for future food security and economic growth in South Africa. In the context of agriculture within the Western Cape, Wiid and Ziervogel (2012: 170) noted that the "most important influence on adaptive decision-making was the fact that the farmers experienced real and measurable shifts in climate over a number of decades".

Environmental changes within the terrestrial social-ecological system of the southern Cape are complex and play out over multiple temporal and spatial scales, where gaps in understanding are present due to insufficient data availability and high uncertainty associated with regional climate forecasting models. It is difficult to predict how different habitats may respond to global changes in natural systems, particularly at local levels. Changes or stressors in natural systems where quantitative data and model outputs are available on global scales are not necessarily translated to local scales, making it challenging to identify regional impacts (Moloney et al., 2013). When dealing with weather uncertainty, perceptions are largely generated through experience and accumulated knowledge – particularly in the case of communities dependent on a natural resource base to secure their livelihoods, such as farmers. As observed by Wiid and Ziervogel (2012), examining experiences, perceptions and responses of stakeholders to relatively recent climate shifts can be beneficial for developing adaptive capacity.

The method of examining farmers' climate experience in conjunction with climate data has proven useful in contributing towards gaining a deeper understanding of climate variability, perceptions and adaptation strategies to local and regional weather systems in South Africa (for example Thomas et al., 2007; Wiid and Ziervogel, 2012; Gandure et al., 2013; Muller and Shackleton, 2014; Elum et al., 2017). This chapter examines the terrestrial component of the social-ecological system in the southern Cape, with a focus on farming communities and their observations of local climate variation over time. Due to the rural agricultural nature of the southern Cape area and the reference local fishers made to farmers in previous research (refer to Section 1.5), farming communities were thought to be knowledge brokers for environmental changes in this area. Farmers are also more invested in environmental impacts due to the reliance of agriculture on weather patterns. This chapter deals with Key Question 1 – "how is climate variability perceived by farmers and are they responding to changes in climate?" and is explored accordingly.

3.2. Research area

This thesis focuses on the local scale of the southern Cape and Agulhas Bank – refer to Section 1.1 (specifically Figure 1.1). As such, the research area for the terrestrial component of this research was conducted in catchment areas adjacent to the above mentioned coastal communities, spanning Witsand, Heidelberg, Riversdale, Albertinia and Still Bay (see Figure 3.1). The majority of the research area was located in the Duiwenhoks and Goukou catchment areas, spanning very slightly into the adjacent Breede and Gouritz catchments. The area was chosen based on farm locality, as some of the larger commercial farms (up to 2000 hectares) spanned over two catchment areas, however all participating farms fell under the same local municipality management area (Hessequa Municipality). The area is bordered by the Langeberg Mountains (part of the Cape Fold Belt) to the north and the Indian Ocean to the south, creating fairly confined micro-climate conditions where the water catchment area for both the Duiwenhoks and Goukou rivers only extend to the seaward side of the bordering mountain range.

Figure 3.1: Research area location within southern Cape and place names found in the text

The Duiwenhoks and Goukou catchments are located in the Hessequa Municipality of the Eden district in the Western Cape Province. The combined catchment size of the Duiwenhoks and Goukou is approximately 2 978 km^2 (River Health Programme, 2007). The geology of this area comprises of sandstones, shales and tillites of the Cape Supergroup. Vegetation consists of temperate and transitional forest and scrub, as well as false sclerophyllous bush (consisting of South Coast Renosterveld and Sandplain Fynbos). Renosterveld shrubland and grassland make up much of natural land-cover in these catchments. The Duiwenhoks and Goukou rivers flow south from the Langeberg Mountains to the coast, entering the sea west of Mossel Bay where both rivers have estuary mouths that are permanently open to the sea (River Health Programme, 2007).

The Duiwenhoks and Goukou catchment areas have several important peat wetland systems that are characteristic of the Langeberg area and provide an array of essential ecosystem services to surrounding land-users. However, both catchments are degraded through anthropogenic activities associated with land-use practices, dam construction and alien plant infestation, making these systems vulnerable to extreme climatic events. The research area forms part of the Greater Cape Floristic Region which has been identified as a biodiversity hotspot – "areas which share large numbers of endemic taxa that are being increasingly threatened by human impacts" (Allsopp et al., 2014: 42).

3.2.1. Land use history

The Duiwenhoks and Goukou catchment area was first settled by early European farmers in the 1700s, where the town of Heidelberg was established in 1885. While urbanisation has not grown extensively from the 19^{th} century, the area has experienced increasing pressure from intensive farming practices over the decades and, coupled with changing climatic conditions, have altered natural ecosystem functioning (Price, 2006). Agricultural production has increased over time predominately in middle and lower catchment areas, while little change to the natural vegetation has occurred in the upper reaches. Land cover changes show distinct temporal patterns in these two adjacent catchments that possibly reflect social and economic drivers related to distance to populated centres. However, significant conversion of natural vegetation has occurred since the 1950s in both catchments (G.F. Midgely, Stellenbosch University. pers. comm.).

In the Duiwenhoks catchment area, Mpfunzeni (2015) examined local land cover changes from the 1940s to late-2000s and found a steady decrease of natural vegetation over time due to land conversion into cultivated and degraded (i.e. clearing land in preparation for agricultural use) areas. The highest rate of natural vegetation clearing in this catchment took place between 1950 and 1960 which coincided with significant increases in cultivation activities; followed by the period of 1970 to 1990 which overlapped with urban (and infrastructure) expansion. Few inland dams were observed in the early decadal data sets, but this increased proportionally with the subsequent intensification of farming activities. Along the coastal belt, the purpose of most agricultural fields have shifted from cultivation practices to livestock farming or been left abandoned. One of the key threats to the catchment area was shown through alien vegetation infestation along the riparian zone, wetlands and streams of the Duiwenhoks River, which have negative ramifications for local water availability.

Similar research conducted by Nzonda (2016) looking at land use change in the Goukou catchment area from 1940 to 2010 also showed a steady increase of cultivated land, disturbed surfaces and associated dam construction over time. Key drivers of land change included the conversion of natural habitat to agricultural fields and invasion of alien vegetation, particularly affecting the riparian zone of the Goukou River. Nzonda (2016) notes that agricultural expansion is the major contributor to natural vegetation and wetland loss in the Goukou catchment, and this further impacts river water quality through the introduction of fertilizers into the larger terrestrial and marine ecosystems. In both Duiwenhoks and Goukou catchments, significant shifts in hydrological function, accelerated soil loss and wetland degradation – coupled with increased river extraction for water storage and irrigation – are most likely to impair ecosystem functioning (Mpfunzeni, 2015; Nzonda, 2016).

Today, the combined Duiwenhoks and Goukou catchment areas are dominated by forestry, dairy farming and tourism activities. Heidelberg, Riversdale and Albertinia constitute the main agricultural/industrial urban hubs in the Hessequa area; while Witsand, Still Bay and (to a lesser extent) Gouritsmond are urban centres for tourism, retirement villages and the local commercial linefishery. Land-use within the Goukou catchment consists mainly of dryland and irrigated agriculture (e.g. vineyards, fruit, vegetables, lucerne and pasture), livestock (e.g. sheep) and commercial forestry (notably pine). In the Duiwenhoks catchment, dominant land-use activities are less varied than in the Goukou and dominated by dryland and irrigated agriculture (e.g. vineyards, lucerne and pasture) (River Health Programme, 2007). Major dams include one in the Duiwenhoks catchment called Duiwenhoks (6.4 million cubic metres) and two in Goukou called Korintepoort (8.3 million cubic metres) and De Novo (0.1 million cubic metres).

3.2.2. Southern Cape climate

The climate of the Western Cape region is influenced by both large-scale atmospheric and locally driven oceanic processes. The western border of the province is influenced by the cold Benguela upwelling system, whereas the southern border is influenced by the warm Agulhas Current. The climate of the southern Cape is determined by its low altitude and the warm Agulhas Current.

3.2.2.1. Rainfall

The Western Cape region comprises of two dominant rainfall seasonality zones – a winter rainfall region west of approximately 20.5°E (the longitude of Cape Agulhas) and a yearround rainfall zone east of that longitude (Allsopp et al., 2014). Patterns of rainfall seasonality are complex and subtle with gradients of declining winter seasonality northwards and eastwards from the south western regions of the Western Cape. For the southwestern Cape region (31–34°S, 17–21°E), which the research area borders on the eastern extent, approximately 60 to 70 percent of the annual rainfall occurs over May to September through cold fronts and (to a lesser extent) cut-off lows (Reason and Jagadheesha, 2005). During summer months, rainfall is typically intermittent and unreliable occurring via mid-latitude systems (i.e. cold fronts and cut-off lows) or tropical-extratropical cloud bands. The southwestern Cape region is characterised by substantial inter-annual variability in rainfall (Reason and Jagadheesha, 2005). The south coast (approximately 21–23°E), where the research area falls into the western and mid-extent, is characterised as an aseasonal rainfall zone, and is a bimodal rainfall region with rainfall usually occurring throughout the year that peaks in spring and autumn (Allsopp et al., 2014). The average annual precipitation for the Duiwenhoks and Goukou catchments combined area is approximately 490 mm – however, this varies from lower rainfall in the coastal region that increases towards the upper catchment areas (Mpfunzeni, 2015; Nzonda, 2016).

Rainfall patterns for the Western Cape are largely underpinned by synoptic drivers and this region is under the influence of the circumpolar, westerly frontal systems (Tyson and Preston-Whyte, 2000). The south-north rainfall seasonality of the Western Cape is driven by these cyclonic air masses that bring rain during winter months when these systems make landfall through shifting northwards of their summer track. In summer, the westerlies are pushed southwards (typically offshore) by the South Atlantic High Pressure Cell – an anticyclonic mass of dry air that produces south to south east winds (resulting in no rain to the western parts of the Western Cape) (Allsopp et al., 2014). The east-west rainfall seasonality gradient is more complex compared to the south-north, influenced by the steep relief of the north-trending Cape Fold Belt and the Great Escarpment, which block eastward penetration of cold fronts during winter months. Additionally, the warmer ocean eastwards of Cape Agulhas has a significant influence on rainfall seasonality for the southern Cape and the majority of rainfall (irrespective of season) is the result of post-frontal conditions, when a high pressure cell ridges in behind a front and advects moist air over the warm ocean causing rainfall (Allsopp et al., 2014).

Cut-off lows (Singleton and Reason, 2007), most frequent in transition seasons (i.e. spring and summer), can also produce large amounts of rain and are more prevalent in eastern regions of the Western Cape, hence influencing the bimodal rainfall seasonality of the research area.

3.2.2.2. Temperature

Temperature regimes around the coastal belt of the Western Cape are generally moderate. Temperatures along the south coast are ameliorated through onshore wind flow and relatively high cloud cover (Allsopp et al., 2014). Average minimum temperatures for the south coast region hover around 6°C, with an average maximum of approximately 25°C (Allsopp et al., 2014). Within the Duiwenhoks and Goukou catchment area, the mean annual day temperature for summer is approximately 26°C and 16°C in winter (Nzonda, 2016). Due to the steep topography in the region, as in the research area, there is a gradient from a mild coastal climate to a more seasonal temperature regime inland (i.e. upper catchment) which is hot in summer but can also receive snow on mountain tops during winter (Allsopp et al., 2014).

3.2.2.3. Local climatic changes

The climate for the Western Cape region has become warmer over time, as well as experienced possible shifts in rainfall patterns with some areas receiving less rainfall in winter. Historical records indicate that climate has become significantly warmer over the last century across the Greater Cape Floristic Region, whereas rainfall trends are spatially heterogeneous and no significant trends have been detected (Allsopp et al., 2014). Across the Western Cape, trends towards drier conditions along the southern coast regions have been detected, and analyses in the southwestern regions suggest that lowland areas are drying whereas mountain areas have received an increased rainfall over time (Midgley et al., 2005; MacKellar et al., 2014). Potential decrease in rainfall could be due to fewer low pressure systems that reach the region in winter; however, gaps in understanding local variability in rainfall trends remain due to the complex dynamics of interacting large-scale atmospheric pressure fields over southern Africa, the southern Atlantic and Indian Oceans (Allsopp et al., 2014).

3.3. Methods

3.3.1. Data collection

Interviews were utilised to collect qualitative data within farming communities. "The strength of qualitative interviews is in providing background information and context, generating ideas, discovering the unexpected, and providing in-depth information on each participant's views, perspectives and motivations" (Newing, 2011: 53). Data were predominately collected using unstructured interviews (free-ranging conversations arranged in advance to explore the climate variability aspect on a local level from different perspectives) and semi-structured interviews (an interview guide was made to cover pre-defined topics). During fieldwork trips, I recorded thoughts and observations in a research journal (termed fieldwork notes) as noted by Bazeley (2013: 102) "(t)his kind of writing is like having a discussion with yourself, and the discipline of doing it adds enormously to the depth of your analytic thinking".

Sampling strategies for this research followed non-probability sampling, as this technique is appropriate for research where the main purpose is to examine specialist knowledge (in this case farmers' observations on climate variability) rather than determine the entire populations' characteristics (Newing, 2011). Following initial introductions into local communities through the SCIFR project (see Section 1.5 for details) in the scoping phase of this study, chain referral was identified as a suitable method to seek out individuals who were most relevant for the research, interview them and then ask if the participants knew of others to interview (Newing, 2011). Farmers recommended to take part in the project were contacted through local forums or trusted key contacts and then a snowball sampling technique (Goodman, 2011) was utilised to obtain a chain of referral details for other local farmers, who were subsequently contacted and, if consented, interviewed by the researcher. In an effort to obtain a fairly diverse sample, six entrance points into local communities were used, as an attempt to talk to people from diverse backgrounds and with different mind sets (see Figure 3.2 for and overview of the snowball technique employed).

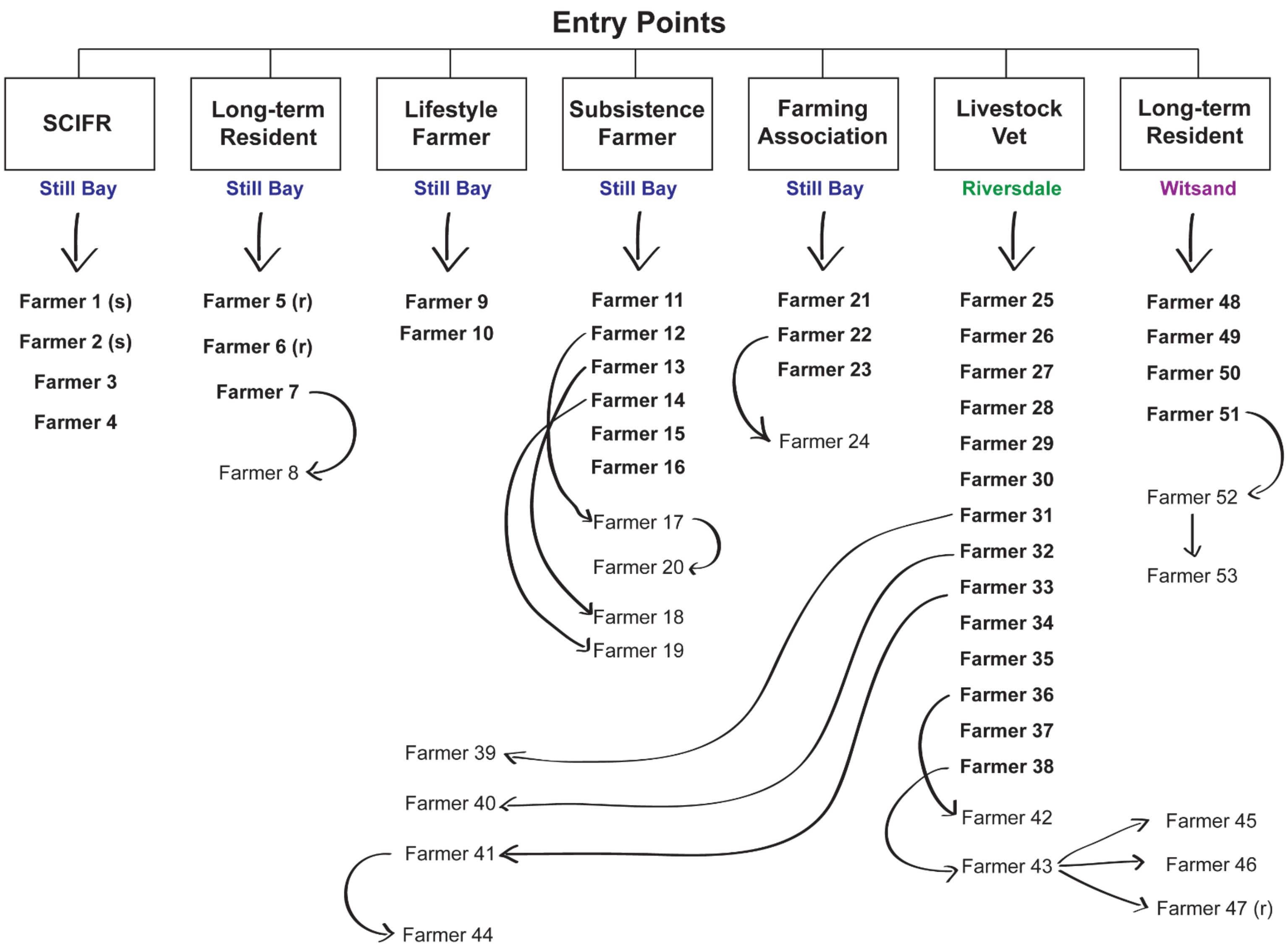


Figure 3.2: Overview of snowball technique employed to survey farmers in research area, where 's' refers to scoping (phase) and 'r' to retired farmers

3.3.1.1. Scoping phase

Initially, the proposed research area was scoped from October 2014 to May 2015. Several field site visits were conducted during this phase to meet key contacts from the SCIFR project and begin the introduction process into the local farming communities. From this process, it was determined that farmers or land owners, rather than farm employees, would be suitable candidates for this research to examine perceptions and experiences of climate variability in relation to decision makers. Farmers (or land owners) determine practices carried out on their lands, which provides a good starting point to examine how climate may or may not influence decision making processes around land practises. This follows a similar approach to the SCIFR project, where the onset of this fisheries project initially focused on skippers and expanded to include crew as the study evolved over time. The terrestrial component of the SCIFR is initiated through this research, hence this study is considered as a baseline study appropriate for the three-year period of a PhD project.

Unstructured interviews were carried out predominantly in the scoping phase of this project to build up a knowledge-base of the research area in relation to climate variability and farming. These discussions explored themes such as local farming practices in the study area and perceptions of climate variability in the southern Cape. Interviewees consisted of local staff from a number of organisations such as Cape Nature, the LandCare office under the Western Cape Department of Agriculture, veterinarian practitioners, the Council for Scientific and Industrial Research (CSIR), and other researchers (for example Mpfunzeni, 2015; Nzonda, 2016) conducting parallel studies in the catchment areas.

Networks in farming communities were initially set up through scoping visits with two local farmers through the SCIFR project in November 2014. These farmers gave insights around farming practices in their respective areas in relation to climate variability through unstructured interviews. One farmer was located in the Goukou catchment and the other in the Duiwenhoks catchment, allowing an initial insight into the proposed research areas. This also provided initial contacts into the local farming community. A group meeting (five participants) was then set up with a local farming association in the Goukou catchment in May 2015 to introduce the project and get insights from the group on farming activities in the area. Retired farmers were also consulted for their long-term expertise on the area. From the feedback gathered through these unstructured interviews and meetings, semi-structured interview schedules were created and piloted on five farmers in July 2015.

3.3.1.2. Interview development

The interview guide was designed along the lines of a survey as a method for information collection that could be used to describe, compare and explain individual knowledge, feelings, values, preferences and behaviour (Fink, 2009). The farmer surveys aimed to ensure an open dialogue was maintained throughout the interview, with some pointed questions to steer the conversation along these themes: background on individual farms and general farming practices in the area; climate; farming challenges; and farming support networks (refer to Appendix 1A). Where possible, personal weather records from respondents living in the research area were requested and used (refer to Chapter Four for detailed analyses) where permission was granted. The survey was dominated with open-ended questions so that participants could determine the path of discussion in an effort to encourage the concept of participant-led research. Individual farm owners or farming families were interviewed – often the farmer was present with his wife, sons or brothers as many farms in the area are run as family businesses. In these cases, one family group counted as one interview to avoid repetitiveness. Interviews were conducted in the preferred language of the participant, either English or Afrikaans.

Ethics was taken into serious consideration for this project. Permission was obtained from the Faculty of Science Research Ethics Committee at the University of Cape Town to carry out this project (see Appendix 1B). At the start of the survey process, each participant was fully informed of their rights during the interview process and their anonymity was guaranteed. Informed consent was obtained in writing as far as possible and it was intended that discussions were audio-recorded to be transcribed in an anonymous fashion. However, due to a general culture of mistrust within these farming communities, audio-recordings were not always possible and so to ensure maximum efficiency the interview processes was conducted by a two person team – the research assistant asked the survey questions to maintain flow while I took detailed notes of the conversation.

At the completion of this project, summarised research findings were communicated to participants where possible through pamphlets in both English and Afrikaans (see Appendix 1C). General feedback sessions were held among the local farmers associations for any interested parties in September 2018 in Still Bay, Riversdale and Heidelberg.

3.3.1.3. Data collection phase

Following fine-tuning of the interview schedule through pilot surveys carried out in the scoping phase, formal data collection from participating farmers through refined semi-structured surveys was carried out from July 2015 to March 2016. According to the provincial Western Cape Department of Agriculture there were approximately 480 farm plots in the Duiwenhoks and Goukou catchments in 2015. However, some farming families and individual land owners own more than one farm, a consequence of commercial agriculture expansion in the area, as well as the due to the introduction of 'lifestyle' farming trends.

According to local agricultural experts, there are approximately 300 farm owners between the Heidelberg/Witsand and Albertinia/Still Bay area. As noted by Newing (2011), there are no 'hard and fast rules' for setting a pre-determined target sample size in semi-structured interviews as appropriate size can depend on information passed along by participants. Newing (2011) recommend between 10 and 50 interviews for this kind of qualitative research, depending on population size. Due to the large number of farms within the research area and time constraints of the project, a sample size of 50 interviews was predetermined and obtained for the semi-structured farm surveys (refer to Table 3.1).

Table 3.1: Farmers and informants sampled during the project

	Scoping (2014)	Pilot (July 2015)	August (2015)	September (2015)	November (2015)	January (2016)	March (2016)
Commercial Farmers		1	7	15	4	9	5
Lifestyle Farmers	2*	2	2		1	1	1
Subsistence Farmers		2					
Retired Farmers		2*					1*
Hessequa Municipality			1*				
Government (Conservation)	2*						
Government (Agriculture)	2*						
Researchers	4*						
Total	**10**	**7**	**10**	**15**	**5**	**10**	**7**

* Participants gave feedback through unstructured interviews, information not included in thematic analyses of semi-structured surveys but rather in narrative accounts

3.3.2. Analysis

Qualitative data were collected in two streams – firstly through unstructured interviews carried out during the scoping phase and secondly through semi-structured surveys in the subsequent phase of data collection. All data analyses were conducted using anonymity to protect respondents' identities.

Data from unstructured interviews and accounts gathered from key participants in the scoping phase were built into a narrative account (Newing, 2011) to provide an overview of the research area in terms of farming practices and climate from local perspectives. These qualitative data were interrogated and summarised in a narrative manner, drawing on recordings from my fieldwork notes and previous studies conducted in the study area by Mpfunzeni (2015) and Nzonda (2016) to add context.

Structured observations and verbal data from the semi-structured interviews were recorded in the form of brief quotes and text summaries. These data were then combined with categorical and ratings information in Microsoft Excel® to create a database for analysis and comparison (Bazeley, 2013). Content analysis was employed as a suitable technique for analysing these texts and frequencies of words, phrases and concepts were counted across this qualitative data set (Newing, 2011). These data were then analysed by means of thematic analyses to identify specific trends or common themes with a focus on climate variability in terms of rainfall and temperature observations. Climatic themes were then selected in terms of challenges experienced by farmers.

3.4. Results

Results are divided up into two parts. Firstly, a general overview of the research area is given though local narratives from unstructured interviews where general farming trends and key issues are summarised. The second component for the results focus on detailed qualitative analyses of farmers who participated in the semi-structured interviews, focusing on observations of climate variability and general challenges experienced by participants.

3.4.1. Local narratives

Narrative accounts described here from knowledgeable experts and retired local farmers focused on the modern farming landscape, typically starting from when the first commercial farms were established by Dutch settlers from the 1880s. Generational farming family names for this specific area hailed primarily from the Netherlands, France and (to a lesser extent) Scotland. Currently, the Hessequa Municipality area has an estimated population size of 56 488 which is demographically comprised of 69 % Coloured, 23 % White and 7 % Black people. Afrikaans is the most widely spoken language (90 %), followed by English (4 %) and IsiXhosa (2 %). Employment for the municipality shows a negative trend, where the largest portion of the working population is employed in commercial services, government services and agriculture sectors (Hessequa Municipality, 2017).

3.4.1.1. Agriculture overview

Historically, farming practices in the research area were determined according to vegetation type. Mountain and coastal areas were considered less 'desirable' due to difficult terrain conditions and poor soil fertility. The lowlands, located between coastal and mountain belts, are the most fertile and therefore seen as prized farmland. The riparian zones of the rivers were viewed as good for pasture but required additional inputs (for example fertilizers and irrigation) to make these zones viable and are also vulnerable to flooding events. Micro-climates are observed between the west and east extents of the study area, where the western side is considered to be drier (i.e. receives less rainfall) compared to the east. Micro-climates are also discussed between the coastal, lowland and mountain belts, with an increasing rainfall/temperature gradient from the coast (low/moderate) to mountains (high/extreme), which influence the type of farming practices carried out over the research area.

3.4.1.2. Change over time

The impact of climate on farming practices in the area over time is complex and nuanced. Long term weather patterns carry an element of high variability and seasonality is not as pronounced as (for example) the west coast of the Western Cape. Retired farmers, born into farming and who have lived in the area for an average of 77 years, observed that rainfall had noticeably changed from the 'old days' (over 20 years ago in their lifetimes, but also extending further back to grandparents farming experience) where seasonal winter rainfall referred to as 'peach rain' (i.e. constant soft drizzle usually over seven days at a time that was deemed good for fruit trees) had shifted to prolonged dry periods, extreme rainfall events and increased unpredictability. Westerly winds, typically associated with winter rainfall, are also deemed to have decreased over time and the traditional onset of seasons was observed to be later in the year. On the eastern boundary of the research area, one participant noted that the inland Karoo climate appeared to have transcended the Langeberg Mountains, resulting in frequent occurrences of thunderstorms on the seaward side and a general increase of drier, hotter weather, where soil moisture decreases more rapidly compared to the past.

While farmers monitor prevailing weather conditions and adapt short-term land use practices to accommodate climate variability, economic and technological trends have most noticeably shaped the physical farming landscape according to local narratives. Coupled with economic markets, technological advancements have mediated change of farming practices within the catchment area over time, as well as other factors such as the price of fuel (i.e. linked to area able to plough) and the introduction of invasive plants (such as black wattle (*Acacia mearnsii*) along the rivers and pine (*Pinus pinaster*) in the mountains).

One of the most discussed themes that determined farming practices over time is the markets, where 'scale of economy' is considered to be a key driving factor to change or impact existing farming strategies. For example, from the 1900s into the 1970s, the Riversdale area supported a large production of vegetables and fruits but closure of processing factories (e.g. fruit canneries) and increased expenses associated with input costs and labour resulted in farmers shifting towards more lucrative dairy production. Dairy farming subsequently dominated both catchments up until the 1990s, however this shifted about a decade ago when the low price of milk (direct payment to farmers) became too little to sustain smaller dairies, and milk buyer corporations (such as Nestle) stopped sending through trucks to collect milk from farms. One participant estimated that of the 3500 dairy farms that had existed between Heidelberg, Riversdale and Albertinia, only 150 (four percent) remain commercially operational today. Smaller dairy farms ceased to exist if they could not expand, were either absorbed into neighbouring farms by wealthy buyers to increase production scale, or other land use practices (such as grain, sheep, beef and ostrich farming) were introduced to diversify economic income. This also led to the introduction of 'lifestyle' farming, where redundant commercial farms (particularly along the inhospitable coastal belt) were carved up into portions and sold to wealthy 'outsiders', typically from large urban centres such as Cape Town, who undertake lifestyle farming such as game, olives and wine.

Advances in technology have also shaped farming productivity in the research area. One participant noted that the boom in wool prices in the 1950s allowed local sheep farmers to intensify farming practices on smaller areas and diversify into mixed farming practices (i.e. wool and cereals) as they were able to afford the new machinery to become more productive. Today, there is a large base of commercially-farmed grain (for example canola, wheat, barley, rye, lucerne) through irrigation in the research area, which is linked to the global economy demand. Advances in technology have allowed grain production to increase substantially, moving away from traditional labour-intensive methods to mechanised machinery. Historical practices made use of intensive ploughing processes, referred to as 'rip and till', to remove natural vegetation and weeds – essentially stripping the topsoil layer bare. Currently, most land use practices employ conservation tillage strategies which aim to build up soil composition and moisture as healthy soils are deemed more economically profitable due to increased yields and less inputs (such as water) that are required. However, farmers are currently needing to expand farmlands to remain financially productive due to the poorly performing local economy, expensive modern machinery (and linked high fuel price) and the weak local agricultural market.

3.4.1.3. Water: Example of multi-stressors

Another common narrative that emerged centred on freshwater, with a particular focus on the local river systems (Duiwenhoks and Goukou rivers). Tensions between conservation bodies, farming practices and increasing urban demand were most evident over water issues. Challenges associated with failing freshwater supplies are three-fold: increased erosion, prolific spread of invasive plants and over-abstraction of river water; which have been exacerbated through big flood events that occurred through the 2000s. The (recent) change in flood regime has resulted in certain protective structures along the rivers to fail as the design cannot handle more than 200 mm of heavy rainfall over two hours, causing erosion problems along the channels.

The sensitive wetland areas of the catchments have been degraded through environmental and anthropogenic impacts, further impairing freshwater sources (Mpfunzeni, 2015; Nzonda, 2016). These wetlands are heavily infested with invasive plant species that shade out natural, stabilising semi-aquatic vegetation such as palmiet (*Prionium serratum*), causing wetlands to be flooded out and high levels of erosion during heavy rainfall events. Invasive plants also absorb a large amount of freshwater out of the systems, and pose a fire hazard. According to one participant, some farmers moved into the wetlands and bulldozed the natural vegetation to create pasture which increased erosion vulnerability of these areas, along with contaminated freshwater through the addition of fertilizers and animal waste. Furthermore, political issues stemming from the National Water Act (Act No. 36 of 1998) have resulted in the river water being over-allocated and hence water abstraction in this area is not adequately managed, with many inland users (both for farming and urban purposes) pumping directly from the river. This has resulted in decreased amounts of freshwater reaching the river mouths along with salt water intrusion upstream.

3.4.2. Agriculture profile

The following results provide an overview of current farming communities through data collected from the 50 farmers (or farming families) through semi-structured interviews.

3.4.2.1. Area profile

The initial research area proposed only to look at farms in the Duiwenhoks and Goukou catchments, however some recommended farmers' lands overlapped into the adjacent catchments and have been grouped accordingly. It is hypothesised that micro-climates would not change drastically between the three groupings as the outlying farms bordered the original Duiwenhoks and Goukou catchments. Therefore, the 50 active farms surveyed fell into three 'catchment' areas, divided up into the Duiwenhoks/Breede, Goukou and Goukou/Gouritz. From this sample, 68 % fell into the Goukou catchment area, 22 % in the Duiwenhoks/Breede and 10 % in the Goukou/Gouritz grouping.

The research area was also divided into three distinctive areas: coastal (farms along the Indian Ocean coast which marks the southern boundary of the study area), vlakte (farms on the lowlands in the middle) and mountain (farms in the Langeberg Mountains) – refer to Figure 3.1. From the 50 active famers sampled, 54 % farmed on the vlakte areas, 24 % on the coast and 22 % in the mountainous areas. In general, crops, livestock and dairy farming practices dominated the research area. Large-scale crop operations are more easily carried out on the vlakte due to suitable environmental and climatic conditions, while coast and mountain farms tended to be a more diversified mix of crop, livestock and dairy farming due to less favourable conditions (refer to Figure 3.3).

Figure 3.3: The six grouping describing location characteristics throughout the research area according to catchment (Duiwenhoks/Breede, Goukou and Goukou/Gouritz) and area (mountain, vlakte and coast)

Vlakte and mountain farms situated on the western side of the research area tended to draw water from the Overberg Water Scheme (from the Duiwenhoks Dam) and vlakte and mountain farms located in the Goukou catchment tended to use the Korentepoort Water Scheme. The majority of these farms used a combination of irrigation and rain-fed techniques. Coastal farms primarily made use of underground springs as the main water supply. The majority of farmers did not observe any changes to water quality over time. One farmer noted that the Overberg Water Scheme was outdated and would require maintenance to avoid burst pipes and expand water supply to meet growing urban and agricultural demands. Another farmer observed that the Goukou River no longer flows constantly as in the past, which he linked to water abstraction activities further upstream.

Approximately 70 % of farmers have noted an improvement to their farm's soil quality due to change in farming practices. Notably amongst the multi-generational commercial farmers, the current farming generation criticised previous methods of 'rip and till' employed by previous generations where soil was cleared, ploughed and left exposed to the elements. From the 1990s, there was a trend of conservation tillage that has now become a common practice amongst the majority of surveyed farmers, usually combined with a rotation grazing scheme to ensure that the soil is not left bare. Conservation farming, which was predominately practised by farmers engaging in large-scale commercial crop production, combines minimum or no tillage, full stubble retention and diverse crop rotations. All farmers who employed conservation or '*min bewerk*' [minimum tillage] strategies noted an improvement in soil moisture retention, as well as a general improvement in soil health (for example, farmers noted an increased presence of earthworms over time). The overall improvement of soil health, particularly in vlakte areas, has allowed farmers to increase their crop yields and subsequent outputs. However, there was a trade-off associated with the improved soil condition – the subsequent increase of weeds which outcompete the crop plants. This has resulted in an increase of spraying pesticides to control the weeds.

Figure 3.4: Since employing conservation farming techniques, some farmers observed an increase of '*watervoël*' [water birds] moving through their fields. This picture was taken during fieldwork conducted in 2015 of Blue Cranes (*Anthropoides paradiseus*) in a farmer's field, where the farmer noted an increase in bird flocks since employing conservation tillage practices

3.4.2.2. Farmer typologies

All the farmers and land owners interviewed were Caucasian, with 90 % native Afrikaans speakers and the remainder English speakers. Depending on the type of land use employed, farmers were characterised into three distinct categories: commercial, lifestyle and subsistence. Of the 50 active farmers surveyed, 82 % were commercial, 14 % lifestyle and 4 % subsistence farmers. Commercial farmers can be further broken down into two distinct categories – multi-generation and first generation (see Table 3.2). While both first and multi-generational farmer typologies have actively farmed for an average of 26/27 years, first generation farmers are new to the area in the sense that they have no prior exposure to farming in the southern Cape. Most of the first generation farmers relocated from 'up country' (i.e. North West Province and Namibia) from the late 1980s and invest in large-scale commercial agriculture which diversifies into more niche markets such as game meat, berries and avocado. The subsistence farmers, although a small sample group, have been farming for three decades and offered valuable narratives into perceived climate patterns, compatible with other participants. The majority of multi-generational farming families have been present in the area for three generations, having settled in the area from the 1940s. Approximately 30 % of multi-generational farming families have farmed (usually in the same location) in the area since the 1880s.

In general, surveyed commercial and subsistence farmers were more invested in weather patterns as it directly affected their livelihoods, whereas lifestyle farm owners tended to have alternative incomes to supplement any hardships experienced on the farms as a result of unfavourable weather conditions. Crop farmers tended to be more observant of rainfall patterns as they were more dependent on the weather to produce agricultural goods. Livestock and dairy farmers are less influenced as they can import stock food if there is a shortage. All commercial farming practices employed 'mixed' strategies where the relationship between different products were adjusted, depending on market and labour trends. Mixed farming methods were used as a type of insurance, for example if the farm's crop harvest failed then the farmer could sell their sheep and/or cattle stock to carry over the losses. Approximately 70 % of participants (predominately commercial farmers) belonged to agricultural associations, ranging from local to provincial affiliations, which were used to exchange farming and related market information.

Table 3.2: Typologies of active farmers who participated in semi-structured interviews

	Farm size (hectares)	^Years on farm (average)	Farming as income	Farming type
***Commercial multi-generation**	Average: 1500 Max: 3500 Min: 180	27	Primary	More common: sheep (wool/meat), grain (e.g. canola, wheat, barley), cattle (beef), dairy (milk) Less common: ostrich, thatch, vegetables, lucerne, goats
***Commercial first generation**	Average: 1375 Max: 3500 Min: 130	26	Primary	More common: dairy, sheep, cattle Less common: ostrich, buffalo (game), grain, avocado, berries, vegetables
Lifestyle	Average: 250 Max: 967 Min: 4	16	Secondary	More common: olives, vegetables, fruit Less common: sheep, cattle, honey, vineyards, thatch, game
Subsistence	Average: 33 Max: 54 Min: 12	31	Mixed	More common: chickens, ducks Less common: sheep, calf-rearing

^ 'Years on farm' refers to number of years surveyed farmer has been actively farming on their farm specifically located in the research area

* Multi- and first generation farmers: There was an even number of first and multi-generational farmers surveyed.

3.4.2.3. Observed changes in farming practices

As observed by one multi-generational commercial farmer whose family has been farming in the southern Cape since 1912, "*'n mens doen nie wat jou pa doen nie*" [a person does not do what their father did] – referring to how agricultural practices have changed over the generations in the area. Approximately 92 % of surveyed farmers observed changes in agricultural patterns in the southern Cape over time, where 90 % of farmers had adjusted or changed their farming practices on their own farms.

Commercial dairy production dominated the 1980s, often referred to as the 'golden years' of milk for the area. The dairy industry subsequently declined in the 1990s due to unfavourable market conditions and labour difficulties, and smaller size dairies largely ceased to exist into the 2000s. Dairies that continued to operate expanded their operations through buying adjacent farmland to remain economically viable. Vlakte areas shifted from livestock (i.e. cattle, sheep and ostrich) in the 1990s to predominately crop (i.e. grain) farming into the 2000s as techniques such as conservation tillage became popular from the 1990s. Ostrich production across the vlakte area decreased from 2010 due to an outbreak of bird flu, which was compounded by a particularly dry period of 2009. After 2010, some surveyed farmers moved away from livestock and dairy practices as these activities required too much water and diversified into more niche markets with products that are considered less water intensive, such as blue berries, avocados and buffalo.

The general economic turndown over the past 10 years, coupled with the demise of small- to medium-sized commercial farms, led to an increase in lifestyle farming from the mid-2000s predominately along the coastal areas. Lifestyle farming shifted away from traditional cattle, sheep and dairy farming practices into permaculture, truffles, wine, olives, game and tourism accommodation. Lifestyle farming is typically associated with high-end, niche markets and land owners generally place an emphasis on rehabilitation of natural vegetation. Some wealthier farm owners have also been associated with increased conservation efforts such as the clearing of invasive plants in catchment areas.

3.4.3. Local climate knowledge

The majority of surveyed farmers (72 %) observed changes in their local weather patterns over time. The length of time participants had spent on the farm, as well as whether they were first generation or multi-generation farmers influenced their observations around changing weather patterns. On average, lifestyle farmers had spent the least amount of time in the area and only noted short-term changes in weather patterns, if any. First generation farmers were fairly established and able to give observations on average for the last two decades, specifically noting changes in 'the last 10 years'. Multi-generation commercial farmers tended to compare their current farming experience against stories from their parents (25 years ago) and grandparents (50 years ago), usually making reference to generational time scales as a measure of change. When referring back to multiple generational experience, many farmers reference the 'old days' – stretching their reference of temporal scale concerning weather patterns up to 75 years ago (i.e. to their great-grandparents generation), similarly to narratives in Section 3.4.1.2.

In general, farming communities spoke to rainfall observations with the greatest ease as this weather element generally influenced farming practices the most. For example, one farming family kept rainfall records that were started from an ancestor in 1880, where this family continuously tracked annual rainfall on the same farm until 2000 and were aware of how the family had experienced changes in weather patterns over generations. Rainfall records were also the most commonly kept accounts on the farms, with 26 % of participating farmers volunteering to share their rainfall records. Temperature and wind observations were less detailed and usually not associated with a specific time scale.

All surveyed farmers stressed that weather patterns in the research area did not necessarily follow predictable trends and were highly variable. Due to the highly variable nature of the climate system in the area, participants only observed subtle changes over time and no clear trends were identified. Farmers who were able to reference their weather experience against previous farming generations did observe more specific changes in the system, particularly in rainfall patterns. Table 3.3 outlines common observations, divided into rainfall, temperature and wind, made by farmers who noticed a change in weather patterns, grouped by location.

Table 3.3: Farmers' observed change in weather patterns over time grouped according to area (i.e. mountain, vlakte and coast) within catchment (i.e. Duiwenhoks/Breede; Goukou and Goukou/Gouritz)

		RAINFALL	TEMPERATURE	WIND
DUIWENHOKS/ BREEDE	Mountain	• Rainfall has become less predictable and increasingly unstable • Increase of single intense rainfall events • Shift of seasonal winter rainfall into summer months • Longer dry periods between rainfall	• Winter season is now cold for shorter period of time	• No noticeable change observed
	Vlakte	• Increase of intense rainfall events • Longer periods of dry spells between rainfall events • Change from predictable drizzle periods over winter (50 + years ago) to more variable/extreme events, but average annual rainfall amount stays consistent overall • Consistently low rainfall years in 1990s and above average rain after 2010 • Seasonal winter rainfall decreased and summer rainfall increased	• Winters are not as cold compared to 20 + years ago • Summers feel hotter (but high uncertainty)	• Less north-westerlies (in winter) and shift to south-westerlies or southerlies
	Coast	• More rainfall in one event	• Hotter daily temperatures over last five years	• No noticeable change observed
GOUKOU	Mountain	• Over last 10 years rainfall shifted a month later but no clear pattern • Increase of single intense rainfall events, but average annual rainfall amount stays consistent overall • Spring and summer months have more extreme rainfall events – winter rainfall become less reliable over time	• Summers are generally hotter	• South-easter blows rain to mountains

	Vlakte	• Last 10 years rainfall patterns shifted to later than usual • Fewer wetter winters – traditional winter rainfall shift into summer months • Increase of single intense rainfall events, no longer spread out over drizzle events (compared to 50 + years ago) • Wet and dry years are harder to predict – increased variability • Longer periods of dry spells between rainfall events • Onset of rainfall season shift by a month – from e.g. March to April	• Last five years had more extreme hot and cold days	• Since 2010, less north-west winds and more southerly to easterly winds (from the sea)
	Coast	• More intense rainfall over shorter period of time and more varied – no longer softer rainfall over longer periods of time • 20 + years ago had set seasons (typical spring and autumn rainfall) now highly variable	• Winters are not as cold • More extreme cold and hot events	• 30 + years ago used to get more regular 'berg' wind (hot dry northerly wind blowing from the interior to coastal district) now shifted to more coastal winds
GOUKOU/ GOURITZ	**Mountain**	• No noticeable change observed	• No noticeable change observed	• No noticeable change observed
	Vlakte	• More varied and unusual rainfall patterns over last 15 years • Increase of intense rainfall events • Opposite trend to western extent of Western Cape – receive good rainfall when drought in (e.g.) the Swartland	• No noticeable change observed	• Less north-west winds recently
	Coast	Not surveyed	Not surveyed	Not surveyed

3.4.3.1. Rainfall observations

Participants continuously stressed that rainfall was highly variable in this area as a whole, with no obvious patterns or conspicuous trends. Seasonality was less pronounced in coastal areas, where rainfall patterns were considered to be varied in general; however, some seasonality (associated with typical spring and autumn rainfall patterns) that was observed by the previous generation of farmers in the coastal area of the Goukou catchment is perceived to be more varied in the recent past (refer to Table 3.3). Rainfall patterns in vlakte areas were observed to have shifted from a typical winter regime into a more varied pattern, where the onset of traditional rainfall periods were perceived to have shifted to a later time. For example, crop farmers located on the vlakte areas noted that their planting season had shifted to a later time – rather than planting crops during the onset of traditional seasonal rainfall in February/March like their parents or grandparents, planting tended to take place in April/May. Mountain areas were observed to have increasingly more unstable and unpredictable rainfall events, where spring and summer rainfall events were considered to becoming more the norm – shifting out of a winter rainfall pattern in recent memory.

Across the research area, farmers observed an increase in intense rainfall events and prolonged dry spells. Farmers often referred to "*kwaai reën*" [fierce rain] or "*kwaai droogte*" [fierce drought], describing these events as becoming more severe and occurring more regularly, when compared to past experience. In living memory, 1969 is considered to be one of the more severe drought years, followed by 2009. Across the vlakte areas, farmers observed the mid-1990s to have been multi-drought years, with consistently low rainfall over a prolonged period of time. In addition to increased dry spells, multi-generational farmers (particularly in the vlakte areas) observed that rainfall patterns had shifted from (winter) periods of soft, drizzle rain from over 50 years ago to more extreme rainfall events that happen over shorter periods of time.

Farms located in the mountain areas appeared to be most vulnerable to flood events, where some participants noted that intense rainfall events often resulted in flash floods that caused roads and tributaries to erode away. One farmer located in the mountain areas noted that while the annual average rainfall amount (approximately 650 mm) on his farm had not changed drastically over time, he had observed that rainfall events had become more intense in recent memory as one event could yield up to 200 mm per day (i.e. 30 percent of the annual rainfall amount in one event). Some participants speculated that the rainfall pattern may have shifted after the infamous Laingsburg floods in January 1981, which was considered a ‘100 Year’ event, where a few farmers based in the mountains observed that extreme flood events tended to occur on a more regular basis after the 1980s, particularly into the 2000s. For example, flood events over the last 10 to 20 years in mountain areas have matched the 1981 flood mark – 2003 (250 mm in one rainfall event); 2004 (320 mm in 24 hours); 2013 (220 mm in four days).

3.4.3.2. Temperature and wind observations

Details and timescales regarding participants’ observations on temperature and wind were less descriptive when compared to rainfall (refer to Table 3.3). None of the surveyed farmers kept long-term temperature records and most of the observations were based on speculation, as highlighted by the participants. Some livestock farmers noted that extreme temperatures (more ‘very hot’ days) had impacted their lambs with some stock dying of exposure in recent years. One livestock farmer noted that ‘very cold’ spells tended to come at unseasonal times of the year over the last five years, which could (and sometimes did) result in mass losses of sheep stock if they were sheared prior to the event. Changes in wind patterns were less certain, with a weak consensus that typical north-westerly winds had shifted to prevailing south or south-easterly directions but timeframes were not specified with confidence by participants.

In turn, the majority of participants did not observe any noticeable or enduring changes in temperature or wind patterns. Most farmers acknowledged that their memories were not necessarily the most reliable source of monitoring temperature and wind, with older participants noting that their ‘old bones’ felt temperature changes more acutely due to their age, rather than the temperature differences meaningfully changing over a prolonged period of time. The lack of long-term monitoring meant that, unlike more commonly kept rainfall records, farmers spent less time reflecting on changes within temperature or wind patterns.

3.4.4. Weather and farming strategies

While the majority of participants did observe changes in weather patterns over time, less than half (45 %) of farmers noted that these changes directly impacted their farming strategies over time. The notable trend of conservation tillage, discussed in Section 3.4.2.1, was often correlated by participants to the dry years experienced in the 1990s which prompted crop farmers to switch strategies to cope with increasingly unpredictable rainfall patterns. Conservation tillage also allowed farmers to be less dependent on the onset of the rainy season as good moisture retention in soils enable crops to survive in increasingly variable rainfall conditions. However, it is not clear whether the majority of farmers who switched to conservation tillage practices did so due to persistent changes in typical weather patterns or because this practice yielded more agricultural outputs and improved profit margins.

Extreme rainfall events were not highlighted by participants as a major hindrance to farming strategies and farmers tended to adapt infrastructure around persistent flooding problems, such as building new bridges. However, one participant was in the process of selling land due to increased losses attributed to flooding and drought events. Prolonged dry periods were deemed problematic for livestock farmers as droughts hindered farmers' abilities to produce pasture for their stock. Many livestock farmers brought in animal feed from external sources during times of drought, to compensate for the lack of pasture. A few livestock farmers in the vlakte areas also lost young livestock, such as lambs and ostrich chicks, due to extreme heat temperatures over the last five years, which prompted some participants to build covered structures for shade.

The impact of weather patterns on farming strategies was largely regarded as an adaptation or coping exercise by farmers, where either farmers changed practices to better suit weather conditions (i.e. adapted) or else persisted using traditional practices (i.e. coped). In the case of adaptation, some participants were able to mitigate the effects of unfavourable weather trends through employing better soil practices, buying in animal feed or adapting infrastructure accordingly. As noted by one participant, "*jy moet saam boer met die weer*" [you must farm together with the weather], implying that people cannot change the weather but can alter the way that they farm, where farming strategies and climatic conditions should be synergistic.

3.4.5. Challenges

Challenges experienced by surveyed farmers were discussed in terms of what participants deemed to be the most important and ranked accordingly. Three major groupings based these rankings and were divided up according to importance: top-ranked (i.e. most important challenge), mid-ranked (i.e. second most important challenge) and low-ranked (i.e. third most important challenge) challenges. As illustrated in Table 3.4, each grouping displays the type of challenge described by participants which is placed according to how often participants brought up a specific issue. Challenge themes were therefore repeated between the three groupings, depending on how individual farmers ranked the importance of specific challenges according to their experience. Pressing challenges in the top-ranked category included finances and politics, while the market was most commonly discussed as a stressor in mid- and low-ranked categories of challenges.

Table 3.4: Top three-ranked challenges according to surveyed farmers

Top-ranked		2nd-ranked		3rd-ranked	
Challenge	**%**	**Challenge**	**%**	**Challenge**	**%**
Finances	26	Market	22	Market	20
Politics	24	*Farming practices	19	Workforce	20
Workforce	13	Finances	16	Finances	9
Water availability	13	Workforce	16	Invasive plants	9
Climate variability	9	Climate variability	15	Politics	9
Market	8	Politics	6	Security	9
Invasive plants	4	Disease (e.g. bird flu)	3	Climate variability	7
Predators	3	Invasive plants	3	Water availability	6
				*Farming practices	6
				Predators	5

* Farming practices refer to challenges around keeping livestock healthy and good stock quality, improving soil conditions for crops, and spraying for weeds

When looking at challenges from an unranked (i.e. importance of challenge was not considered) perspective (see Figure 3.5), the most common challenges discussed by farmers (i.e. more than one individual) were finances (16 %); politics (15 %) and market (15 %). Similarly to ranked challenges, emphasis is placed on economic and political influencers as being the most pressing challenges experienced by farmers. Climatic and other environmental stressors (such as water and invasive plants) were not seen as the most important challenges when compared to economic and political factors, but still featured in the top-ranked grouping of challenges, showing their relative significance within these multi-stressor systems.

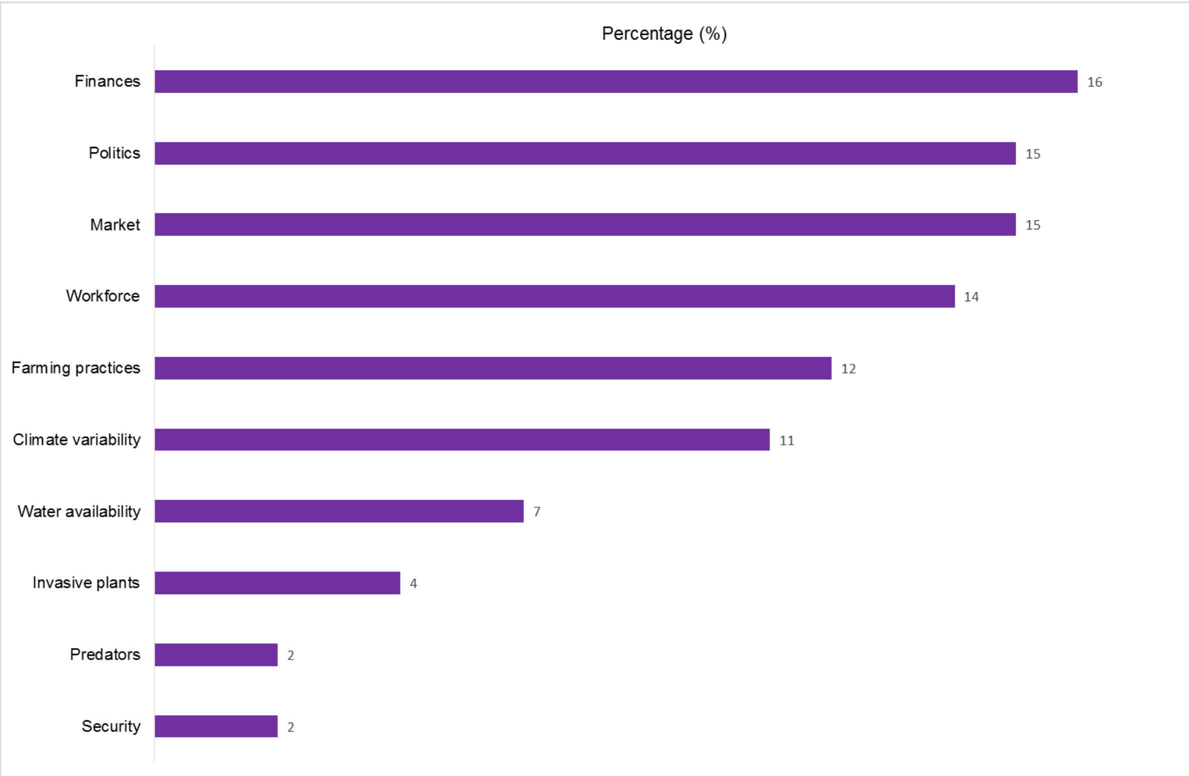


Figure 3.5: Unranked challenge themes experienced by surveyed farmers

3.4.5.1. Economic and political stressors

The overall sense from participants, particularly commercial farmers, was that the current political and economic climates in South Africa were not favourable towards farmers. Finances were seen as a key stressor in that farmers were limited by financial constraints due to high costs associated with input costs, for example expensive modern technology (i.e. machinery to carry out commercial-scale farming processes). Most commercial farming practices only become viable as a long-term investment, where returns and profits are only yielded after a number of years and cash flow from farming activities are not consistent from year to year. Some farmers also expressed that it was difficult to make decisions around land use change if they did not have access to large amounts of financial capital in the event that their agricultural ventures would fail.

The financial constraints felt by farmers were further compounded by high political and economic uncertainty. As a result of this uncertainty surrounding market drivers or political decisions, farmers felt constrained in their agricultural activities. From an economic point of view, farmers experienced challenges in that their input costs exceeded what their agricultural products were bought for, where farmers were forced to sell at low rates to remain competitive within the market. Most participants referred to the 'economy of scale', where commercial profitability was only viable if agricultural activities expanded on a large-scale basis, but this required large amounts of capital investment to (for example) buy more land, modernise machinery and expand their workforce. This example is discussed in Section 3.4.1.2, where land use in the area changed in the 1990s as the dairy industry rapidly declined due to small- and medium-scale dairy farmers being unable to survive, which was partly attributed to input costs far exceeding the price large corporations were willing to pay for milk.

Participants viewed local markets as being hostile towards agriculture, in that farmers indicated that they were competing against monopoly industries which were not well regulated, hence farmers carried all the risk with no price guarantee. Many surveyed farmers viewed the current government as agriculturally 'unfriendly' and were concerned that unfavourable trade agreements brokered with international agricultural imports would hurt local farm producers. Another key concern for participants centred on the politics of land reform, where many farmers were hesitant to make investments into expanding or changing their agricultural practices due to perceived uncertainty around whether the government would allow them to keep the land.

3.4.5.2. Climate and environmental stressors

Climate variability featured as a stressor for farmers across the three groupings of challenges where participants noted that increased extremes had negative consequences, such as big flooding events that result in erosion and loss of topsoil. Prolonged dry periods also placed additional stress on farming activities and water availability, where (for example) livestock farmers had to increase financial expenditure to buy in animal feed due to the lack of pasture. Climate variability was viewed by many participants as a stressor that aggravated existing challenges of farming, and worked in concert with other stressors within a complex social-ecological system (see Figure 3.5), as highlighted above.

Linked to increased climate variability, water availability was also highlighted as a key stressor by farmers. As highlighted in Section 3.4.1.3, the complexity around water issues are nuanced in environmental, social and political stressors that interact over different temporal scales over time. Changes in rainfall patterns over time, increased anthropogenic demand, degradation of catchment areas through invasive plants and policy changes can be viewed as interacting stressors that result in limited water availability for different user groups, such as farmers. Most farmers highlighted water as a key constraint in that they did not have access to sufficient water for agricultural activities, which was attributed to numerous factors such as traditional rainfall patterns shifting, increased flooding and drought events and allocation and storage restrictions through policy.

Another environmental stressor linked to water was invasive plants, as many farmers observed that the prolific distribution of invasive species such as black wattle degraded their land and choked water in catchment areas. In addition to these negative environmental challenges posed by invasive plants, some farmers also noted that it was extremely costly to control the invasive species and only very wealthy land owners had the luxury to do so, as this exercise usually required permanent staff to continually clear these plants for a number of years, as well as additional financial capital to remove the debris.

3.4.5.3. Workforce stressors

Challenges around workforce featured across all three groupings and were considered an important issue for most participants. The change in farming practices across the research area from labour-intensive dairies towards more mechanised crop production created a skills gap within the traditional workforce, where some farmers observed that the younger generation of farm workers had moved away to seek alternative employment and the older generation could not operate the new technology due to poor education. Many participants noted that traditional support services for farm workers provided through government initiatives had decreased over time and there were limited opportunities for staff to improve their livelihoods. Farm workers were also viewed by some participants as being most vulnerable to change within the system, as land use changes resulted in loss of employment due to the mechanisation of agricultural activities, along with the rise of lifestyle farms which do not always require intensive labour activities (in contrast to traditional commercial farms).

More sensitive issues were also raised around workforce challenges relating to political and social aspects of farm workers, which warrant more in-depth and focused research on this particularly vulnerable group. Some participants observed that high input costs of agricultural activities hindered some farmers from employing more staff as these expenses offset minimum wage requirements, particularly in the context of unfavourable markets (i.e. low selling price of agricultural produce which translated into low profits), thus forcing these farmers to move away from labour-intensive farming or to stop agricultural activities by selling their land. A few participants perceived alcohol-related issues resulting in anti-social behaviour as a challenge within their workforce, which is a persisting legacy from the infamous '*dop*' [alcoholic drink] system that has continued to trap traditional farm workers in impoverished cycles, despite the use of alcohol as a form of payment being illegal from the 1960s.

3.5. Discussion and conclusion

Climate variability and change is a key concern for South Africa, where climate changes are already taking place and are likely to continue (Zietsman, 2011; DEA, 2013). Adaptive management requires conventional ecological and economic data, along with qualitative information from feedbacks within social-ecological systems, to determine the best direction management actions should pursue (Berkes et al., 2003). The need for learning and flexibility in social systems confronted with uncertain explanations of ecosystem change is essential to build the capacity of social-ecological systems in order to adapt to and shape change (Folke, 2006; Cundill et al., 2014). Particularly in regions such as the southern Cape, which is characterised by high variability in both short- and long-term weather patterns, understanding changes over time at local scales is important. It is also equally important to contextualise observed environmental changes within complex systems that experience multiple stressors at different temporal and spatial scales, which further shape perceptions of risk and subsequent decisions made around how to adapt to these changes. Importantly, results indicate that climate variability is only one of several important stressors farmers experience in the area.

3.5.1. Examining local climate perspectives

Across the research area, pockets of micro-climates emerged that shared similar characteristics based on location. The most distinctive differences in terms of farming practices were seen between the mountain, vlakte and coastal zones where soil suitability and rainfall amount determined farming practices. A study carried out by MacKellar et al. (2014) found that rainfall showed high inter-annual variability and little consistency across the Western Cape region, which was also observed by surveyed farmers for the southern Cape in particular. Presently, participants described the research area as being largely an aseasonal rainfall zone with substantial inter-annual variability, however some farmers perceived that rainfall patterns had shifted over a number of decades from a reliable winter rainfall regime into the current more varied patterns.

The most commonly observed change in weather patterns across the research area was an increase in extreme events over time, for example more intense rainfall events and prolonged dry periods – similar to farmers located in the adjacent Little Brak River area, who observed increased flooding events and frequent drought conditions over the last decade (Wiid, 2009). As noted by Midgley et al. (2005), flood activity over the last decade in some sub-regions of the Western Cape, for example districts of Montagu, Swellendam and Robertson, had resulted in major financial losses within the agricultural sector as this region is prone to extreme climatic events. In my research, the increased intensity of flood events was observed particularly by farmers located in the mountainous areas of the research catchments. Another common observation by participants was that the typical onset of the rainy season appeared to have shifted to a later period, particularly by farmers located on the vlakte areas. Similarly, farmers located in Limpopo, North West and KwaZulu-Natal provinces observed changes in, along with unpredictability of, weather patterns in seasonality – for example, the onset of traditional rainy season began later and that rainfall patterns were not as reliable as in the past (Thomas et al., 2007). Here it was found that local farmers' views on change in climate parameters corresponded with regionalisation scenarios (Thomas et al., 2007).

While studies indicate that temperatures have increased over time in the Western Cape region (Allsopp et al., 2014; MacKellar et al., 2014), local farmers were less certain of how or if temperature had changed over time. While some participants speculated that temperature extremes had increased, particularly in summer, very short time frames were given (i.e. five years) and all observed changes were made with reference to high uncertainty of the participants' memories. Observations around changes in wind patterns by farmers were even less certain and, although there was a weak preference for less north-westerly (inland) winds and an increase in south-easterly (coastal) winds, given time frames for change were similarly short to temperature.

3.5.2. Contextualising climate stressors

Generally, adaptive actions within agricultural sectors are shaped by perceptions of risk, direct climate change effects on productivity, as well as complex changes in markets, policies and government institutions. As illustrated by participants, climate concerns are generally not the first priority, let alone the only priority. Similar findings were observed in farming communities based in the Eastern Cape (South Africa) by Muller and

Shackleton (2014), where although climate was viewed as a stressor to agricultural livelihoods, it did not rank highly when compared to other stressors such as high input costs, lack of government support and decrease in water availability. In the current political, economic and social landscape of South Africa, farmers experience multiple stressors that usually drive change within the social-ecological system faster than climate variability and change, and the southern Cape is no exception.

When considering land use change in the research area from the 1950s to present, it appears that economic forcing and technological advances have predominately shaped the area – where farming generations have adapted land use according to market trends and mechanised agriculture. This is mirrored to an extent in the rest of South Africa, where countrywide the number of commercial farms has decreased from 120 000 to 37 000 between 1950 to 2015 (DAFF, 2015). This national trend is correlated with an increase in average farm size along with mechanisation of farming activities, resulting in less reliance on labour and more emphasis on capital and industrial inputs. DAFF (2015) report that this overall trend has been associated with job losses in the agricultural sector amid deepening rural unemployment within South Africa. These challenges were observed by participants in that key challenges highlighted included finances, politics, markets and workforce issues.

Priority challenges associated with agriculture therefore focused rather on economic and political factors, which were viewed as the primary drivers or hindrances of change within the system. This is again in line with the DAFF (2015) report, which notes that the competitiveness of agriculture across South Africa is being eroded due to high input costs. For many years, the value of imported fertilizers, diesel and machinery has exceeded the value of agricultural exports, thus having given the agricultural sector a false positive contribution to the trade balance at the expense of farmers and associated workforce. Interestingly, the DAFF (2015) report argues for the promotion of 'climate-smart agriculture', which includes conservation agriculture, over conventional farming methods as a way to reduce production inputs while still achieving good productivity. In addition to supporting environmental sustainability, it is hypothesised that farmers will become more competitive by lowering input costs and increase agriculture's contribution to the trade balance (DAFF, 2015).

The widespread use of conservation agriculture throughout the research area has been deemed by participants as a positive shift in terms of changing traditional land use methods – improving soil quality, increasing ground moisture content, requiring fewer inputs related to ploughing activities and increasing produce outputs. Similarly, commercial farmers in the Eastern Cape noted that, unlike previous generations, contemporary farmers tended to be more informed on better farming practices (that are environmentally sensitive) – which was a good indication of these farmers' future capacity to implement appropriate management strategies in the face of projected climate changes (Muller and Shackleton, 2014). However, it should also be noted that the increased spraying for weeds as a result of land use change to conservation agriculture methods in the southern Cape was viewed as a negative repercussion by some farmers – a concern that requires further research. While it is unclear whether economic benefits or changes in weather patterns are the major driving force behind the land use change to conservation agriculture, it is apparent that multiple stressors here interact in subtle ways across numerous scales and responses to these changes are complex.

Climate and environmental forcing within the social-ecological system of the southern Cape are intertwined and often exacerbate primary economic or political stressors. The complex interactions between climate variability, water availability and invasive plants (see Section 3.4.5.2 for details) make these stressors tangible threats to the ecosystem health of the research area, which are further compounded by political and economic constraints that hinder adaptation strategies for the farming community. In line with my results, farmers located in the adjacent catchment (Little Brak River) to the research area also experienced stressors linked to water availability that were entwined with climate changes, such as intensified flood and drought events, and institutional pressures linked to water restrictions – which amounted to financially costly adaptation solutions such as altering farming strategies or increasing water storage capacities (Wiid, 2009; Wiid and Ziervogel, 2012).

3.5.3. Responding to climate variation and change

From an individual perspective, farmers base their responses on whether they perceive a need, an ability and motivation to act to stressors affecting their livelihoods (Frank et al., 2011). As illustrated in the previous section, stressors playing out in farming contexts are numerous, varied and depending on individual capacity to adapt – so while climate variability is considered a stressor within southern Cape farming communities, it is one of many stressors and usually not a priority concern by farmers. As such, it is important to understand why and how farmers are responding to environmental challenges associated with climate variability through their perceptions of risk, as well as to other social, economic and political drivers that may affect their perceived or actual ability to respond. When considering climate variability, farmers in the southern Cape were generally more concerned over economic and political stressors and basing decisions around their ability to financially meet high input costs, market feasibility concerning economy of scale and political concerns linked to land reform (refer to Section 3.4.5.1 for detailed explanations). Climate or weather challenges were considered by many southern Cape farmers as a stressor that intensified economic or political stressors.

However, whether economically motivated or driven in response to long-term changing weather patterns, the increase of conservation agriculture in the southern Cape indicates a response of adaptability by farmers in the research area. Additionally, the farming community (particularly multi-generational farming families) had been monitoring weather patterns, specifically rainfall, over long periods of time and invested in agricultural methods accordingly. It is also interesting to note that the majority of participants (70 %) belonged to agricultural associations that were used as platforms to exchange farming information. Factors linked to strong adaptive capacity that influence farmers' responses to climate variability include access to capital or resources, good understanding of local weather systems and well-established information networks (Reid and Vogel, 2006), and my results support this observation from KwaZulu-Natal.

Farmers in the southern Cape are responding to climate variability in different ways (Smit and Wandel, 2006): (1) anticipatory (change practices to better suit weather conditions; (2) concurrent (persist using traditional practices); and (3) reactive (unplanned or undesirable response such as selling land or supplementing income with alternative livelihoods); further discussed in Section 6.4. These adaption paths are most relevant to commercial and subsistence farmers, who are primarily dependent on agriculture as a livelihood. Lifestyle farmers are less prone to stressors associated with agriculture as they tend to have additional or alternative primary livelihood sources.

In conclusion, climate stressors can act as the ‘straw breaking the camel’s back’ if not well integrated into farming systems, which could have serious future implications for food and job security in the southern Cape. Climate-smart agricultural systems will depend on climate projections that are geographically specific and agriculturally relevant in the near and medium term; effective adaptive management strategies; and agricultural practices that enhance the systems’ resilience to climate variability and extreme weather events. It is also important to situate perceived responses to climate variability into the greater context of agricultural social-ecological systems, to better understand how farmers adapt (or not) to climate stressors within the southern Cape.

CHAPTER 4

THE TERRESTRIAL PERSPECTIVE: RAINFALL AND TEMPERATURE PATTERNS IN THE SOUTHERN CAPE

4.1. Introduction

Changes in local climate could have significant implications for communities reliant on weather, such as farmers. Local climate impacts have numerous consequences for the future development of South Africa and require a deeper understanding into the dynamics around such environmental changes within the complex realm of social-ecological systems. In order to make informed climate adaptation decisions in South Africa, it is important to understand local context to create policies relevant to experience and in line with observed and projected environmental changes.

Changes in natural systems, particularly in climate patterns, are associated with high levels of uncertainty and natural stressors are complex in that they can play out over multiple temporal and spatial scales. While large scale shifts are currently manifesting at a global level (IPCC, 2014), these changes are experienced at regional and local scales at different rates. There are gaps in understanding concerning how possible shifts in climate will affect local livelihoods dependent on natural resource bases, such as in the agricultural sector.

In an effort to better understand complex, social-ecological systems at a local scale, this chapter examines how weather patterns have shifted over time in the southern Cape from a terrestrial perspective, tying into local farming knowledge around observed changes in weather as described in Chapter Three. Drawing on this experience and accumulated knowledge of farmers in the southern Cape, this chapter examines Key Question 2: How have climate (weather) patterns changed in the southern Cape?

4.2. Methods

4.2.1. Location

As described in Chapter Three, the terrestrial component of this study focused on the Goukou and Duiwenhoks catchments located in the southern Cape (see Figure 3.1). For a full overview of climate in the research area refer to Section 3.2. The research area was divided into two distinctive categories: 'catchment' and 'area' locations (refer to Section 3.4.2.1 for a detailed description on how these categories were determined). Participating farmers noted that weather patterns were not necessarily uniform across the general research area and varied depending on location, which influenced agricultural strategies employed – depending largely on favourable soil, water availability and prevailing climate conditions. These micro-climates were hypothesised to exist between catchment and area groupings, as illustrated in Figure 4.1.

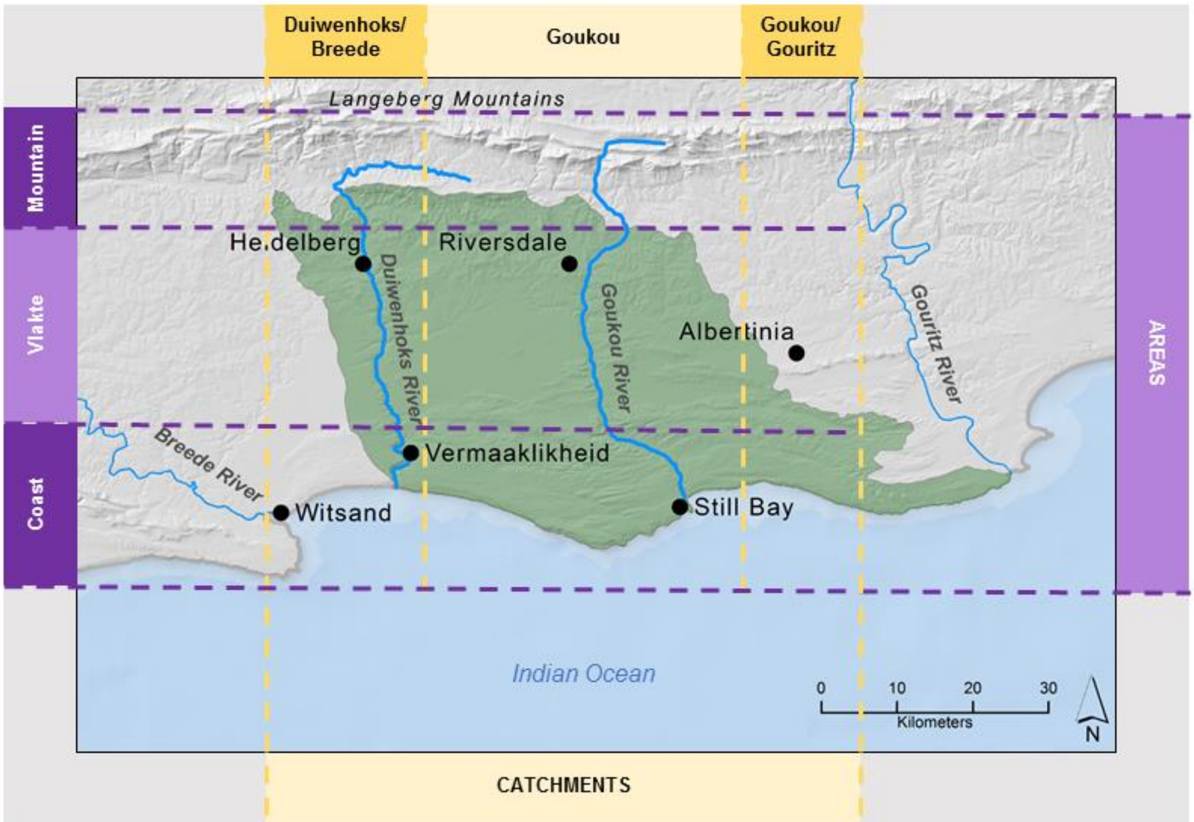


Figure 4.1: Different catchment and area groupings across the research area

Catchment categories were classified as the following (see Figure 4.1):

1. Duiwenhoks/Breede
2. Goukou
3. Goukou/Gouritz

Area categories were classified as the following (see Figure 4.1):

1. Coast
2. Vlakte
3. Mountain

4.2.2. Data

Data were collected using two sources: local farmer weather records and scientific observation stations. During farmer surveys, refer to Section 3.3 for details, each respondent was asked if they kept any weather records that they would be willing to share for this research. Of the farmers who did keep weather records, only rainfall data were kept over time. Farmers who did monitor temperature tended to discard records at the end of each year. Of the 50 farmers interviewed, 13 farmers shared complete rainfall records. Official terrestrial weather data were obtained from scientific observation stations in the research area from the South African Weather Service, Agricultural Research Council (Western Cape Department of Agriculture) and Riversdale Co-operation (agriculture). These data sources included rainfall and temperature records.

It is noted that quality control between these two groups differed in that scientific observation stations strive to follow common, traceable protocols while farmers collected data in an individual capacity and methods are difficult to trace (particularly if collected over generations). Older rainfall records were measured in inches, which were converted to millimetres (mm) for this research (see example in Figure 4.2). Monthly rainfall records were most commonly kept by farmers over time, with one time series providing annual records only. All scientific observation weather stations recorded daily rainfall measurements.

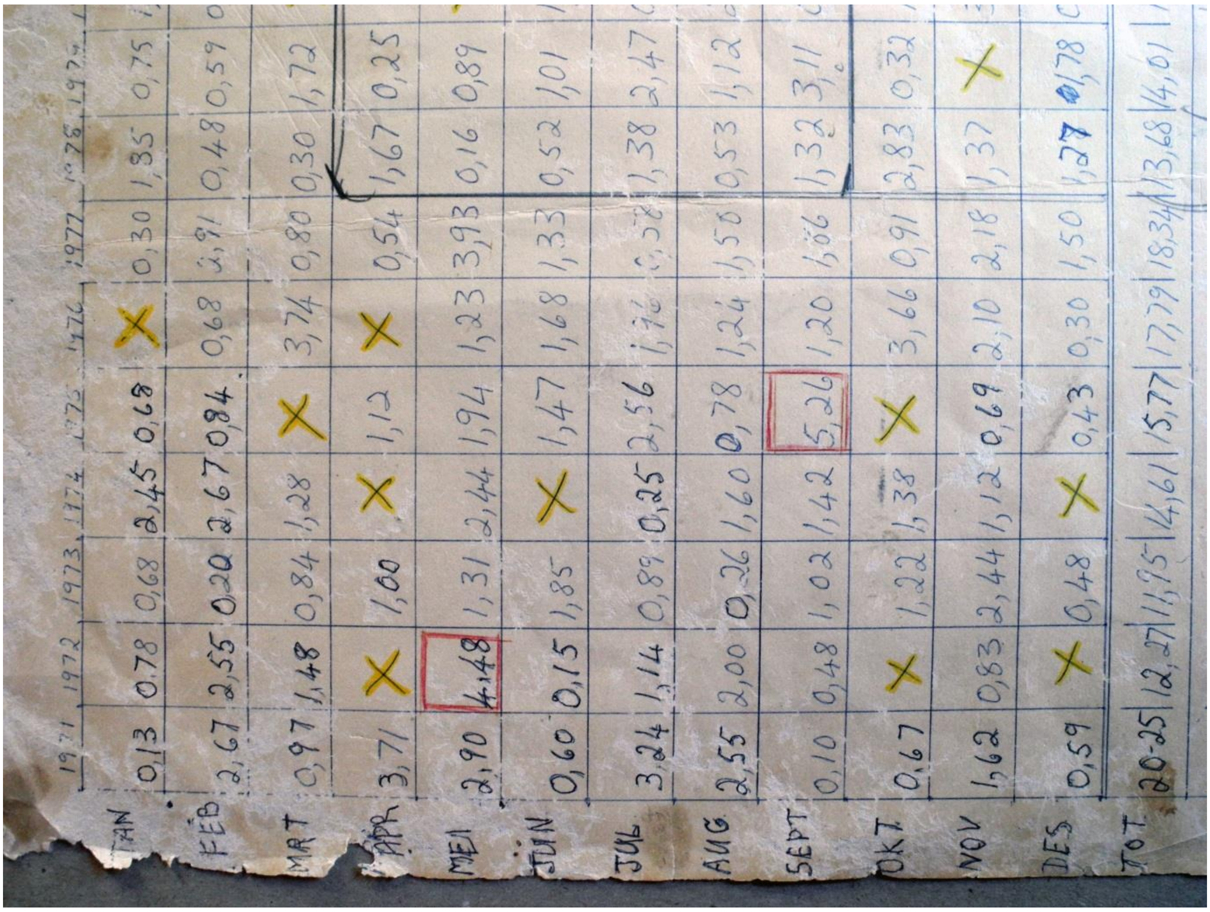


Figure 4.2: Example of rainfall records (units in inches) kept by a farmer in the southern Cape and shared for the purpose of this research

All rainfall data were coded accordingly and summarised according to their attributes based on time period and location – catchment and area (refer to Table 4.1). To minimise potential problems associated with accumulation of daily rainfall only recorded after a few days, which could be present in farmer records and were indicated in scientific observation recordings, data were analysed at monthly and annual scales. In general, farmers were most observant of rainfall patterns and were able to give comprehensive accounts of how they perceived changes in this weather pattern, particularly when comparing their current experience to past generations of farmers (see Chapter Three). Key observations around rainfall patterns from the southern Cape agricultural community were examined according to the following themes:

- Micro-climates between catchment and area groupings
- Observed changes in extreme rainfall events (dry and wet)
- Perceived shifts in the onset of traditional rainfall season

Table 4.1: Summary of farmer and station records with rainfall (mm) data

	FARM (MONTHLY)	FARM (MONTHLY)	STATION (DAILY)	STATION (DAILY)
Name	Farm 1	Farm 9	Albertinia SAWS**	Still Bay SAWS
Period	1950-1989	2008-2014	1925-2012	1994-2015
Catchment	Duiwenhoks/Breede	Goukou	Goukou/Gouritz	Goukou
Area	Coast	Mountain	Vlakte	Coast
Name	Farm 2	Farm 10	Blackdown SAWS	Witsand SAWS
Period	1964-1982	1993-2015	1922-2009	1986-2007
Catchment	Duiwenhoks/Breede	Goukou/Gouritz	Duiwenhoks/Breede	Duiwenhoks/Breede
Area	Coast	Mountain	Mountain	Coast
Name	Farm 3	Farm 11	Breede SAWS	
Period	2001-2013	1958-2015	2008-2015	
Catchment	Duiwenhoks/Breede	Goukou/Gouritz	Duiwenhoks/Breede	
Area	Coast	Mountains	Coast	
Name	Farm 4	Farm 12	Goukou Dam (Co-operation)	
Period	1983-2012	2000-2015	1993-2015	
Catchment	Goukou	Goukou/Gouritz	Goukou	
Area	Coast	Vlakte	Mountains	
Name	Farm 5 **(annual only)**	Farm 13	Heidelberg SAWS	
Period	1880-2000	1971-2015	1925-2015	
Catchment	Goukou	Goukou/Gouritz	Duiwenhoks/Breede	
Area	Vlakte	Vlakte	Vlakte	
Name	Farm 6		Mon Desir SAWS	
Period	2006-2014		1967-2003	
Catchment	Goukou		Duiwenhoks/Breede	
Area	Vlakte		Vlakte	
Name	Farm 7		Riversdale ARC***	
Period	1984-2012		1973-2014	
Catchment	Goukou		Goukou	
Area	Mountain		Vlakte	
Name	Farm 8		Riversdale SAWS	
Period	1937-1995		1992-2006	
Catchment	Goukou		Goukou	
Area	Mountain		Vlakte	

*** South African Weather Service (SAWS)*　　****Agricultural Research Council (ARC)*

Similarly to rainfall time series, temperature data from official stations were sorted (Table 4.2). However, as these data were limited in terms of stations located within a good proximity of the research area, the data were not broken up by catchment but rather by coastal and vlakte areas only. Farmers were also less certain of long-term changes in temperature over time and made fewer observations when compared to rainfall patterns. None of the surveyed farmers kept long-term monitoring records of temperature data as in the case of rainfall. Temperature data were therefore examined according to more general questions, rather than specific observations due to the high uncertainty associated with changes in temperature by the southern Cape farming community. General characteristics examined were seasonality and regime shifts.

Table 4.2: Summary of station records with temperature (maximum and minimum) data

	TEMPERATURE (DAILY)
Name	Mossel Bay SAWS
Period	1920-2015
Area	Coast
Name	Still Bay SAWS
Period	1994-2014
Area	Coast
Name	Riversdale SAWS
Period	2008-2015
Area	Vlakte
Name	Riversdale ARC
Period	1973-2014
Area	Vlakte

4.2.3. Analyses

Data were divided up and analysed according to rainfall and temperature. Within each group, data analysis was divided into three overarching steps. Firstly, data were collated, summarised and basic analysis was performed in Microsoft Excel. This provided a preliminarily overview for each section as an initial scoping for the data analysis. Only complete, sequential time series were considered, where data sets containing missing annual values or numerous missing monthly values were discarded. In the case of missing data at monthly scales (not exceeding three consecutive months), values were substituted by averaging the previous five years of the missing month. Four out of the ten scientific observation stations and three out of the 13 farmer rainfall records contained missing monthly values. Secondly, descriptive analyses were conducted and possible trends were visually inspected. In the third step, appropriate statistical tests were chosen and data analysed to answer tailored research questions. Within each grouping (rainfall and temperature), a number of research questions were formulated to examine weather trends observed by farmers who participated in the surveys.

4.2.3.1. Examining rainfall data

Research Questions to examine rainfall data consisted of:

Question 1: Are extreme years (high and low) the same between farms?

Question 2: Are extreme years (high and low) the same between farms and other data sources?

Question 3: How does rainfall change between catchments?

Question 4: How does rainfall change between areas?

Question 5: Have extreme rainfall events shifted over time?

- **a.** Dry months: Total monthly dry/light rain days (<10mm)
- **b.** Wet months: Total monthly heavy rain days (>75th percentile of observed wet days)
- **c.** Wet months: Total monthly heavy rain days (>95th percentile of observed wet days)

Question 6: Have seasons shifted according to planting seasons from March-May (Old Season) to April-June (New Season)?

Initially, rainfall data were visually inspected through scatter and bar graphs using a combination of Excel and R packages. Data were then interrogated using correlations between data sets to test for similarities or differences between multiple data sets at annual scale. Spearman's rank correlation and Kruskall-Wallis tests were used (based on the non-parametric nature of data) using a combination of R packages and SPSS.

Rainfall data were divided into time periods to examine any possible changes in climate variability. The time periods were determined according to farmer observations and work done by Blamey et al. (2012) on (marine) regime shifts in the southern Benguela. To encompass as much of the data as possible, four time periods were determined:

1. Before to 1981 (based on farmers' observations of weather pattern shifts)
2. 1982 to 1995 (Blamey et al. (2012) noted wind shifts in the southern Benguela mid-90s)
3. 1996 to 2007 (Blamey et al. (2012) noted wind shifts in the southern Benguela in 2000s)
4. 2008 to present

Finally data were tested for significance according to locality (catchment or area) and/or time period using a two-tailed two proportion z-test with equal variances. All z-tests were carried out manually using Microsoft Excel and significant z-statistic results are displayed. Only significantly different results are discussed. The calculations were based on monthly data sets to refine the scale from the initial annual data scoping phase. Daily data proved to be problematic, particularly in rainfall measurements. This fine scale data was not always accurately recorded, in both farming and station examples. Often the data was only recorded after accumulation of a few days of (for example) rainfall, which was particularly problematic before the introduction of automatic weather stations in the early 2000s.

4.2.3.2. Examining temperature data

Research Questions to examine temperature data consisted of:

Question 7: How does temperature change according to seasonality?

Question 8: Have temperature regimes changed over time?

Temperature data were visually inspected through line graphs using Excel and longer time series were examined in terms of data distribution and summary statistics using R packages. Seasonality of longer time series were then examined using R packages.

Longer temperature time series were interrogated using sequential regime shift detection software (refer to www.beringclimate.noaa.gov) to examine possible regime shifts. This method was chosen due to its ability to automatically detect statistically significant shifts in the mean level and the magnitude of fluctuations in time series, along with its ability to detect regime shifts towards the end of a time series and process time series with multiple shifts (Rodionov and Overland, 2005; Howard et al., 2007; Blamey et al., 2012). Compared to change point analysis and the Chow test (using ARMA/ARIMA models), Blamey et al. (2012) found that the sequential regime shift detection method was most effective in detecting robust regime shifts. This method was applied to terrestrial temperate time series, as well as to marine wind time series examined in Chapter Five using the same parameters described below.

Using sequential regime shift detection method, a regime shift occurs when a statistically significant difference exists between the mean value of the variable before and after a certain point based on the t-test (refer to Rodionov (2004) for detailed methodology). A probability level equal to 0.01 and the mean function were selected for all analyses carried out in this research. Building on work carried out by Howard et al. (2007) and Blamey et al. (2012) and for comparative reasons, the cut-off length (l) of 10 was chosen to examine possible regime shifts as they are known to be associated with decadal-scale oceanic variability. The Huber parameter (H = 1, 3 and 6) was set at 1 for analyses of this research as this parameter had little effect on the detection of regime shifts in the Benguela (as discussed by Blamey et al., 2012).

When examining the mean for temperature and marine wind data sets, Red Noise estimation (or serial correlation) was handled using Inverse Proportionality with 4 corrections (IP4) which is based on the assumption that the bias is approximately inversely proportional to the size of the sample (Rodionov, 2006). The 'prewhitening' option was also selected to detect regime shifts for all the filtered time series, which removes potential autocorrelation from the data series prior to running the analyses. Red Noise estimation was not selected when examining variability for marine wind data sets (only).

4.3. Results and Discussion

The results are explored in two parts for the terrestrial weather patterns in the southern Cape, divided up into sections of rainfall and temperature.

4.3.1. Rainfall data

4.3.1.1. Overview

Initially, all time series of rainfall data were plotted using annual and monthly scatterplots to take a superficial look at the data. Examples of some of the longest time series can be seen below in Figure 4.3 as annual rainfall (refer to Appendix 2A for complete annual series). Similarities in rainfall were noted when grouped by locations, which were also observed by farmers, for example farms located in mountainous areas tended to experience higher rainfall than those located towards the coast (see Appendix 2B for example cumulative plots of farm in coastal, vlakte and mountain locations).

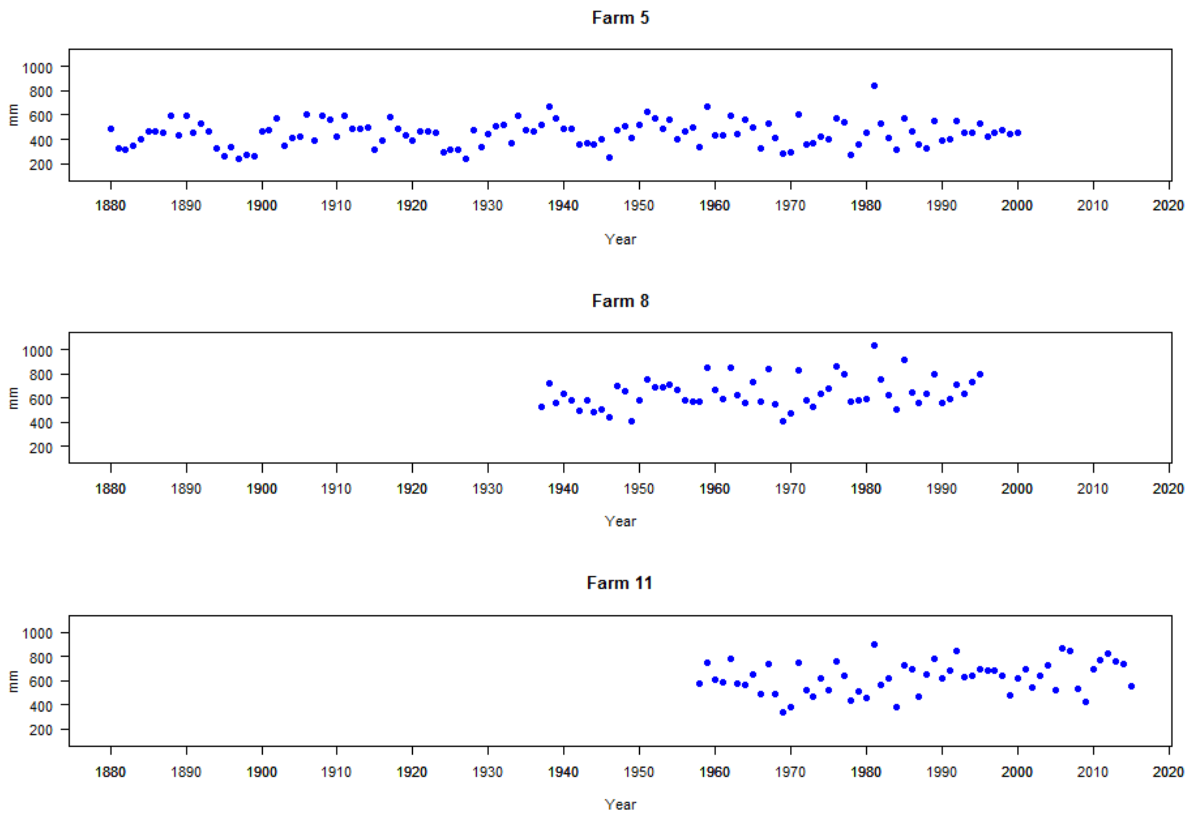


Figure 4.3: Longest rainfall time series gathered made available by participant farmers

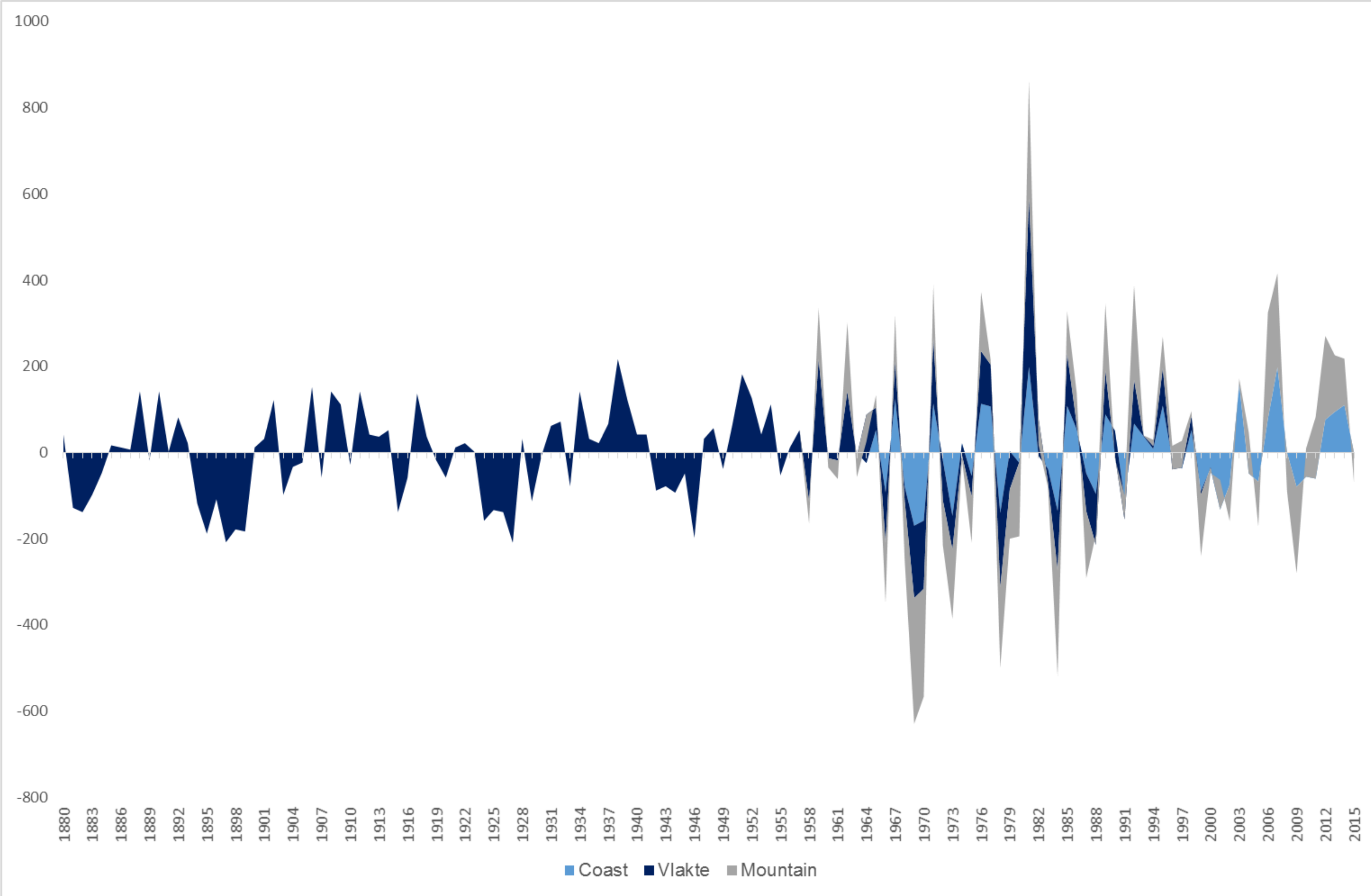


Figure 4.4: Stacked area graph of rainfall anomalies from the longest time series given by farmers – examples taken from coast, vlakte and mountain

Rainfall anomalies from the longest time series given by farmers were then investigated using the total average rainfall against each year per time series (see Figure 4.4). This initial examination of the rainfall data revealed that these data were highly variable over time and while regression analyses detected no significant trends for coastal and vlakte farms, rainfall anomalies did show a trend of increased positive anomalies over time in the mountain farm example (see Appendix 2C). Rainfall data sets were then critically assessed to check their suitability in terms of consistency and outliers. A Shapiro-Wilk normality test was run and revealed these data were not normally distributed ($W = 0.9692$, $p\text{-value} < 0.001$).

Question 1: Are extreme years (high and low) the same between farms?

Spearman's rank correlation (2-tailed) was chosen to test correlation between farms in terms of rainfall and statistics for each pair of variables are based on all the cases with valid data for that pair (Table 4.3). Monthly data were selected as more data points were available for the analysis, as opposed to if annual data were used. Farms with overlapping time series were tested (blank cells indicate no overlapping data) and data sets were all correlated, indicating that the data were consistent. This indicated that the data, despite originating from different farms, showed similar temporal patterns and could be used to compare the different rainfall time series. None of the farms produced conflicting data and measurements were consistent between overlapping time series.

Question 2: Are extreme years (high and low) the same between farms and other data sources?

Farm rainfall data were then compared to rainfall data from local stations of the South African Weather Service (SAWS), the Department of Agriculture and the Riversdale Co-operation. Spearman's rank correlation (2-tailed) was chosen to test correlation in Table 4.4. Table 4.5 shows correlation results on rainfall between farms and official stations. As in Question 1, overlapping time series between different weather stations indicated significant correlations between the different data sources confirmed that there were no inconsistencies across the research area.

Table 4.3: Spearman's rank correlation for farmers' rainfall records (all correlation is significant at the 0.01 level (2-tailed))

	Farm 1	Farm 2	Farm 3	Farm 4	Farm 6	Farm 7	Farm 8	Farm 9	Farm 10	Farm 11	Farm 12	Farm 13
Farm 1	1											
Farm 2	.817	1										
Farm 3		.880	1									
Farm 4	.802	.758	.823	1								
Farm 6		.867	.831	.784	1							
Farm 7	.738	.657	.721	.623	.772	1						
Farm 8	.686	.659		.578		.899	1					
Farm 9		.608	.619	.592	.630	.753		1				
Farm 10		.702	.711	.665	.761	.855	.910	.780	1			
Farm 11	.705	.686	.680	.642	.734	.802	.813	.734	.872	1		
Farm 12		.758	.773	.729	.798	.698		.641	.787	.758	1	
Farm 13	.668	.736	.811	.771	.828	.760	.732	.691	.835	.777	.855	1

Table 4.4: Spearman's rank correlation for rainfall recorded at official weather stations (all correlation is significant at the 0.01 level (2-tailed))

	Albertinia	Blackdown	Breede	Goukou Dam	Heidelberg	Mon Desir	Riversdale ARC	Riversdale	Still Bay	Wistand
Albertinia SAWS	1									
Blackdown SAWS	.708	1								
Breede SAWS	.673	.717	1							
Goukou Dam	.611	.797	.647	1						
Heidelberg SAWS	.728	.842	.688	.755	1					
Mon Desir SAWS	.701	.844		.683	.847	1				
Riversdale ARC	.718	.772	.705	.709	.801	.803	1			
Riversdale SAWS	.730	.840		.811	.850	.796	.896	1		
Still Bay SAWS	.704	.664	.725	.676	.731	.578	.720	.712	1	
Witsand SAWS	.600	.586		.486	.619	.608	.615	.633	.680	1

Table 4.5: Spearman's rank correlation for rainfall recorded between farms and official weather stations (all correlation is significant at the 0.01 level (2-tailed))

	Farm 1	Farm 2	Farm 3	Farm 4	Farm 6	Farm 7	Farm 8	Farm 9	Farm 10	Farm 11	Farm 12	Farm 13
Albertinia	.755	.736	.730	.683	.772	.669	.706	.574	.688	.733	.710	.759
Blackdown	.740	.729	.759	.648	.770	.845	.776	.859	.816	.738	.703	.694
Breede		.793	.804	.729	.655	.623		.528	.679	.646	.729	.812
Goukou Dam		.629	.640	.595	.715	.909	.894	.808	.839	.792	.699	.716
Heidelberg	.760	.751	.81	.705	.805	.816	.774	.553	.771	.731	.744	.702
Mon Desir	.779	.758	.741	.640		.749	.777		.737	.740	.636	.687
Riversdale	.759	.763	.803	.709	.980	.775	.830	.635	.778	.779	.791	.779
Riversdale		.780	.777	.733	.851	.844	.902		.864	.839	.745	.855
Still Bay		.755	.790	.765	.782	.693	.541	.664	.690	.684	.794	.774
Witsand	.903	.709	.767	.640	.65	.521	.485		.546	.527	.629	.638

4.3.1.2. Linking local areas

This section specifically examines the 13 rainfall records received from participating farmers and how these data related to the geographical research area. It was hypothesised that rainfall would not change drastically between the three catchments. Coastal and vlakte farms were hypothesised to not vary greatly in terms of rainfall, but there may be a difference between coastal/vlakte and mountain farms. Coastal farms were hypothesised to have varied rainfall patterns in general, while vlakte farms may have a slight preference to winter rains, and mountain farms were observed to experience big flood events (that wash downstream in the Duiwenhoks and Goukou Rivers) in transition months largely due to cut-off lows.

Question 3: How does rainfall change between catchment locations?

a. Duiwenhoks/Breede

b. Goukou

c. Goukou/Gouritz

Annual rainfall was displayed through boxplots depicting each catchment area (see Figure 4.5). From initial examination, the Duiwenhoks/Breede farms appeared to be different from farms located in Goukou and Goukou/Gouritz catchment areas. Levene's Test for Homogeneity of Variance revealed a significant difference between Duiwenhoks/Breede catchment (variance = 12605.12) when compared to similar Goukou (variance = 28264.91) and Goukou/Gouritz (variance = 23359.62) catchment locations. Kruskal-Wallis rank sum test found difference in variance between Duiwenhoks/Breede versus Goukou (observed difference = 167.80057) and Duiwenhoks/Breede versus Goukou/Gouritz (observed difference = 166.70172). However, no difference in variance was determined by this multiple comparison test for Goukou versus Goukou/Gouritz (observed difference = 1.09885). Refer to Appendix 2D for detailed calculations.

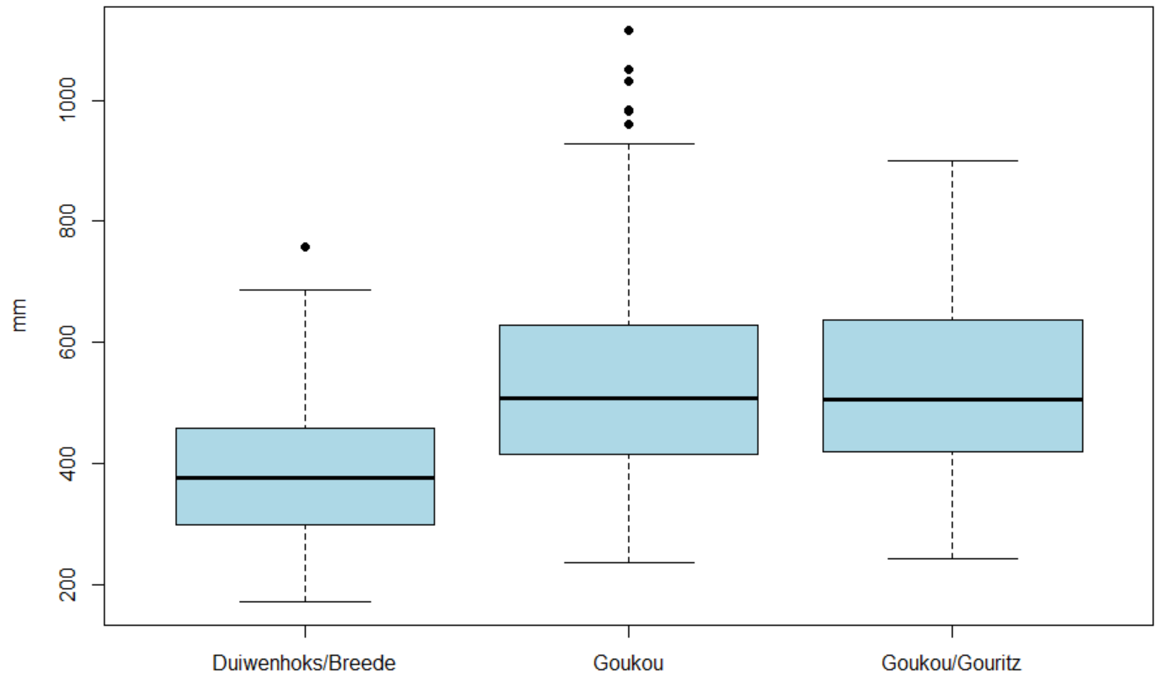


Figure 4.5: Boxplot of annual rainfall (mm) as divided up between catchment locations

As the Duiwenhoks/Breede catchment did not contain any farm rainfall records from the mountain area, another variance and comparison test was run that excluded mountain farms from the other two catchments to see if this influenced the results. Figure 4.6 displays data without mountain farm rainfall for comparison purposes. Levene's Test for Homogeneity of Variance found no significant difference when comparing the three catchment areas: Duiwenhoks/Breede (variance = 12605.12); Goukou (variance = 11269.51); Goukou/Gouritz (variance = 11725.37). Similarly to the previous tests which included mountain farms, Kruskal-Wallis rank sum test found difference in variance between Duiwenhoks/Breede versus Goukou (observed difference = 74.43579) and Duiwenhoks/Breede versus Goukou/Gouritz (observed difference = 53.38974). Again, no difference was determined by this multiple comparison test for Goukou versus Goukou/Gouritz (observed difference = 21.04606). See Appendix 2E for detailed analyses.

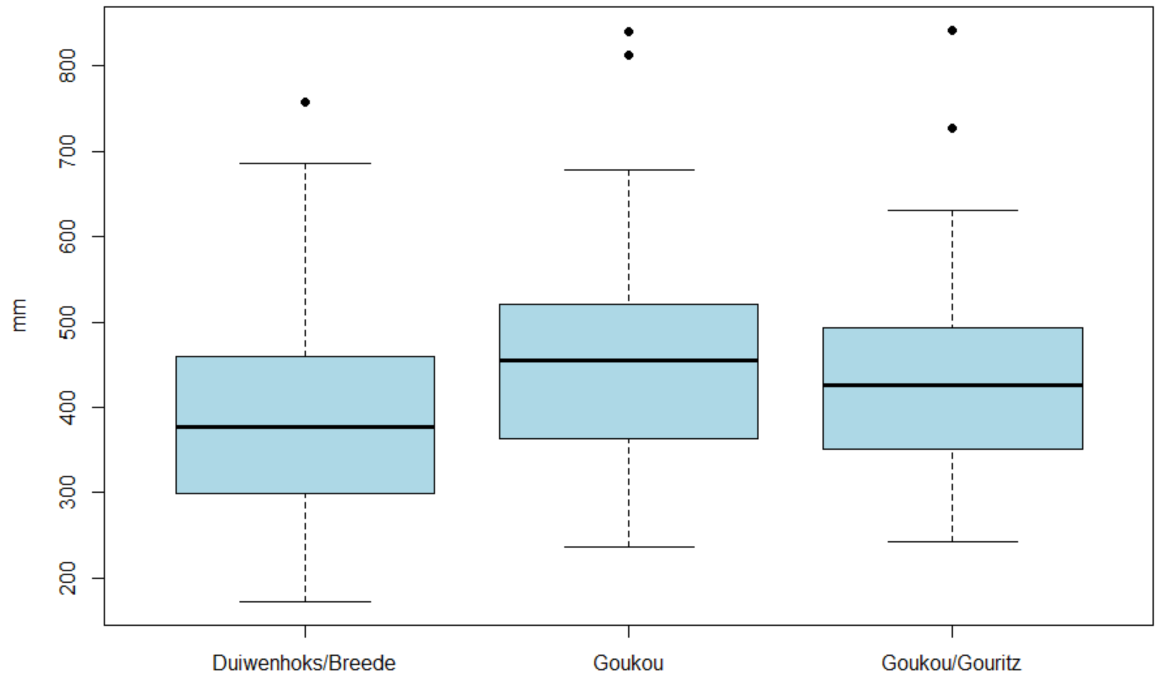


Figure 4.6: Boxplot of annual rainfall (mm) as divided up between catchment locations, excluding mountain farms

Rainfall recorded by farmers in the Duiwenhoks/Breede catchment area differed significantly from Goukou and Goukou/Gouritz catchment areas, indicating a difference between the catchment groups. On average over the past 50 years, the Duiwenhoks/Breede (annual average 386mm) catchment tended to experience lower annual rainfall amounts, while Goukou (annual average 535mm) and Goukou/Gouritz (annual average 530mm) experienced similar higher average rainfall across the catchment areas. Despite annual averages decreasing for both the Goukou and Goukou/Gouritz catchment areas when mountain farms were excluded, a difference was still found between these two catchments and Duiwenhoks/Breede catchment. Overall, annual rainfall was highly variable within catchments as depicted by the boxplots.

Question 4: How does rainfall change between areas?

a. Coastal

b. Vlakte

c. Mountain

As with Question 3, rainfall was displayed through boxplots depicting each area, namely coastal, vlakte and mountain (Figure 4.7). Mountain farms were shown to differ from coastal and vlakte farms due to higher rainfall. Levene's Test for Homogeneity of Variance found a significant difference between mountain farms (variance = 20105.29) when compared to vlakte (variance = 11445.40) and coastal (variance = 12701.21) farm areas. Kruskal-Wallis rank sum test indicated that all areas were significantly different: mountain versus vlakte (observed difference = 238.92610); coastal versus vlakte (observed difference = 61.92908); and coastal versus mountain (observed difference = 300.85518). Mountain farms were vastly different from vlakte and coastal farms in terms of rainfall. Refer to Appendix 2F for detailed calculations.

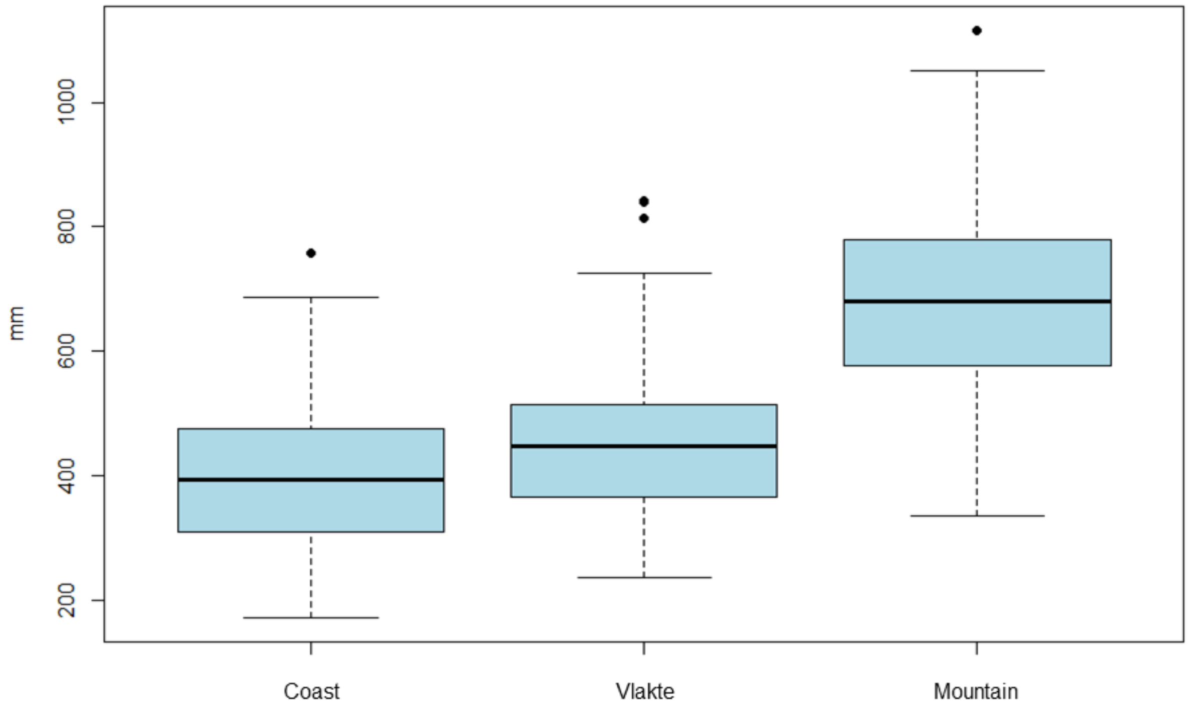


Figure 4.7: Boxplot of annual rainfall (mm) as divided up between areas

When examined according to areas, rainfall was significantly different between coastal, vlakte and mountain areas. Farms located in mountainous areas experienced the highest annual rainfall with an average of 679mm per annum, decreasing along the gradient towards the sea. While vlakte (annual average 448mm) and coastal (annual average 399) areas tended to experience similar rainfall amounts, the areas were still significantly different. Rainfall was highly variable with all areas.

4.3.1.3. Examining extreme rainfall patterns over time

This section incorporated the farm rainfall data with similar area data from the South African Weather Service (SAWS), Department of Agriculture and Riversdale Co-operation. The questions posed are related to observations made by participating farmers (refer to Chapter Three) and examine the possible trends across the different rainfall data sets. Most farmers observed the bulk of changes in weather patterns over the last 15 to 20 years, however this should be examined in the context of memory in addition to possible long-term decadal change. Some farmers observed that rainfall had appeared to have changed in that the farms no longer experienced reliable, long periods of soft drizzle-like rain as experienced by previous generations of farmers (usually their grandparents). Farmers speculated that rather than the amount of annual rainfall varying drastically from the past, rainfall tended to be experienced in more extreme events or floods over shorter periods of time. Some farmers, particularly those based in high lying areas along the Langeberg, speculated that the rainfall pattern may have shifted after the '100 Year' flood in January 1981.

Monthly rainfall data was used to examine whether rainfall patterns had changed over four time periods: Period 1 (before to 1981); Period 2 (1982-1995); Period 3 (1996-2007) and Period 4 (2008 to present). The three categories (less than 10mm; 75th percentile; 95th percentile) depict 'extreme' events based on monthly rainfall data – less than 10 mm per month is considered to be well below the monthly average rainfall for the area, even considering the high variability. Rainfall data falling into the 75th and 95th percentile is considered above average monthly rainfall for the research area. Data were divided up and examined according to catchment and areas identified in Questions 3 and 4. Data from both farms and official stations were included in the analyses so that the geographical area was well represented with a spread of rainfall records from multiple locations.

Question 5: Have extreme rainfall events shifted over time?

- **a.** Dry months: Total monthly rainfall less than 10mm
- **b.** Wet months: Total monthly heavy rainfall more than 75th percentile
- **c.** Wet months: Total monthly heavy rainfall more than 95th percentile

Table 4.6 shows the three different categories (less than 10mm; 75th percentile; 95th percentile) divided up into the four time periods according to catchment area. The percentages are based on frequencies (see Appendix 2G for individual calculation tables). Significance was tested between each time period for each category and group. Where significant, the t-test statistic was greater than 1.96 (corresponding p-value of less than 0.05) and hence was significant at the 95 percent significance level.

Table 4.6: Monthly rainfall according to three 'extreme' categories divided up into catchment locations

	< 10mm		
	Duiwenhoks/Breede	**Goukou**	**Goukou/Gouritz**
Period 1 (before-1981)	18 %^	6 %^	18 %*
Period 2 (1982-1995)	20 %	9 %	11 %^^
Period 3 (1996-2007)	19 %	7 %^	14 %^
Period 4 (2008-present)	23 %*	10 %*	16 %*
	75th percentile		
	Duiwenhoks/Breede	**Goukou**	**Goukou/Gouritz**
Period 1 (before-1981)	26 %	24 %	24 %
Period 2 (1982-1995)	24 %	24 %	27 %
Period 3 (1996-2007)	23 %	26 %	24 %
Period 4 (2008-present)	24 %	25 %	26 %
	95th percentile		
	Duiwenhoks/Breede	**Goukou**	**Goukou/Gouritz**
Period 1 (before-1981)	4 %	4 %	3 %^^
Period 2 (1982-1995)	6 %	5 %	6 %*
Period 3 (1996-2007)	5 %	6 %	5 %
Period 4 (2008-present)	5 %	5 %	6 %*

* indicates significance p<0.05; ^ indicates corresponding value for *

Table 4.7 shows the three different categories (less than 10mm; 75th percentile; 95th percentile) divided up into the four time periods according to area. The percentages are based on frequencies. As in the previous table, significance was tested between each time period for each category and group.

Table 4.7: Monthly rainfall according to three 'extreme' categories divided up into areas

	< 10mm		
	Coast	**Vlakte**	**Mountain**
Period 1 (before-1981)	22 %	19 %*	10 %*
Period 2 (1982-1995)	21 %	15 %^	7 %^
Period 3 (1996-2007)	19 %	15 %^	6 %^
Period 4 (2008-present)	18 %	20 %*	7 %
	75th percentile		
	Coast	**Vlakte**	**Mountain**
Period 1 (before-1981)	24 %	25 %	25 %
Period 2 (1982-1995)	25 %	24 %	25 %
Period 3 (1996-2007)	25 %	24 %	24 %
Period 4 (2008-present)	26 %	26 %	24 %
	95th percentile		
	Coast	**Vlakte**	**Mountain**
Period 1 (before-1981)	4 %	4 %	4 %
Period 2 (1982-1995)	5 %	6 %	6 %
Period 3 (1996-2007)	5 %	5 %	6 %
Period 4 (2008-present)	5 %	5 %	5 %

* indicates significance $p<0.05$; ^ indicates corresponding value for *

Significant differences were found across all three catchment locations in the drier category (less than 10mm per month) as seen in Table 4.6. In both the Duiwenhoks/Breede and Goukou catchments, there was a significant increase in drier months from Period 1 to Period 4. However, in the Goukou/Gouritz catchment the drier months decreased significantly from Period 1 to Period 4. There was very little change in the 75th percentile group for both the catchments and area categories. In the 95th percentile (unusually large amount of rainfall per month), only the Goukou/Gouritz catchment increased over time from Period 1 to Period 4. In the area category, no significant differences were found between periods in the 75th and 95th percentile categories (Table 4.7). The mountain area showed significant decrease in extreme dry months from Period 1 and Period 3. For the vlakte area, drier months decreased significantly in Period 2 and 3, but Period 1 and 4 experienced more dry spells.

To summarise results from Tables 4.6 and 4.7, extreme dry spells appeared to change more drastically (i.e. less than 10mm of rainfall experienced per month) than in the other two 'wet' categories. Significance was only found between groups that displayed a change of four percent or more. More significant changes were revealed within catchments rather than areas between the different time periods. While the Duiwenhoks/Breede and Goukou catchments showed a tendency for drier months to increase across periods, the Goukou/Gouritz catchment displayed a decrease in drier months across the periods. The Goukou/Gouritz catchment also showed an increase in extreme wetter months across the time periods. Coastal areas showed very little variation between the different rainfall extremes across time periods. Only mountain areas experienced fewer dry extremes over time.

4.3.1.4. Examining shifting rainfall patterns over time

In general crop farmers noted that their planting season had shifted to a later period when comparing farming practices to their grandparents' generation. For example, some crop farmers observed that instead of planting in February or March like their predecessors, they now plant in April or May. However, it is important to note that almost all farms interviewed changed over from 'rip the soil open' tillage (i.e. ploughing) methods to conservation agriculture which subsequently improved moisture retention in the soils – making farmers less dependent on needing the first 'big' (substantial) rains to come before planting. Monthly rainfall data were used to examine whether seasonality patterns had changed over four time periods: Period 1 (before to 1981); Period 2 (1982-1995); Period 3 (1996-2007) and Period 4 (2008 to present). Data were compared in terms of average differences between the cumulative 'Old Season' (March, April, May) and 'New Season' (April, May, June) against the four time periods for each farm and station.

Question 6: Have seasons shifted according to planting seasons from March-May (Old Season) to April-June (New Season)?

Across the research area, Period 1 changed by 6.6; Period 2 changed by 0.4; Period 3 changed by 29.5; and Period 4 changed by -31.5. A positive difference indicates more rainfall in the Old Season and a negative difference indicates more rainfall in the New Season. On average, it appears that the onset of the traditional rainfall season has shifted to a later time period over time. When examining shifts in rainfall across catchment locations and area (see Table 4.8), the New Season dominated Period 4, while the Old Season was mainly observed in Period 3.

Table 4.8: Average differences between Old and New Seasons for catchment and area locations

Location	Period 1 Before to 1981	Period 2 1982-1995	Period 3 1996-2007	Period 4 2008 to present
Duiwenhoks/Breede	1.9	-9.0	25.1	-28.8
Goukou	20.5	14.0	32.8	-32.9
Goukou/Gouritz	5.3	-4.9	31.7	-35.2
Coast	-7.2	-10.7	16.5	-30.3
Vlakte	4.0	-6.2	24.3	-29.9
Mountain	20.3	16.4	50.8	-34.1

Figure 4.8 indicates each individual farm and station shifts in terms of seasonality for each time period. Mountain locations tended to show the highest variation in terms of shifting seasons. In Period 3, the traditional Old Season tended to show higher rainfall in comparison to the New Season. The New Season tended to display higher rainfall in Period 4. Overall, it appears that the trends in rainfall data are in line with farmers' observations in that the onset of the rainfall season has shifted by a month when compared to their predecessors' experience.

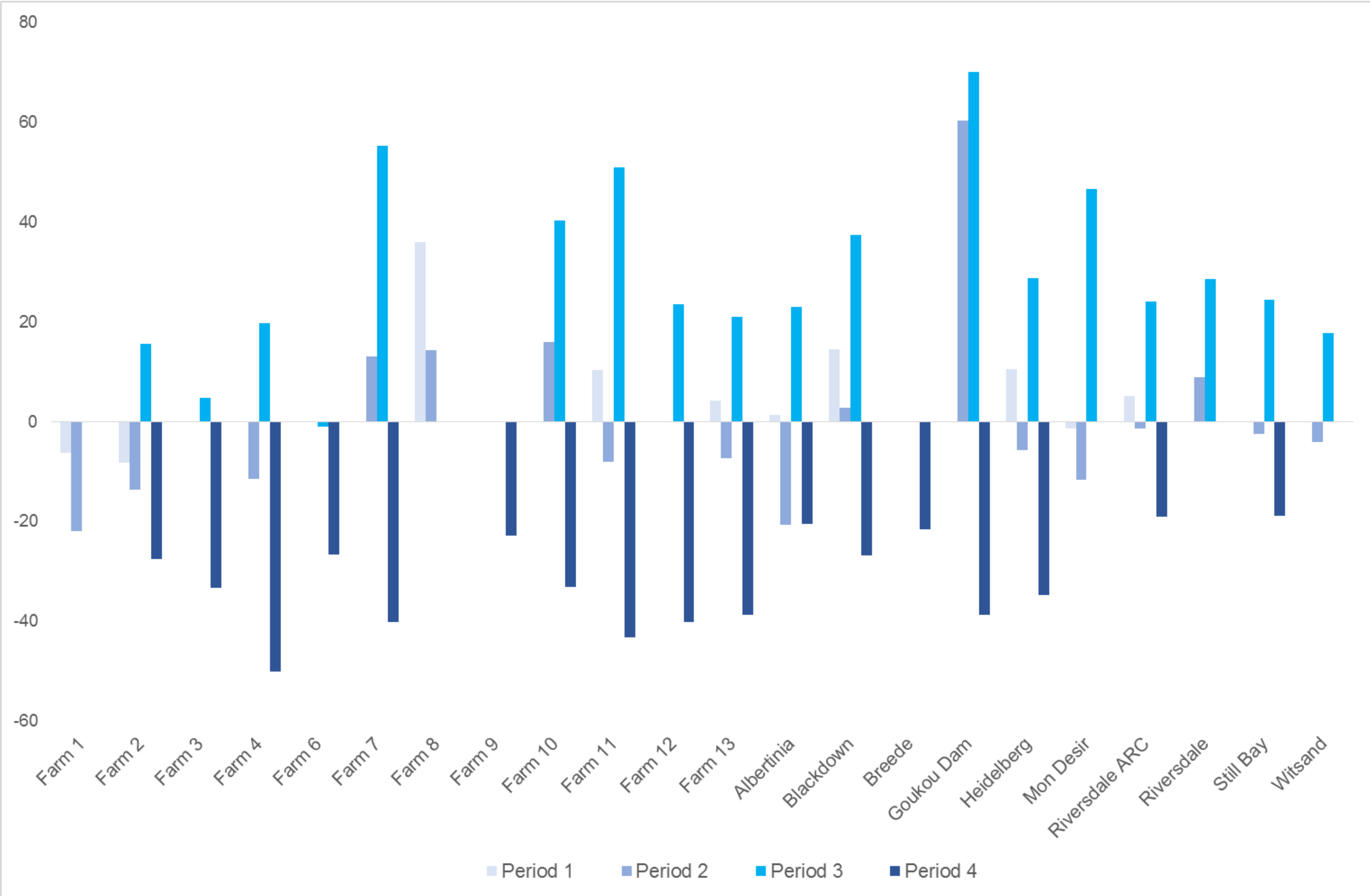


Figure 4.8: Average differences between Old and New Seasons for the data sets examined: Positive difference indicates more rainfall in 'Old Season' and a negative difference indicates more rainfall in 'New Season'

4.3.2. Temperature data

4.3.2.1. Overview

Available temperature data for the study were limited and examined according to coastal and inland stations. Data were examined in terms of minimum and maximum values on a monthly scale. Of the four temperature data sets were available (see Table 4.2), only two had an adequate range over time to examine possible trends – namely Mossel Bay (SAWS) and Riversdale (ARC). When examining mean annual temperature, these data do not show any clear trends and inland and coastal stations do not vary greatly (see Appendix 2H). When comparing maximum average temperatures across time, as seen in Figure 4.9 below and according to expectations, inland stations tended to be warmer than coastal stations. Inland stations also tended to have lower minimum temperatures. Overall, there were no clear trends when examining minimum and maximum averages individually over time.

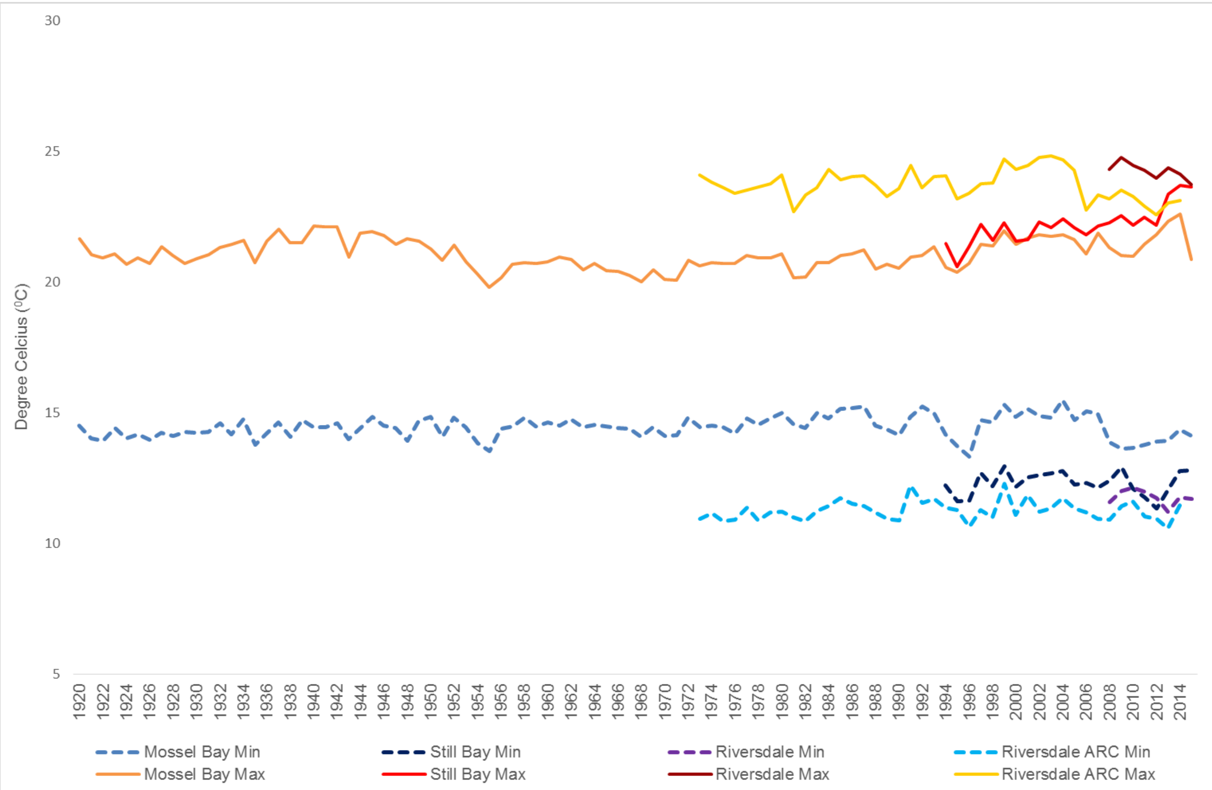


Figure 4.9: Average minimum (Min) and maximum (Max) annual temperatures across all four data sets: Mossel Bay (SAWS), Still Bay (SAWS), Riversdale (SAWS) and Riversdale (ARC)

The two longest time series for temperature, namely Mossel Bay from SAWS and Riversdale from ARC, were then inspected separately due to their favourable time lengths as a time series of 40 years or more is preferable for trend indication and shorter time series were disregarded. The location of these time series, namely coastal (i.e. Mossel Bay) and inland (i.e. Riversdale), were also useful for comparison purposes within the research area. Summary statistics and distribution were examined for both Mossel Bay and Riversdale (see Appendix 2I). It was noted for future analyses that the temperature time series for Mossel Bay had station changes (moved physically within the urban area) in 2002 and again in 2008; while the Riversdale station changed from manual operation in 2005 to automatic operation in 2006.

Boxplots (daily data) of the two longest time series did not give a clear indication of any changes in trends of average temperature over time. As seen in Figure 4.10 and Figure 4.11, there is high variability across both data sets. Overall, more outliers were observed above average readings, indicating warmer extreme temperatures rather than cold. This was also reflected in boxplots depicting maximum and minimum observations (see Appendix 2J).

Mossel Bay and Riversdale time series were then examined for temperature anomalies. As seen in Figure 4.12, there were no significant trends when using mean annual temperature data for both the inland and coastal stations (see Appendix 2K). However, note the period of warm temperatures in Mossel Bay from 1930 to 1950; the cold period from 1953 to 1996; the following warm period from 1997 to 2006; and the corresponding shift to colder temperatures in Riversdale in 2005/6.

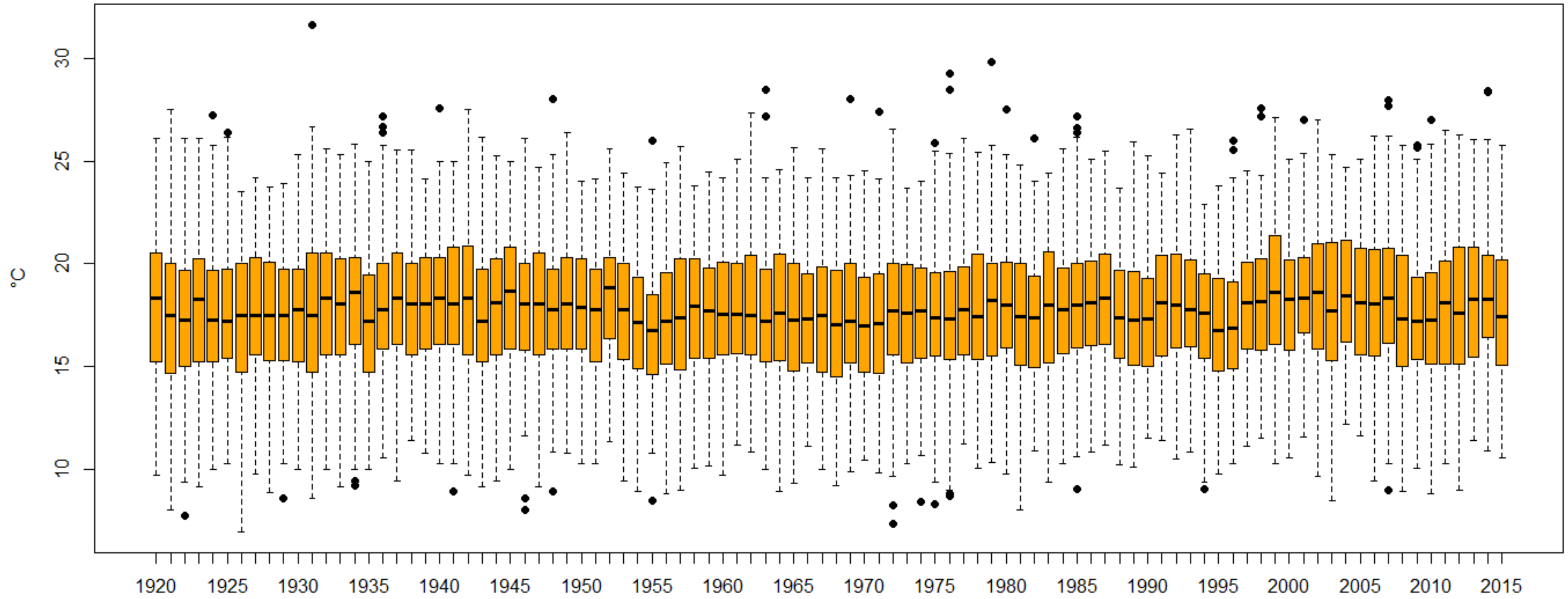


Figure 4.10: Boxplot of average daily temperatures with outliers across all years for Mossel Bay

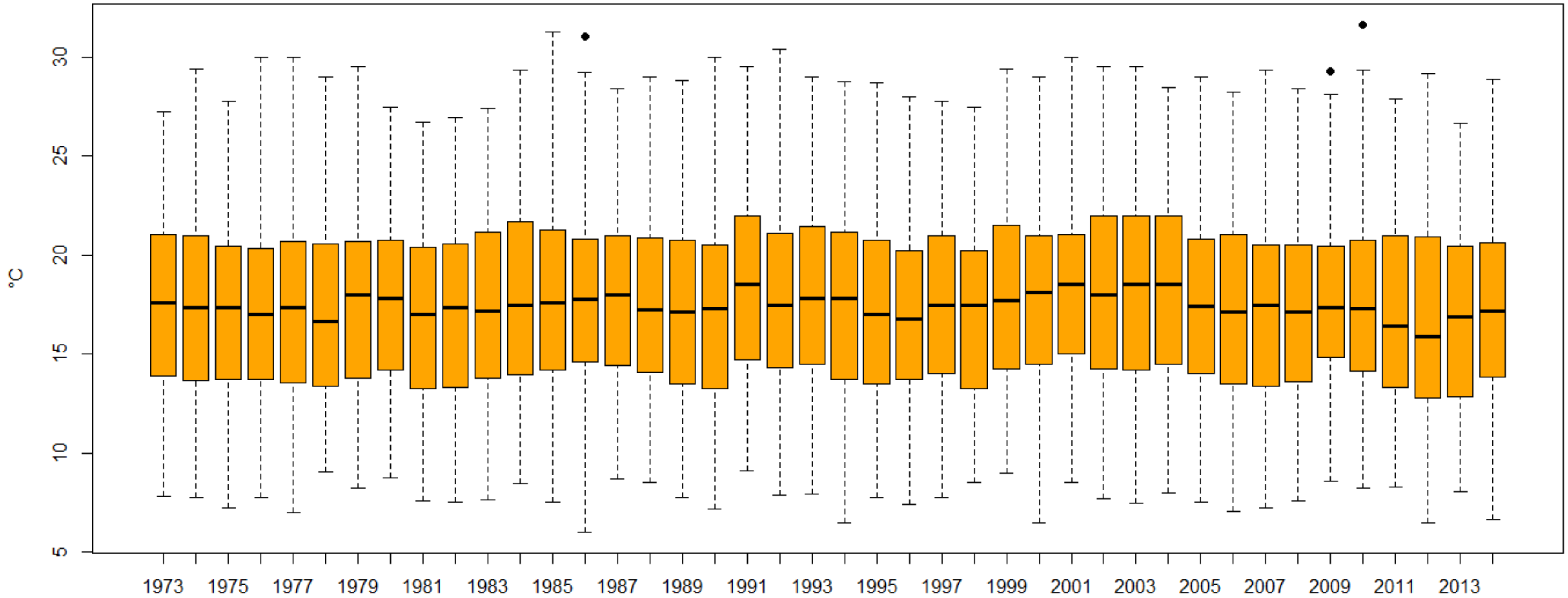


Figure 4.11: Boxplot of average daily temperatures with outliers across all years for Riversdale

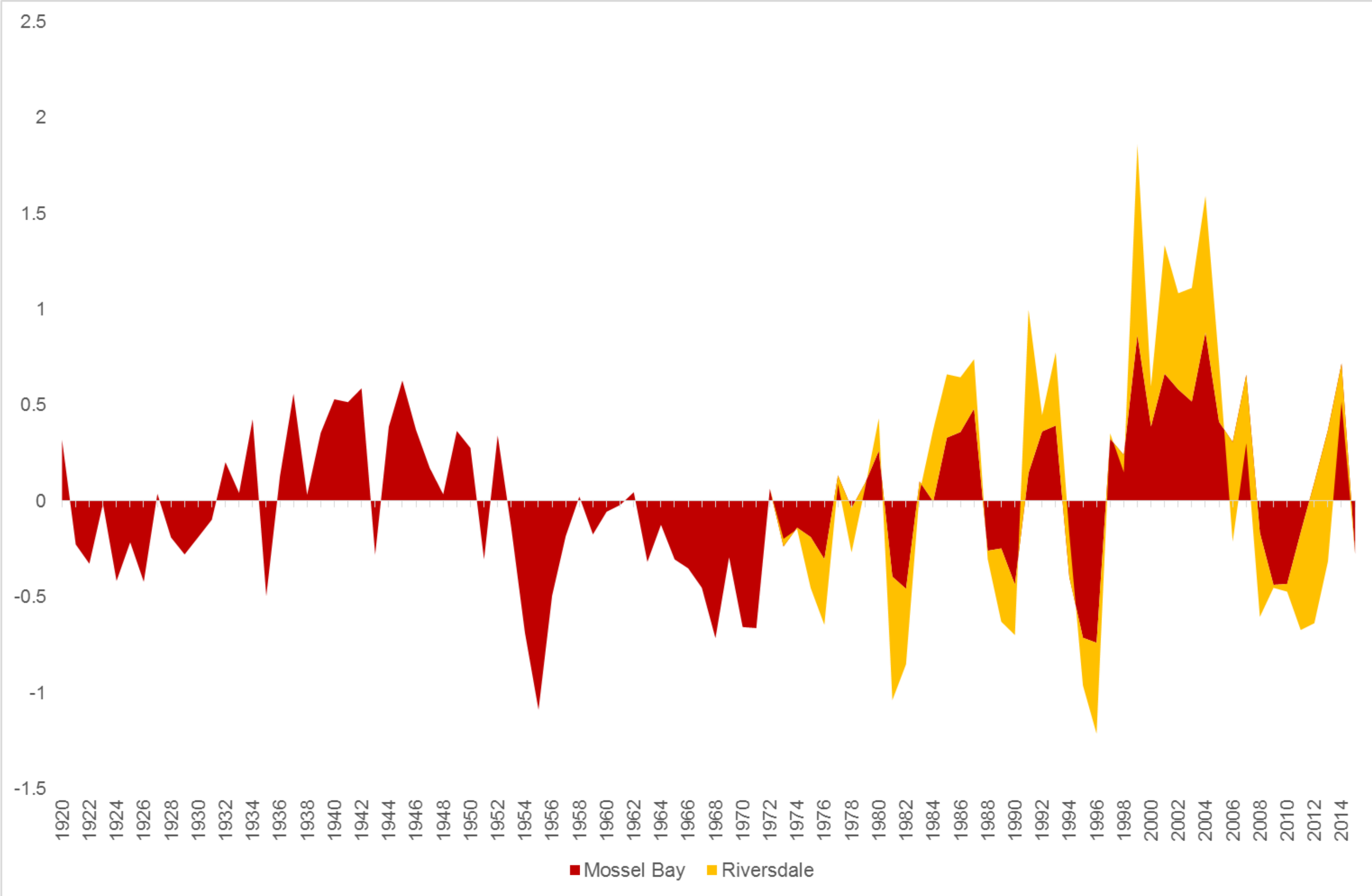


Figure 4.12: Stacked area graph of temperature anomalies from the longest time series where Mossel Bay represents coastal areas and Riversdale represents inland areas

4.3.2.2. Seasonality

Seasonality was examined at both inland and coastal stations using boxplots. Initially, annual seasonality was plotted across the 12 months in a year from both time series using daily data.

Question 7: How does temperature change according to seasonality?

As seen in Figure 4.13 and Figure 4.14 below, the coastal (Mossel Bay) and inland (Riversdale) data sets showed a clear seasonality within the year, which can be divided up as follows:

- Winter: June, July, August
- Spring: September, October, November
- Summer: December, January, February
- Autumn: March, April, May

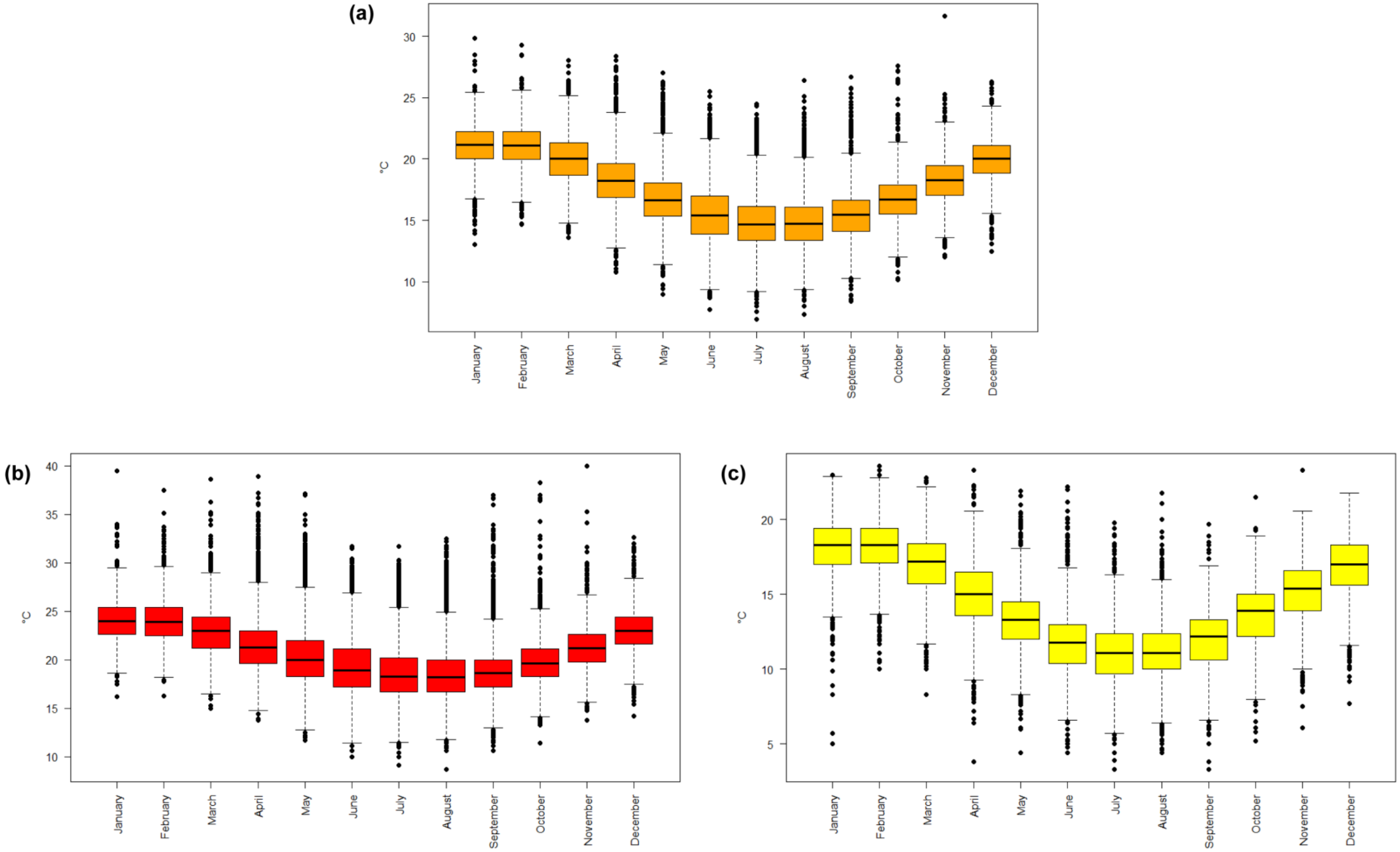


Figure 4.13: Daily temperature per month across all years (1920-2015) for Mossel: (a) Average; (b) Maximum; and (c) Minimum

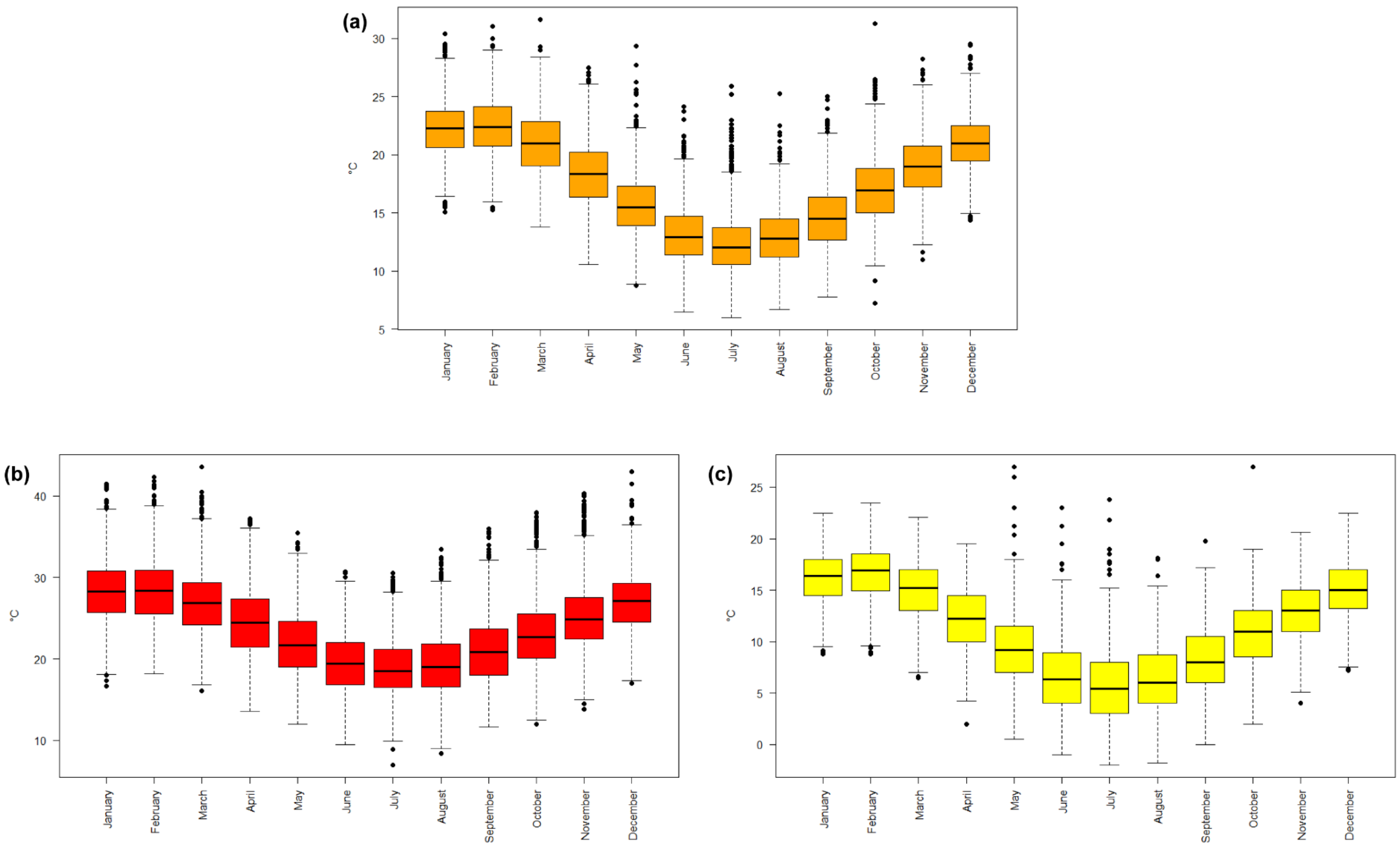


Figure 4.14: Daily temperature per month across all years (1973-2014) for Riversdale: (a) Average; (b) Maximum; and (c) Minimum

Overall, coastal temperatures did not vary greatly between minimum and maximum averages while inland experienced hotter and colder changes within the average year. Mossel Bay contained more outliers than Riversdale, indicating variability in temperature on the coast. Warm outliers were more common for both data sets, noticeably concentrated over the winter months that were most pronounced at the inland station. Clear seasonality is evident in both data sets. The coldest months were found over the winter period (June, July and August), while the hottest months were found over the summer period (December, January and February). Further boxplots according to seasonality revealed similar results and no clear trend was established (refer to Appendix 2L).

4.3.2.3. Regime shifts

The longest temperature time series were tested for regime shifts to further explore possible changes in climate at a local scale. Regime shifts were noted when a statistically significant difference existed between the mean value of the variable before and after a certain point based on the sequential regime shift detection method.

Question 8: Have temperature regimes changed over time?

Initially, data for Mossel Bay and Riversdale were organised to examine the year according to season, so as not to break up a summer season when running an annual January to December scenario. Figure 4.15 indicates five regimes for the Mossel Bay temperature series, starting the annual cycle from winter 1921. Figure 4.16 shows three regime shifts for the Riversdale time series, beginning the annual cycle from winter 1974.

The regime shifts for the coastal data set are divided up into the following time periods: 1920 – 1935; 1936 – 1952; 1953 – 1996; 1997 – 2007; 2008 – 2014 (Figure 4.15). It should be noted that a station change occurred in 2008 and therefore may have influenced the detection of a regime shift. The regime shifts for the inland data set are divided up into the following time periods: 1973 – 1996; 1997 – 2004; 2005 – 2013 (Figure 4.16). It should be noted that a station change occurred between 2005 and 2006 at the Riversdale weather station, possibly influencing the detection of a regime shift.

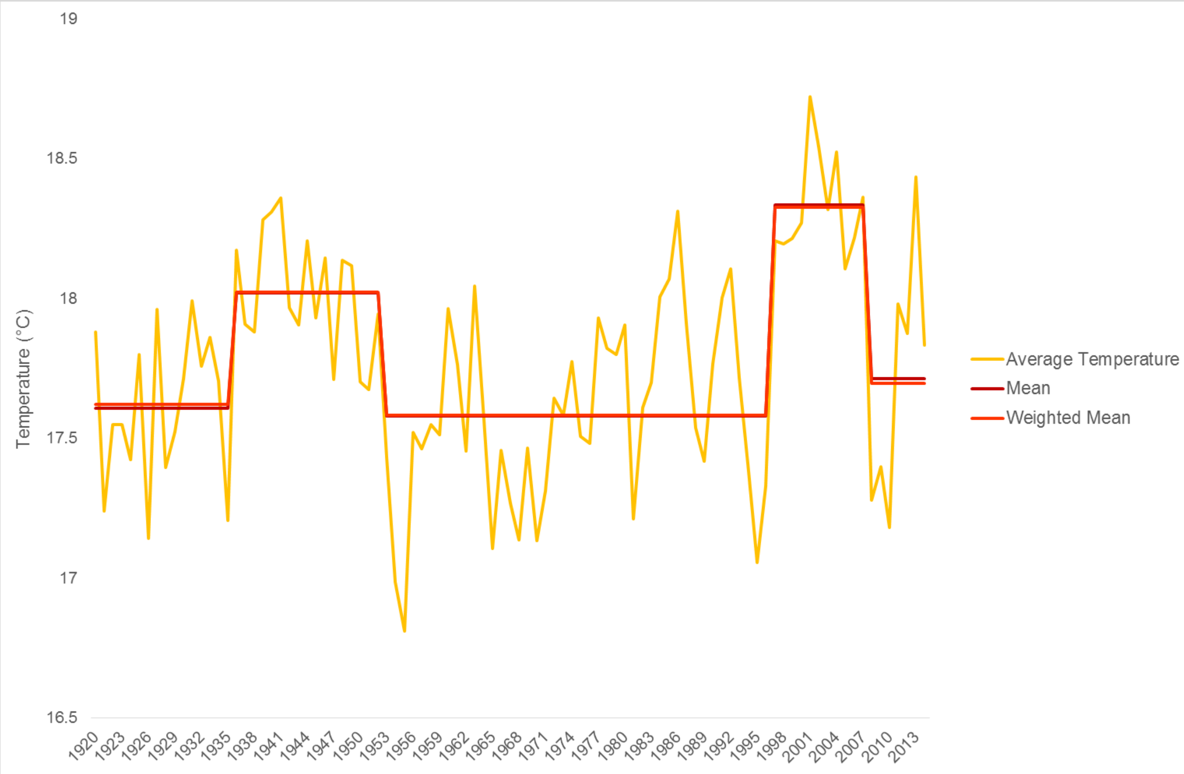


Figure 4.15: Average annual temperature (running from June to May) with regime shifts for Mossel Bay

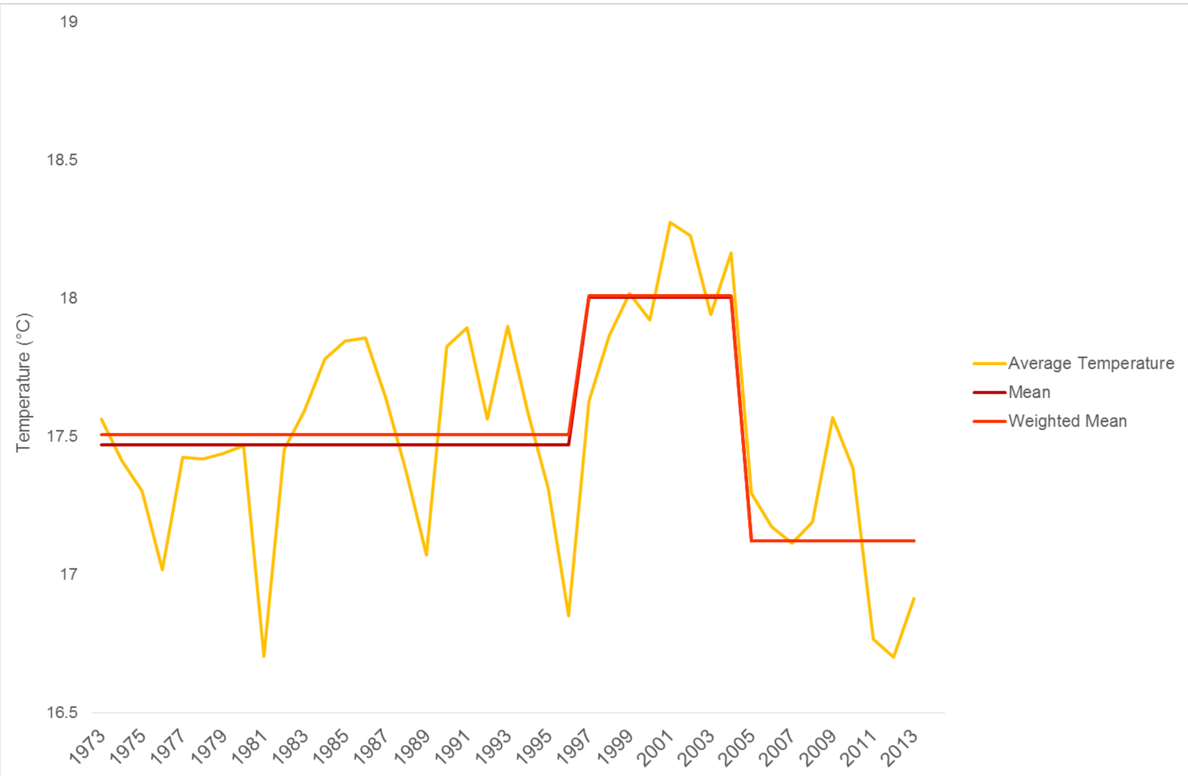


Figure 4.16: Average annual temperature (running from June to May) with regime shifts for Riversdale

Data were then divided up according to seasons and tested for regime shifts. Table 4.9 and Table 4.10 display results of the regime shift tests according to season.

Table 4.9: Regime shifts according to seasons (tri-month average temperature) for Mossel Bay

Season	Number of regime shifts	Periods of regimes	Mean average temperature	Direction of change per regime period
Winter	3	1920 – 1935	14.8	Down
		1936 – 2014	15.3	Up
		2015	14.1	Down
Spring	5	1920 – 1938	16.8	Down
		1939 – 1948	17.3	Up
		1949 – 1996	16.6	Down
		1997 – 2007	17.6	Up
		2008 – 2014	16.7	Down
Summer	5	1921 – 1939	20.6	Down
		1940 – 1950	21.1	Up
		1951 – 1998	20.4	Down
		1999 – 2008	21.5	Up
		2009 – 2015	20.8	Down
Autumn	5	1920 – 1931	18.2	Down
		1932 – 1952	18.7	Up
		1953 – 1997	18.2	Down
		1998 – 2014	18.8	Up
		2015	17.9	Down

Table 4.10: Regime shifts according to seasons (tri-month average temperature) for Riversdale

Season	Number of regime shifts	Periods of regimes	Mean average temperature	Direction of change per regime period
Winter	2	1973 – 2010	12.9	Up
		2011 - 2014	11.9	Down
Spring	4	1973 - 1996	16.8	Down
		1997 – 2004	17.7	Up
		2005 – 2013	16.2	Down
		2014	17.1	Up
Summer	---	1973 – 2014	21.9	N/A
Autumn	---	1973 – 2014	18.3	N/A

In both data sets for the overall seasonal average, a regime shift is indicated in the late 1990s without interference from station changes. The coastal data indicates changes occurring between 1930s to 1950s and the late 1990s when the different seasons are overlaid. There is agreement between seasonal data sets from the coast that temperature regime shifts occurred in the late 1990s (to a warmer period) and again in the late 2000s (to a cooler period). The inland data, while more restricted due to its shorter timeline, shows changes in the late 1990s (to a warmer period) as well as after 2010 (to a cooler period) when seasonality is considered. The warming of temperatures in the late 1990s could signal a shift in the larger system and should be investigated in conjunction with regime shifts in the southern Benguela marine ecosystem as discussed by Blamey et al. (2012).

4.4. Overall Discussion

Local terrestrial rainfall and temperature data obtained specifically within the research area of the southern Cape revealed subtle changes over time rather than definitive trends. While patterns within these data were not clear-cut, it is still important to consider local variability within over-arching climate change patterns of South Africa as this is important to monitor for livelihoods dependent on a natural resource base, such as farmers. It is also equally important to consider the quality of the database examined, which influences the results – as discussed below.

4.4.1. Challenges

Challenges associated with the data sets analysed for rainfall and temperature time series are summarised as follows:

1. Data quality

- Collection methods for rainfall on a daily scale was not always consistent for both farmers and stations. A common problem was the accumulation of rainfall over a few days thus not giving accurate daily rainfall readings;
- Change in rainfall and temperature stations for observation data in terms of altering station location and updating or switching gauge technology resulted in

possible inconsistent time series, thus possibly skewing results particularly associated with regime shifts in the temperature data series.

2. Limited available data

- Only a few functioning weather stations were present in the research area which is problematic for scientific research due to a lack of available, reliable data on a local scale;
- Of the handful of weather stations recording temperature in the research area, only two data time series were used for analyses due to the poor quality of available data in terms of very short time series and missing values;
- Furthermore, farmers did not keep detailed records of temperature and discarded annually recorded temperatures at the end of each year thus further limiting accessible temperature data.

3. Length of time series

- Many available data sets were not long enough to access long term changes in climate variability on a local scale;
- A minimum of 40 years is recommended to access any change in trends over time for climate analyses, corresponding to two cycles of decadal-scale change.

4. Scale

- Problematic to analyse subtle changes at fine scale as annual timeframes do not account for seasonality changes, however daily timeframes present problems with data quality;
- The use of numerous data points (i.e. daily) can also result in skewed significance due to volume rather than change.

4.4.2. Rainfall patterns and change over time

In the initial inspection of rainfall data, there were no clear trends over time and high variability across the research area, generally supporting observations of farmers in the southern Cape. Key findings for rainfall data in relation to observations of participating farmers, as well as research questions, are summarized below in Table 4.11.

Table 4.11: Summary of rainfall results in relation to research questions

Question	Results
Question 1: Are extreme years the same between farms?	Yes
Question 2: Are extreme years the same between farms and other data sources?	Yes
Question 3: How does rainfall change between catchments?	• Duiwenhoks/Breede catchment is drier compared to other two catchments • No difference between Goukou and Goukou/Gouritz catchments
Question 4: How does rainfall change between areas?	• Mountain areas received highest average rainfall (679mm/year) • Vlakte areas had intermediate average rainfall (448mm/year) • Coastal areas experienced the most variable and driest average rainfall (399mm/year) • Differences between areas are significant
Question 5: Have extreme events shifted over time (monthly)? a) Dry months (<10mm) b) Wet months (>75th percentile) c) Wet months (>95th percentile)	**Catchment:** a) Duiwenhoks/Breede increased significantly between Period 1 (before-1981) and Period 4 (2008-present). Goukou increased between Period 1/Period 3 (1996-2007) and Period 4. Goukou/Gouritz decreased in Period 2 (1982-1995) and Period 3, but increased in Period 1 and Period 4. b) No significant changes across all catchments. c) Goukou/Gouritz increased significantly in Period 2 and Period 4 compared to Period 1. **Area:** a) Vlakte significantly increased in Period 1 and 4 in comparison to Period 2 and 3. Mountain decreased from Period 1 to 3. b) No significant changes across all areas c) No significant changes across all areas
Question 6: Have seasons shifted according to planting seasons from Old Season (March-May) to New Season (April-June)?	Across the research area, the Old Season experienced the most rainfall in Period 3, while the New Season experienced the most rainfall in Period 4.

Farmers noted that experience of rainfall differed across the research area, depending on where farms were located (see Section 3.4.3). Analysis confirmed that rainfall was significantly different across areas with a decreasing rainfall gradient from the mountains (highest rainfall) towards the vlakte (mid-range rainfall) and then coast (least rainfall). Similarly, rainfall changed between catchment areas with the Duiwenhoks/Breede catchment area in the western extent of the research area significantly differing from the Goukou and Goukou/Gouritz catchment areas located in the centre and eastern parts. The western extent of the research area experienced a lower annual average rainfall amount when comparted to the other two catchment areas (which had similar higher annual average rainfall). These data were highly variable, again mirroring farmers' observations that rainfall did not have any clear trends over time. This also highlights the importance of scale, emphasizing the subtle changes of rainfall experience when examining these patterns at a local level and how this impacts strategies employed depending on where farms are located.

A study by MacKellar et al. (2014) noted that trends in rainfall indices were generally not significant and inconsistent across the Western Cape region, where the number of rain days indicated drier conditions along the southern coastal regions. During my research, southern Cape farmers noted that rather than the amount of rain drastically changing over time when compared to the experience of their predecessors, rainfall patterns differed. According to farmers, rainfall no longer fell typically over a lengthy period of time as soft drizzle, but rather in shorter, erratic and at times extreme events with longer dry periods. Rainfall data from the research area indicated a significant increase in extremely dry months over the past few decades in the Duiwenhoks/Breede and Goukou catchments, while the Goukou/Gouritz catchment indicated a decrease in drier months across the time periods. More significant changes between different time periods were found between catchments rather than areas, where only mountain areas displayed significantly fewer dry spells over the past few decades.

Seasonality and associated rainfall was deemed important by crop farmers in the research area as this had implications for the time of year that farmers could begin their planting season. Farmers observed that they started the planting season later into the traditional month when compared to previous generations as the onset of the seasonal rainfall had appeared to have shifted by a month or so. This was supported when the traditional planting season was compared to the new planting season in terms of rainfall, indicating that the onset of the typical autumn rainfall season had shifted to a month later over the past decade.

4.4.3. Temperature patterns and change over time

Work carried out by MacKellar et al. (2014) on observed and modelled trends in rainfall and temperature for South Africa (from 1960 to 2010) found that maximum temperatures had significantly increased for all seasons in the Western Cape area, with strong warming occurring over the last ten years. Temperature data from the southern Cape investigated here were highly variable over time, indicating more complexity on smaller scales. Temperature time series did display periods of consistent warm or cool periods over time, which interestingly overlaid between coastal and inland observation stations with a highly variable period from the 1970s to mid-1990s, then a consistent warm period from late 1990s to mid-2000s, and subsequently followed by a consistently cooler period after 2006 (see Figure 4.15 and 4.16). Key findings for temperature data in relation to research questions are summarized in Table 4.12.

Temperature in the research area did have clear seasonal differentiation with the hottest months found in summer (December, January and February) and coldest months experienced in winter (June, July and August). Transition seasons of spring and autumn were also clearly shown by decreasing temperatures in autumn (March, April and May) and increasing temperatures in spring (September, October and November). Coastal temperatures were more variable than inland, where the inland station displayed hotter (in summer) and colder (in winter) averages, according to expectations. It is interesting to note that outliers were more prevalent for warmer temperatures, particularly in winter months. Warmer outliers indicate more unseasonably hot days which could have implications for drought-like conditions, particularly when linked to subtle changes in long term rainfall patterns and some farmers' observations that winter months appear to be less cold in recent memory. Work carried out by Wiid (2009) in the southern Cape region also noted an increase in temperature extremes and frequent drought conditions.

Table 4.12: Summary of temperature results in relation to research questions

Question	Results
Question 7: How does temperature change according to seasonality?	**Seasons were well defined:** ▪ Winter: June – August ▪ Spring: September – November ▪ Summer: December – February ▪ Autumn: March – May • There was greater seasonality inland, which matched expectations. • Seasonality did not change significantly over time.
Question 8: Have temperature regimes changed over time?	**Mossel Bay (1920-2014) annual regime shifts:** 1. 1935-1936 = increase 2. 1952-1953 = decrease 3. 1996-1997 = increase 4. 2007-2008 = decrease* *But station change could influence results **Riversdale (1973-2013) annual regime shifts:** 1. 1996-1997 = increase 2. 2004-2005 = decrease* *But station change could influence results • Mossel Bay and Riversdale annual time series were consistent with each other in 1997 to 1998 with a shift of increasing temperature. • Mossel Bay seasonal time series are in agreement with annual time series of shift to warmer period in late 1990s. • Riversdale spring time series in agreement with annual and coastal seasonal time series of shift to warmer period after mid-1990s. • Both stations adjusted downwards in annual and seasonal time series to a cooler temperature regime period from mid 2000s; however this is possibly due to station change for both sites over this period and results should be treated with caution.

Temperature displayed significantly cooler and warmer periods over time, with a long cooler period experienced from the 1950s to mid-1990s and again after the mid-2000s. On the coast, a warm period occurred between 1940 and 1950 and both inland and coastal temperature data sets indicated a clear warm period from the late 1990s to mid/late 2000s. At both observation stations, spring was the season most sensitive to regime shifts for temperature. These shifts in temperature in the 1990s correspond findings in regime shifts in the southern Benguela marine ecosystem by Blamey et al. (2012). While temperature shifts in the late 2000s are also possibly in agreement with marine findings (Blamey et al., 2015; Jarre et al., 2015), these should be treated with caution due to station gauge changes in both coastal and inland locations during this time period.

4.4.4. Summary

Data from both rainfall and temperature time series in the research area showed complexity and high variation, only displaying subtle changes over time rather than clear-cut trends. Experiences of farmers were largely in agreement with rainfall variation within different areas and catchments, particularly when seasonality was considered with the later onset of seasonal autumn rainfall since the mid-2000s. Across the catchment areas, the western and central extent of the research area experienced an increase of dry spells over time. While the eastern extent of the area experienced the highest frequency of dry spells before 1981, there is an increase in dry spells after the early 1980s to present. Increased dry spells and commonly occurring extreme outliers of temperature that tend to fall above average could have significant impacts on farming livelihoods in the research area. The eastern extent of the research area also experienced an increase in extremely high rainfall months since the 1980s, again showing complexity at a local scale and that change is not necessarily a uniform experience for farmers located in the area.

Change in temperature patterns were more difficult to discern from a farming perspective and analyses did not clearly link changes in temperature regimes to subtle changes in rainfall patterns. It should be noted that temperature analyses were limited to only one coastal and one inland point, whereas rainfall data sets were more abundant and could therefore examine fine-scale changes at a local level in more detail. Findings from terrestrial temperature stations indicating warming in the late 1990s could signal a shift in the larger system and this is in agreement with work carried out by Blamey et al. (2012) on the marine component of the ecosystem. To better understand terrestrial changes in climate patterns in the research area and contextualize subtle changes within a broader scale in this coastal region, it will be useful to overlay terrestrial climate variability with changes in the local marine system.

4.5. Conclusion

In conclusion, points highlighted from this chapter include:

Rainfall:

- Corroboration of farmers' observations on rainfall changes and analyses of rainfall patterns over time;
- No clear, significant trends of change over time in rainfall and temperature time series but decadal-scale variability present;
- Increasingly more dry spells experienced since 1980s across all three catchment categories and vlakte area;
- The eastern extent of research area experienced an increase in extreme monthly rainfall events since the 1980s;
- Across the research area, the onset of seasonal autumn rainfall has shifted to a month later after the mid-2000s.

Temperature:

- Analyses showed clear seasonal differentiation in temperature that were in agreement between the coastal and inland stations;
- Coastal temperatures displayed more variability in comparison to inland temperatures;
- Outliers were more prevalent for warmer temperatures, particularly in winter months;

- Inland and coastal temperature annual time series were consistent with each other for shift to warmer regime in late 1990s until mid/late 2000s, which correspond to regime shifts in the southern Benguela marine ecosystem.

Scale:

- It is important to consider fine geographical scale as weather patterns differ within and across research area, as evident in results;
- Changes in rainfall patterns differed across catchments and areas could potentially give greater insight in challenges faced by local farmers;
- The warmer temperature regime of the late 1990s into the 2000s could indicate a larger shift in the system, thus it will be useful to overlay terrestrial climate variability with changes in the local marine system;
- Fine-scale complexity is important to understand within the broader context of climate variability and how this influences local livelihood strategies under change.

CHAPTER 5

THE MARINE PERSPECTIVE:
WIND PATTERNS ON THE AGULHAS BANK

5.1. Introduction

While global climate change has impacted and will continue to impact marine fish and fisheries (for example Roessig et al., 2004), this change is not impacting all ocean regions at the same rate. Some regions, referred to as marine hotspots, are experiencing sea surface temperature warming at several times the average global warming rate (Hobday and Pecl, 2014). The Agulhas Current is characterised as a marine hotspot and is influencing changes on the Agulhas Bank such as decreasing abundance of commercially important linefish species and declining catches within handline fishery sectors (Hobday et al., 2016). Since the beginning of the 20th century, historically valuable fish stocks have largely been depleted across the Agulhas Bank (Currie, 2017). The decrease in economic yield of inshore demersal fish communities, upon which local handline fishers in the southern Cape depend, appears to be due to the replacement of high value fish (for example *Argyrosomus* species) with fish species of marginal value (Currie, 2017). As shown by Currie (2017), substantial ecosystem alteration has taken place on the Agulhas Bank over time and he suggests that climate is a major driver in recent changes in distribution.

The marine social-ecological system of the Agulhas Bank, linked to the southern Cape, embody the theme of change as highlighted by local fishers, where these systems appear to be in constant flux from anthropogenic to biophysical pressures that ultimately threaten livelihoods of the local small-scale commercial linefishery (Gammage et al., 2017a). Coastal systems present a unique set of challenges to communities reliant on their ecosystem services, as they are exposed to multi-scale spatial drivers of change that can play out over extended periods of time or through sudden shifts (Jarre et al., 2015). Given the environmental complexity associated with the marine environment of the Agulhas Bank (for example Blamey et al., 2015), gaps persist in scientific understanding of how these local marine ecosystems are impacted by biophysical drivers of change due to limited available data, bay to shelf scale mismatches and high uncertainty in model predictions. How anthropogenic forcing plays out in the local marine social-ecological system is also poorly understood, further complicating the sustainability of small-scale fishers' livelihoods in the southern Cape.

As described by Ommer et al. (2012: 317), marine ecosystems and fishers are linked in that this "social-ecological fishery system is dynamic and interactive: whatever affects the fish assemblages in marine ecosystems will affect the human communities to which that ecosystem is tied and of which those human communities, by extension, are an interdependent part". Responding to change within local marine systems is challenging due to high uncertainty around the trajectory of environmental change, the volatile consequences of resource depletion and future impacts of globalisation. Adaptation strategies and policy implementation that are effective in response to change will therefore need to draw on different knowledge systems and account for social and ecological interaction within local areas (Ommer, 2007). As noted by Tengö et al. (2014), diverse knowledge used in parallel can build understanding around a complex issue (see Section 2.7), which can be valuable in the case of small-scale fisheries where scientific data are scarce and model outputs for natural systems show discrepancies.

Building on work carried out by the SCIFR project on commercial linefishery communities in the southern Cape, this chapter focuses on examining this local marine ecosystem variability through wind patterns. This chapter investigates Key Question 3 – "how have marine climate (weather) patterns changed in relation to fisher communities located in the southern Cape?", linking into local fishers' experiences through the SCIFR project research.

5.2. Research area

The research area for the SCIFR project (refer to Figure 1.1) consists of the inshore section of the Agulhas Bank as it represents the fishing grounds of the small-scale commercial linefishery operating in the southern Cape (Gammage et al., 2017a). Fisher communities that participated in the SCIFR research project are located in six towns within a 155 km stretch of the southern Cape coastline: Mossel Bay, Gouritsmond, Melkhoutfontein, Still Bay, Vermaaklikheid and Witsand. The research area for this chapter extends offshore to include the Central Agulhas Bank, marine regions that connect the southern Cape with offshore southern Cape coast (see Figure 5.1).

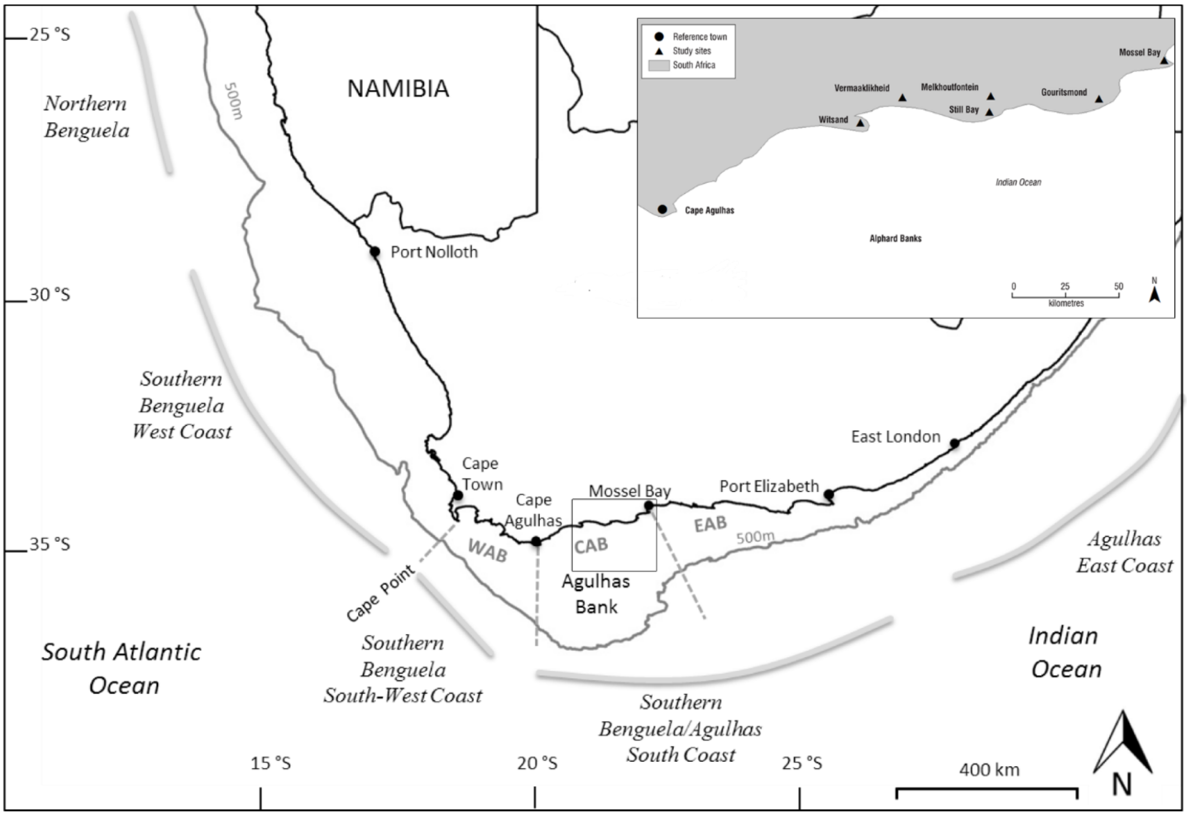


Figure 5.1: Location of the research area (square) within the southern Benguela and place names found in the text. The Agulhas Bank is divided into the Western Agulhas Bank (WAB) that forms part of the west coast system; and south coast that consists of the Central (CAB) and Eastern Agulhas Bank (EAB). The edge of the shelf is indicated by the 500 m isobath (adapted from Watermeyer, 2015; Gammage et al., 2017a)

Assessing changes from atmospheric and climate forcing in marine ecosystems are important, as climatic variability can alter local marine fish populations and thus impact fisheries, as already recorded in the Benguela ecosystems (Hutchings et al., 2012). Environmental variability has been documented to change over time in the southern Benguela inshore region, resulting in socio-economic implications for fisheries and communities dependent of these marine resources (Blamey et al., 2012). The highly variable nature of the Agulhas Bank, particularly sub-surface features such as stratification dynamics and the Cool Ridge, present a challenge when assessing and understanding possible trends of change on the Agulhas Bank (Jarre et al., 2015). This is further confounded by the lack of high resolution, long-term environmental data for meteorological and oceanographic measurements within the southern Benguela region (Jarre et al., 2015; Lamont et al., 2017).

The following section gives a brief description of the dynamics and drivers of change on the Agulhas Bank and its associated linefishery.

5.2.1. The Agulhas Bank

The Agulhas Bank is the triangular section of the continental shelf that widens between Cape Point and East London, extending off Cape Agulhas for 117 km and is fully situated within the South African Exclusive Economic Zone (EEZ). The south coast, which includes the Agulhas Bank, exhibits characteristics of both temperate shelf and upwelling systems. Major drivers of the hydrology of the Agulhas Bank include the wind regime, seasonal overturn of shelf water and the Agulhas Current that flows along the shelf break (Jarre et al., 2015). The Agulhas Bank is dominated by warm subtropical water from the Indian Ocean and wind-driven upwelling is localised and occurs over the summer period at prominent capes (Lamont et al., 2017). The Agulhas Current, which flows along the east coast of South Africa, is an energetic current driven by the wind field over the Indian Ocean that affects local climate and coastal ecosystems of South Africa and plays an important role in the global ocean circulation (Zietsman, 2011).

The Agulhas Bank can be divided into three regions based on hydrography, plankton and forage fish patterns – Western, Central and Eastern Agulhas Bank as shown in Figure 4.1. While the Western Agulhas Bank is similar to the west coast of the southern Benguela system as it is characterised by wind-driven coastal upwelling and higher nutrient levels; the Central and Eastern Agulhas Bank experience less coastal upwelling, predominately driven by the seasonal increase of easterly winds (typically in summer and autumn). The Central and Eastern Agulhas Bank also experience enrichment along the shelf-break due to either shelf-edge upwelling from interaction between the Agulhas Current and the shelf-break, or eddies coming from this current that move along the self-break in a south west direction (Watermeyer, 2015).

Over time, the Agulhas Current appears to have become more variable, is meandering more and there is an indication of warming since the 1980s. While some studies indicate an offshore warming and inshore cooling trend for the Agulhas Bank (Roy et al., 2007; Rouault et al., 2010), more recent analysis shows that the cooling trend is no longer present on the south coast but confirms the warming of the Agulhas system (Blamey et al., 2015). Due to the simultaneous presence of localised upwelling and subtropical waters, the Agulhas Bank experiences a much larger range of inter-annual temperature and variability compared to west and east coast areas.

While wind-driven upwelling along the south coast is not as prominent as off the west coast of South Africa, it is an important driver for local environmental processes. Work carried out on upwelling indices, derived from geostrophic winds (using data from over the period of 1981 to 2010), by Blamey et al. (2012) on the central Agulhas Bank indicate an increase in upwelling in early to mid-1990s and decrease in early 2000s. This research also indicated that intra-annual upwelling has increased towards the end of the 1980s and again in 2007 in this region (Blamey et al., 2012). Similar research using total cumulative upwelling indices based on NCEP-DOE Reanalysis 2 wind vectors by Lamont et al. (2017) show an overall increasing trend on the Agulhas Bank, with periods of high upwelling featuring in the early to mid-1980s, mid-1990s to early 2000s, and between 2007 to 2014. Since 1993, Lamont et al. (2017) also noted that there have been consistently more upwelling days per year, where most of these years exceed the long-term mean for this region. Observed variations in upwelling on the Agulhas Bank are consistent with sea surface temperature fluctuations and coastal cooling (Roy et al., 2007; Rouault et al., 2010; Lamont et al., 2017).

Coastal upwelling on the south coast is likely to play an important role in terms of seasonality and driving localised scale changes. Increased upwelling variability may result in increased instability within the ecosystem, particularly as coastal upwelling stimulates biological productivity at all ecosystems levels and hence drives fisheries (Zietsman, 2011; Blamey et al., 2012). Around southern Africa, the complexity and variability of the marine environment is partly due to the latitude and its associated weather. In summer, the oceanic high-pressure cells either side of southern Africa dominate the wind field, driven by the South Atlantic and South Indian Anticyclones (also referred to as high pressure systems) that result in coastal upwelling along the west coast and Agulhas Bank through south-easterly winds (Nchaba et al., 2017). During winter the westerly belt migrates north resulting in cold fronts and strong westerly winds moving into southern Africa (Tyson and Preston-Whyte, 2000). Jarre et al. (2015) found that the South Atlantic Anticyclone system made a significant southerly shift from the late 1980s to early 2000s, after which it showed signs of retreating northwards again. This shift could be linked to the increase in southerly/south-easterly winds and upwelling experienced during the 1990s in the southern Benguela, as discussed by Blamey et al. (2015).

5.2.2. Southern Cape linefishery

5.2.2.1. Overview: South African context

The South African linefishery consists of a multi-species, multi-sector, multi-area group of low to medium technology fisheries that spans over a large geographical range, where more than 200 fish species are targeted through hand-line or rod and reel methods (Blamey et al., 2015). Linefish species (typically predatory in nature) are usually classified as warm-temperate reef fish, cool-temperate reef fish or pelagic nomads. These species tend to display diverse life-history strategies, such as long lifespans, estuarine-dependence, sex change and aggregating behaviour, which can make these populations vulnerable to over-fishing (DAFF, 2016). Most linefish caught along the South African coast are not exclusively targeted by the linefishery, but also constitute bycatch (or form important components of the catch) of other fisheries, which complicates the management of these fisheries. There are three recognised sectors within the linefishery, namely commercial, recreational and small-scale co-operatives.

The commercial linefishery of South Africa dates back to the mid-1800s, making it one of the oldest commercial fisheries in the country (Griffiths, 2000). For example, along the southern Cape coast, a commercial linefishery off Still Bay and Mossel Bay has been operating for over 100 years (Duggan et al., 2014; Visser, 2015). Today, the commercial linefishery around the South African coast is a boat-based, labour-intensive and low-earning sector that has an important human livelihood dimension. In the late 1990s, an estimated 700 registered vessels operated in this sector nationwide, but this has since decreased to 455 boats from the mid-2000s (DAFF, 2016). The linefishery employs approximately 27 percent of all fishers in South Africa and has the lowest average employment income. Despite the commercial linefishery having the largest fleet size in terms of boat numbers, it only contributes around six percent to the total estimated value of all South African marine fisheries in the formal sector (DAFF, 2016).

Concerns around overfishing around the South African coast were first highlighted in the 1940s, however regulation measures for this fishery were only implemented in the mid-1980s. Due to an increase in fishing effort and complimentary technological advances (such as the introduction of motorised skiboats and improved fishing technology) during the 20th century, linefish were subsequently over-exploited and catches began to decrease over time (Griffiths, 2000; DAFF, 2016). In 2000, an emergency in the linefishery was declared by the Minister of Environmental Affairs and Tourism due to the critical status of many linefish stocks. Fishing effort was subsequently reduced and a Linefish Management Protocol (LMP) was developed to manage the sector, which remains the basis of current management (DAFF, 2016). Despite some positive signals since the long history of severe over-exploitation in the linefishery, most linefish species remain in an unknown or collapsed state (Blamey et al., 2015).

5.2.2.2. Southern Cape commercial linefishery

Initial and ongoing research carried out by the SCIFR project is focused on the small-scale commercial linefishery that operates in the inshore area of the Agulhas Bank. Fishing activities typically take place between three to 60 km off-shore in depths between 20 and 60 m over reef structures surrounded by muddy sea bed (Duggan et al., 2014). Silver kob (*Argyrosomus inodorus*) are predominately targeted by this handline fishery as these fish are regarded the most commercially viable, however other species such as silvers/carpenters (*Argyrozona argyrozona*) and red roman (*Chrysoblephus laticeps*) are also targeted in the absence of silver kob (Gammage et al., 2017a). Geelbek (*Atractoscion* *aequidens*), snoek (*Thyrsites atun*) and yellowtail (*Seriola lalandi*) are not commercially exploited here as these species are not abundant in the area. In the past, fishers noted that Cape hake (*Merluccius capensis*) had been present in this area in the past, but this species has not been caught recently (Gammage et al., 2017a).

Silver kob are the most abundant sciaenid species in South Africa and are reef-associated fish with large home ranges, where fish retreat offshore in winter and return to inshore waters when coastal upwelling resumes in summer (Winker et al., 2014; Gammage et al., 2017a). Fishers in the southern Cape expect silver kob to migrate inshore at the beginning of spring for the start of the fishing season, where fish typically remain inshore until the onset of autumn (Gammage et al., 2017a). Most large-bodied silver kob are over-exploited and the South African stock status is depleted for this species, with fishing pressure classified as heavy (DAFF, 2016). While this stock has shown improvements on the south coast since 1987, when it was severely over-exploited at 13 percent of unexploited carrying capacity, the present stock remains over-exploited at 18 percent of unexploited carrying capacity (Winker et al., 2014; Currie, 2017).

During the research period of the SCIFR project (where preliminary research began in 2010 until present), silver kob catches peaked in 2010 and skippers were able to land 1.5 tonnes of fish up to three times a week (Duggan et al., 2014). However, silver kob catches plummeted in early 2011 and have remained low until present, with fishers noting that these fish altered behaviour in terms of decreasing their residence time inshore and disruption to fish migration patterns on the Agulhas Bank (Duggan et al., 2014). Fishers have highlighted a direct relationship between diminishing kob catches (specifically from 2011) and changes, including increased variability, in the local climate (Gammage et al., 2017a). Gammage et al. (2017a: 4) caution that the "uncertainty regarding the source, depth and context of the fishers' knowledge of climate change warrants further research"; however, these observed changes in distribution and catch of silver kob could be partly linked to recent regime shifts in the southern Benguela. For example, changes in environmental drivers and subsequent intensified fishing efforts are thought to be responsible for the southward and eastward shift of small pelagic fish, sardines (*Sardinops sagax*) and anchovies (*Engraulis encrasicolus*), in the late 1990s and early 2000s (Coetzee et al., 2008), which is supported by changes in the distributions of predatory fish in relation to their prey in the southern Benguela (Watermeyer et al., 2016). The availability of these small pelagics on the south coast are also thought to modify silver kob availability and behaviour (Duggan, 2012). While other fishing industries such as inshore trawl also impact silver kob stocks on the Agulhas Bank through bycatch, the degree to which environmental forcing impacts local stocks is unclear (Winker et al., 2014; Gammage et al., 2017a).

5.3. Methods

5.3.1. Data

Data were obtained from three different sources: Southern Cape handline fisher observations of climatic change, with specific reference to wind variability over time; and two wind data products derived from a blended wind product based on scatterometer retrievals and NCEP-DOE Reanalysis 2 (https://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis2.html).

5.3.1.1. Fishers' observations

Fishers' observations were obtained from fieldwork carried out by researchers of the SCIFR project on the southern Cape handline fishery. Initial participant observation fieldwork was carried out between 2010 and 2011 by Duggan (2012) with a focus on commercial skippers from Still Bay and Melkhoutfontein. Skippers make the majority of decisions regarding when, where and how to fish, as well as being fishers themselves – making this group of fishers ideal knowledge brokers for the area. These skippers represented a diverse range of backgrounds and, while all experienced in their fishery, also included multi-generational fishers. These fishers gave detailed accounts of their experiences and observations within the small-scale commercial handline fishery of the Southern Cape. In addition to participant observation, Duggan (2012) drew on semi-structured interviews carried out in terrestrial and marine working environments.

Following this research, Gammage (2015) conducted research between 2013 and 2014 in six towns located on the southern Cape coastline - Mossel Bay, Gouritsmond, Melkhoutfontein, Still Bay, Vermaaklikheid and Witsand. The sample size for this component of fieldwork was expanded to 50 participants comprising of skippers, boat owners, crew, members from associated industry and spouses/partners. Research was carried out using semi-structured interviews, as well as several group interviews of varying sizes. This research focused on multiple stressors to which fishers and fishing communities are exposed that play out over numerous temporal and spatial scales (see details in Gammage et al., 2017a;b). For the purpose of this thesis, the focus of fisher observations were selected from narratives from participating skippers, to keep consistency between earlier research carried out by Duggan (2012), as well as for comparative purposes to bridge farmer dialogue from Chapter Three. As farmers interviewed in my research are decision makers in terms of what and how they farm, this is comparable to skippers who are primary decision makers for their fishing activities.

However, Gammage et al. (2017a) note that participant responses across different groupings remained consistent throughout the research, thus crew observations are also considered from work arising from the subsequent Global Understanding and Learning for Local Solutions (GULLS) project (Hobday et al., 2016; Aswani et al., 2018) and further research conducted by Gammage (in progress). The GULLS project, carried out in the southern Cape between 2015 and 2016, focused on crew households who self-identified as fishery-dependent and research was conducted using a household social vulnerability survey (Aswani et al., 2018). Observations from fishers other than skippers were only considered when examining more refined topics, such as direct questions to crew concerning how they perceive changes in wind patterns for the area.

5.3.1.2. Wind data products

The first wind data product is the NCEP-DOE Reanalysis 2 (Kanamitsu et al., 2002), which is an upgraded forecast model and diagnostic package of the NCEP/NCAR Reanalysis 1 project – created by a complex system of programs, libraries, scripts and data sets. Thus NCEP-DOE Reanalysis 2 is an updated 6-hourly global analysis and human error-fixed version of Reanalysis 1, focusing on long term trends (beginning from 1979) through assimilating rainfall, satellite radiances and other remote observations based on spatial and temporal resolution of the first version (T62, 28 levels). Lamont et al. (2017) found

NCEP-DOE Reanalysis 2 wind vectors to be suitable for assessing shelf-scale upwelling variability in the southern Benguela as this product provided the most consistent, up-to-date, high temporal frequency data across the region when compared to other long-term data sets. When referring to the NCEP-DOE Reanalysis 2 product in this thesis, it will be termed NCEP-DOE wind data. For the purposes of this research, NCEP-DOE wind data is considered to be representative of offshore wind patterns, as the nearest data point is situated approximately 100 km offshore (shelf scale).

The second data set examined is a multi-year wind product created by Desbiolles et al. (2017) which retrieves scatterometer data from 1992 to present from four separate missions – ERS-1, ERS-2, QuikSCAT and ASCAT. Surface winds, or equivalent neutral wind velocities at 10 m, from these scatterometer missions were used to make a 20 year climate series, where optimal interpolation and kriging methods were applied to continuously provide surface wind speed and direction estimates over the global ocean which are consistent in time and space. This was further enhanced by using other data sources such as radiometer data (SSM/I) and atmospheric wind reanalyses (ERA-Interim) to build a blended product, which is available at 1/4^{o} spatial resolution and every 6 hours. This blended wind product is suitable for studying air-sea interactions at climate mesoscale, as the product was validated through comparison to buoy winds, and also compared well with other long-term wind analyses that examined seasonal cycle and inter-annual variability.

While the blended wind product is considered robust due to its high resolution and high quality nature of satellite data; there are some limitations that need to be considered. For example, satellites are 'blind' in the coastal zone and lack observation data from the coast to approximately 50 km offshore, the prime area of the handline fishery. This blended wind product merges data from different satellites and models at different spatial and temporal resolution to minimize this blind coastal zone. The blended wind product is therefore considered to be a good surrogate to examine wind temporal variability in coastal zones in the absence of reliable local wind measurements. When referring to this blended wind product for the remainder of the chapter, it will be termed 'scatterometer' wind data. For the purposes of this research, scatterometer wind data are considered to be representative of near-shore wind patterns.

5.3.2. Analyses

Data were assessed initially in two separate streams, namely fisher observations and wind data, and results discussed in a comparative manner after initial analyses. Data were examined at annual and monthly scales so that it was comparable to terrestrial data analyses (Chapter Four). Data analyses were guided by a number of research questions formulated to examine climate variability observed by fishers from the SCIFR research project, with a specific focus on coastal wind patterns.

5.3.2.1. Examining fishers' observations

Research Questions to examine fishers' observations on climate variability consisted of:
Question 1: How do fishers perceive climate variability in the southern Cape?
Question 2: How do fishers place wind as a climate stressor?
Question 3: How have long-term wind trends changed over time according to fishers?

Fisher observations, based primarily on skipper experiences, from Duggan (2012) and Gammage (2015) were collated and summarised with a focus on climate change and variability. Finer details on specific wind-related questions from the GULLS project and subsequent by Gammage (in progress) were also included. Key information distilled in summary format to analyse fisher knowledge were extracted from detailed ethnography and interviews based on observations predominately from skippers who lived in Witsand, Still Bay, Melkhoutfontein and Mossel Bay during the research period of the SCIFR project.

5.3.2.2. Examining wind data

Research Questions to examine wind data consisted of:
Question 4: How well do off-shore (NCEP-DOE) and near-shore (scatterometer) wind data agree?
Question 5: Have 'extreme' (10 m/s or above) wind days increased over time for Witsand, Still Bay and Mossel Bay? Is this reflected in NCEP-DOE and aggregate scatterometer wind data?

Question 6: How do NCEP-DOE and scatterometer wind data compare in the research area when examining annual and seasonal mean wind speed and variability?

For wind data analyses, wind speed, U (positive for a west to east flow) and V (positive for a south to north flow) components were considered. Year determination for time series was based on the starting point of the onset of the selection or season. Annual and seasonal time series were divided up as follows:

- Annual: June to May
- Austral summer: October to March;
- Austral winter: April to September
- Autumn: March to May
- Winter: June to August
- Spring: September to November
- Summer: December to February

NCEP-DOE data were extracted for the Agulhas Bank (specific location of 35°S, 22.5°E) as the off-shore component of this analysis. Scatterometer data, representative of the near-shore component of this analysis, were extracted from three coastal fishing towns sampled in the SCIFR project, namely Witsand (34.4°S, 20.8°E); Still Bay (34.3°S, 21.4°E) and Mossel Bay (34.1°S, 22.1°E). Scatterometer data were also aggregated to scale up to the Agulhas Bank (covering an area between corner points 33.75°S, 21.25°E; 33.75°S, 23.75°E; 36.25°S, 21.25°E; 36.25°S, 23.75°E) level for comparative purposes against the off-shore component. Wind data were analysed for 12pm data points across all data sets.

Initially, NCEP-DOE (1979 to 2015) and aggregate scatterometer (1993 to 2016) data points were tested for similarities or differences using Spearman's rank correlation tests (due to the non-normal distribution of these data) and linear regression using a combination of R packages and Excel. When examining 'extreme' wind days, wind speeds of 10 m/s or above were selected from scatterometer data sets as this was considered to be too strong for fishers to successfully go to sea. These days were then counted per month and compared on a seasonal basis using linear regression at both five (to identify significant trends) and 10 (to identify meaningful tendencies) percent significant levels. NCEP-DOE and scatterometer wind data for components U and V were then assessed using sequential regime shift detection software (www.beringclimate.noaa.gov) to examine possible regime shifts for both the mean and variability of the time series. Refer to Section 4.2.3 for details on software methods and parameters used.

5.4. Results and discussion

Results are divided up and discussed in two parts, focusing on wind patterns and variability on the Agulhas Bank and more specifically Witsand, Still Bay and Mossel Bay. The first part examines fisher observations around climate (specifically wind) variability and the second part examines near- and off-shore wind patterns.

5.4.1. Fishers' observations

5.4.1.1. Fishers in changing marine environments

Initial detailed ethnography from fieldwork carried out by Duggan (2012) revealed that fishers viewed their marine environment as a complex system of interconnections, where the availability of the highly prized silver kob was dependent on a variety of factors – seasonal upwelling for the fish to migrate inshore, prevailing winds and currents, water temperature, tidal considerations, sea state and healthy reefs. Therefore, fishers hold valuable understanding of these interacting factors and the larger functioning of the marine ecosystem, drawing on past experience to successfully fish in the present.

Question 1: How do fishers perceive climate variability in the southern Cape?

During the first phase of the SCIFR project, changing weather patterns in the southern Cape were highlighted as key stressors that impacted negatively on fishery livelihoods for the handline fishers on the south coast (Duggan, 2012). Compounded with other stressors such as policy hindrances, increased competition from other fishing sectors, and other socio-economic constraints that interact over multiple spatial and temporal scales, fisher livelihoods became increasingly vulnerable over time (Gammage et al., 2017a;b). When discussing numerous stressors that affected fishers' livelihoods during research conducted by Gammage (2015), climate variation was identified as the second most important stressor by participants (see Table 5.1). As observed by Duggan (2012: 106), "(v)ariability and vulnerability are clearly hallmarks of the small-scale commercial handline industry".

Table 5.1. Stressors identified by fishers: major stressors classified as stressors identified by 80 % or more of participants; mid-range by 50 to 70 %; and minor stressors by less than half of participants (from Gammage et al., 2017a)

Major stressors		Mid-range stressors		Minor stressors	
Stressor	**%**	**Stressor**	**%**	**Stressor**	**%**
Policy and regulation	92%	Enforcement and implementation of policy	76%	Geography of area	48%
Climate variation	90%	Economic (in terms of capital)	76%	Inadequate infrastructure	46%
Other fishing sectors (such as inshore trawl)	84%	'Political issues' (amongst fishers and sector)	76%	Social factors	46%
		Socio-economic	70%	Lack of knowledge (financial planning, literacy level, etc.)	44%
				Fishing methods	26%
				Other marine species (e.g. seals)	14%

While many fishers perceived variable natural cycles that repeat over different temporal scales within their marine environments as normal, these cycles were thought to typically occur with an element of predictability. Duggan (2012) highlighted that the variability observed in wind directions and water temperatures was outside of the norm expected by fishers during his research time period and this was echoed in subsequent research carried out by Gammage (2015).

When considering longer term changes in weather patterns, such as wind conditions, time frames given by fishers varied to describe 'recent' changes varied between participants. There was no group consensus on exact periods or onset of perceived climatic variation, other than notable changes occurring in the 'last five years', which would shift the timeframes depending on whether fieldwork was conducted in 2010/2011 or 2013/2014. Despite no concrete timeframes given by participants, it should be noted that many participants observed that recent changes in weather patterns had become increasingly unpredictable and unseasonal, disrupting expected patterns and creating high uncertainty for fishers who have depended on their own knowledge and experience (in many cases over 30 years) in their decision-making processes.

5.4.1.2. Winds of change

Question 2: How do fishers place wind as a climate stressor?

Climate variability was one of the factors attributed by fishers to the recent scarcity of silver kob stocks in the Agulhas Bank system, where fishers assigned the greatest changes in variability to sea temperatures and prevailing wind conditions (Duggan, 2012; Gammage, 2015). The climate variability stressor had two facets which impacted fishing activities: firstly, through the more immediate impact of influencing daily weather conditions that determined the ability to go to sea; and secondly, through the longer term impact of increased climate fluctuation that influences water temperatures, winds, currents and rainfall (Gammage, 2015).

In terms of fishers' experiences, prevailing wind conditions were important to fishers when considering daily weather conditions, as wind has a direct impact on sea state thereby influencing the behaviour of the fish (Gammage, 2015). While some fishers attributed longer term changes in wind conditions (specifically unusual weather patterns) to anthropogenic climate change, other fishers viewed these changes as cyclic. There was no consensus between different participants as to whether changes in wind patterns and variability were cyclic or unidirectional, but in general fishers observed that wind direction and prevalence had shifted in recent memory.

Question 3: How have long-term wind trends changed over time according to fishers?

Duggan (2012) noted that skippers discussed what they saw as a noticeable increase in intra-seasonal variability in wind conditions for their fishing grounds. Particularly towards to end of 2010, fishers had experienced an unusually prolonged period of relentless onshore winds that prevented them from going to sea. Typically, fishers expect south easterly winds to blow during the fishing season (austral summer) but only for a few days at a time, whereas observed changes in intra-seasonal wind patterns hindered Still Bay fishers from going to sea for months at a time (Duggan, 2012). Fishers also noted that wind patterns had shifted, where in the past the onset of south easterly winds typically began from the beginning of August, but in the recent past these winds only started to blow from the end of September. Skippers interviewed by Gammage (2015) also highlighted increased variability outside of the expected norm for prevailing wind conditions.

Respondents from the GULLS project indicated that fishers were going to sea less often, partly attributed to increasingly unfavourable weather conditions specifically during the traditional fishing season (austral summer). While fishers based decisions to go to sea on multiple factors that include suitability of sea state, some key weather patterns, such as wind, were specifically highlighted by fishers. Drawing on interviews conducted by the GULLS project, the majority of respondents (88 %) reported wind as a key factor of environmental change experienced in their local marine system (Gammage et al., in review). When compared to other factors such as rainfall, water temperature, current strength, air temperature, wave height, rough seas and sea level, this placed wind variability as the most notable environmental change experienced by fishers.

5.4.2. Near- and off-shore wind patterns

When working with fisher knowledge on climate variability, the issue of scale becomes important, particularly in the case of the small-scale linefishery operating in the southern Cape. Large shelf-scale processes may not necessarily impact fishers as acutely as bay-scale processes, particularly as this fishery typically does not operate more than 60 km (ca. 30 nautical miles) off-shore. This section looks at bridging near- and off-shore resolutions based on the comparison of the two different wind products.

5.4.2.1. Comparing geostrophic and scatterometer winds

Question 4: How well do off-shore (NCEP-DOE) and near-shore (scatterometer) wind data agree?

To test correlation between the different wind products, Spearman's rank correlation (r_s) was used to test NCEP-DOE data against the scaled up aggregate data of scatterometer wind product for resultant speed, U component and V component (see Figure 5.2).

For resultant wind speed (see Figure 5.2a), there was good correlation between the aggregate scatterometer and NCEP-DOE data points ($r_S = 0.76$). Using linear regression to test significance, results for resultant wind speed indicated highly significant correlation ($p < 0.05$) between the two data products. Therefore, overall (resultant) wind speeds are a good match between the two data sets. When examining Figure 5.3, however, it appears that resultant wind speeds from the aggregate scatterometer data set are higher than those from NCEP, notably in the range less than 10 m/s – which is of particular interest to the handline fishery.

For the U component (Figure 5.2b), there was a strong correlation between the scatterometer and NCEP-DOE data points ($r_S = 0.95$) and results from linear regression were significant ($p < 0.05$). Therefore, the U wind component between the two data sets are a good match.

For the V component (see Figure 5.2c), there was a weaker correlation between the scatterometer and NCEP-DOE data points ($r_S = 0.85$) compared to U wind component, nevertheless the correlation was still strong. Results from linear regression were significant ($p < 0.05$). Therefore, the V wind component between the two data sets are a match. NCEP-DOE wind data appear to report stronger winds from the north (i.e. negative V wind), but the bias appears to be less strong for southerly winds (i.e. positive V wind). Correlation between negative NCEP-DOE data ($r_S = 0.60$) and positive NCEP-DOE data ($r_S = 0.69$) with scatterometer data were similarly moderate, with a slightly stronger correlation for positive values.

In summary, when comparing NCEP-DOE and scatterometer data at the off-shore scale (refer to Figure 5.2), there is agreement between the U and V wind components but more so for the U component. For the purpose of the southern Cape linefishery, scatterometer data outputs are used to assess coastal wind patterns and regimes due to the fine-scale nature of the data product.

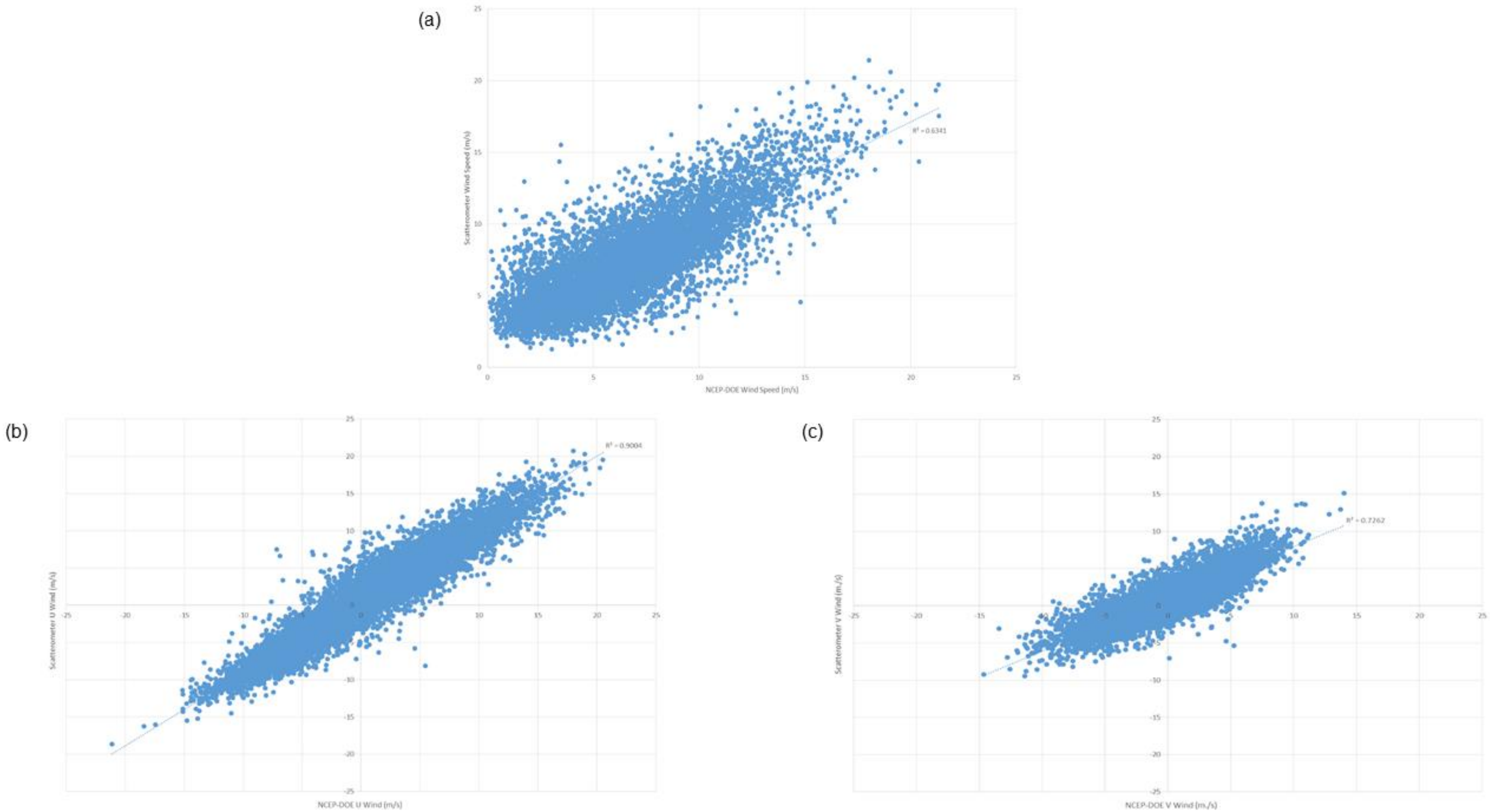


Figure 5.2: Scatterplot of aggregate scatterometer data points compared to NCEP-DOE data (1993 – 2015) for (a) wind speed; (b) U wind component; and (c) V wind component

5.4.2.2. 'Extreme' wind days

Some fishers interviewed during the SCIFR project indicated that increased wind variability was observed in both wind direction and speed. While fewer sea days for fishers are usually the result of multiple interacting factors that impact day-to-day fishing activities, such as rough sea state, unsuitable prevailing wind conditions, limited fish availability and fuel price increases, this component of data analyses focus specifically on extreme wind days.

'Extreme' wind days were classified as wind speeds that are considered to be a serious hindrance for fishers to successfully undertake fishing activities. Skippers typically consider wind speeds of 10 m/s or above as unfavourable for fishing activities. Figure 5.3 show the different frequencies of wind speed experienced in the coastal locations (harbour scale) of Witsand, Still Bay and Mossel Bay. In terms of wind speed, Witsand and Mossel Bay are correlated ($r_S = 0.87$; $p < 0.05$), whilst Still Bay wind speeds are not correlated with those off Witsand ($r_S = - 0.002$, $p = 0.82$) or Mossel Bay ($r_S = 0.005$; $p = 0.01$).

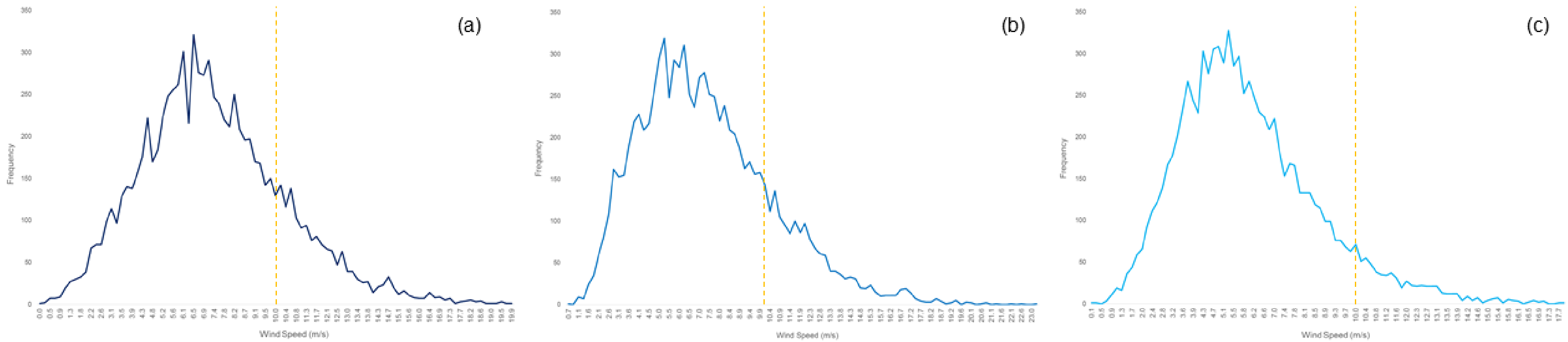


Figure 5.3: Wind speed frequency between 1993-2016 with dashed line to delineate ± 10 m/s mark for (a) Witsand (median = 6.93 m/s); (b) Still Bay (median = 6.77 m/s); and Mossel Bay (median = 5.49 m/s)

Question 5: Have 'extreme' (10 m/s or above) wind days increased over time for Witsand, Still Bay and Mossel Bay (at near-shore scale)? How is this reflected at the off-shore scale?

Extreme wind days at near-shore scale

Overall, no discernible trends were detected in Witsand, Still Bay and Mossel Bay (see Figures 5.4, 5.5 and 5.6). Wind patterns were highly variable across all seasons for all three locations and no significant trends (at both five and 10 percent significance) were identified (see Appendix 3A). These were assessed using linear regressions.

In winter and spring for the Witsand location (Figure 5.4), there was a slight decrease of extreme wind days over time, whereas wind speeds during summer and autumn displayed a marginal increase. No significant trends were identified in Witsand. Noteworthy are the low number of extreme days in spring during 2004, which are not reflected in the other seasons.

Similarly to Witsand, linear regressions for all four seasons were not significant in Still Bay (Figure 5.5). Most seasons in Still Bay did not display any trends, except in summer where there was a slight increase in extreme wind days over time.

In Mossel Bay, no significant linear regressions were detected across all seasons (Figure 5.6), similar to Witsand and Still Bay. A slight increase in extreme wind days for Mossel Bay were indicated in autumn, winter and spring, with no discernible trend was present for summer.

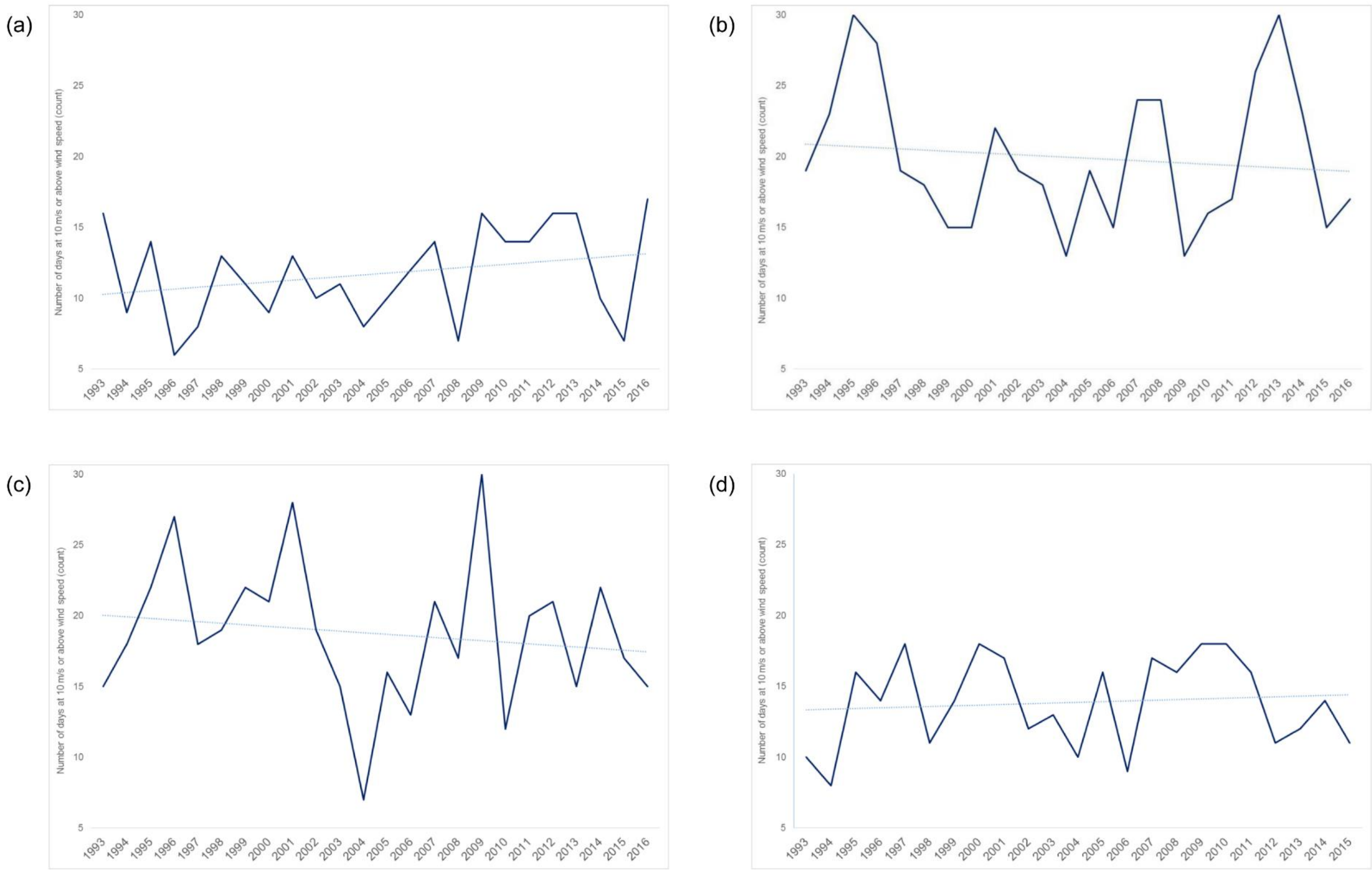


Figure 5.4: Number of extreme wind days (>10 m/s) off Witsand by (a) autumn, (b) winter and (c) spring and (d) summer

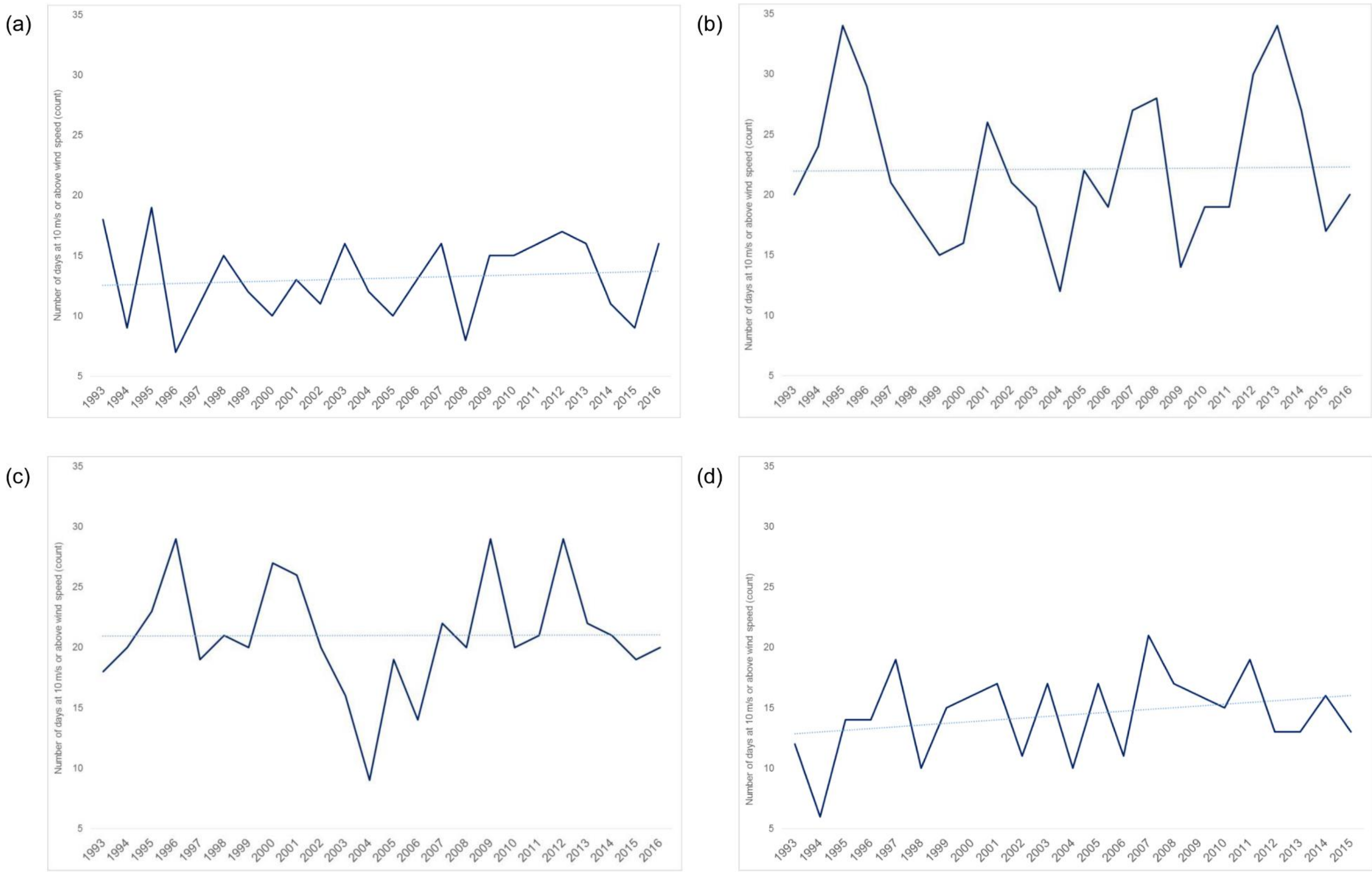


Figure 5.5: Number of extreme wind days (>10 m/s) off Still Bay by (a) autumn, (b) winter and (c) spring and (d) summer

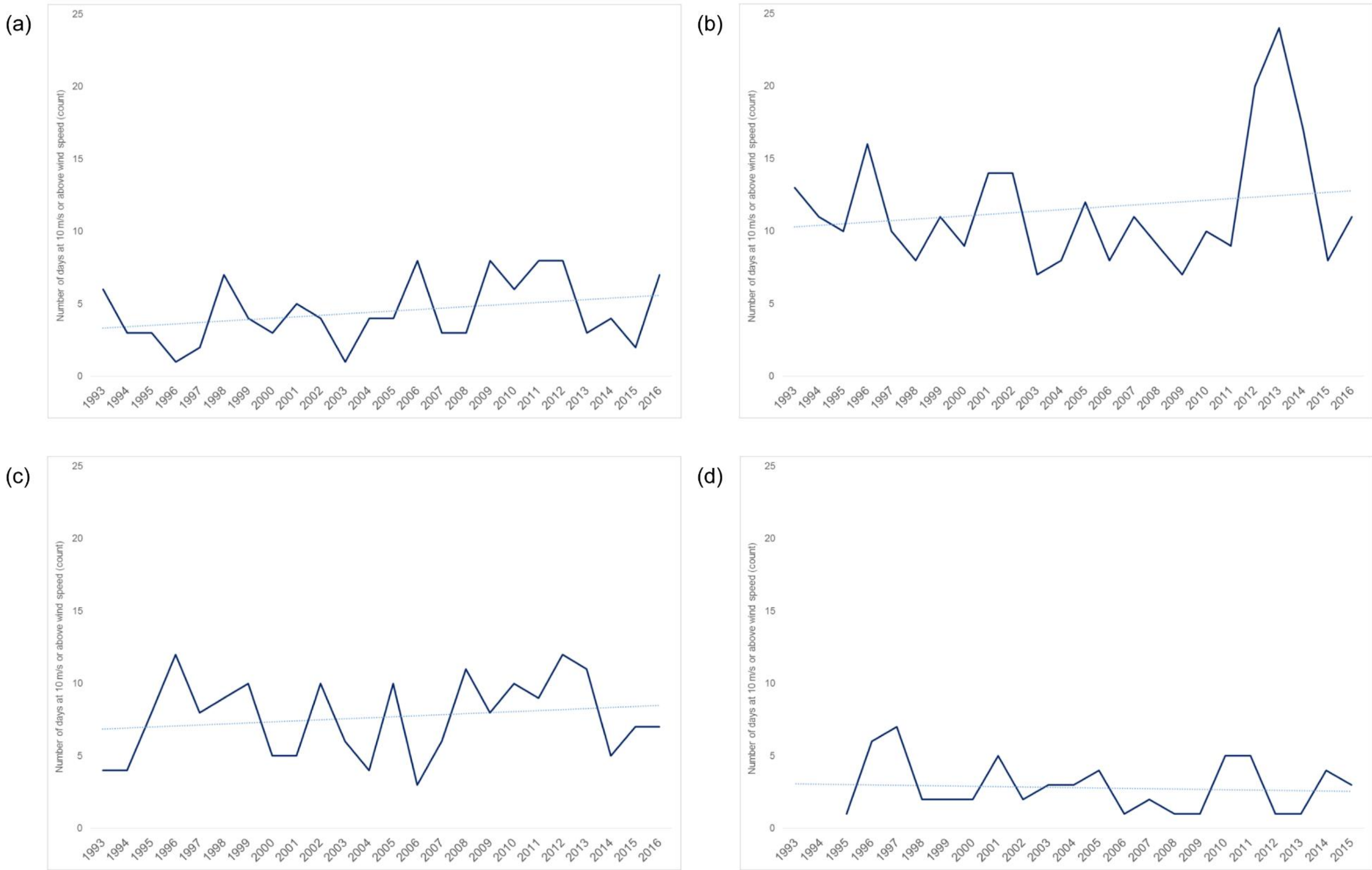


Figure 5.6: Number of extreme wind days (>10 m/s) off Mossel Bay by (a) autumn, (b) winter and (c) spring and (d) summer

Extreme wind days at off-shore scale

As scatterometer data have some limitations in terms of the blind coastal zone, austral summer and austral winter seasons for each location were also examined for approximately 30 km and 50 km offshore. Scatterometer satellites give real-time data inputs to the scatterometer blended wind product at approximately 50 km offshore, hence results could be compared to points closer to the coast to check consistency. Trends were assessed using linear regressions.

Results indicated no significant trends of extreme wind days at either 30 or 50 km off-shore at both five and 10 percent significant levels – refer to Tables 5.2 and 5.3 (see Appendix 3B for detailed analyses). All austral summer months showed a slight increase in extreme wind days over time, whereas austral winter months gave no trend indication. In summary, extreme wind days gave no clear indication of change over time when moving from coastal points to 50 km off-shore.

Table 5.2: Extreme wind day trends at approximately 30 km off-shore

	Witsand	**Still Bay**	**Mossel Bay**
Austral summer	Slight upward tendency No significance	Slight upward tendency No significance	Slight upward tendency No significance
Austral winter	No trend No significance	No trend No significance	No trend No significance

Table 5.3: Extreme wind day trends at approximately 50 km off-shore

	Witsand	**Still Bay**	**Mossel Bay**
Austral summer	Slight upward tendency No significance	Slight upward tendency No significance	Slight upward tendency No significance
Austral winter	No trend No significance	No trend No significance	No trend No significance

Further off-shore, data from aggregate scatterometer and NCEP-DOE points were then also investigated for austral summer and winter seasons. In both data sets, austral winter showed no trend, similar to results from 30 km and 50 km off-shore. Both aggregate scatterometer and NCEP-DOE points did show an upward tendency over time for austral summer months (see Figures 5.7 and 5.8, respectively) – refer to Appendix 3B for detailed analyses. While the aggregate scatterometer upward tendency was not significant at either five or 10 significance levels for austral summer, the NCEP-DOE point had a significant upward trend where p-value = 0.029 (Appendix 3B).

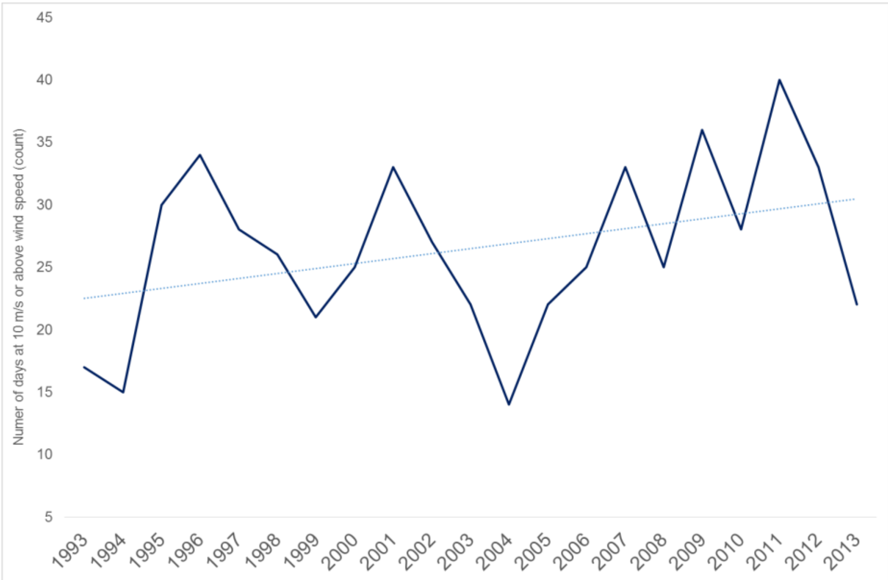


Figure 5.7: Number of extreme wind days (>10 m/s) at aggregate scatterometer data point

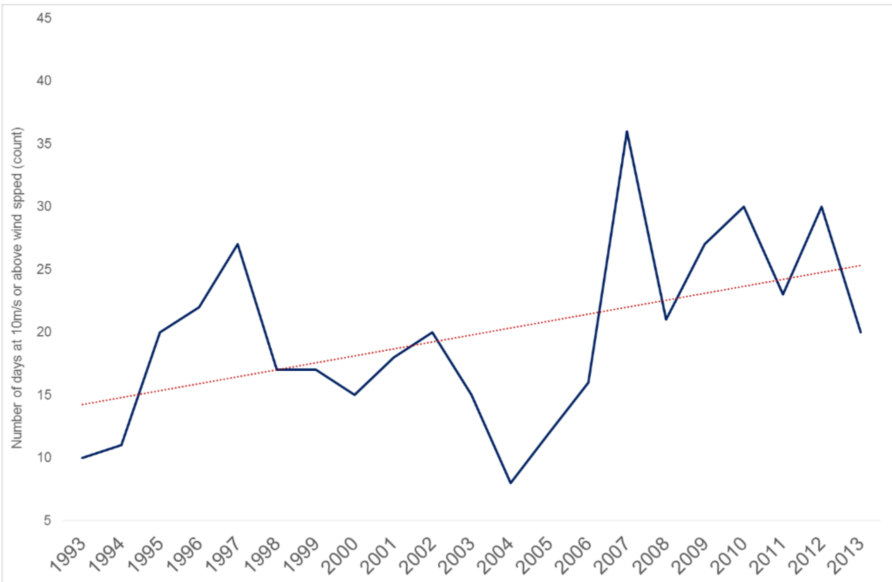


Figure 5.8: Number of extreme wind days (>10 m/s) at NCEP-DOE data point

5.4.2.3. Decadal-scale changes in mean wind speed and variability

Long term shifts in wind direction are important to consider as this has implications for biological functions (such as silver kob migration patterns associated with localised upwelling which is wind driven) and environmental forcing (such as driving upwelling processes or rainfall patterns). It is important to take scale into consideration when examining different data sets, particularly in the case of the southern Cape linefishery which operates largely at a bay scale rather than off-shore.

Question 6: How do NCEP-DOE and scatterometer wind data compare in the research area when examining annual and seasonal mean wind speed and variability?

Looking at wind patterns through examining regime shifts in wind direction through mean and variability, NCEP-DOE and scatterometer data points were compared where there was overlay in time series analysed. Data were compared on an annual and seasonal basis. In accordance with the findings in Section 5.3.2.1, each section is discussed separately according to U and V wind components.

Regime shifts in direction of the mean wind speed

Firstly, change in mean wind speed in relation to direction was considered through calculating the average of annual and seasonal data sets. The results for summer and autumn are shown in Figures 5.9 to 5.12, while the remaining analyses are summarised in Table 5.4 and 5.5, with details provided in Appendix 3C. The results show general agreement for U components between near- and off-shore wind data products. In the case of austral summer, results across all time series show a decrease in westerlies from the mid-2000s, which corresponds with studies indicating that upwelling increased over this period on the Agulhas Bank (Blamey et al., 2015; Lamont et al., 2017). For the most part, U components were internally consistent over time at a qualitative level. For the V components, results are for the most part internally consistent on a qualitative level between scatterometer points in that low wind years are consistent between sites. However, near- and off-shore points gave the opposite trends where off-shore trends tended to increase, whereas near-shore trends tended to decrease over time.

In summer, U wind components for NCEP-DOE results show a regime shift in 1992/1993 (decreasing westerly wind to easterly component) (Figure 5.9). Witsand and Mossel Bay results indicate a regime shift in 2014/2015 towards a more easterly wind component. Aggregate scatterometer results do not detect any regime shifts, similar to overlapping NCEP data. All time series show a large trough in 2010, indicating a stronger easterly wind season for that year.

In the V wind component for summer (see Figure 5.10), NCEP-DOE and scatterometer results are not in agreement and, similar to autumn and spring seasons, give the opposite trend when near-shore and off-shore results are compared. NCEP-DOE results show a regime shift in 2012/2013 towards an increase in southerly wind. While Witsand and Mossel Bay results show a regime shift towards a decrease in south winds, the regime shift took place in 2005/2006 for Witsand and 2006/2007 for Mossel Bay (i.e. a year apart). Aggregate scatterometer results are similar to Witsand and indicate a regime shift in 2005/2006 towards decreasing southerly winds.

In the U wind component for autumn (Figure 5.11), while qualitatively similar to NCEP-DOE, Witsand and Mossel Bay results are consistent for all three time series. While qualitatively similar to Witsand and Mossel Bay (i.e. internally consistent with scatterometer data), the aggregate scatterometer results indicate a regime shift in 2000/2001 (increasing westerlies) and again in 2014/2015 (decreasing westerlies). Outliers appear to be treated differently by the regime detection analysis and thus give quantitatively different results.

In autumn, V wind component for NCEP-DOE and scatterometer results are not consistent and give opposite trends (see Figure 5.12). NCEP-DOE results indicate a regime shift at the end of the time series, which can be problematic, towards increasing southerly winds. Scatterometer results are internally consistent, but give opposite trends to NCEP-DOE results. Near-shore wind results are consistent with local fisher ethnography from 2010, where fishers observed that winds were weaker in autumn and winter seasons from the mid-2000s when compared to past seasonal experience.

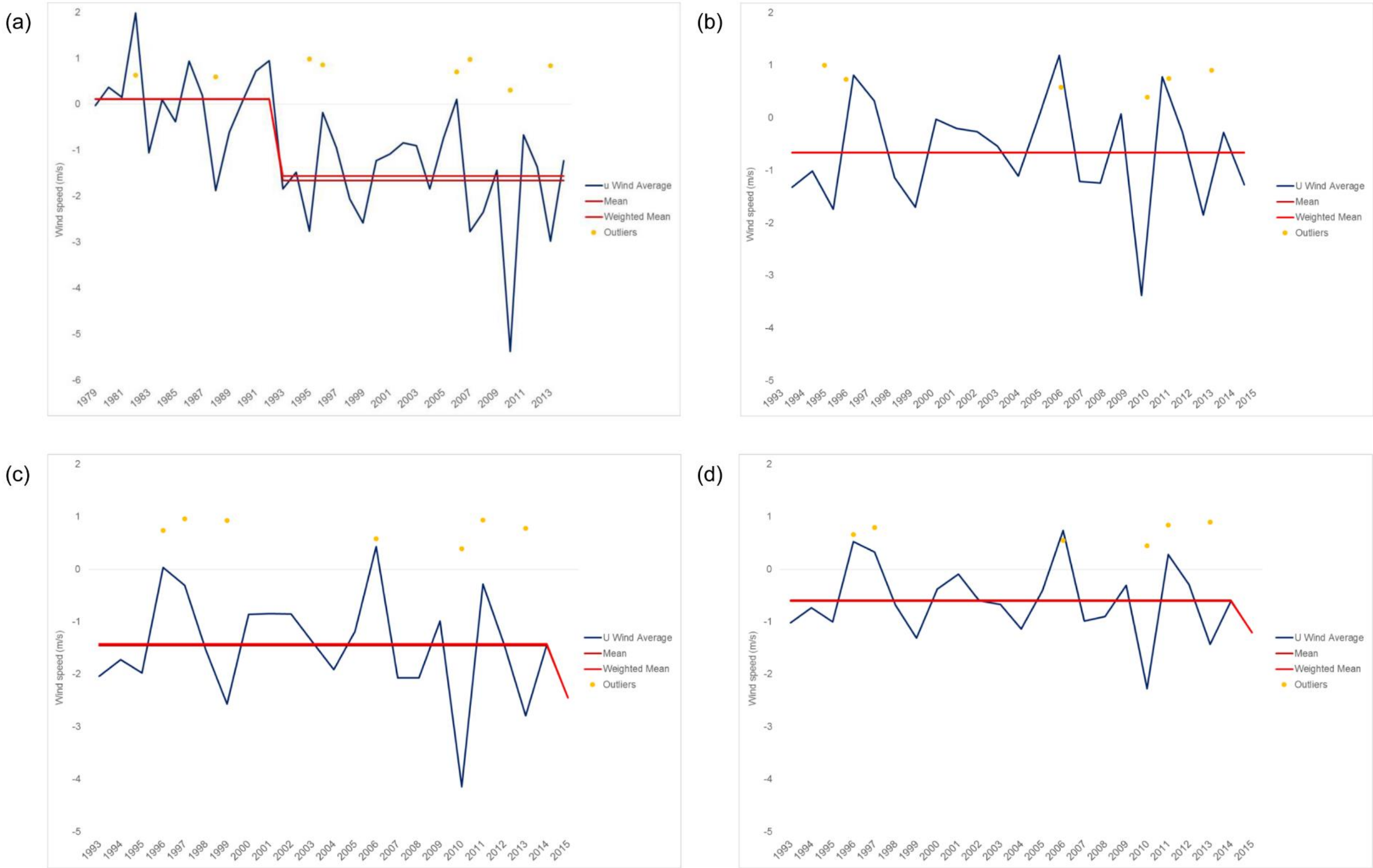


Figure 5.9: Summer mean values for U component of wind speed for (a) NCEP-DOE, (b) scatterometer aggregate, (c) Witsand and (d) Mossel Bay

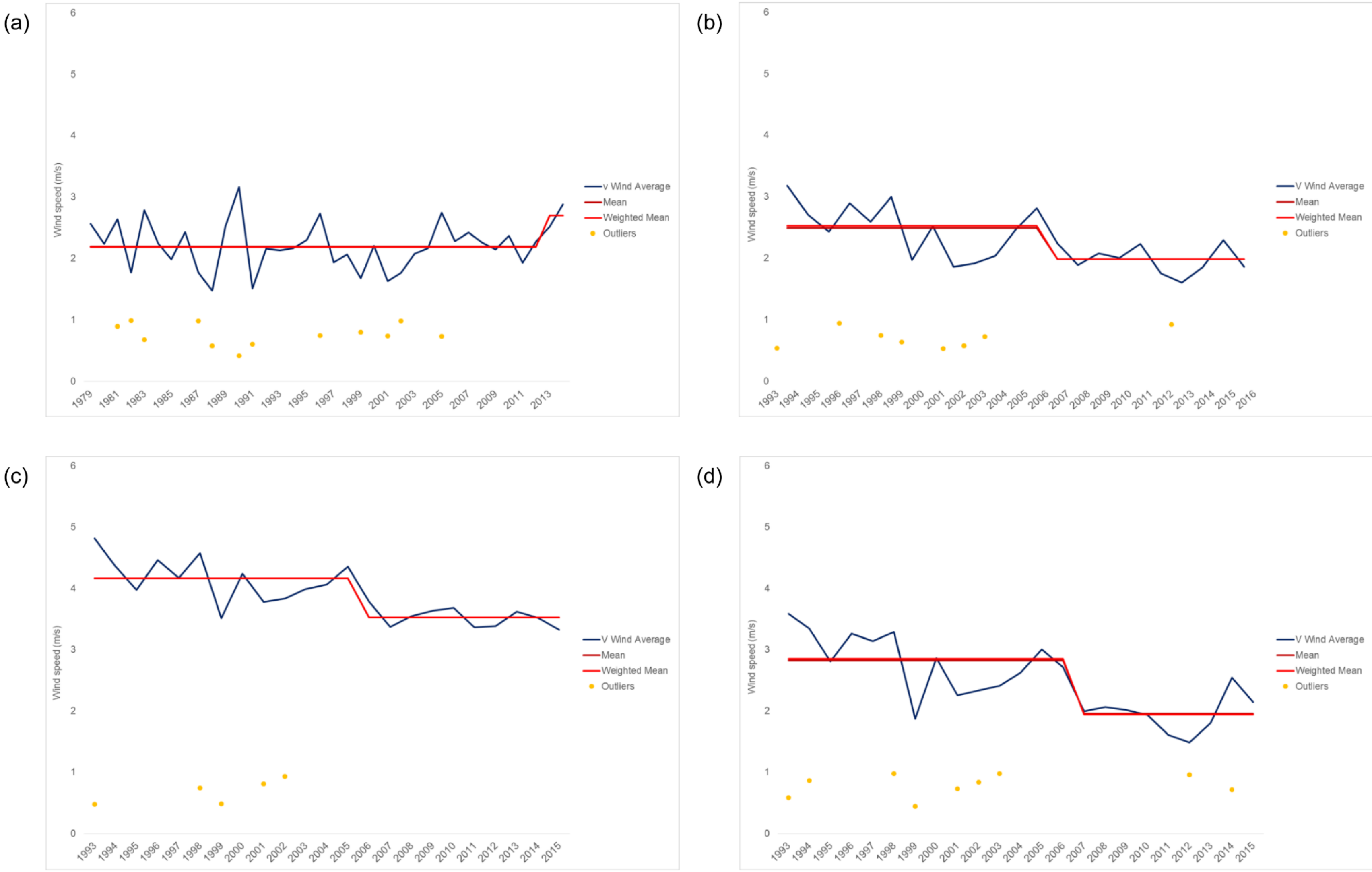


Figure 5.10: Summer mean values for V component of wind speed for (a) NCEP-DOE, (b) scatterometer aggregate, (c) Witsand and (d) Mossel Bay

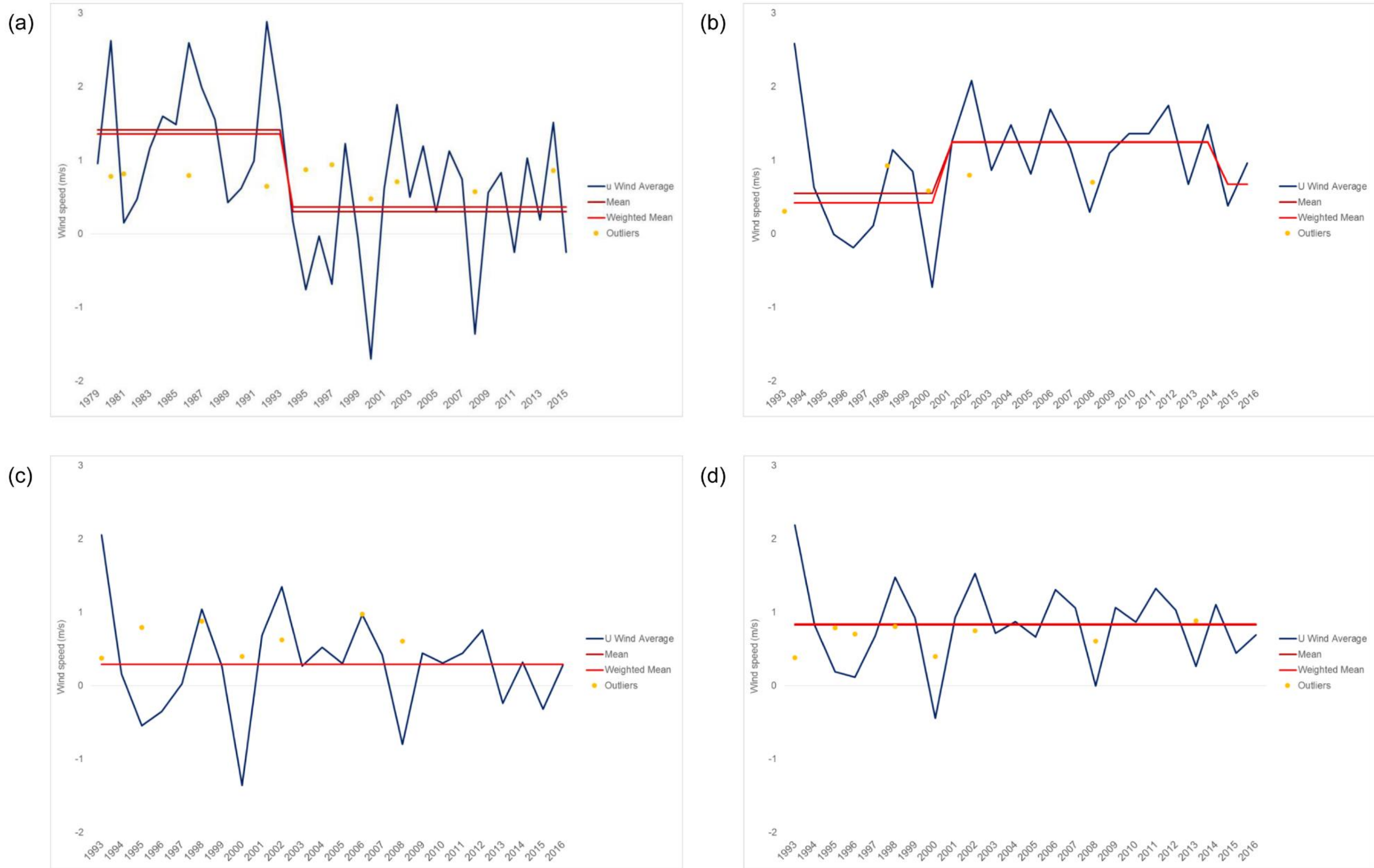


Figure 5.11: Autumn mean values for U component of wind speed for (a) NCEP-DOE, (b) scatterometer aggregate, (c) Witsand and (d) Mossel Bay

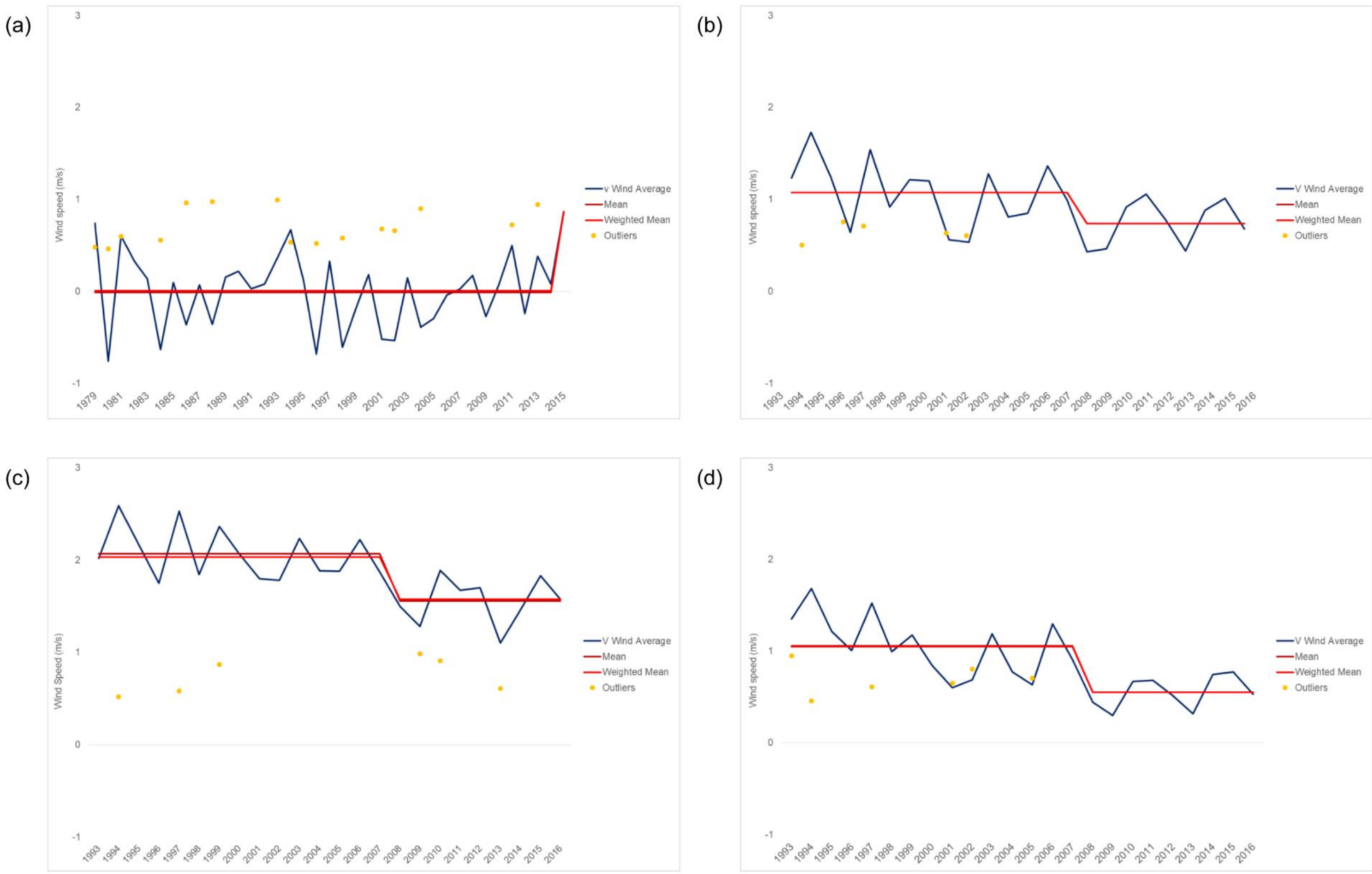


Figure 5.12: Autumn mean values for V component of wind speed for (a) NCEP-DOE, (b) scatterometer aggregate, (c) Witsand and (d) Mossel Bay

Table 5.4: Wind regime patterns for annual and austral seasons between near- and off-shore time series analysing the mean

	NCEP-DOE	Aggregate	Witsand	Mossel Bay	Comments
Annual U Wind	1992/1993 ↓ 2013/2014 ↓	2013/2014 ↓	2013/2014 ↓	2013/2014 ↓	**Comparable:** The peaks and toughs across all four data sets, where comparable, were consistent (for example, higher peaks in 1996 and 2005; lower toughs in 1999 and 2010).
Annual V Wind	1996/1997 ↓ 2009/2010 ↑	——	2006/2007 ↓	2006/2007 ↓	**Non-comparable:** Aggregated data were qualitatively more similar to Witsand and Mossel Bay points, despite not displaying regime shifts. Inshore dynamics were more pronounced than the aggregate point.
Austral Summer U Wind	1992/1993 ↓ 2006/2007 ↓	2006/2007 ↓	2006/2007 ↓	2006/2007 ↓	**Comparable:** Decreasing westerlies are relative to increasing easterlies, which correspond to increasing upwelling in the system and thus more productivity on the Agulhas Bank. This is consistent with findings from Blamey et al. (2012) and Lamont et al. (2017) regarding increased upwelling on the Agulhas Bank over time.
Asutral Summer V Wind	2011/2012 ↑	2008/2009 ↓	2005/2006 ↓ 2014/2015 ↓	2005/2006 ↓ 2013/2014 ↑	**Non-comparable:** Witsand and Mossel Bay points agree qualitatively with aggregated scatterometer points. Near-shore south easterly winds have appeared to have shifted to east rather than south from mid-2000s. However, southerly winds have increased off-shore towards the end of the time series according to NCEP-DOE and Mossel Bay results.
Austral Winter U Wind	2011/2012 ↑	2014/2015 ↓	2014/2015 ↓	2014/2015 ↓	***Non-comparable:** * However, all four time series indicate a strong peak between 2012 and 2013, thus possibly influencing the NCEP-DOE results as the off-shore time series only runs until 2014. It is noted that all of the time series have similar peaks and toughs.
Austral Winter V Wind	1995/1996 ↓ 2009/2010 ↑	——	——	——	**Non-comparable:** Near-shore wind results suggest that there was no significant change during winter, which is contradicted by off-shore winds that show an increase in northerly winds from the mid-1990s to late 2000s.

Table 5.5: Wind regime patterns for specific seasons between near- and off-shore time series analysing the mean

	NCEP-DOE	Aggregate	Witsand	Mossel Bay	Comments
Winter U Wind	1987/1988 ↑ 2012/2013 ↑	2014/2015 ↓	2014/2015 ↓	2014/2015 ↓	***Non-comparable:** *It should be noted that the second regime shift for the NCEP-DOE time series is at the end of the time series and may have insufficient data. Both near- and off-shore time series have similar very low troughs in 2011 and all of the time series show a peak in 2012/2013 (which subsequently decreases in the more complete scatterometer series that run until 2016).
Winter V Wind	1998/1999 ↓ 2009/2010 ↑	2010/2011 ↑	2014/2015 ↑	2014/2015 ↑	**Non-comparable:** Aggregate scatterometer results show a regime shift in 2010/2011 towards increasing southerly winds. Witsand and Mossel Bay are internally consistent, but only indicate a regime shift in 2014/2015 towards increasing southerly winds. Scatterometer and NCEP-DOE time series are consistent in that they show increasing southerly winds but at different times during the 2000s.
Spring U Wind	2013/2014 ↓	2013/2014 ↓	2013/2014 ↓	2013/2014 ↓	**Comparable:** In the scatterometer data, the new regime shift has resulted in wind direction changing from west to east in Witsand, although wind speed is weak. Mossel Bay's westerly direction also decreased, but remains westerly and weak in speed.
Spring V Wind	1996/1997 ↓ 2005/2006 ↑	2015/2016 ↑	2007/2008 ↓	2007/2008 ↓	**Non-comparable:** Similarly to Autumn V Wind, NCEP-DOE and scatterometer time series give an opposite trend. Aggregate scatterometer data are qualitatively similar to Witsand and Mossel Bay. It should be noted that the regime shift for Aggregate scatterometer time series is at the end of the time series and may have insufficient data.

Regime shifts in variability of the mean wind speed

Secondly, change in the variability of mean wind speed in relation to direction was considered through calculating the variance of annual and seasonal (monthly) data sets over time. The analyses are summarised in Table 5.6 and 5.7, with details provided in Appendix 3D.

Regime shifts for the variance were highly varied, with limited internal consistency between near-shore (Witsand and Mossel Bay) and offshore (NCEP-DOE and aggregate points). Overall, it appears that variability has decreased or shown no change in the V wind component across inter-annual and seasonal time scales. For the NCEP-DOE point, variability generally increases for the U wind component (with the exception of austral summer) particularly from the late 2000s. Both NCEP-DOE and scatterometer data points indicate increased variability when analysed at an annual scale, which is consistent with fishers' descriptions of increased variability over time. However, when variance is examined on a finer scale (inter-annual and seasonal), scatterometer data points for the U wind component tend to show a decrease in variance over time (with the exception of autumn in Witsand).

Variability appears to be inconclusive on six monthly and three monthly season scales for both NCEP-DOE and scatterometer data, where an increase in variability on an annual scale (in the U wind component) is not necessarily reflected on finer scales. Inconsistencies between the data sets underline that there is no strong signal of change within these data at the scale at which they have been analysed – annual and seasonal.

Table 5.6: Wind regime patterns for annual and austral seasons between near- and off-shore time series analysing variance

	NCEP-DOE	Aggregate	Witsand	Mossel Bay	Comments
Annual U Wind	1987/1988 ↑ 2006/2007 ↑	2011/2012 ↑	2012/2013 ↑	2011/2012 ↑	Variability increased over time across all data sets where aggregated, Witsand and Mossel Bay experienced increased variability after 2010, whereas NCEP-DOE results indicated mid-2000s (consistent with Blamey et al., 2012).
Annual V Wind	——	2008/2009 ↓	2001/2002 ↓ 2014/2015 ↓	2000/2001 ↓ 2008/2009 ↓	Variability decreased over time for scatterometer points and did not show any change in the NCEP-DOE time series.
Austral Summer U Wind	1989/1990 ↓	——	——	——	No change in variability occurred for scatterometer points and variability decreased into the 1990s according to NCEP-DOE results.
Asutral Summer V Wind	——	2012/2013 ↓	——	2010/2011 ↓	Variability decreased after 2010 for the aggregate and Mossel Bay points, however did not change for NCEP-DOE and Witsand points.
Austral Winter U Wind	1988/1989 ↑ 2013/2014 ↑	2002/2003 ↓	2002/2003 ↓	2002/2003 ↓ 2014/2015 ↓	Over time, variability increased for the NCEP-DOE points and decreased for all scatterometer points.
Austral Winter V Wind	2010/2011 ↓	2001/2002 ↓	2001/2002 ↓ 2011/2012 ↓	2001/2002 ↓	Variability decreased across both NCEP-DOE and scatterometer points, with shifts taking place in the early 2000s for the scatterometer points and again after 2010 for the NCEP-DOE and Witsand points.

Table 5.7: Wind regime patterns for specific seasons between near- and off-shore time series analysing variance

	NCEP-DOE	Aggregate	Witsand	Mossel Bay	Comments
Summer U Wind	—	—	—	—	No change in the variance was detected for both NCEP-DOE and scatterometer points.
Summer V Wind	2013/2014 ↑	—	—	—	Variability only increased at the end of the NCEP-DOE time series in the late 2000s, whereas the scatterometer points did not change.
Autumn U Wind	2014/2015 ↑	2015/2016 ↓	2014/2015 ↑	2002/2003 ↓ 2015/2016 ↓	NCEP-DOE and Witsand results showed an increase in varability after 2014, whereas the aggregate and Mossel Bay points decreased.
Autumn V Wind	—	—	2015/2016 ↓	2010/2011 ↓	Variability decreased after 2010 for Witsand and Mossel Bay points, however did not change for NCEP-DOE and aggregate points.
Winter U Wind	2013/2014 ↑	—	—	—	Variability only increased at the end of the NCEP-DOE time series and the scatterometer points did not change over time.
Winter V Wind	—	2008/2009 ↓	2001/2002 ↓	2008/2009 ↓	There was on change in variability for the NCEP-DOE point, however the scatterometer points showed a decrease in variability after 2008 for the aggregate and Mossel Bay points, and after 2001 for Witsand.
Spring U Wind	2011/2012 ↑	—	—	—	NCEP-DOE results show an increase in variability after 2011, but scatterometer points do not show any change.
Spring V Wind	—	—	—	—	No changes in variability were detected for all time series.

5.5. Overall Discussion

As highlighted by Blamey et al. (2015), current knowledge on the Agulhas Bank system is incomplete, particularly at the inshore scale. Gaps in understanding are largely due to the following factors:

- The shallow coastal zone is hydrodynamically complex
- Lack of long term, high resolution data sets
- Disagreement between signals depending on data set analysed
- Remotely sensed data problematic for dynamic coastal inshore zone

To better interpret complexities associated with the dynamic inshore system of the south coast, this chapter overlays fishers' observations with scientific data with a view of increasing insight into uncertainties associated with gaps in understanding on the Agulhas Bank.

5.5.1. Placing fisher knowledge

People dependent on natural resources for their livelihoods make good knowledge brokers on environmental and climatic change within local social-ecological systems. While research carried out by the SCIFR project demonstrated that fishers operating within the small-scale, commercial linefishery of the southern Cape are impacted by multiple stressors playing out over varying temporal scales, climate variability was considered a key stressor (Gammage et al., 2017a). While different timeframes and level of importance were assigned to how climate was changing within this fishery, there is overwhelming consensus from fishers that variability has increased outside of the considered 'norm'.

As where farmers in the southern Cape monitored rainfall as a key driver of change in their systems, fishers focused on prevailing wind conditions and long-term trends as a key environmental variable that determined the success of fishing activity off the south coast. For example, fishers found it increasingly difficult to fish during summer months due to prolonged south easterly winds from the late 2000s. This is supported by both scatterometer and NCEP-DOE wind data trends for austral summer – indicating an increase of intensifying south easterly winds from 2007 (Table 5.4). These findings are further corroborated by studies showing increased upwelling on the south coast over time (Blamey et al., 2012; Blamey et al., 2015; Lamont et al., 2017). Particularly in the summer period of 2010, a strong increase of easterly winds is indicated in wind product data (refer to Figure 5.9), which coincides with fisher observations that the summer of 2010 shifted toward extreme increased south-easterly winds (which made it difficult for fishers to go to sea that particular summer season).

Unseasonal weather allowing the fishing season to extend into the winter months was not clearly illustrated from wind data analysed in subsequent sections. However, near-shore data showed that weaker winds were detected in autumn and winter seasons from the mid-2000s, which is consistent with fisher ethnography obtained from Duggan (2012) in 2010. When linking wind product data and fisher observations, it becomes increasingly apparent that wind products need to be at the scale of the fishers' experience, hence handline fishers specifically require near-shore, high resolution data.

5.5.2. Comparing different wind products

Previous studies examining upwelling in the southern Benguela made use of geostrophic winds as researchers found strong significant correlations between measured and geostrophic winds, as well as between scatterometer and geostrophic winds (Blamey et al., 2012). Similarly, Lamont et al. (2017) based upwelling indices on NCEP-DOE data, rather than wind data from local coastal stations and scatterometers, as NCEP-DOE wind vectors provided suitable data for the Agulhas Bank at shelf scale.

However, spatial and temporal scale resolutions are critical to evaluate when deciding what kind of data should be used to assess environmental and climatic change at local levels. While NCEP-DOE data sets have been successful in examining larger scale trends associated with off-shore processes, they are not the best suited products for drawing conclusions on changes in the inshore areas (see Section 5.3.1.2). Near-shore wind products, such as the blended product derived from scatterometer data by Desbiolles et al. (2017), are preferable to NCEP-DOE when examining inshore trends. When examining near- and offshore wind data, one cannot expect the same results as wind components are part of different systems due to the influence of orography. While the blended wind product used for this research does merge data from different satellites and models at different spatial and temporal resolution to minimize the blind coastal zone, it should be noted that this methodology can result in a spurious shift in resultant wind time series (C. Roy, IRD, Brest, France, pers. comm.). However, the blended wind product has been validated through comparison with buoy data and Desbiolles et al. (2017) found that all statistics between blended winds and buoys were in better agreement across the time series than (for example) similar ERA-Interim calculations.

When comparing NCEP-DOE and scatterometer wind products in this chapter, the U wind component (west-east, i.e., roughly alongshore in the southern Cape) is consistent for both near-shore and off-shore results; however, the V wind component (south-north, i.e. roughly perpendicular to the southern Cape coast) displays the opposite trend on comparison. As confirmed by oceanographers, orography can have an effect 50 km out to sea on wind speed observed perpendicularly to the coast. Therefore it is important to use a wind product that is sensitive to features at local scale when analysing bay-scale effects, particularly in the case of the southern Cape linefishery which generally operates within 60 km. Results also highlight the need to use the most specific points (i.e. not aggregated data but rather Witsand or Mossel Bay points) one can obtain when working inshore with handline fishers in the southern Cape due to local scale dynamics (for example Section 5.4.2.3).

5.5.3. Examining local marine environments

When examining extreme wind events over time in the near-shore environment of the research area, results did not yield any significant trends of change, even when data were examined further offshore to eliminate possible data bias from the blind coastal zone. Extreme wind days on the coast are therefore less likely to impact fishers' ability to go to sea and other factors, such as socio-economic stressors (see Gammage et al., 2017a) or wind direction (including associated changes in the availability of fish as discussed above) are more likely to play an important role. However, off-shore environments showed a tendency of increased extreme wind days at shelf scale for austral summer periods (see Figure 5.8). Lyttle (in progress) found that near-shore (coastal) wave height between Witsand and Mossel Bay increased significantly between 1997 and 2012. Wave height is driven by off-shore processes associated with swell and wind, so increased extreme wind days at shelf scale could be in agreement with increased wave height along the coast of the research area.

When analysing marine regime shifts in wind direction in terms of mean wind speed, the time series for the scatterometer wind product was too short to detect 1990s regime shift (as detected by the NCEP-DOE wind data), but did display the environmental regime shift that took place in the mid-2000s, shown in both wind product data sets. This is comparable with studies showing similar environmental shifts over this time period for the southern Benguela, specifically the south coast (Blamey et al., 2012; Blamey et al., 2015; Lamont et al., 2017). These findings are also complementary with work by Currie (2017), who speculates that current changes in the linefish community in the Agulhas Bank subsystem are likely to be climate-related or environmentally driven as fishing pressure from trawl fisheries have eased over most of the area. My results do not contradict the observation that linefish communities on the Agulhas Bank are moving westwards away from the warming Agulhas Current (Currie, 2017), where these species have not had to move into deeper waters due to the increase in coastal upwelling in the area (Lamont et al., 2017). This is complementary to increased south easterly winds over austral summer periods in near-shore research area analysed here (see Section 5.4.2.3). Due to the difficulty to detect inshore regime shifts due to the complex coastal zone, it is highly likely that these shifts are taking place if near-shore data results match changes in the off-shore data.

Looking at marine regime shifts in terms of variability of wind direction was problematic as results were highly variable and not internally consistent between near-shore and off-shore environments (see Tables 5.6 and 5.7). When analysed at an annual scale, variability for the east/west directional component for all wind data points did increase over time. In particular, the NCEP-DOE point indicated a shift of increased variance at shelf scale in the late 1980s and mid-2000s that is consistent with findings from Blamey et al. (2012) on increased variance at Cape Agulhas. However, variability was not discernible at a seasonal scale at both near-shore and off-shore data points in the research area. Analyses on the finer temporal scale were beyond the scope of this study.

5.6. Conclusion

Overlaying different knowledge systems can be useful in identifying points of agreement and, as importantly, mismatches between data sets. Small-scale, commercial linefishers operating out of the southern Cape provide a wealth of knowledge on their social-ecological system and have long since identified increased climatic variability as a key point of discussion within this system. Matches between fisher observations and other studies can be drawn from near- and off-shore wind data products analysed in this chapter, where it is important to note that fine scale wind data sets are more valuable in the context of understanding the social-ecological system of the study area.

When examining Research Questions 1 to 3 that focused on local fisher knowledge regarding climate variability in the southern Cape, results show a highly complex and dynamic natural system that is characterised by variability and influenced by a number of social and political stressors. When examining long-term climatic change over time, fisher observations were less definitive and this was largely attributed to the naturally high variability in this area. On shorter time scales (i.e. inter-annual and seasonal), fisher observations did match wind data products. The variability of the system was also reflected in the wind data products used to address Research Questions 4 to 6 where, as in fisher observations, definitive data trends were difficult to identify over long periods of time – with subtle changes or tendencies observed that do not manifest in statistical significance.

In conclusion, highlights from this chapter include:

- Scale is important – when examining near-shore fisheries, there is a need for data to be complementary at bay-scale;
- The scatterometer model performed closer towards the inshore region, making it a useful product within the context of climate variability in the southern Cape linefishery as data is required to be region (i.e. town or area) specific;
- Mid-2000s marine environmental regime shift confirmed (in 2007) for wind direction;

- Subtle changes in wind speed and direction in coastal zone are evident; however while these changes are taking place, fishers are influenced by a number of variables such as sea temperature, the Agulhas Current and fish species shifts that play out at different temporal and spatial scales;
- Spatial and temporal scale mismatches still evident between fisher observations and scientific data which could be attributed to the use of annual and monthly scale data only for analyses – further research is required to examine these systems at daily scale.

CHAPTER SIX

SYNTHESIS:
OVERLAYING TERRESTRIAL AND MARINE PERSPECTIVES IN THE SOUTHERN CAPE

6.1. Introduction

This synthesis chapter draws together results from Chapters Three to Five to address the final key questions. Firstly, terrestrial and marine components of the southern Cape and Agulhas Bank are overlaid through comparing farmers' and fishers' perceptions of climate variability in relation to change observed from scientific weather data sets to examine Key Questions 4: Are local knowledge of climate variability (i.e. weather patterns) by farmers and fishers in agreement and how do these compare to scientific observations, and are there synergies or mismatches across local and scientific knowledge strands examined? Secondly, responses of local farming communities to climate variability are contrasted against local fishing communities' responses to address Key Question 5: How are farmers responding to change within the context of climate variability compared to fishers in the southern Cape?

Through overlaying the different strands of knowledge, this chapter builds a picture of the local social-ecological system in the southern Cape, intertwining local and scientific knowledge across its terrestrial and marine subsystems. As illustrated in Figure 6.1, local knowledge was examined through farmers and fishers (specifically skippers) based in the southern Cape research area by focusing on local perceptions of climate variability. Scientific knowledge was assessed drawing on local weather station observations, in tandem with rainfall recordings from farmers, and model outputs based on satellite and other observations. Initially, local and scientific knowledge strands were examined from a terrestrial view (Chapters Three and Four) and marine view (Chapter Five). These different strands of knowledge are now brought into dialogue across the terrestrial/marine divide and synthesised accordingly.

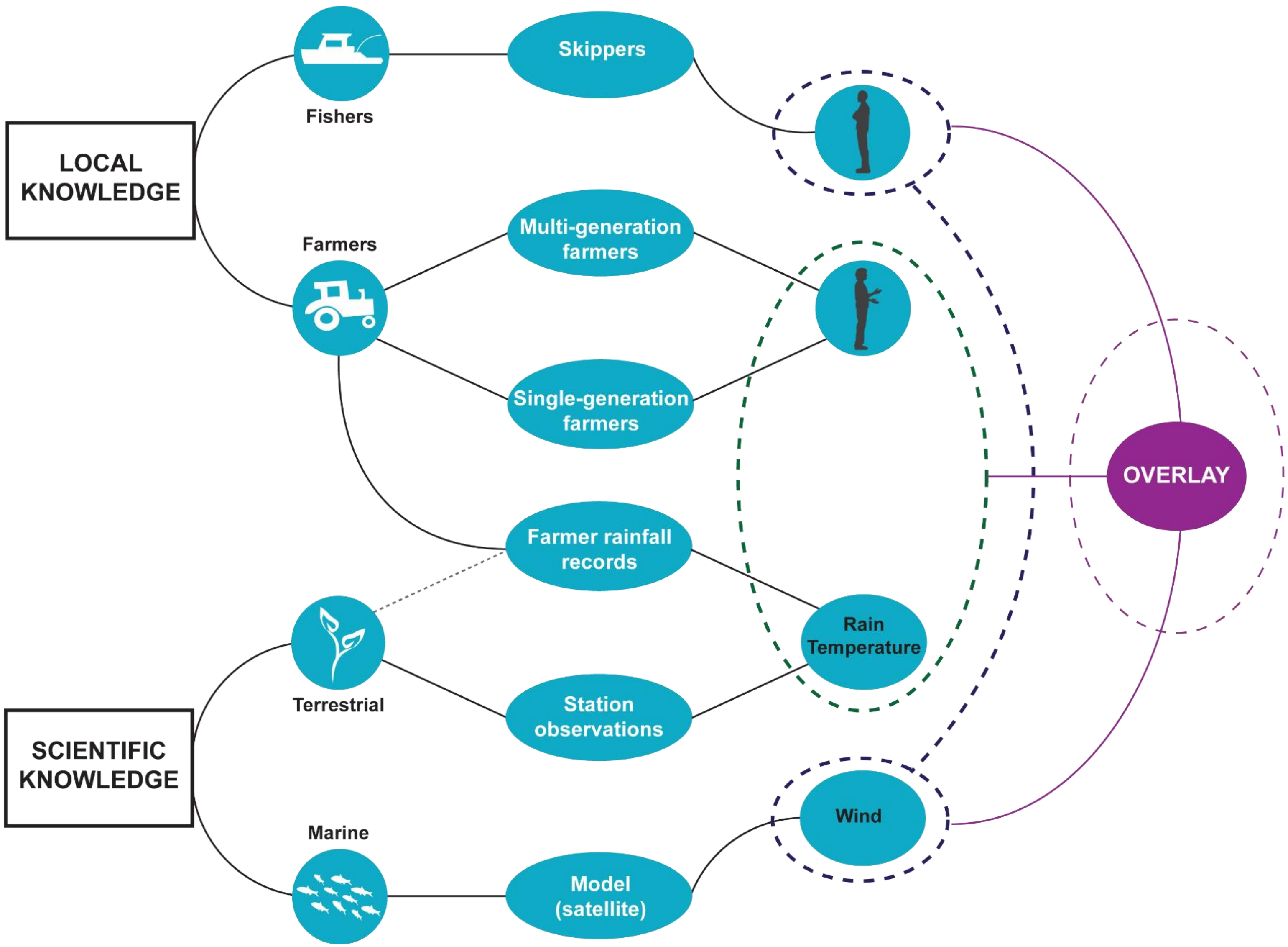


Figure 6.1: Different strands of knowledge examined in this thesis and how they are brought into dialogue

6.2. Linking farmers and fishers through climate drivers

As social-ecological systems are inherently complex and operate at multiple scales that are interconnected, it is important to examine these systems from more than one aspect drawing on diverse perspectives (Ommer et al., 2012; Tengö et al., 2014). Through comparing and integrating knowledge from a wider spectrum of backgrounds, this thesis contributes to better understanding complex system change, focusing on the common theme of climate variability, at the local scale of the southern Cape and Agulhas Bank by overlaying terrestrial and marine perspectives.

6.2.1. Farmer and fisher local knowledge of climate variability

Local climate knowledge from farmers and fishers in the southern Cape was locale specific and typically incorporated a mix of scientific and practical knowledge around agricultural and fishing activities, in line with definitions discussed in Chapter Two (refer to Section 2.7.1). Climate knowledge was often contextualised from a multi-generational perspective for both farmers and fishers, where current generations drew on observations passed down through previous generations and evolved their knowledge bases accordingly. This deep-seated understanding of climate through generations of local experimentation can provide valuable narratives on past patterns of local ecosystems, particularly where historical baseline information is not readily available (Fabricius et al., 2006; Tengö et al., 2014), which was useful for this research in terms of establishing historic experiences of farming and fishing families to interpret current perceptions of climate variability. Farmer and fisher typologies in the research area were comparable in that many of the participants interviewed during this project and the SCIFR research project had long-term experience within their respective agricultural or fishery sector, which included some multi-generational farmers or fishers – bringing a more long-term outlook on how climate variability had changed over generational scales.

In general, both terrestrial and marine climate systems of the southern Cape were deemed highly variable by both farmers (Section 3.4.3) and fishers (Section 5.4.1) and both groups did not observe any definitive trends of change in the system over time. The narrative that emerged from these local climate knowledge strands were more nuanced, where subtle changes were teased out over different temporal and spatial scales. The multi-decadal variability of climate was perceived by some fishers to be a normal characteristic of the local marine environment where different cycles of weather were repeated over time, however these systems were thought to have increased in variability that exceeded the norm in recent memory. Similarly to fisher observations, farmers emphasised the naturally variable nature of the local terrestrial environment but echoed that recent extreme events and subtle shifts in weather patterns appeared to be outside of the expected norm.

Farmers were most invested in rainfall patterns and gave more detailed observations on possible rainfall changes over time, with some participants placing their long-term monitoring records at my disposal (refer to Chapter Three). Changes in extreme weather events – typically associated with intense rainfall events or prolonged dry periods – were one of the key observations made by farmers for the terrestrial environment. Later onset of seasonal autumn rainfall patterns in the current farming generation were also highlighted. Farmers were less certain of changes within temperature and wind regimes as these drivers were deemed highly variable over time and participants' questioned the reliability of their memories concerning observations or perceptions of change. Fishers discussed wind variability as a key environmental change experienced within their marine environments and thus the focus of analyses for this thesis followed up on fishers' wind narratives (see Chapter Five). Perceived changes in prevailing wind patterns were more subtle and varied mirroring the complexity of the local marine system, where narratives around change focused around increased variability in intra-seasonal wind patterns. Fishers also attributed a recent decline of suitable sea days to persisting unfavourable weather conditions, where changes in wind patterns were highlighted as a key contributing variable.

6.2.2. Linking local climate narratives to weather analyses

In agreement with farmers' and fishers' observations of the highly variable climate system of the southern Cape; analyses across (terrestrial) rainfall, (terrestrial) temperature and (marine) wind data sets did not yield clear-cut trends of change over time, but rather decadal-scale variability.

Generally, farmers' observations on rainfall changes corroborated analyses of rainfall patterns over time (see Section 4.3.1). Since the 1980s, prolonged dry periods have increased across the research area and an increase in extreme monthly rainfall events was detected in the eastern extent of the catchment areas. Complexity of local climate shifts across different spatial scales for the research area matched the farming communities' perceptions that changes in local weather patterns were not necessarily a uniform experience, and micro-climates were important when determining suitable farming activities to match fine-scale environmental conditions (Section 3.4.2). Farmer observations around recent shifts in the onset of the traditional autumn rainfall season were in agreement with data analyses that indicated this shift (i.e. onset of rainfall occurring a month later) taking place across the research area from the 2000s to present (Section 3.4.3). This was also observed in a study by du Plessis and Schloms (2017), where rainfall data indicated a possible shift of the rainfall season by a month (from March to April) for the larger South Coast Region, including my results.

While temperature analyses were limited in terms of data availability, data quality and high variability, a shift was detected in the 1990s towards a warmer regime, which changed to a cooler period in the mid- to late-2000s (refer to Section 4.3.2). Narratives from farmers generally associate the 1990s with dry years, in line with warmer temperature tendencies overlapping with this time period. The 1990s saw a shift of farming practices away from conventional plough methods towards conservation agriculture that improved soil moisture retention, which was partly attributed to these prolonged dry periods, along with economic considerations for improving agricultural outputs (see Section 3.4.2). Shifts in terrestrial temperatures for the southern Cape can be linked to larger-scale changes in the southern Benguela system. Marine environmental shifts occurred in the south coast region of the Agulhas Bank in the mid-1990s and mid- to late-2000s (in agreement with Blamey et al., 2012; Blamey et al., 2015; Lamont et al., 2017), which is comparable to analysed terrestrial temperature shifts (Section 4.3.2). Additionally, analysed wind data also indicate regime shifts in the mid-1990s towards an increasing easterly wind pattern, and again in the mid-2000s indicating a further dominance of easterly winds (refer to Section 5.4.2), corresponding to time frames from existing scientific work and analysed temperature shifts described above.

Fishers' narratives around changes experienced in wind patterns for the south coast focused on changes in intra-seasonal patterns, specifically referencing a noticeable change in the late 2000s where prevailing wind directions across different seasons shifted to persistent south-easterlies. These observations are in agreement with my wind data analyses (refer to Section 5.4.2). Wind data also indicated possible shifts towards the end of the time series (after 2010, as most series ended in 2014) – but this requires further investigation before interpretation, as time series methods are unreliable towards the end of the time series in question. Definitive shifts based on wind data are present in the mid-1990s and again in 2007, which are supported by local climate knowledge (Section 5.4.1) and scientific knowledge (Blamey et al., 2015; Lamont et al., 2017) for the research area.

While fishers' observations of increased extreme wind days did not match my analyses of near-shore wind products, which did not yield any discernible trends of change over time for extreme wind days, off-shore drivers showed a clearer tendency towards increased wind speeds over time at shelf scale (Section 5.4.2.2). Along with findings of increased wave height (Lyttle, in progress), possibly influenced by off-shore wind and swell (Hanley et al., 2010), an increased tendency of extreme wind days at shelf scale in the research area may suggest that fishers' observations of deteriorating conditions suitable for them to go to sea (particularly in austral summer during fishing season) are matched at off-shore rather than near-shore scale in scientific data. Perceptions of increased variability by fishers were only reflected in annual time series of wind data products, notably where increased variability over time in east/west wind components were found at both off- and near-shore points (Section 5.4.2.3). However, increased variability was not reflected at the seasonal scale of the scientific data, which underlies the need to examine these data at daily scale in relation to fishers' observations – which is beyond the scope of this thesis.

6.2.3. Linking terrestrial and marine narratives

A common thread linking farmer and fisher narratives can be distilled from accounts linking broader environmental interactions between land and sea as described by some participants. One account that emerged from the fishing community linked rainfall and fish availability (refer to Section 1.5), weaving in complex narratives around past experience that hypothesised good fish catches were related to poor rainfall years on land whereas good rainfall years could result in poor catches. This narrative generally translated into a fisher folklore that claims that if the farmers were 'happy' (i.e. good rainfall which meant a profitable agricultural year), the fishers were 'sad' (i.e. poor fish catches that equated to economic losses in the fishery sector) and vice versa, hence qualifying this statement is problematic as it is unspecific and not easy to interpret at face value. It is not clear whether this narrative refers to the larger interplay of the environmental system between local sea conditions and related weather patterns, or more point specific impacts of river systems that run into the sea. While the altering of river systems through agricultural impacts (for example, chemical inputs and degradation of wetland systems) and freshwater flow (for example, more fresh water entering the sea during flood events and less during drought events) could have an impact on local fish abundance (Acker et al., 2005; Auricht et al., 2017), farmers clearly linked the relationship between land and sea to a larger interplay of environmental factors.

Box 6.1: Selected farmer narratives linking land and sea environmental patterns from the old days

"Well we know that when the sea temperatures are warm we get rain."
Farmer (2015)

"When sea temperatures are cold and *stokvis* [hake] are biting then we're in for a dry spell, especially early in the year."
Farmer (2015)

"If water (sea) temperature is cold early in the year, then the guys catch a lot of hake – it's not a good sign (rain) for us (farmers). But when they catch Kob in December and January, it's good for us."
Farmer's son (2015)

Multi-generational farmers, drawing on previous generations' accounts, linked rainfall patterns to sea temperatures and described similar theories on how this larger system interplays (see Box 6.1). Referring to the 'old days' (refer to Section 3.4.3 for detailed description of temporal scale) as reference, these farmers relayed that warmer sea temperatures at the beginning of the calendar year generally foretold a good rain season over the mid-year period for farmers. The reverse was narrated for colder sea temperatures, which entailed poor rains in the research area. When referring back to ethnography from a skipper regarding the interconnected nature of the natural marine and terrestrial systems (refer to Section 1.5), rainfall time series from farmers show that 1969 as a particularly low rainfall year in line with the skipper's observation.

While 1969 is not the lowest recorded rainfall year, which raises issues in relation to distortion of knowledge through shifting baselines (for example Pauly, 1995), individuals tend to remember extreme weather events more clearly – which is a natural reflection of human perception and memory (Osbahr et al., 2011). The high availability of silver kob noted by this skipper during this associated drought year could be linked to numerous possibilities – ranging from fishing effort to climatic conditions. Currie (2017) suggests that kob species abundances on the Agulhas Bank had already declined substantially from the 1930s and that inshore trawl landings of silver kob decreased considerably between the mid-1960s and early 1980s, possibly reflecting the long-term decline of this fish species in the research area. However, decreased inshore trawl effort from the mid-1960s may have allowed handline skippers of the southern Cape to land more silver kob as a result of decreased competition from the other fishing sector.

Alternatively, 1969 to 1970 was a weak El Niño period, where El Niño events are typically associated with less prevalent southerly winds in the southern Benguela system (Field and Shillington, 2005). This El Niño event over the traditional summer fishing season of 1969-70 could have resulted in unusually calm conditions and thus skippers in the southern Cape could have increased fishing effort as a result of numerous sea days. El Niño–Southern Oscillation (ENSO) primarily influences summer rainfall patterns in southern Africa (Dieppois et al., 2015), while variability of winter southern African rainfall is related to the Southern Annular Mode (SAM) that also impacts on South Atlantic sea surface temperature (Reason and Rouault, 2005). However, positive influence of ENSO on winter rainfall areas of South Africa has been noted, where more frequent dry spells are associated with El Niño events (Philippon et al., 2012). It should be cautioned that southern coastal regions, such as the southern Cape, have a more complex relationship with ENSO signals as this aseasonal rainfall area is affected by climate processes driving both summer and winter rainfall variability (Dieppois et al., 2016).

Farmers tended to link terrestrial to marine systems through fish catches as they would spend their Christmas (December) vacation period on the coast, engaging in recreational fishing activities. Due to the scenic location of Still Bay, farming families would camp there over the summer period and fish off the beach – a custom which was well established by the 1860s (Visser, 2015). Specifically, farmers hypothesised that if they caught silver kob in Still Bay, then this indicated warmer sea temperatures as these fish species were perceived to take the bait more readily in these conditions. This generally pre-empted a good rainfall season for the farmers. Conversely, if farmers caught hake then this indicated cold sea water as these fish were perceived to bite during colder conditions – hence anticipating a poor rainfall year. Through overlaying fisher and farmer observations we can investigate this narrative. For example, Still Bay skippers noted an influx of hake in the their fishing grounds in the late 1990s due to colder in-shore waters favoured by this species (Duggan, 2012) and farmers associated the 1990s as a relatively dry period compared to past memory (Section 3.4.4).

While this rainfall prediction was deemed reliable in 'old days', current farming generations noted that this relationship was not as clear as in the past, also noted by Thomas et al. (2007). Some farmers speculated that the winter rainfall regime had changed over time and it appeared that typical wind patterns associated with winter rainfall from cold fronts had altered in recent memory. As noted by Allsopp et al. (2014), while it is possible that fewer low pressure systems reach the research area in winter, gaps in understanding persist due to the complex nature of interacting large-scale atmospheric pressure fields (see Section 3.2.2 for detailed description). The South Atlantic High Pressure System (or South Atlantic Anticyclone) is responsible for the dominant wind system over the southern Atlantic Ocean and work synthesised by Jarre et al. (2015) indicated that this system shifted in a southerly direction from the 1980s to 2000s, after which it shifted back northwards. This shift is linked to an increase in increased south or south-easterly winds in the 1990s across the southern Benguela (Blamey et al., 2015; Jarre et al., 2015). Farmers in the southern Cape associate the 1990s with a particularly dry period, which is further reflected in a clear warm period from terrestrial temperature data analyses during this time period (refer to Figures 4.16 and 4.17). The 1990s are also overlaid with decreasing off-shore westerly winds over summer periods (refer to Figure 5.10; Table 5.4), where corresponding increases in easterly winds are linked to increased upwelling coupled with associated colder sea temperatures on the Agulhas Bank (Blamey et al., 2012; Lamont et al., 2017). This is possibly linked to the influx of hake in the Still Bay area that were driven inshore by colder waters in the late 1990s (Duggan, 2012).

6.3. Examining synergies and mismatches

The complexities around environmental shifts in systems that are driven through complex natural processes that unfold over multiple temporal and spatial scales pose a challenge when trying to gauge adaptation to change while grappling with uncertainty. Understanding change from the context of different knowledge bases can help identify mismatches between different understandings, as well as highlight the importance of scale relevant data when assessing possible environmental or climatic trends. Different knowledge strands were examined over varying temporal and spatial scales depending on data availability, as illustrated in Figure 6.2.

When looking at local climate knowledge in this thesis, farmers focused on their immediate surroundings (i.e. on their farm), which could stretch back a 100 years in the case of some multi-generational farming families. Fishers' local climate knowledge tended to focus on adjacent areas as their fishing grounds are located in the inshore area of the Agulhas Bank, stretching back a few decades in the case of some fishing families. The terrestrial component examined through scientific data bases spanned immediate and adjacent (i.e. coast, vlakte or mountain areas or Breede/Duiwenhoks, Goukou, Goukou/Gouritz locations) spatial scales, stretching back a few decades. The marine component ran from immediate (i.e. coastal) to adjacent (i.e. inshore Agulhas Bank) to distant (i.e. offshore Agulhas Bank) spatial scales, but data sets were on average shorter compared to terrestrial data sets.

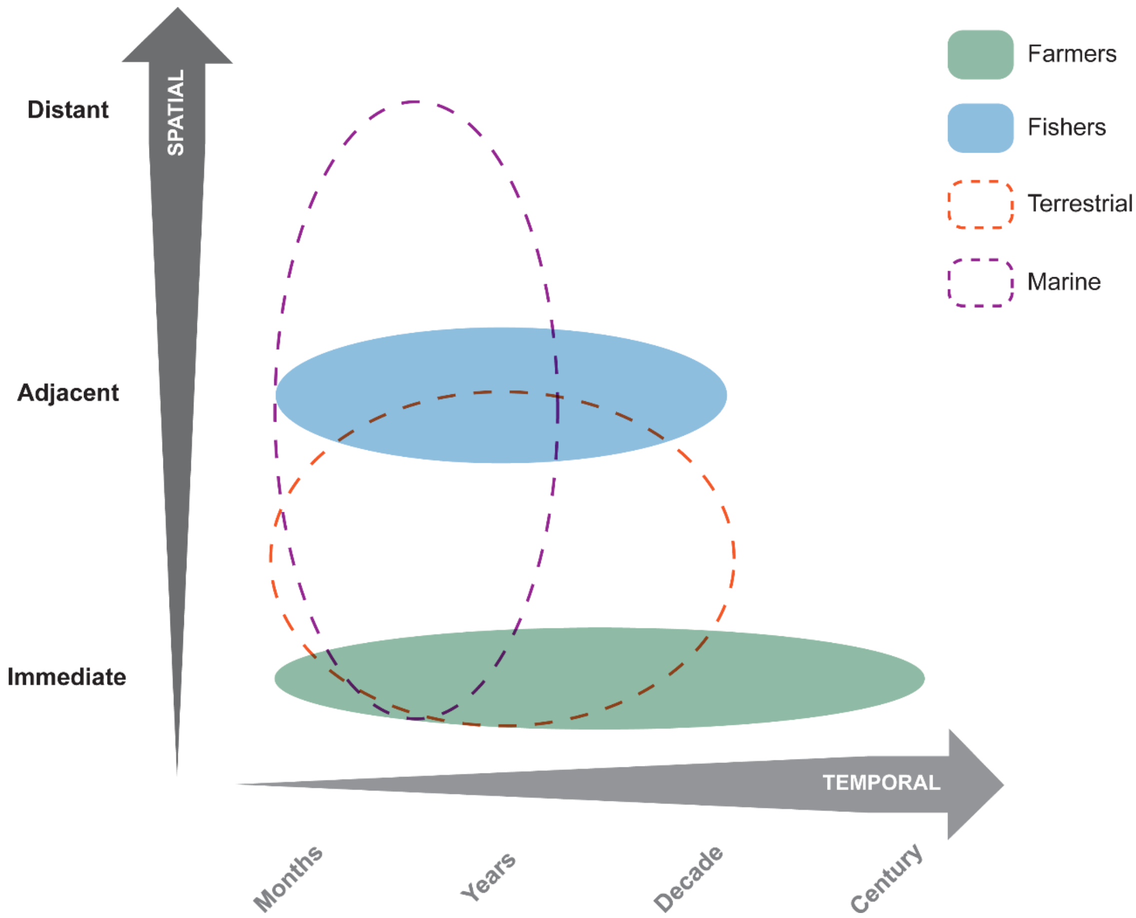


Figure 6.2: Different knowledge strands, namely local knowledge of farming and fishing communities in the southern Cape and terrestrial and marine scientific data, examined over varying temporal and spatial scales. Spatial scale can be described as immediate (farm or specific location on the coast), adjacent (catchment or bay) and distant (southern Cape region or Agulhas Bank)

Social-ecological systems usually involve groups of resource users that are interlinked with each other and to numerous resources that occur across multiple scales, and therefore influenced by spatial and temporal changes within these complex systems (for example Janssen et al., 2007). While local climate knowledge of farmers and fishers was difficult to compare on a spatial scale as there was no overlap, the temporal scale offered the opportunity to overlay terrestrial and marine perspectives concerning different time periods that described changes in environmental regimes. Those terrestrial and marine scientific data sets allowed synergies to emerge in terms of periods of significant change in environmental regimes on both temporal and spatial scales. Through overlaying multiple knowledge strands, synergies and mismatches in the social-ecological system of the research area become apparent and are discussed below.

6.3.1. Synergies through multiple dimensions of knowledge

Through examining multiple dimensions of knowledge relating to environmental change in complex social-ecological systems and overlaying these knowledge bases, a more nuanced understanding was obtained. For example, the triangulation of data analyses of terrestrial weather elements with local climate knowledge from farmers (Chapter Four) gave a comprehensive overview of possible climate shifts in the southern Cape, and synergies were detected particularly for shifting rainfall patterns between farmers' observations and data analyses – generally in line with analyses at a larger scale (see Section 6.2.2).

While traditional scientific research and existing policies tend to focus on larger scale climate trends at (for example) provincial or national levels (Ziervogel et al., 2014), my research illustrated the importance of contextualising temporal and spatial changes in relation to local climate variability – which was highlighted through the dimension of local knowledge from multi-generational farming communities. Climate variability and associated changes need to be contextualised, as these changes were not uniform across the terrestrial and marine research area and differed across temporal and spatial scales. This can have considerable implications for communities reliant on natural resource bases, such as farmers and fishers, as considering different strategies based on changing micro-climate characteristics will enhance the adaptive capacity of these users. Given the complexity of local systems in the context of global change, my results support the general recommendation that strategies for sustainability should take on many different forms as there is no 'one size fits all' approach when the future is concerned (Walker et al., 2004).

Overlaying multiple data sets and observations from numerous sources also proved useful when grappling with the high uncertainties characteristic of complex systems. Tendencies observed in marine wind data patterns could be overlaid with shifts detected from terrestrial temperature time series, thus strengthening the outlook for possible time periods of environmental regime shifts for the research area. Local fisher and farmer knowledge bases also overlapped to an extent when comparing timeframes of possible environmental regime shifts (see Section 6.2.2). The complexity of the natural system for the southern Cape and Agulhas Bank was most evident in narratives around marine wind tendencies and terrestrial temperature patterns, where overlaying multiple knowledge dimensions was useful to build a more comprehensive understanding around possible climate shifts, in view of the high uncertainty associated with climate variability.

My results from Chapter Four and Five underline the importance of considering subtle changes in climate which are specific to a particular area within the broader context of climate variability at a national level, in order to better understand challenges presented to livelihoods at a local scale. Thomas et al. (2007) discuss how only considering climate criteria important to institutional decision-making processes, such as concepts of drought or flooding, may not be sufficient for natural resource users to succeed in the face of localised climate variability. Farmers, for example, might underpin strategies on subtle climate variables such as the timing of the onset of rainfall associated with planting season, which are representative of real criteria that are locally relevant to resilient farming strategies (Thomas et al., 2007). Through examining themes in relation to climate variability that were generated through perceptions of local farmers and fishers in the southern Cape, synergies between local and scientific knowledge bases added meaningful insights to climate realities in my research area. An example of this is discussed in Section 6.2.3 – linking farmers' and fishers' narratives of land and sea change through overlaying these narratives with terrestrial and marine scientific results of the research area.

6.3.2. Knowledge disconnects

Knowledge disconnects are important to understand in the context of sustainable management of human activities in a systems-based paradigm (Tengö et al., 2014). Conflicting data or contrasting views and values (for example Verran, 2002), whether held by scientists, policy makers or resource users, can undermine sustainable adaptation or transformation of local social-ecological systems. Miscommunication, misdirected resources, and policy failure can result due to knowledge disconnects (Sterling et al., 2017). Persisting knowledge gaps and poor understanding around environmental and climate variability in the southern Cape region and Agulhas Bank system – from local-scale drivers such as shifting rainfall patterns or localised marine upwelling; to large-scale processes linked to the interaction between the South Atlantic and South Indian Anticyclone – pose challenges when dealing with high uncertainty in these complex social-ecological systems. Data-poor environments further hinder our ability to better manage anthropogenic impacts on these local systems or devise scale-appropriate policies that simultaneously benefit people while protecting or enhancing ecosystem services.

Knowledge disconnects existed within the marine part (refer to Chapter Five) of this research, which can largely be attributed to a lack of long-term, high quality monitoring environmental data (also present in Chapter Four describing the terrestrial component), coupled with a naturally variable climate system that is complex given its geographic location. For example, mismatches between fishers' perceptions and data analyses occurred when examining extreme wind days in the near-shore environment (Section 5.5.3), where perceptions held by fishers that sea days had decreased over time partly due to unfavourable wind conditions were not reflected in the scientific data. However, these knowledge disconnects could also arise from scale mismatches, as changes in the off-shore environment showed a tendency of increased extreme wind days over time – corroborating fishers' perceptions at shelf scale but not necessarily in the in-shore environments where these fishers operate.

From the terrestrial perspective, an example of knowledge disconnects can be drawn from the complexities surrounding freshwater in the southern Cape. Similar to complex system stressors experienced by fishers (Gammage et al., 2017a;b), water issues are played out within environmental, social and political spheres for farmers. Knowledge disconnects are present between perceived changing rainfall patterns, policy restrictions on allocation or storage from local river systems, and increasing agricultural demand (Section 3.4.5.2). Many farmers expressed frustration with current water allocation policies, which are considered to be limiting and not in tune with changing weather patterns – such as increased intense rainfall events (i.e. the freshwater floods straight into the sea in one event) and prolonged dry periods (i.e. policies limit storage of water on farms). Scientific data on possible changing rainfall patterns were highly varied and not uniform across the research area, but an indication of increased dry months over time across two out of three catchment locations was found (Section 4.4.2). The disjointed nature of managing at the scale of watershed areas by local, provincial and natural government, in conjunction with highly variable local climate systems such as the southern Cape, can lead to local resource users reaching the limit of their adaptive capacity if adaptation measures do not account for possible future climate shifts (Wiid and Ziervogel, 2012).

Shifting baselines are also important to consider when examining knowledge disconnects (Pauly, 1995), as the interpretation of present variability observed in natural resources (such as water availability or fish abundance) by natural resource users (such as farmers or fishers) is dependent on historical knowledge of these resources (for example Sáenz-Arroyo et al., 2005; Ainsworth et al., 2008; Papworth et al., 2009). For example, together with high environmental and climatic variability, there are often challenges associated with examining the extent to which fish stocks have changed over time due to a lack of historical data – which can result in knowledge mismatches within fishers' observations of how and why fish stocks are altering over time (Gammage et al., 2017a). Recent research conducted by Currie (2017) shows substantial depletion of economically important fish stocks (such as *Argyrosomus* (kob) species) over the last 100 years on the Agulhas Bank, examined under a multitude of drivers ranging from fishing pressure to climate and environmental change dynamics. Currie (2017) noted that consistent, large catches of large-sized kob species historically fished on the Central and Eastern Agulhas Bank are difficult to imagine for contemporary fishers and scientists, thus illustrating the importance of historical data to counter shifting baselines – demonstrating how these fish communities have changed drastically since the 1900s. Shifting baselines are problematic in that human societies become tolerant to the creeping loss of biodiversity (Sáenz-Arroyo et al., 2005), which can undermine the sustainability of social-ecological systems (Folke et al., 2011).

This section highlights the importance of overlaying different bodies of knowledge when working within complex social-ecological systems, as synergies and mismatches described above reduce uncertainty and highlight potential knowledge gaps. This has contributed to confirming environmental regime shifts in the research area, identifying knowledge disconnects for ecosystem services linked to terrestrial water availability, and highlighted scale disconnects in fisher perceptions in near- and off-shore change.

6.4. Responding to change

Considering factors that drive decisions around land use practices or fishing methods are important to contextualise in order to understand how farmers or fishers operate in relation to environmental change. This section discusses local farming communities' responses to change, with a focus on climate variability, in relation to those of fishing communities. Responses of farmers and fishers to change in southern Cape communities are contextualised through Figure 6.3, where adaptation can be characterised through stressors (for example climate variability, economic drivers and governance), characteristics (for example resilience, vulnerability and adaptive capacity), multiple scales and responses (for example reactive, concurrent and anticipatory (Bryant et al., 2000; Smit and Wandel, 2006).

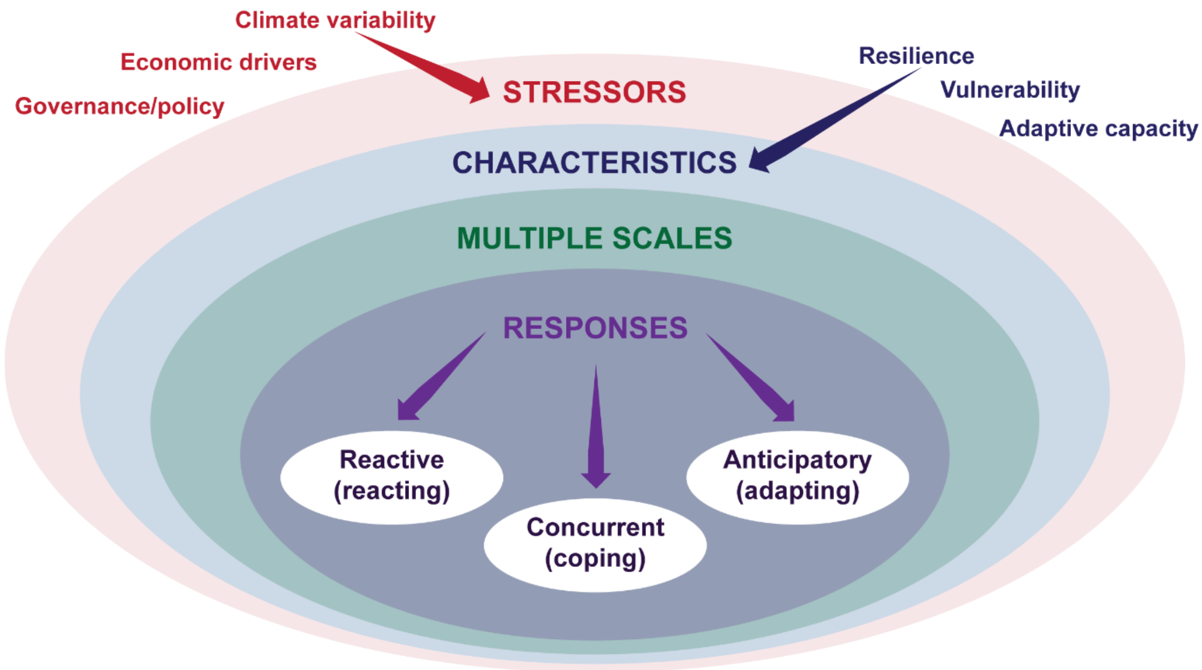


Figure 6.3: Four main components of adaptation as identified by and adapted from Bryant et al. (2000): (1) the characteristics of the stress, (2) the characteristics of the system, (3) multiple scales and (4) adaptive responses – reactive, concurrent and anticipatory (based on Smit and Wandel (2006))

6.4.1. Contextualising responses to change

When examining responses in relation to climate variability, both farming and fishing communities in the research area did not place this stressor as the top concern (refer to Tables 3.4 and 5.1). As noted by Thomas et al. (2007: 319), "(l)ivelihoods change and people adapt to the pressures and opportunities provided by many variables operating at a range of scales, of which climate is only one". Understanding how people respond to changes in their environment can be examined through how local practices have evolved over time, driven by various factors across multiple scales, as examined below.

6.4.1.1. Southern Cape farming communities

Substantial changes in the agricultural sector of the southern Cape have taken place recently, altering the agricultural landscape and (more noticeably) the type of farmers. When examining farmer typologies described in Section 3.4.2.2, the majority of farmers in the area engaged in large-scale commercial agriculture but could be distinguished between multi-generational farming families (present in the area for more than one generation) and first generation farmers, who had moved into the area from the 1980s. Multi-generation farmers tended to employ less diversified farming practices in that they focus on more traditional sheep, grain, cattle and dairy production – employing mixed farming strategies (for example altering livestock to grain ratio*) to build resilience, depending on access to technology, conservation practices, market demands and (more minor) climate variation. First generation farmers, while engaging primary in commercially viable agriculture associated with dairy, sheep and cattle, tended to diversify into more 'niche' markets such as game meat, berries and avocado to strengthen livelihood income strategies. While these large-scale commercial farmers can be considered resilient in that they employ a number of farming strategies and alter them

*For example, multi-generation farmers located on the vlakte areas observed that their parents' generation had a larger livestock to grain ratio – for example 60 % livestock and 40 % grain. In the present farming generation, these farmers have altered this practice and have a larger grain to livestock ratio – for example 70 % grain and 30 % livestock. This shift was prompted due to advances in mechanised technology, successes with conservation agriculture methods, and market demands. Farmers still employed some strategy diversification in the event that the primary strategy (e.g. grain) failed one year.

according to market, technology and climate considerations; a large amount of financial capital is required to support this livelihood strategy, and this was listed as a key challenge within farming communities. Wiid and Ziervogel (2012) cautioned that, in the context of challenges associated with costly financial solutions and heightened water limitations, commercial farmers in the Western Cape may soon reach their adaptive capacity limit if future climate variability becomes more pronounced in this region.

The most noticeable recent change in the southern Cape is the decline of the dairy industry that took place from the 1990s, during which agricultural practices shifted from dairy-dominated activities to grain, sheep and ostrich farming due to unfavourable market forces (see Section 3.4.1.2). This also saw a marked decline of small- and medium-scale dairy farmers across the area, where 96 % of these farms ceased to exist by local estimates – either sold off to neighbouring farmers or outside (wealthy) buyers if they could not buy additional land to expand commercial operations. The decline of small- and medium-scale farmers are largely due to reactive strategies – where unfavourable market forces, compounded by harsh dry spells experienced in the 1990s, pushed vulnerable farmers into changing their livelihood strategies and leaving the agricultural sector. Additionally, the remaining subsistence farmers in the research area can also be viewed as more vulnerable to change within the agricultural context when compared to their large-scale commercial counterparts. These small-scale farmers are unable to derive a viable income through farming activities alone and are required to diversify livelihood strategies outside of the agricultural sector (for example one participant worked full-time as a mechanic), but still consider themselves as farmers. This change in the southern Cape is linked to the narrative of 'scale of economy', where farmers whose primary livelihood is agriculture note that it is not feasible to successfully compete in modern contexts as smallholders. This is reflected in a study by Collier and Dercon (2014), who examine economies of scale (skills and technology; finance and access to capital; and trading, marketing and storage) in relation to small-scale African agriculture and argue that a focus on smallholder agriculture for growth is not proven to succeed and that development strategies need to be more inclusive of new forms of commercialization. More research is required into the different levels of vulnerability, resilience and adaptive capacity of farmers in relation to economies of scale and how this impacts the sustainability of local social-ecological systems.

The recent decline of commercial small- and medium-scale farmers in the research area has also seen the introduction of a new type of land use, namely 'lifestyle' farming – where the land owner does not derive primary income from agricultural activities, but can still be a producer of agricultural goods and impact the physical landscape (Pinto-Correia et al., 2014). In Europe lifestyle farming forms a socio-technological niche as it introduces novel land uses (Pinto-Correia et al., 2014), which is reflected in the southern Cape as these lifestyle farmers have introduced agricultural products such as olives, wine and game that have altered the traditional farming landscape. This relatively new form of farming in the southern Cape also places a focus on land practices linked to conservation (i.e. clearing of alien vegetation and rehabilitation of indigenous plants), where similar trends are observed in Australia (Pannell and Wilkinson, 2009; Gill et al., 2010). While lifestyle farmers in my research area can be seen as resilient as they have agency through access of large amounts of financial capital to support their desired farming strategies, this shift in farming practices could also create vulnerabilities in the larger system. For example, the shift from labour-intensive dairy farming to mechanised crop production or lifestyle agriculture in the southern Cape has affected the traditional farm workforce (see Section 3.4.5.3 for details). These shifts have most likely left farm workers more vulnerable and adversely affects their livelihoods as they have limited agency in terms of financial and social capital, coupled with burdens of health problems such as the abuse of alcohol (London, 2003). Vulnerabilities in the farming workforce, which are possibly exacerbated through land owners' decisions to change practices or sell due to adverse market, political and climate conditions, warrants future research.

6.4.1.2. Southern Cape fishing communities

The commercial, small-scale handline fishery in the southern Cape has a history of marginalisation in terms of policy that has tended to favour large-scale commercial trawl fisheries since the twentieth century (Visser, 2015). Additionally, these handline fisheries have traditionally struggled to access markets, either due to the remoteness of geographic location or competition with commercial trawlers (Visser, 2015). In the last five years, this fishery has not had a productive or lucrative fishing season as fishers have not been able to harvest sufficient quantities of silver kob to make their livelihoods financially viable (Gammage et al., 2017b). Gammage et al. (2017b) found that southern

Cape handline fishers responded to stressors either through adapting in the long term or pursued strategies such as waiting for the poor fishing conditions to improve through coping or reacting. While farmers and their responses to change can be grouped according to typology (i.e. commercial, lifestyle or subsistence), fishers were grouped in terms of geographic location – communities of fishers from (1) Mossel Bay, Witsand and Gouritsmond; (2) Still Bay and Melkhoutfontein; and (3) Vermaaklikheid.

Fishers who employed adapting strategies, linked to diversification in terms of changing fishing craft and target fish species, tended to have a more business-orientated approach and these individuals had access to sufficient capital making these fishers more resilient to change (Gammage et al., 2017b). This strategy was more in line with large-scale commercial farmers in the southern Cape, who were able to respond to change by relying on financial capital. While this perceived advantage can make these particular farmers and fishers resilient, there is also the danger that this resilience will be compromised if their adaptive capacity to meet financial challenges is exceeded. In contrast, fishers who employed coping or reacting strategies tended to rely on supplementary livelihood strategies such as alternative informal employment, spousal income and social grants, while either decreasing fishing effort or targeting alternative (usually less lucrative) fish species (Gammage et al., 2017b). As research conducted by Gammage et al. (2017b) included both skipper and crew when examining linefishers, participants experienced stressors differently as their capacities to respond were influenced by alternative skill sets, access to capital and education level (Smit and Wandel, 2006) – also highlighting the need to conduct future research on farm workers responses to change.

6.4.2. Responding to uncertainty

The majority of farmers who participated in my research observed shifts in their local weather patterns, specifically referencing rainfall as this was what most farmers deemed important in terms of impacting farming strategies (Chapter Three). However, less than half of these farmers noted that these climate variations directly influenced their farming strategies, where the impact of weather patterns on farming strategies was regarded as either an adapting (medium-term) or coping (short-term) exercise by farmers. All farmers stressed that weather patterns in the research area were highly variable and not characterised by predictable trends, which possibly contribute to the outlook that other factors linked to finances, politics and socio-economic are more important considerations for the farming community – whereas the already highly variable weather patterns of the southern Cape are regarded as part of the agricultural environment. Similarly, commercial farmers in the highly variable climate of the Karoo also regarded these weather risks as inherently part of the system and as such there was a level of expectation that accompanied perceived shifts in rainfall and temperatures over time (Muller and Shackleton, 2014). The aseasonal weather characteristics of the southern Cape described in Section 3.2.2 could dampen changes that signal permanent shifts in climate patterns (Maddison, 2007) and farmers who employ coping rather than adapting strategies may become more vulnerable over time (Ziervogel et al., 2008).

Similar to farmers, fishers in the southern Cape also observed changes in the weather patterns associated with their fishing grounds in the in-shore region of the Agulhas bank with specific reference to prevailing wind conditions, as this was considered an important factor that impacted sea state (see Section 5.4.1.2 for detailed description). As in the case of farmers in my research area, fishers also highlighted that their local marine system had always been inherently variable in terms of weather patterns, where discrepancies emerged between different observations as to whether this variability was cyclic or had become linearly more extreme over time (Gammage et al., 2017a). Gammage et al. (2017a) caution that the failure to correctly identify local climate drivers can hamper fishers' abilities to successfully respond to these stressors; which is reinforced by the lack of good quality, long-term environmental data and the naturally variable climate system of the Agulhas Bank (Section 5.2).

This high uncertainty presents a major challenge in both farming and fishing communities in terms of local climate adaptation, as knowledge disconnects are translated into perceptions of climate variability and thus responses by farmers and fishers may not be sufficient due to the complexities associated with the natural system (Section 6.3.2). Farmers placed challenges associated with finances, politics, workforce and water availability as more pressing in relation to climate variability (see Section 3.4.5), which are reflected in the drivers discussed in Section 6.4.2 as these are perceived as motivators to respond to changes. Similarly in fishing communities, the long history of fisher's marginalisation within the linefishery sector from a political stance (Visser, 2015) has resulted in fishers identifying policy and regulation as a major stressor over climate variability (Gammage et al., 2017b). Both farmers and fishers in my research area viewed markets as hostile entities, where they felt they were competing against monopoly industries that were not well regulated. Overall, priority challenges and stressors of farmers and fishers focused on economic and political factors, which were seen as major drivers or hindrances of change within the terrestrial and marine social-ecological system of the southern Cape.

6.4.3. Examples of climate-related responses

As discussed in this section, the failure to recognise changes in climate variability by local communities could lead these natural resource users to be pushed into vulnerable states should the natural system experience sudden changes or regime shifts. While both farmers and fishers in the southern Cape do not necessarily place climate variability as the key stressor to which they plan for future adaptation, conservation agriculture and 'thinking like a fish' (Duggan et al., 2014) provide intricate narratives from these communities on climate-related adaption strategies playing out in the southern Cape.

Interestingly, 70 % of participants engaged in some form of conservation agriculture and while farmers acknowledged the benefits of this practice in terms of successfully mitigating effects of (for example) the later onset of the traditional rain season for planting or improving soil moisture retention due to prolonged dry periods, this shift in practice was largely described in terms of economic benefits due to improved crop outputs. Mase et al. (2017) found that social norms were important among commercial crop farmers in the United States, particularly where the implementation of conservation practices and technologies were concerned, and that these norms would likely influence farmers' adaptation behaviours as they are 'on-the-ground' and easily observed by neighbours. While not examined in detail by this research, some participating farmers in the southern Cape noted that wealthier, more established commercial farmers tended to experiment with new farming strategies first and, depending on their successes (or failures), neighbouring farmers would follow suit if deemed profitable. In the case of conservation agriculture, this farming strategy became popular in the 1990s when a few large-scale commercial farmers located in the vlakte area shifted farming practices from livestock to crop to accommodate an increase in dry periods and market trends.

Within the southern Cape linefishery, Duggan et al. (2014) explored an outlook referred to as 'thinking like a fish' – where fishers link fish and the act of fishing as dynamic and inherent with variability. From the fishers' perspective, thinking like a fish entails a process of thinking more empathetically, where fishers learn from these relational engagements and then adapt fishing strategies accordingly, which vary between individual fishers and are defined through context to shift roles where required (Duggan et al., 2014). This strategy is used by fishers to locate, attract and catch fish that is situated in a framing of learning from the fish, which is underpinned through thinking of ways to conserve fish populations and their marine habitat. Duggan et al. (2014) note that this outlook provides a range of adaptive strategies that enable fishers to respond to shifting environmental variability, with the possibility of decreasing social vulnerability and enhancing marine stewardship. Similarly to the concept of conservation agriculture, 'thinking like a fish' has been highlighted as a potential ethical, ecological and economically-viable strategy for local fishers (Duggan et al., 2014). Both conservation agriculture and 'thinking like a fish' can be viewed in terms of responses to complex changes, specifically in the context of climate adaptation, in terrestrial and marine social-ecological systems as a potential means to build resilience in local livelihoods by making them economically viable, without eroding ecosystem services by employing sustainable environmental practices (Folke et al., 2011).

In line with work done by Grothmann and Patt (2005), this thesis shows that perceptions of climate variability play a critical role in determining the motivation of these communities to respond to multiple stressors within complex social-ecological systems. Dynamic and complex social-ecological systems need to be built upon resilience strategies, as strategies that aim for maximum production and short-term gain can jeopardise ecosystems and human well-being in the medium to long term (for example Folke et al., 2011). Opportunities for adaptation are presented within the operating context of decision making, access to effective adaptation options and the capacity of individuals and institutions to adapt under stressors (Smit and Wandel, 2006).

6.5. Conclusion

Bringing together terrestrial and marine perspectives from natural resource users (i.e. farmers and fishers) on environmental changes in complex terrestrial and marine systems of the southern Cape (Figure 6.1) gives a detailed perspective of climate variability in relation to local farming and fishing communities of the southern Cape. Local knowledge can be coupled with scientific data and research in order to make understanding on a particular issue more robust, thus contributing to more grounded and diverse knowledge bases for adaptive management practices in society (Ommer, 2007; Tengö et al., 2014). By triangulating local knowledge with data from other sources, thus expressing symmetry of knowledge systems, a more comprehensive understanding of environmental change was developed and possible knowledge disconnects identified, supported through work carried out by Tibby et al. (2007); Tengö et al. (2014). This research highlights synergies (see Section 6.3.1) and mismatches (see Section 6.3.2) between terrestrial and marine social-ecological systems through examining different knowledge bases within these systems (Figure 6.2).

Through incorporating mixed methods that uses a convergent parallel design to analyse different strands of qualitative and quantitative data (see Figure 2.5), a multi-evidence base emerged from diverse knowledge strands of farmers, fishers and scientific observations under the common theme of climate variability. Parallel approaches used to assess farmer and fisher narratives, in conjunction with scientific observations, were deemed a useful approach as each knowledge stream added value within an individual context, but were equally valuable when used in parallel to examine complex systems, in line with Tengö et al. (2014). The individual context allowed this research to investigate perceptions of climate variability of farmers and fishers to understand why individuals responded (or not) to system stressors. This was then built into scientific knowledge through interrogating databases by asking questions specific to climate experiences of local actors, after which local and scientific knowledge strands were inspected in parallel to better understand complex local systems under climate variability. Inspecting complementary, contradictory and synergies of diverse knowledge systems strengthen learning and improve understanding of complex social-ecological systems (Tengö et al., 2014), which was demonstrated through this research (Figure 6.1).

From a historical perspective, narratives from farmers (Chapter Three) and fishers (Chapter Five) in the southern Cape provide a multi-generational perspective of change that in turn creates a rich backdrop to understanding how the agricultural and handline fisheries sectors have evolved in this area. This also provides context for how climate variability has been experienced over multiple decadal scales in the southern Cape, which assists in addressing complex knowledge disconnects as a result of shifting baselines (Sáenz-Arroyo et al., 2005). Local knowledge on climate variability and change from farmers and fishers provided insight into complex, multi-scale drivers of change that play out over different temporal and spatial timeframes (Figure 6.2). The benefits of examining these diverse knowledge systems in parallel across terrestrial and marine systems were evident in the synergies and disconnects that emerged from the integrative analysis. While impossible to eliminate uncertainty around projected climate variability and change, this multi-evidence base confirmed environmental regime shifts that have taken place and strengthens advice for evidence-based, strategic decision-making that is locally relevant.

Examining multiple knowledge bases can also add insights into how social components of these complex systems interact with (and even exacerbate) environmental change. Large-scale environmental change is often difficult to quantify through only using scientific approaches, particularly in data poor areas that lack long-term monitoring programmes (such as the Agulhas Bank). Local knowledge from farmers and fishers, particularly communities that have been active in an area over a few generations, can provide valuable insights for researchers, managers and policy makers – for example enhancing the understanding of subtle changes in rainfall distribution across micro-climates in the southern Cape, which has implications for agricultural strategies and freshwater use. Another example relates to the requirement for scientific data that is scale appropriate, which was highlighted through subtle changes in wind observations by fishers and the compatibility of bay-scale wind data products to assess environmental change that is locally relevant to users.

CHAPTER SEVEN

REFLECTIONS AND CONCLUSIONS

7.1. Introduction

As discussed in Chapter One, South Africa has experienced a suite of challenges in the last two decades in both agriculture and fishery sectors, linked to both biophysical and anthropogenic components of these complex local systems. The 'new normal' of variability in local climate, as discussed by Wolski (2017), usher in an era of change for South African communities dependent on natural resources, such as farmers and fishers. While adaptation to environmental shifts and climatic variability should embody innovation, it should also build on the best available research-based knowledge (United Nations, 2012). Environmental drivers of change remain poorly understood within the highly variable natural systems of the southern Cape and Agulhas Bank and current regional or global projections of climate change do not necessarily translate when scaled down to the local context of the research area. Uncertainty also persists in the relationship between local terrestrial and marine climate drivers, and the extent to which these systems interact has not been extensively researched, providing motivation for the present research. When dealing with high uncertainty, particularly related to climate change in complex natural environments that are poorly understood, drawing on diverse knowledge assists in addressing gaps or directing focus to specific changes that are relevant to local livelihoods dependent on natural resource bases, detailed in Chapter Six.

How do we then place local adaptation in terms of sustainability into conversation with the bigger context of the Anthropocene? This concluding chapter reflects on the different framings and concepts used to situate and interpret work carried out by this PhD research. Specifically, this chapter looks at how sustainability can be characterised for southern Cape communities in relation to the Anthropocene through unpacking human-environment interactions presented in different academic discourses (introduced in Section 2.2). Understanding how the research discussed throughout this thesis is interpreted in the context of resilient social-ecological systems brings a nuanced appreciation of local complex systems operating across multiple scales (introduced in

Sections 2.3 and 2.4), where the drawbacks of these concepts are also highlighted. This moves the conversation into a space that considers the future of local communities operating in the Anthropocene.

7.2. Reflections on academic discourses

This thesis focused on a planetary stewardship discourse to interpret sustainability, which allowed this research to be depicted through a social-ecological framing. This discourse was a fitting framing to examine links between terrestrial and marine systems in farming and fishing communities of the southern Cape as these natural and social systems are dynamic, complex and connect across multiple scales. Ecosystem services are central to livelihoods dependent on natural resources, such as farmers (see Chapter Three) and fishers (see Chapter Five). Understanding how local ecosystems function within the larger framing of Earth system goods and services as described by Steffen et al. (2011) is important when unpacking ecological and social systems in tandem (for example in Section 6.2.3).

However, as highlighted by Preiser et al. (2017), there is a need to integrate existing framings of broad academic discourses (eco-modernism, biosphere stewardship, sustainable pathways and critical post-humanism, see Table 2.1) so that management policy responses to challenges experienced in the Anthropocene are nuanced, socially considerate and credible. Drawing on elements across these broad academic discourses, different features can be incorporated to assist management policies through transformation pathways in southern Cape communities, in order to create viable livelihoods under uncertain climate variability. As it is difficult to predict the exact climate trajectory of this region, natural resource users need to plan with this uncertainty in mind and theoretical plurality can assist in the development of meaningful scenarios for exploring possible future responses. Figure 7.1 outlines the four broad academic discourses discussed by Preiser et al. (2017) in the context of challenges (such as climate variability, regime shifts and land-use change) of the Anthropocene; which are scaled down to local community level and selected elements across the academic discourses are discussed below.

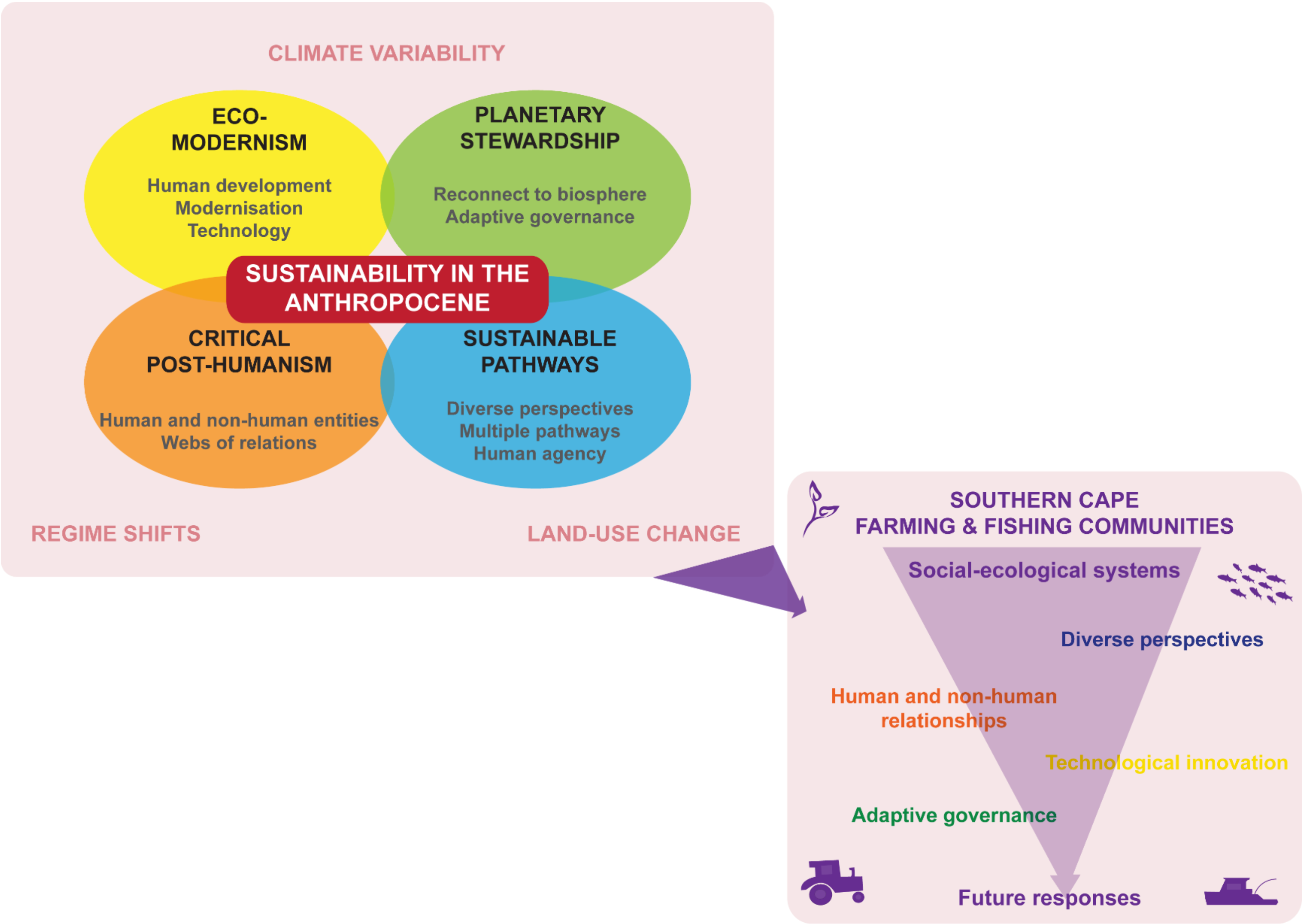


Figure 7.1: Integrating features from broad academic discourses of eco-modernism, biosphere stewardship, sustainable pathways and critical post-humanism to characterise responses to challenges of the Anthropocene in southern Cape communities

When framing future responses to challenges of the Anthropocene within the local context of southern Cape communities; integrating **social-ecological systems** thinking from the planetary stewardship approach with **diverse perspectives** from the sustainable pathways approach builds a more holistic understanding of complex systems under change; rather than exclusively relying on a natural-scientific outlook that may be limited in terms of data availability or monitoring records for the southern Cape and its associated Agulhas Bank region (refer to Chapter Six). However, in the context of this research, using an approach that heavily characterised communities in terms of social-ecological systems was limiting in that the complexity of humanity was restricted within a systems perspective with an environmental focus. This speaks to the complexity of scale, where social and ecological components embody two different dimensions that operate on different scales from the individual (both social and ecological) to community (social) or assemblage (ecological) to province/nation (social) or region (ecological). My research focused on the individual scale of decision-makers (i.e. farmers and fishers) and weather stations that were scaled up to assess commonalities at community or assemblage level across the region from both social and ecological dimensions. While examining natural systems of the southern Cape at a (sub-)system scale provides a meaningful overview of the ecological component, similarly demonstrated through research by Watermeyer (2015); the social dimension was difficult to capture in my research through a climate variability lens.

As summarised in Section 6.4, driving forces of change that influenced natural resource users within farming and fishing communities of the southern Cape were not necessarily linked to changes in local climate or environment, but rather a complex web of connections between human agency, economic forces or political will. For example, a prominent change in the agricultural community of the southern Cape was linked to individual choice associated with the rise in lifestyle farming that constituted land-use change, influenced by the scale of economy through the collapse of the dairy industry in this area. The complexity of humanity and their relationship with the environment requires a nuanced view that interrogates social components of social-ecological systems not only across different scales (i.e. individual, community and province/nation), but should also include themes such as **circumstances** that relate to individual decisions that affect communities; **connections** between human and non-human entities; and non-human aspects that are integral to modern human experience such as **technology**.

Drawing on academic disciplines such as critical post-humanism and eco-modernism, features such as human and non-human relationships and technological innovation can be extracted and translated into themes to add value to the social-ecological systems approach used in my research. From a critical post-humanism outlook, intricate relationships between people and the environment are connected through the agency of all species and entities, where agricultural and farming communities of the southern Cape will have to exist with temporalities in and of the earth that have been damaged in modern times (see Haraway (2016) for further explanation). From an eco-modernism perspective, technology has played an important role in shaping the historical agricultural landscape of the southern Cape (refer to Section 3.4.1.2) and the future of agriculture in the area was discussed in terms of increased mechanisation (linked to machinery) and technological advancements (linked to internet and cellular phone resources) by local farmers, thus emphasising the importance of such development in planning for the future. Local adaptation strategies within different segments of farming communities also need to consider how increased mechanisation can have the potential to make the livelihoods of farm workers redundant, discussed in Section 3.4.5.3.

When determining possible future responses of natural resource users to change in social-ecological systems, adding more robust themes to the social component will better depict why and how people respond to environmental change. Possible themes include unpacking individual agency, relationships between social and ecological dimensions that include economic and political factors, and the incorporation of technology as part of the human experience. For future consideration, technology could be incorporated as an additional dimension to the social-ecological plane to form a formal third dimension of systems research for transformation. Technology as a dimension is scalable from small scale (cellular phone and internet resources) to large scale (mechanisation) and can have a profound impact on the social dimension in terms of access to information that infers adaptation potential, and an equally important impact on the environment as it can determine natural resource use (for example, land use change through mechanisation).

Finally, moving response strategies forward, social-ecological thinking provides a good research paradigm but can be limiting when linking to policy. While this thesis did not delve into governance of natural resource uses, it is an important feature to consider within complex systems and this was highlighted by both farmers and fishers alike in the southern Cape. Within the planetary stewardship discourse, Folke et al. (2016) argue that sustainability within the Anthropocene can be achieved through **adaptive governance** that link people (socially driven) to the biosphere (scientifically driven). As discussed above, this should also consider the complexity of humanity operating in nuanced spaces (when adopting economic strategies for national policy). This requires a stronger link from social-ecological research to tangible governance (for example Gammage, in progress) that has traction in the context of South Africa's neo-liberal economy, where current local markets are seen as hostile entities by farmers and fishers in the southern Cape (see Section 6.4.2), who are operating in altering and possibly degraded ecosystems.

As cautioned by Paterson et al. (2013: 66) from the example of the Namibian Hake Fishery, "(a)s long as the larger political economy of the country is such that important decisions regarding resource access and the rights for exploitation are made without transparency, without the appropriate application of approaches to linkage development and export-led growth, and without reliable data, …objectives…will not be achieved, no matter how well intended the policies of the government may be". In local examples such as the southern Cape, a systems approach for management strategies based on the best available research would be integral to translating policy into practice through applying best-practice methodology into the application of these policies (for example Gammage, in progress). In terms of transparency in decision making, a social-ecological systems perspective that integrates environmental realities into the social realm of adaptation that considers individual agency; relationships between communities and their environmental, economic and political realities; as well as technological aspirations of communities can add value to planning future responses of local communities under global change.

7.3. Reflecting on resilient social-ecological systems

Framing this thesis in terms of social-ecological systems provided a good starting point for understanding complex interactions between social and ecological system components, where interactions and feedbacks between these components characterised the overall dynamics (Ommer, 2007; Biggs et al., 2015). As both farmers and fishers in my research area are heavily dependent on their natural resource base, the complex linkages between ecosystem services and local livelihoods have become more apparent. Contextualising ecosystem services in terms of larger global processes, as described by Steffen et al. (2011) through Earth System goods and services, is a useful framing as people tend to focus on changes that occur on land or in the atmosphere and overlook the role of the ocean. While this thesis focuses on climate processes at local scale within the social-ecological system of the southern Cape, the importance of climate drivers at different spatial scales has become clear when linking terrestrial and marine processes (see Section 6.2.3).

7.3.1. A resilience lens

Placing a resilience lens on social-ecological systems in the southern Cape and Agulhas Bank is useful to contextualise change in terms of how these systems respond to feedback and thresholds with the aim of supporting human well-being, particularly in the face of unexpected change. The importance of understanding resilience is determined through tipping points and thresholds (Folke et al., 2011), which were examined in both terrestrial and marine systems of my research area. Additionally, these changes in social-ecological systems can be linked to key environmental challenges associated with the Anthropocene (described in Section 2.1) that include climate variability, ecological regime shifts and changes in land-use.

Tipping points were characterised through ecological regime shifts in the form of large changes in ecosystems that persisted for an extensive period of time (deYoung et al., 2004). Noteworthy regime shifts that occurred in my research area in both terrestrial temperature and marine wind patterns, determined by overlaying local and scientific knowledge strands, occurred in the mid- to late-1990s; mid- to late-2000s (specifically

2007); and after 2010 (see Section 6.2.2). These regime shifts caused the related climate drivers to shift into different states for periods at a time, affecting local farming and fishing communities either directly or indirectly as livelihood strategies in one period may not have been successful under longer-term, shifted climate conditions. Other changes in thresholds in my research area, linked to climate variability (see Section 2.1.1), were subtle changes in rainfall patterns, which also pushed farmers to adapt their farming strategies accordingly (see Section 3.4.3.1).

Land use change was also observed as a key characteristic of the recent agricultural landscape of the southern Cape, influencing adaptation strategies the local farming community (Section 6.4.2.1). Tipping points in this local system were not exclusively defined in terms of environmental and climatic shifts, but were also driven through economic considerations. For example, the agricultural community of the southern Cape was dominated by dairy production in the 1980s, which declined in the 1990s due to unfavourable market conditions and smaller agricultural operations ceased to exist into the 2000s (Section 3.4.2.3). However, climatic stressors such as the particularly dry period in the 1990s and in 2009, enhanced this economic tipping point in the agricultural sector and, as discussed in Section 3.5, these underlying drivers can act as the 'straw that breaks the camel's back' – pushing land use change into a new state.

7.3.2. Placing climate into adaptation strategies

Adaptive capacity, commonly shared by resilience and vulnerability concepts, is useful to contextualise local responses to climate variability (see Section 2.6.3). While it is important to examine the larger multi-layered context in which uncertainty occurs under global environmental change, a good starting point to evaluate adaptive capacity is to gauge how current changes are experienced, interpreted and responded to at the local level (Vincent, 2007; Gammage et al., 2017a;b). Understanding how natural resource users make decisions based on their perceptions of climate variability, within the context of multi-stressor environments, can provide valuable understanding into how key decision-makers (i.e. farmers and skippers) formulate strategies based on risk perceptions and adapt (or not) their activities accordingly (Section 6.4).

External factors like regional environmental dynamics, institutions, resource availability and access to capital require consideration when examining adaptive capacity (Wiid and Ziervogel, 2012; Gammage et al., 2017a;b). Planning for climate adaptation "on land" in the southern Cape is weakened due to the lack of consideration of multi-stressors that could affect the capacity of farmers to adapt to changes in local contexts. While climate variation featured as a prominent stressor for the majority of farmers and fishers, other drivers related to political and economic factors were viewed as higher priority in terms of perceived risk or influences on changing strategies (Section 6.4.2). I have argued that an over-sight of climate changes, although subtle at present, could erode adaptive capacity in the long-term.

7.3.3. Possible limitations of a resilient social-ecological framing

The social-ecological framing provides a good research paradigm, as illustrated throughout this thesis, however it can be limited in terms of policy recommendation. From social perspectives, resilience does not always capture and reflect social dynamics in their entirety – where this framing can be limiting when considering issues of agency and power (Béné et al., 2012). Agency – the freedom people have to negotiate their lives under adverse conditions – is often overlooked in the context of resilient social-ecological systems in favour of the ability of the system (in its entirety) to recover from shocks, overshadowing individual choices that may or may not shape resilience within the system. This also calls into question the ability of the resilience concept to adequately capture or analytically handle issues around power embodied in social systems.

An example from my research has been provided through contextualising the (recent) change in farming practices in the southern Cape in response to economic changes in the southern Cape, such as the rise of lifestyle farming practices and increased mechanisation of large commercial farming methods. These farmers tend to rely less on labour-intensive practices, which exacerbates vulnerability in the workforce due to job losses. While lifestyle and mechanised commercial farming practices can be viewed as resilient in the larger system due to their economic success based on access to financial capital, individual choices regarding the traditional workforce are likely playing a significant role in shaping vulnerability of linked social systems in the southern Cape. To address these drawbacks, the diverse components of co-evolving social-ecological systems can be better analysed and understood using adaptation activity spaces through a transformation lens, as described by Pelling et al. (2015). Within the context of adaptation to climate change, the transformation lens adds ethical and procedural considerations for policy makers that were limited within the context of my research through a resilience perspective. However, the resilience lens was more suitable in the context of my research as it provided a good starting point to analyse both terrestrial and marine social-ecological dimensions in tandem for the southern Cape.

Another example can be linked to regime shifts, where research highlighted in this thesis (see Chapter 5) could be relevant to policy and overlaid with adaptation strategies, as discussed in section 7.3.1. However, while useful for policy, regime shifts have not yet been taken up in fisheries management in South Africa despite having been demonstrated for over a decade (Howard et al., 2007). This could be related to power dynamics that are highlighted by Jarre et al. (2018) in connection to political dynamics of small pelagic fisheries. Implementation of policy is a hindering factor in the South African context and should be examined in detail, which is beyond the scope of this thesis.

7.4. Conclusion

"Science has responsibility to provide a better understanding of the challenges facing humanity, and to explore pathways toward a sustainable world" (Folke et al., 2011: 733)

The work presented in this thesis is unique in that it brings together two entities that are traditionally viewed in isolation – land and sea. Through integrating different knowledge bases from terrestrial and marine social-ecological systems of the southern Cape and Agulhas Bank, this thesis contributes a multi-evidence base of knowledge towards improving our understanding of local climate variability and change over time. Furthermore, this thesis highlights the importance of interpreting pressing challenges of the Anthropocene within the context of local livelihood realities to better inform adaptation practices at different scales.

In the context of social-ecological systems in the southern Cape, planning for the future under high uncertainty of climate variability and regime shifts can be realised through recognising that human well-being and healthy ecosystems are closely connected. The concept of human well-being can be expanded to include individual agency, webs of relations between human and non-human entities, and technological innovation. My results have highlighted that there continues to be an urgent need to improve data collection on the regional scale in order to better inform decision makers of state and possible trajectories in the near future, irrespective of whether the decision makers be local natural resource users or representatives of government. My results have also shown that it is possible to incorporate multiple knowledge systems and this approach can be used to identify synergies and gaps in management strategies of natural resource use both in farming and in the handline fishery. Moving forward, this thesis has contributed to enriching understanding of terrestrial and marine systems in the southern Cape under the theme of climate variability, thus providing content to explore further strategies at local levels to global challenges in the Anthropocene.

REFERENCES

Abel, T. & Stepp, J. R. 2003. A new ecosystems ecology for anthropology. *Conservation Ecology,* 7**:** 12.

Acker, J. G., Harding, L. W., Leptoukh, G., Zhu, T. & Shen, S. 2005. Remotely-sensed chl a at the Chesapeake Bay mouth is correlated with annual freshwater flow to Chesapeake Bay. *Geophysical Research Letters,* 32**.**

Adger, W. N. 1999. Social Vulnerability to Climate Change and Extremes in Coastal Vietnam. *World Development,* 27**:** 249-269.

Adger, W. N. 2006. Vulnerability. *Global Environmental Change,* 16**:** 268-281.

Adger, W. N., Hughes, T. P., Folke, C., Carpenter, S. R. & Rockström, J. 2005. Social-Ecological Resilience to Coastal Disasters. *Science,* 309**:** 1036-1039.

Adger, W. N. & Vincent, K. 2005. Uncertainty in adaptive capacity. *Comptes Rendus Geoscience,* 337**:** 399-410.

Ainsworth, C. H., Pitcher, T. J. & Rotinsulu, C. 2008. Evidence of fishery depletions and shifting cognitive baselines in Eastern Indonesia. *Biological Conservation,* 141**:** 848-859.

Allsopp, N., Colville, J. F. & Verboom, G. A. 2014. *Fynbos: ecology, evolution, and conservation of a megadiverse region,* Oxford University Press, Oxford, UK.

Anderies, J. M., Janssen, M. A. & Ostrom, E. 2004. A framework to analyze the robustness of social-ecological systems from an institutional perspective. *Ecology and Society,* 9**:** 1-18.

Aswani, S., Howard, J., Gasalla, M. A., Jennings, S., Malherbe, W., Martins, I. M., Narayanakumar, R., Van Putten, I. E., Salim, S. S., Swathilekshmi, P. S. & Watmough, G. R. 2018. An integrated framework for assessing coastal community vulnerability across cultures, oceans and scales. *Climate and Development*.

Auricht, H. C. C., Clarke, K. D., Lewis, M. M. & Mosley, L. M. 2017. Have droughts and increased water extraction from the Murray River (Australia) reduced coastal ocean productivity? *Marine and Freshwater Research***.**

Bazeley, P. 2013. *Qualitative data analysis: Practical strategies*, SAGE Publications. 320 pp.

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W. & Courchamp, F. 2012. Impacts of climate change on the future of biodiversity. *Ecology Letters,* 15**:** 365-377.

Béné, C., Wood, R. G., Newsham, A. & Davies, M. 2012. *Resilience: New Utopia or New Tyranny? Reflection about the Potentials and Limits of the Concept of Resilience in Relation to Vulnerability Reduction Programmes*. IDS Working Papers. 61 pp.

Bennett, N. J., Dearden, P. & Peredo, A. M. 2014. Vulnerability to multiple stressors in coastal communities: a study of the Andaman coast of Thailand. *Climate and Development,* 7**:** 124-141.

Berkes, F., Colding, J. & Folke, C. 2003. *Navigating social-ecological systems: Building resilience for complexity and change.* Cambridge University Press, Cambridge, UK**.** 393 pp.

Biggs, R., Carpenter, S. R. & Brock, W. A. 2009. Turning back from the brink: Detecting an impending regime shift in time to avert it. *Proceedings of the National Academy of Sciences,* 106**:** 826-831.

Biggs, R., Schlüter, M., Biggs, D., Bohensky, E. L., Burnsilver, S., Cundill, G., Dakos, V., Daw, T. M., Evans, L. S., Kotschy, K., Leitch, A. M., Meek, C., Quinlan, A., Raudsepp-Hearne, C., Robards, M. D., Schoon, M. L., Schultz, L. & West, P. C. 2012. Toward Principles for Enhancing the Resilience of Ecosystem Services. *Annual Review of Environment and Resources,* 37**:** 421-448.

Biggs, R., Schlüter, M. & Schoon, M. L. 2015. *Principles for Building Resilience: Sustaining Ecosystem Services in Social-Ecological Systems*, Cambridge University Press, Cambridge, UK. 290 pp.

Blamey, L. K., Howard, J. a. E., Agenbag, J. & Jarre, A. 2012. Regime-shifts in the southern Benguela shelf and inshore region. *Progress in Oceanography,* 106**:** 80-95.

Blamey, L. K., Shannon, L. J., Bolton, J. J., Crawford, R. J. M., Dufois, F., Evers-King, H., Griffiths, C. L., Hutchings, L., Jarre, A., Rouault, M., Watermeyer, K. E. & Winker, H. 2015. Ecosystem change in the southern Benguela and the underlying processes. *Journal of Marine Systems,* 144**:** 9-29.

Bohle, H. G., Downing, T. E. & Watts, M. J. 1994. Climate change and social vulnerability: Toward a sociology and geography of food insecurity. *Global Environmental Change,* 4**:** 37-48.

Brook, R. K. & Mclachlan, S. M. 2008. Trends and prospects for local knowledge in ecological and conservation research and monitoring. *Biodiversity and Conservation,* 17**:** 3501-3512.

Bryan, E., Deressa, T. T., Gbetibouo, G. A. & Ringler, C. 2009. Adaptation to climate change in Ethiopia and South Africa: Options and constraints. *Environmental Science & Policy,* 12**:** 413-426.

Bryant, C. R., Smit, B., Brklacich, M., Johnston, T. R., Smithers, J., Chiotti, Q. & Singh, B. 2000. Adaptation in Canadian Agriculture to Climatic Variability and Change. *In:* KANE, S. M. & YOHE, G. W. (eds.) *Societal Adaptation to Climate Variability and Change.* Springer Netherlands, Dordrecht.

Burgman, M. 2005. *Risks and Decisions for Conservation and Environmental Management,* Cambridge University Press, Cambridge, UK. 488 pp.

Burns, M. & Weaver, A. 2008. *Exploring Sustainability Science: A Southern African Perspective,* African SUN MeDIA, Stellenbosch**.** 625 pp.

Chambers, R. 1989. *Editorial Introduction: Vulnerability, Coping and Policy*. IDS Bulletin 20**.** 7 pp.

Chambers, R. & Conway, G. 1991. *Sustainable rural livelihoods: practical concepts for the 21st century*. Institute of Development Studies. IDS Discussion Paper 296.

Cheung, W. W. L., Lam, V. W. Y., Sarmiento, J. L., Kearney, K., Watson, R. & Pauly, D. 2009. Projecting global marine biodiversity impacts under climate change scenarios. *Fish and Fisheries,* 10**:** 235-251.

Cinner, J. E., Adger, W. N., Allison, E. H., Barnes, M. L., Brown, K., Cohen, P. J., Gelcich, S., Hicks, C. C., Hughes, T. P., Lau, J., Marshall, N. A. & Morrison, T. H. 2018. Building adaptive capacity to climate change in tropical coastal communities. *Nature Climate Change,* 8**:** 117-123.

Coetzee, J. C., Van Der Lingen, C. D., Hutchings, L. & Fairweather, T. P. 2008. Has the fishery contributed to a major shift in the distribution of South African sardine? *ICES Journal of Marine Science,* 65**:** 1676-1688.

Collie, J. S., Richardson, K. & Steele, J. H. 2004. Regime shifts: Can ecological theory illuminate the mechanisms? *Progress in Oceanography,* 60**:** 281-302.

Collier, P. & Dercon, S. 2014. African Agriculture in 50Years: Smallholders in a Rapidly Changing World? *World Development,* 63**:** 92-101.

Creswell, J. W. & Plano Clark, V. L. 2011. *Designing and conduction mixed methods* research, 2nd Edition, SAGE Publications, United States of America.

Crutzen, P. J. 2002. Geology of mankind. *Nature,* 415**:** 23-23.

Cundill, G., Lotz-Sisitka, H., Mukute, M., Belay, M., Shackleton, S. & Kulundu, I. 2014. A reflection on the use of case studies as a methodology for social learning research in sub Saharan Africa. *NJAS - Wageningen Journal of Life Sciences,* 69**:** 39-47.

Currie, J. C. 2017. *Historical baselines and a century of change in the demersal fish assemblages on South Africa's Agulhas Bank.* Degree of Doctor of Philosophy thesis, University of Cape Town.

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E. & Webb, J. 2008. A place-based model for understanding community resilience to natural disasters. *Global Environmental Change,* 18**:** 598-606.

Department of Agriculture, Fisheries and Forestry (DAFF) 2012. *Strategic Plan 2012/3 - 2016/7*. Department of Agriculture, Forestry and Fisheries, Pretoria.

Department of Agriculture, Fisheries and Forestry (DAFF) 2014. *Status of the South African marine fishery resources*. Department of Agriculture, Forestry and Fisheries, Pretoria.

Department of Agriculture, Fisheries and Forestry (DAFF) 2015. *Strategic Plan: 2015/6 to 2019/20*. Department of Agriculture, Forestry and Fisheries, Pretoria.

Department of Agriculture, Fisheries and Forestry (DAFF) 2016. *Status of the South African marine fishery resources 2016*. Department of Agriculture, Forestry and Fisheries, Cape Town.

Darwin, C. R. 1859. *On the Origin of Species*, D. Appelton and Company, New York.

Department of Environmental Affairs (DEA) 2013. *Long-Term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa. Climate Trends and Scenarios for South Africa*. Department of Environmental Affairs. Pretoria.

Dentlinger, L. 2017. Westerb Cape declared disaster zone amid drought. *EWN Eyewitness News*. URL: http://ewn.co.za/2017/05/22/western-cape-declared-disaster-zone-amid-drought.

Desbiolles, F., Bentamy, A., Blanke, B., Roy, C., Mestas-Nuñez, A. M., Grodsky, S. A., Herbette, S., Cambon, G. & Maes, C. 2017. Two decades [1992–2012] of surface wind analyses based on satellite scatterometer observations. *Journal of Marine Systems,* 168**:** 38-56.

deYoung, B., Harris, R., Alheit, J., Beaugrand, G., Mantua, N. & Shannon, L. 2004. Detecting regime shifts in the ocean: Data considerations. *Progress in Oceanography,* 60**:** 143-164.

Dieppois, B., Pohl, B., Rouault, M., New, M., Lawler, D. & Keenlyside, N. 2016. Interannual to interdecadal variability of winter and summer southern African rainfall, and their teleconnections. *Journal of Geophysical Research: Atmospheres,* 121**:** 6215-6239.

Dieppois, B., Rouault, M. & New, M. 2015. The impact of ENSO on Southern African rainfall in CMIP5 ocean atmosphere coupled climate models. *Climate Dynamics,* 45**:** 2425-2442.

Dixon, J., Stringer, L. & Challinor, A. 2014. Farming System Evolution and Adaptive Capacity: Insights for Adaptation Support. *Resources,* 3**:** 182.

Driver, A., Sink, K. J., Nel, J. N., Holness, S., Niekerk, L. V., Daniels, F., Jonas, Z., Majiedt, P. A., Harris, L. & Maze, K. 2012. *National Biodiversity Assessment 2011: An assessment of South Africa's biodiversity and ecosystems. Synthesis Report.* South African National Biodiversity Institute and Department of Environmental Affairs, Pretoria.

Du Plessis, J. A. & Schloms, B. 2017. An investigation into the evidence of seasonal rainfall pattern shifts in the Western Cape, South Africa. *Journal of the South African Institution of Civil Engineering,* 59**:** 47-55.

Duggan, G. 2012. *In the realm of Kob Kings: Rethinking knowledges and dialogue in small-scale fishery.* Master of Social Science, University of Cape Town.

Duggan, G. 2018. *Return to the Realm of the Kob Kings: Social Capital, Learning, Resilience and Action Research in a Changing Fishery.* Degree of Doctor of Philosophy thesis, University of Cape Town.

Duggan, G. L., Green, L. J. & Jarre, A. 2014. 'Thinking like a fish': adaptive strategies for coping with vulnerability and variability emerging from a relational engagement with kob. *Maritime Studies,* 13**:** 4.

Eakin, H. & Luers, A. L. 2006. Assessing the Vulnerability of Social-Environmental Systems. *Annual Review of Environment and Resources,* 31**:** 365-394.

Eakin, H. C. & Wehbe, M. B. 2009. Linking local vulnerability to system sustainability in a resilience framework: two cases from Latin America. *Climatic Change,* 93**:** 355-377.

Easterling, D. R., Evans, J. L., Groisman, P. Y., Karl, T. R., Kunkel, K. E. & Ambenje, P. 2000. Observed Variability and Trends in Extreme Climate Events: A Brief Review. *Bulletin of the American Meteorological Society,* 81**:** 417-425.

Easterling, W. E. 1996. Adapting North American agriculture to climate change in review. *Agricultural and Forest Meteorology,* 80**:** 1-53.

Ellis, E. C. 2011. The planet of No return: human resilience on an artifical earth. *Breakthrough Journal,* 2**:** 37–44.

Elum, Z. A., Modise, D. M. & Marr, A. 2017. Farmer's perception of climate change and responsive strategies in three selected provinces of South Africa. *Climate Risk Management,* 16**:** 246-257.

Engle, N. L. 2011. Adaptive capacity and its assessment. *Global Environmental Change,* 21**:** 647-656.

Evans, J. 2017. Western Cape R295m 'day zero' water plan kicks in. *News24*. URL: https://www.news24.com/SouthAfrica/News/western-cape-r295m-day-zero-water-plan-kicks-in-20170831.

Fabricius, C., Scholes, R. & Cundill, G. 2006. Mobilizing Knowledge for Integrated Ecosystem Assessments. *In:* REID, W., WILBANKS, T., CAPISTRANO, D. & BERKES, F. (eds.) *Bridging Scales and Knowledge Systems: Concepts and Applications in Ecosystem Assessment.* World Resources Institute and Millennium Ecosystem Assessment.

Field, J. G. & Shillington, F. A. 2005. Variability of the Benguela Current System. *In:* ROBINSON, A. R. & BRINK, K. H. (eds.) *The Sea: The Global Coastal Ocean.*

Fink, A. 2009. *How to conduct surveys: A step-by-step guide*, 4th Edition, SAGE Publications.

Foley, J. A., Defries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., Gibbs, H. K., Helkowski, J. H., Holloway, T., Howard, E. A., Kucharik, C. J., Monfreda, C., Patz, J. A., Prentice, I. C., Ramankutty, N. & Snyder, P. K. 2005. Global Consequences of Land Use. *Science,* 309**:** 570-574.

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Mueller, N. D., O'connell, C., Ray, D. K., West, P. C., Balzer, C., Bennett, E. M., Carpenter, S. R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D. & Zaks, D. P. M. 2011. Solutions for a cultivated planet. *Nature,* 478**:** 337.

Folke, C. 2006. Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change,* 16**:** 253-267.

Folke, C., Biggs, R., Norström, A. V., Reyers, B. & Rockström, J. 2016. Social-ecological resilience and biosphere-based sustainability science. *Ecology and Society,* 21.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L. & Holling, C. S. 2004. Regime Shifts, Resilience, and Biodiversity in Ecosystem Management. *Annual Review of Ecology, Evolution, and Systematics,* 35**:** 557-581.

Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T. & Rockström, J. 2010. Resilience Thinking: Integrating resilience, adaptability and transformability. *Ecology and Society,* 15**:** 20.

Folke, C. & Gunderson, L. 2012. Reconnecting to the Biosphere: A Social-Ecological Renaissance. *Ecology and Society,* 17.

Folke, C., Jansson, Å., Rockström, J., Olsson, P., Carpenter, S. R., Chapin, F. S., Crépin, A.-S., Daily, G., Danell, K., Ebbesson, J., Elmqvist, T., Galaz, V., Moberg, F., Nilsson, M., Österblom, H., Ostrom, E., Persson, Å., Peterson, G., Polasky, S., Steffen, W., Walker, B. & Westley, F. 2011. Reconnecting to the Biosphere. *AMBIO,* 40**:** 719.

Frank, E., Eakin, H. & López-Carr, D. 2011. Social identity, perception and motivation in adaptation to climate risk in the coffee sector of Chiapas, Mexico. *Global Environmental Change,* 21**:** 66-76.

Frankenberger, T., Mueller, M., Spangler, T. & Alexander, S. 2013. *Community Resilience: Conceptual Framework and Measurement Feed the Future Learning Agenda*. USAID, Rockville, MD.

Gallopín, G. C. 2006. Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change,* 16**:** 293–303.

Gammage, L. C. 2015. *Considering one's options when the fish leave: A case study of traditional commercial hand-line fishery in southern Cape.* Master of Science thesis, University of Cape Town.

Gammage, L. C., Jarre, A. & Mather, C. 2017a. A case study from the southern Cape linefishery 1: The difficulty of fishing in a changing world. *South African Journal of Science,* 113**:** 1-8.

Gammage, L. C., Jarre, A. & Mather, C. 2017b. A case study from the southern Cape linefishery 2: Considering one's options when the fish leave. *South African Journal of Science,* 113**:** 1-10.

Gammage, L. C., Jarre, A. & Mather, C. in review. A changing fishery system: perspectives from crew in the southern Cape's handline fishery.

Gammage L.C. in progress. *Development of a scenario-based approach for adaptation to change in fishery systems: A case study in the small scale fisheries of the southern Cape*. Degree of Doctor of Philosophy thesis, University of Cape Town.

Gandure, S., Walker, S. & Botha, J. J. 2013. Farmers' perceptions of adaptation to climate change and water stress in a South African rural community. *Environmental Development,* 5**:** 39-53.

Gephart, J. A., Deutsch, L., Pace, M. L., Troell, M. & Seekell, D. A. 2017. Shocks to fish production: Identification, trends, and consequences. *Global Environmental Change,* 42**:** 24-32.

Gill, N., Klepeis, P. & Chisholm, L. 2010. Stewardship among lifestyle oriented rural landowners. *Journal of Environmental Planning and Management,* 53**:** 317-334.

Goodman, L. A. 2011. Comment: On Respondent-Driven Sampling and Snowball Sampling in Hard-to-Reach Populations and Snowball Sampling Not in Hard-to-Reach Populations. *Sociological Methodology,* 41**:** 347-353.

Gordon, L. J. & Enfors, E. 2008. Land degradation, ecosystem services and resilience of smallholder farmers in Makanya catchment, Tanzania. *In:* BOSSIO, D. & GEHEB, K. (eds.) *Conserving land, protecting water.* CABI, UK.

Government Gazette 2000. *Notice 4727 of 2000*. The Minister of Environmental Affairs and Tourism, Pretoria.

Griffiths, M. H. 2000. Long-term trends in catch and effort of commercial linefish off South Africa's Cape Province: snapshots of the 20th century. *South African Journal of Marine Science,* 22**:** 81-110.

Grothmann, T. & Patt, A. 2005. Adaptive capacity and human cognition: The process of individual adaptation to climate change. *Global Environmental Change,* 15**:** 199-213.

Haggan, N., Turner, N., Carpenter, J., Jones, J. T., Mackie, Q. & Menzies, C. R. 2006. *12,000+ years of change: Linking traditional and modern ecosystem science in the Pacific Northwest*. Fisheries Centre Working Paper.

Hanley, K. E., Belcher, S. E. & Sullivan, P. P. 2010. A Global Climatology of Wind–Wave Interaction. *Journal of Physical Oceanography,* 40**:** 1263-1282.

Haraway, D. J. 2016. *Staying with the Trouble: Making Kin in the Chthulucene.* Duke University Press, Durham and London**.** 312 pp.

Hauge, K. H., Cleeland, B. & Wilson, D. C. 2009. *Fisheries Depletion and Collapse*. International Risk Governance Council, Geneva.

Hessequa Municipality 2017. *Hessequa Municipality: Annual Report 2016-2017*. Hessequa Municipality, Riversdale.

Hitayezu, P., Wale, E. & Ortmann, G. 2017. Assessing farmers' perceptions about climate change: A double-hurdle approach. *Climate Risk Management,* 17**:** 123-138.

Hobday, A. J., Cochrane, K., Downey-Breedt, N., Howard, J., Aswani, S., Byfield, V., Duggan, G., Duna, E., Dutra, L. X. C., Frusher, S. D., Fulton, E. A., Gammage, L., Gasalla, M. A., Griffiths, C., Guissamulo, A., Haward, M., Jarre, A., Jennings, S. M., Jordan, T., Joyner, J., Ramani, N. K., Shanmugasundaram, S. L. P., Malherbe, W., Cisneros, K. O., Paytan, A., Pecl, G. T., Plagányi, É. E., Popova, E. E., Razafindrainibe, H., Roberts, M., Rohit, P., Sainulabdeen, S. S., Sauer, W., Valappil, S. T., Zacharia, P. U. & Van Putten, E. I. 2016. Planning adaptation to climate change in fast-warming marine regions with seafood-dependent coastal communities. *Reviews in Fish Biology and Fisheries,* 26**:** 249-264.

Hobday, A. J. & Pecl, G. T. 2014. Identification of global marine hotspots: sentinels for change and vanguards for adaptation action. *Reviews in Fish Biology and Fisheries,* 24**:** 415-425.

Hoffman, T. & Ashwell, A. 2001. *Nature divided: Land degradation in South Africa,* University of Cape Town Press, Cape Town**.** 168 pp.

Holling, C. S. 1961. Principles of Insect Predation. *Annual Review of Entomology,* 6**:** 163-182.

Holling, C. S. 1973. Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics,* 4**:** 1-23.

Howard, J. a. E., Jarre, A., Clark, A. E. & Moloney, C. L. 2007. Application of the sequential t-test algorithm for analysing regime shifts to the southern Benguela ecosystem. *African Journal of Marine Science,* 29**:** 437-451.

Hutchings, J. A. & Myers, R. A. 1994. What Can Be Learned from the Collapse of a Renewable Resource? Atlantic Cod, Gadus morhua, of Newfoundland and Labrador. *Canadian Journal of Fisheries and Aquatic Sciences,* 51**:** 2126-2146.

Hutchings, L., Jarre, A., Lamont, T., Van Den Berg, M. & Kirkman, S. P. 2012. St Helena Bay (southern Benguela) then and now: muted climate signals, large human impact. *African Journal of Marine Science,* 34**:** 559-583.

Hutchings, L., Van Der Lingen, C. D., Shannon, L. J., Crawford, R. J. M., Verheye, H. M. S., Bartholomae, C. H., Van Der Plas, A. K., Louw, D., Kreiner, A., Ostrowski, M., Fidel, Q., Barlow, R. G., Lamont, T., Coetzee, J., Shillington, F., Veitch, J., Currie, J. C. & Monteiro, P. M. S. 2009. The Benguela Current: An ecosystem of four components. *Progress in Oceanography,* 83**:** 15-32.

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) 2018. *Summary for policymakers of the assessment report on land degradation and restoration of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. R. Scholes, L. Montanarella, A. Brainich, N. Barger, B. ten Brink, M. Cantele, B. Erasmus, J. Fisher, T. Gardner, T. G. Holland, F. Kohler, J. S. Kotiaho, G. Von Maltitz, G. Nangendo, R. Pandit, J. Parrotta, M. D. Potts, S. Prince, M. Sankaran and L. Willemen (eds.). IPBES secretariat, Bonn, Germany. 44 pp.

International Panel on Climate Change (IPCC) 2007. *Climate change 2001: impacts, adaptation, and vulnerability*. Intergovernmental Panel on Climate Change, Geneva, Switzerland.

International Panel on Climate Change (IPCC) 2014. *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *In:* PACHAURI, R. K. & MEYER, L. A. (eds.). International Panel on Climate Change, Geneva, Switzerland.

Jackson, J. B. C., Kirby, M. X., Berger, W. H., Bjorndal, K. A., Botsford, L. W., Bourque, B. J., Bradbury, R. H., Cooke, R., Erlandson, J., Estes, J. A., Hughes, T. P., Kidwell, S., Lange, C. B., Lenihan, H. S., Pandolfi, J. M., Peterson, C. H., Steneck, R. S., Tegner, M. J. & Warner, R. R. 2001. Historical Overfishing and the Recent Collapse of Coastal Ecosystems. *Science,* 293**:** 629-637.

James, N. 2015. Climate change is hitting South Africa's coastal fish. *The Conversation*. URL: https://theconversation.com/climate-change-is-hitting-south-africas-coastal-fish-44802.

Janssen, M. A., Anderies, J. M. & Ostrom, E. 2007. Robustness of Social-Ecological Systems to Spatial and Temporal Variability. *Society & Natural Resources,* 20**:** 307-322.

Janssen, M. A. & Ostrom, E. 2006. Resilience, vulnerability, and adaptation: A cross-cutting theme of the International Human Dimensions Programme on Global Environmental Change. *Global Environmental Change,* 16**:** 237-239.

Jarre, A., Hutchings, L., Kirkman, S. P., Kreiner, A., Tchipalanga, P. C. M., Kainge, P., Uanivi, U., Van Der Plas, A. K., Blamey, L. K., Coetzee, J. C., Lamont, T., Samaai, T., Verheye, H. M., Yemane, D. G., Axelsen, B. E., Ostrowski, M., Stenevik, E. K. & Loeng, H. 2015. Synthesis: climate effects on biodiversity, abundance and distribution of marine organisms in the Benguela. *Fisheries Oceanography,* 24**:** 122-149.

Jarre, A., Ragaller, S. M. & Hutchings, L. 2013. Long-term, Ecosystem-Scale Changes in the Southern Benguela Marine Pelagic Social-Ecological System: Interaction of Natural and Human Drivers. *Ecology and Society,* 18.

Jarre, A., Shannon, L. J., Cooper, R., Duggan, G. L., Gammage, L. C., Lockerbie, E. M., Mcgregor, E. S., Ragaller, S. M., Visser, N., Ward, C., Watermeyer, K. E., Weller, F. G. & Ommer, R. E. 2018. Untangling a Gordian knot that must not be cut: Social-ecological systems research for management of southern Benguela fisheries. *Journal of Marine Systems*.

Johnson, R. B., Onwuegbuzie, A. J. & Turner, L. A. 2007. Toward a Definition of Mixed Methods Research. *Journal of Mixed Methods Research,* 1**:** 112-133.

Kanamitsu, M., Ebisuzaki, W., Woollen, J., Yang, S.-K., Hnilo, J. J., Fiorino, M. & Potter, G. L. 2002. NCEP–DOE AMIP-II Reanalysis (R-2). *Bulletin of the American Meteorological Society,* 83**:** 1631-1643.

King, D. N. T., Skipper, A. & Tawhai, W. B. 2008. Māori environmental knowledge of local weather and climate change in Aotearoa – New Zealand. *Climatic Change,* 90**:** 385.

Lamont, T., García-Reyes, M., Bograd, S. J., Van Der Lingen, C. D. & Sydeman, W. J. 2017. Upwelling indices for comparative ecosystem studies: Variability in the Benguela Upwelling System. *Journal of Marine Systems*.

Leach, M., Raworth, K. & Rockström, J. 2013. Between social and planetary boundaries: Navigating pathways in the safe and just space for humanity. *World Social Science Report 2013: Changing Global Environments.* OECD Publishing/UNESCO Publishing, Paris.

Leach, M., Rockström, J., Raskin, P., Scoones, I., Stirling, A. C., Smith, A., Thompson, J., Millstone, E., Ely, A., Arond, E., Folke, C. & Olsson, P. 2012. Transforming Innovation for Sustainability. *Ecology and Society,* 17**:** 11.

Leichenko, R. M. & O'brien, K. L. 2002. The Dynamics of Rural Vulnerability to Global Change: The Case of southern Africa. *Mitigation and Adaptation Strategies for Global Change,* 7**:** 1-18.

Lewis, S. L. & Maslin, M. A. 2015. Defining the Anthropocene. *Nature,* 519**:** 171-180.

London, L. 2003. Human Rights, Environmental Justice, and the Health of Farm Workers in South Africa. *International Journal of Occupational and Environmental Health,* 9**:** 59-68.

Lutz, J. S. & Neis, B. 2008. *Making and Moving Knowledge: Interdisciplinary and Community-based Research in a World on the Edge.* McGill-Queen's University Press, Montreal and Kingston**.** 338 pp.

Lyttle, C. in progress. *The variability and change in sea state as relevant to the small-scale handline fishery of the Southern Cape, South Africa*. Master of Science thesis, University of Cape Town.

Mackellar, N., New, M. & Jack, C. 2014. Observed and modelled trends in rainfall and temperature for South Africa: 1960–2010. *South African Journal of Science,* 110.

Mackinson, S. & Nottestad, L. 1998. Points of View: Combining Local and Scientific Knowledge. *Reviews in Fish Biology and Fisheries,* 8**:** 481-490.

Maddison, D. 2007. *The Perception of and Adaptation to Climate Change in Africa*. Policy Research Working Paper. World Bank, Washington, DC.

Marshall, N. A., Marshall, P. A., Tamelander, J., Obura, D., Malleret-King, D. & Cinner, J. E. 2009. *A Framework for Social Adaptation to Climate Change: Sustaining Tropical Coastal Communities and Industries*. International Union for Conservation of Nature and Natural Resources, Gland, Switzerland.

Mase, A. S., Gramig, B. M. & Prokopy, L. S. 2017. Climate change beliefs, risk perceptions, and adaptation behavior among Midwestern U.S. crop farmers. *Climate Risk Management,* 15**:** 8-17.

Masipa, T. S. 2017. The impact of climate change on food security in South Africa: Current realities and challenges ahead. *Jàmbá: Journal of Disaster Risk Studies*, 9: 1.

May, R. M. 1977. Thresholds and breakpoints in ecosystems with a multiplicity of stable states. *Nature,* 269**:** 471.

Mcsweeney, K. & Coomes, O. T. 2011. Climate-related disaster opens a window of opportunity for rural poor in northeastern Honduras. *Proceedings of the National Academy of Sciences,* 108**:** 5203-5208.

Mead, A., Griffiths, C. L., Branch, G. M., Mcquaid, C. D., Blamey, L. K., Bolton, J. J., Anderson, R. J., Dufois, F., Rouault, M., Froneman, P. W., Whitfield, A. K., Harris, L. R., Nel, R., Pillay, D. & Adams, J. B. 2013. Human-mediated drivers of change - impacts on coastal ecosystems and marine biota of South Africa. *African Journal of Marine Science,* 35**:** 403-425.

Midgley, G. F., Chapman, R. A., Hewitson, B., Johnston, P., De Wit, M., Ziervogel, G., Mukheibir, P., Van Niekerk, L., Tadross, M., Van Wilgen, B. W., Kgope, B., Morant, P. D., Theron, A., Scholes, R. J. & Forsyth, G. G. 2005. *A Status Quo, Vulnerability and Adaptation Assessment of the Physical and Socio-economic Effects of Climate Change in the Western Cape*. Report to the Western Cape Government, Stellenbosch.

Midgley, S., New, M. & Methner, N. 2016. *A Status Quo Review of Climate Change and the Agriculture Sector of the Western Cape Province*. Western Cape Department of Agriculture and the Western Cape Department of Environmental Affairs & Development Planning, Cape Town.

Millennium Ecosystem Assessment 2003. *Ecosystems and human well-being: a framework for assessment.* Island Press, Washington, DC**.** 245 pp.

Millennium Ecosystem Assessment 2005. *Ecosystems and Human Well-being: Synthesis.* Island Press, Washington, DC**.** 137 pp.

Moench, M. 2014. Experiences applying the climate resilience framework: linking theory with practice. *Development in Practice,* 24**:** 447-464.

Moloney, C. L., Fennessy, S. T., Gibbons, M. J., Roychoudhury, A., Shillington, F. A., Von Der Heyden, B. P. & Watermeyer, K. 2013. Reviewing evidence of marine ecosystem change off South Africa. *African Journal of Marine Science,* 35**:** 427-448.

Morehouse, B. J., Ferguson, D. B., Owen, G., Browning-Aiken, A., Wong-Gonzalez, P., Pineda, N. & Varady, R. 2008. Science and socio-ecological resilience: examples from the Arizona-Sonora Border. *Environmental Science & Policy,* 11**:** 272-284.

Mpfunzeni, T. 2015. *Quantifying decadal changes in land cover in the Duiwenhoks catchment using spatial analysis techniques.* Master of Science thesis, University of KwaZulu-Natal.

Muller, C. & Shackleton, S. E. 2014. Perceptions of climate change and barriers to adaptation amongst commonage and commercial livestock farmers in the semi-arid Eastern Cape Karoo. *African Journal of Range & Forage Science,* 31**:** 1-12.

Nchaba, T., Mpholo, M. & Lennard, C. 2017. Long-term austral summer wind speed trends over southern Africa. *International Journal of Climatology,* 37**:** 2850-2862.

Neis, B. & Felt, L. F. 2000. *Finding Our Sea Legs: Linking Fishery People and Their Knowledge with Science and Management.* ISER Books, Newfoundland.

Nelson, D. R., Adger, W. N. & Brown, K. 2007. Adaptation to Environmental Change: Contributions of a Resilience Framework. *Annual Review of Environment and Resources,* 32**:** 395-419.

Newing, H. and contributors 2011. *Conducting Research in Conservation: A Social Science Perpective*. Routledge, Oxon.

Ngoepe, K. 2015. 5 provinces declared drought disaster areas. *News24*. URL: https://www.news24.com/SouthAfrica/News/5-provinces-declared-drought-disaster-areas-20151113.

Nicolson, C. R., Starfield, A. M., Kofinas, G. P. & Kruse, J. A. 2002. Ten Heuristics for Interdisciplinary Modeling Projects. *Ecosystems,* 5**:** 376-384.

Nyong, A., Adesina, F. & Osman Elasha, B. 2007. The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. *Mitigation and Adaptation Strategies for Global Change,* 12**:** 787-797.

Nzonda, G. 2016. *Characterising historical land cover change, and understanding trends in the Goukou catchment, Western Cape, South Africa.* Master of Science thesis, University of KwaZulu-Natal.

Olsson, P. & Folke, C. 2001. Local Ecological Knowledge and Institutional Dynamics for Ecosystem Management: A Study of Lake Racken Watershed, Sweden. *Ecosystems,* 4**:** 85-104.

Ommer, R. E. and team 2007. *Coasts Under Stress: Restructuring and Social-Ecological Health.* McGill-Queen's University Press, Montreal.

Ommer, R. E., Ian Perry, R., Murray, G. & Neis, B. 2012. Social–ecological dynamism, knowledge, and sustainable coastal marine fisheries. *Current Opinion in Environmental Sustainability,* 4**:** 316-322.

Osbahr, H., Dorward, P., Stern, R. & Cooper, S. 2011. Supporting agricultural innovation in Uganda to respond to climate risk: Linking climate change and variability with farmer perceptions. *Experimental Agriculture,* 47**:** 293-316.

Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action.* Cambridge University Press, Cambridge, UK**.** 280 pp.

Pannell, D. J. & Wilkinson, R. 2009. Policy mechanism choice for environmental management by non-commercial "lifestyle" rural landholders. *Ecological Economics,* 68**:** 2679-2687.

Papworth, S. K., Rist, J., Coad, L. & Milner-Gulland, E. J. 2009. Evidence for shifting baseline syndrome in conservation. *Conservation Letters,* 2**:** 93-100.

Paterson, B., Isaacs, M., Hara, M., Jarre, A. & Moloney, C. L. 2010. Transdisciplinary co-operation for an ecosystem approach to fisheries: A case study from the South African sardine fishery. *Marine Policy,* 34**:** 782-794.

Paterson, B., Kirchner, C. & Ommer, R. E. 2013. A Short History of the Namibian Hake Fishery: A Social-Ecological Analysis. *Ecology and Society,* 18.

Pauly, D. 1995. Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology and Evolutions,* 10**:** 430.

Pelling, M., O'brien, K. & Matyas, D. 2015. Adaptation and transformation. *Climatic Change,* 133**:** 113-127.

Perry, R. I. & Ommer, R. E. 2003. Scale issues in marine ecosystems and human interactions. *Fisheries Oceanography,* 12**:** 513-522.

Perry, R. I., Ommer, R. E., Barange, M., Jentoft, S., Neis, B. & Sumaila, U. R. 2011. Marine social-ecological responses to environmental change and the impacts of globalization. *Fish and Fisheries,* 12**:** 427-450.

Philippon, N., Rouault, M., Richard, Y. & Favre, A. 2012. The influence of ENSO on winter rainfall in South Africa. *International Journal of Climatology,* 32**:** 2333-2347.

Pinsky, M. L., Jensen, O. P., Ricard, D. & Palumbi, S. R. 2011. Unexpected patterns of fisheries collapse in the world's oceans. *Proceedings of the National Academy of Sciences of the United States of America,* 108**:** 8317-8322.

Pinto-Correia, T., Gonzalez, C., Sutherland, L.-A. & Peneva, M. 2014. Lifestyle farming: countryside consumption and transition towards new farming models. *In:* SUTHERLAND, L.-A., DARNHOFER, I., WILSON, G. & ZAGATA, L. (eds.) *Transition Pathways towards Sustainability in Agriculture: Case Studies from Europe.* CAB International, UK.

Poloczanska, E. S., Burrows, M. T., Brown, C. J., García Molinos, J., Halpern, B. S., Hoegh-Guldberg, O., Kappel, C. V., Moore, P. J., Richardson, A. J., Schoeman, D. S. & Sydeman, W. J. 2016. Responses of Marine Organisms to Climate Change across Oceans. *Frontiers in Marine Science,* 3.

Preiser, R., Pereira, L. M. & Biggs, R. 2017. Navigating alternative framings of human-environment interactions: Variations on the theme of 'Finding Nemo'. *Anthropocene,* 20**:** 83-87.

Price, P. 2006. *A Case Study of the Town of Heidelberg, Western Cape Province, South Africa*. The Institutional Response to the 22nd November 2004 Extreme Rain Event, Cape Town.

Reason, C. J. C. & Jagadheesha, D. 2005. Relationships between South Atlantic SST Variability and Atmospheric Circulation over the South African Region during Austral Winter. *Journal of Climate,* 18**:** 3339-3355.

Reason, C. J. C. & Rouault, M. 2005. Links between the Antarctic Oscillation and winter rainfall over western South Africa. *Geophysical Research Letters,* 32.

Reid, P. & Vogel, C. 2006. Living and responding to multiple stressors inSouth Africa - Glimpses from KwaZulu-Natal. *Global Environmental Change,* 16**:** 195–206.

River Health Programme 2007. *Rivers of the Gouritz Water Management Area*. River Health Programme, South Africa.

Rodionov, S. N. 2004. A sequential algorithm for testing climate regime shifts. *Geophysical Research Letters,* 31.

Rodionov, S. N. 2006. Use of prewhitening in climate regime shift detection. *Geophysical Research Letters,* 33.

Rodionov, S. N. & Overland, J. E. 2005. Application of a sequential regime shift detection method to the Bering Sea. *ICES Journal of Marine Science,* 62**:** 328–332.

Roessig, J. M., Woodley, C. M., Cech, J. J. & Hansen, L. J. 2004. Effects of global climate change on marine and estuarine fishes and fisheries. *Reviews in Fish Biology and Fisheries,* 14**:** 251-275.

Rogers, K. H., Luton, R., Biggs, H., Biggs, R., Blignaut, S., Choles, A. G., Palmer, C. G. & Tangwe, P. 2013. Fostering Complexity Thinking in Action Research for Change in Social and Ecological Systems. *Ecology and Society,* 18.

Rosenzweig, M. L. 1971. Paradox of enrichment: destabilization of exploitation ecosystems in ecological time. *Science,* 171**:** 385-7.

Rosin, C. J., Campbell, H. & Stock, P. V. 2012. *Food Systems Failure: The global food crisis and the future of agriculture,* Earthscan, Oxon.

Rouault, M., Pohl, B. & Penven, P. 2010. Coastal oceanic climate change and variability from 1982 to 2009 around South Africa. *African Journal of Marine Science,* 32**:** 237-246.

Roy, C., Van Der Lingen, C. D., Coetzee, J. C. & Lutjeharms, J. R. E. 2007. Abrupt environmental shift associated with changes in the distribution of Cape anchovy Engraulis encrasicolus spawners in the southern Benguela. *African Journal of Marine Science,* 29**:** 309-319.

Ruddiman, W. F., Ellis, E. C., Kaplan, J. O. & Fuller, D. Q. 2015. Defining the epoch we live in. *Science,* 348**:** 38-39.

Sáenz-Arroyo, A., Roberts, C., Torre, J., Cariño-Olvera, M. & Enríquez-Andrade, R. 2005. Rapidly shifting environmental baselines among fishers of the Gulf of California. *Proceedings of the Royal Society B: Biological Sciences,* 272**:** 1957-1962.

Salinger, M. J. 2005. Climate Variability and Change: Past, Present and Future – An Overview. *Climatic Change,* 70**:** 9-29.

Scheffer, M., Carpenter, S., Foley, J. A., Folke, C. & Walker, B. 2001. Catastrophic shifts in ecosystems. *Nature,* 413**:** 591.

Scholes, R. J., Reyers, B., Biggs, R., Spierenburg, M. J. & Duriappah, A. 2013. Multi-scale and cross-scale assessments of social–ecological systems and their ecosystem services. *Current Opinion in Environmental Sustainability,* 5**:** 16-25.

Schrank, W. E. & Roy, N. 2013. The Newfoundland Fishery and Economy Twenty Years after the Northern Cod Moratorium. *Marine Resource Economics,* 28**:** 397-413.

Scoones, I. 1998. *Sustainable rural livelihoods: A framework for analysis*. Institute of Development Studies, Working Paper 72.

Scoones, I. 1999. New Ecology and the Social Sciences: What Prospects for a Fruitful Engagement? *Annual Review of Anthropology,* 28**:** 479-507.

Seeliger, L. & Turok, I. 2013. Towards Sustainable Cities: Extending Resilience with Insights from Vulnerability and Transition Theory. *Sustainability,* 5**:** 2108.

Singleton, A. T. & Reason, C. J. C. 2007. Variability in the characteristics of cut-off low pressure systems over subtropical southern Africa. *International Journal of Climatology,* 27**:** 295-310.

Smit, B., Burton, I., Klein, R. J. T. & Street, R. 1999. The science of adaptation: a framework for assessment. *Mitigation and Adaptation Strategies for Global Change* 4**:** 199-213.

Smit, B. & Wandel, J. 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change,* 16**:** 282-292.

Solesbury, W. 2003. *Sustainable Livelihoods: A Case Study of the Evolution of DFID Policy*. Overseas Development Institute, London.

Srinivasan, U. T., Cheung, W. W. L., Watson, R. & Sumaila, U. R. 2010. Food security implications of global marine catch losses due to overfishing. *Journal of Bioeconomics,* 12**:** 183-200.

Steffen, W., Crutzen, P. J. & Mcneill, J. R. 2007. The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature. *AMBIO: A Journal of the Human Environment,* 36**:** 614-621.

Steffen, W., Persson, Å., Deutsch, L., Zalasiewicz, J., Williams, M., Richardson, K., Crumley, C., Crutzen, P., Folke, C., Gordon, L., Molina, M., Ramanathan, V., Rockström, J., Scheffer, M., Schellnhuber, H. J. & Svedin, U. 2011. The Anthropocene: From Global Change to Planetary Stewardship. *AMBIO: A Journal of the Human Environment,* 40**:** 739-761.

Sterling, E. J., Filardi, C., Toomey, A., Sigouin, A., Betley, E., Gazit, N., Newell, J., Albert, S., Alvira, D., Bergamini, N., Blair, M., Boseto, D., Burrows, K., Bynum, N., Caillon, S., Caselle, J. E., Claudet, J., Cullman, G., Dacks, R., Eyzaguirre, P. B., Gray, S., Herrera, J., Kenilorea, P., Kinney, K., Kurashima, N., Macey, S., Malone, C., Mauli, S., Mccarter, J., Mcmillen, H., Pascua, P. A., Pikacha, P., Porzecanski, A. L., De Robert, P., Salpeteur, M., Sirikolo, M., Stege, M. H., Stege, K., Ticktin, T., Vave, R., Wali, A., West, P., Winter, K. B. & Jupiter, S. D. 2017. Biocultural approaches to well-being and sustainability indicators across scales. *Nature Ecology & Evolution*.

Tansley, A. G. 1935. The Use and Abuse of Vegetational Concepts and Terms. *Ecology,* 16**:** 284-307.

Tengö, M., Brondizio, E. S., Elmqvist, T., Malmer, P. & Spierenburg, M. 2014. Connecting Diverse Knowledge Systems for Enhanced Ecosystem Governance: The Multiple Evidence Base Approach. *Ambio,* 43**:** 579-591.

The World Commission on Environment and Development 1987. *Report of the World Commission on Environment and Development: Our Common Future*, Oxford University Press, Oxford. 383 pp.

Thomas, D. S. G., Twyman, C., Osbahr, H. & Hewitson, B. 2007. Adaptation to climate change and variability: farmer responses to intra-seasonal precipitation trends in South Africa. *Climatic Change,* 83**:** 301-322.

Tibby, J., Lane, M. B. & Gell, P. A. 2007. Local knowledge and environmental management: a cautionary tale from Lake Ainsworth, New South Wales, Australia. *Environmental Conservation,* 34**:** 334-341.

Tol, R. S. J., Fankhauser, S. & Smith, J. B. 1998. The scope for adaptation to climate change: what can we learn from the impact literature? *Global Environmental Change,* 8**:** 109-123.

Tyson, P. D. & Preston-Whyte, R. A. 2000. *The Weather and Climate of Southern Africa,* Oxford University Press Southern Africa, Cape Town**.** 396 pp.

United Nations 1992. *United Nations Conference on Environment & Development Rio de Janerio, Brazil, 3 to 14 June 1992 AGENDA 21*. United Nations Sustainable Development, Brazil.

United Nations 2012. *Back to Our Common Future: Sustainable Development in the 21st century (SD21) project*. Department of Economic and Social Affairs, New York.

United Nations Development Programme 2014. *Community-Based Resilience Analysis (CoBRA) Conceptual Framework and Methodology*. Drought Risk Reduction Action Plan, UNDP Drylands Development Centre. 21 pp.

Van Sittert, L., Branch, G., Hauck, M. & Sowman, M. 2006. Benchmarking the first decade of post-apartheid fisheries reform in South Africa. *Marine Policy,* 30**:** 96-110.

Verran, H. 2002. A Postcolonial Moment in Science Studies: Alternative Firing Regimes of Environmental Scientists and Aboriginal Landowners. *Social Studies of Science,* 32**:** 729-762.

Vincent, K. 2007. Uncertainty in adaptive capacity and the importance of scale. *Global Environmental Change,* 17**:** 12-24.

Visser, N. 2015. The origins of the present: economic conflicts in the fisheries of the South African south coast, circa 1910 to 1950. *Maritime Studies,* 14**:** 9.

Walker, B., Holling, C. S., Carpenter, S. R. & Kinzig, A. 2004. Resilience, adaptability and transformability in social–ecological systems. *Ecology and Society,* 9**:** 5.

Walker, B. H., Anderies, J. M., Kinzig, A. P. & Ryan, P. 2006a. Exploring Resilience in Social-Ecological Systems Through Comparative Studies and Theory Development: Introduction to the Special Issue. *Ecology and Society,* 11.

Walker, B. H., Gunderson, L. H., Kinzig, A. P., Folke, C., Carpenter, S. R. & Schultz, L. 2006b. A handful of heuristics and some propositions for understanding resilience in social-ecological systems. *Ecology and Society,* 11**:** 13.

Wardekker, J. A., De Jong, A., Knoop, J. M. & Van Der Sluijs, J. P. 2010. Operationalising a resilience approach to adapting an urban delta to uncertain climate changes. *Technological Forecasting and Social Change,* 77**:** 987-998.

Watermeyer, K. E. 2015. *Ecosystem implications of the recent southward shift if key components in the southern Benguela.* Degree of Doctor of Philosophy thesis, University of Cape Town.

Watermeyer, K. E., Hutchings, L., Jarre, A. & Shannon, L. J. 2016. Patterns of Distribution and Spatial Indicators of Ecosystem Change Based on Key Species in the Southern Benguela. *PLOS ONE,* 11.

Watermeyer, K. E., Jarre, A., Shannon, L. J., Mulumba, P. & Botha, J. 2018. A frame-based modelling approach to understanding changes in the distribution and abundance of sardine and anchovy in the southern Benguela. *Ecological Modelling,* 371**:** 1-17.

Watts, M. J. & Bohle, H. G. 1993. The space of vulnerability: the causal structure of hunger and famine. *Progress in Human Geography,* 17**:** 43-67.

Westley, F., Olsson, P., Folke, C., Homer-Dixon, T., Vredenburg, H., Loorbach, D., Thompson, J., Nilsson, M., Lambin, E., Sendzimir, J., Banerjee, B., Galaz, V. & Van Der Leeuw, S. 2011. Tipping Toward Sustainability: Emerging Pathways of Transformation. *AMBIO,* 40**:** 762.

White, G. F. & Haas, J. E. 1975. *Assessment of Research on Natural Hazards.* MIT Press, Cambridge, MA.

Wiid, N. 2009. *Adaptation, adaptive capacity and water management : Evidence of a shifting climate and the Impacts on farming in the Little Brak River area.* Bachelor of Science Honours thesis, University of Cape Town.

Wiid, N. & Ziervogel, G. 2012. Adapting to climate change in South Africa: commercial farmers' perception of and response to changing climate. *South African Geographical Journal,* 94**:** 152-173.

Winker, H., Kerwath, S. E. & Attwood, C. G. 2014. *Report on age-structured stock assessments and the simulation of the impact of various fisheries management options for the South African linefishery*. Department of Agriculture, Forestry and Fisheries, Cape Town.

Winterhalder, B. 1980. Environmental analysis in human evolution and adaptation research. *Human Ecology,* 8**:** 135-170.

Wolski, P. 2017. Is Cape Town's drought the new normal? *GroundUp*. URL: https://www.groundup.org.za/article/cape-towns-drought-new-normal.

Wolski, P., Hewitson, B. & Jack, C. 2017. Why Cape Town's drought was so hard to forecast. *The Conversation*. URL: http://theconversation.com/why-cape-towns-drought-was-so-hard-to-forecast-84735.

Yin, R. K. 2009. *Case study research: Design and methods*, 4th Edition (Volume 5), SAGE Publications, United States of America. 219pp.

Young, O. R., Berkhout, F., Gallopin, G. C., Janssen, M. A., Ostrom, E. & Leeuw, S. V. D. 2006. The globalization of socio-ecological systems: An agenda for scientific research. *Global Environmental Change,* 16**:** 304–316.

Ziervogel, G., Cartwright, A., Tas, A., Adejuwon, J., Zermoglio, F., Shale, M. & Smith, B. 2008. *Climate change and adaptation in African agriculture*. Report Prepared for the Rockefeller Foundation by the Stockholm Environment Institute.

Ziervogel, G., New, M., Archer Van Garderen, E., Midgley, G., Taylor, A., Hamann, R., Stuart-Hill, S., Myers, J. & Warburton, M. 2014. Climate change impacts and adaptation in South Africa. *Wiley Interdisciplinary Reviews: Climate Change,* 5**:** 605-620.

Zietsman, L. 2011. *Observations on Environmental Change in South Africa*, African SUN MeDIA, Stellenbosch.

APPENDIX

APPENDIX 1A: FARMER QUESTIONNAIRE

January 2016

Farmer Questionnaire: Research Project

Coping with change in the southern Cape – assessment of past and present challenges in the Goukou and Duiwenhoks catchment area, with a focus on climate

1. General information:

1.1. Role of interviewee on farm: ____

1.2. Farm name and location: ____

1.3. Farm size: ____

1.4. Number of years on farm: ____

1.5. Number of years family in possession of farm: ____

1.6. Permanently live on the farm: Yes No

1.7. Main source of income: ____

1.8. Alternative sources of income: ____

1.9. What kind of farmer: Commercial Subsistence Lifestyle Other

2. Farming practices:

2.1. What do you farm today?

____

____

____

____

2.2. Has the type of farming or activities on your farm changed since you started farming? Yes No

If yes – when (year), how and why?

____

____

____

____

2.3. Has the type of farming in the area changed since you started farming? Yes No

If yes – when (year), how and why?

____

____

____

____

____

1

3. Attributes of farm:

3.1. Water

3.1.1. What is the main source of water for your farm?

____

____

3.1.2. Have you noticed changes in the water quality since you started farming? Yes No

If yes, when (year), how and why?

____

____

____

3.2. Soil

3.2.1. What are the main types of soil on your farm?

____

____

3.2.2. Have you made any changes to your soil composition since you started farming? Yes No

If yes, when (year, how and why?

____

____

____

3.2.2. Have you noticed changes in the soil quality since you started farming? Yes No

If yes, when (year), how and why?

____

____

____

4. Climate:

4.1. Do you use any environmental indicators to assist you in making decisions around farming activities? For example weather forecasting systems, seasonal indicators like the timing of the first rains, life cycles of plants and animals (plant fruiting timing or insect activities), sea temperatures. Yes No

If yes, what do you use, when did you start using it (year) and why?

____

4.2. Have you noticed climatic (weather) features such as the **time of main rainfall, rainfall amounts, severe storms, temperature changes and wind direction** that have noticeably changed during the time that you have farmed? Yes No

If yes, what, when (year) and how?

Where applicable – break up into time periods: **1980s; 1990-1999; 2000-2010; 2011-2015**

____

4.3. Have experienced any major flood and/or drought events since you have been on the farm? Yes No

If yes, when (years) and have you noticed any changes (frequency, severity) in when these events occur?

____

____

____

____

____

____

4.4. Has the weather impacted your farming methods or strategies? Yes No

4.4.1. If yes, when (year) and how?

____

____

____

____

4.4.2. What did you do to deal with these climatic (weather) shifts?

____

____

____

____

4.4.3. What would you have preferred to do to deal with these changes but were not able to?

____

____

____

____

4.5. How do you understand the term ‘climate change’? Do you think it will be important to consider in the future for farmers?

____

____

____

____

____

____

5. Challenges:

5.1. What are the major challenges have you faced while you have been farming on this farm?

Challenge 1: ____Year(s):_________________

____

____

Consequences:____

____

____

How did you deal with this challenge? ____

____

____

____

Challenge 2: ____Year(s):_________________

____

____

Consequences:____

____

____

How did you deal with this challenge? ____

____

____

____

Challenge 3: ____Year(s):_________________

____

Consequences:____

____

____

How did you deal with this challenge? ____

____

____

____

Challenge 4: ____Year(s):_________________

____

____

Consequences:____

____

____

How did you deal with this challenge? ____

____

____

____

Challenge 5: ____Year(s):_________________

____

____

Consequences:____

____

____

How did you deal with this challenge? ____

____

____

____

5.2 From the challenges you have faced on the farm and shifts in climatic (weather) features we have discussed, how would you rank the order of importance?

For example, which challenges or changes that you have experienced as a farmer have had the biggest impact on your farming methods/livelihood to the least important.

5.3. If you had unlimited resources and no constraints, what would you have liked to do to solve these challenges?

____

____

____

____

____

____

____

6. Associations:

6.1. Do you belong to any associations that assist you with strategic, institutional or social support for your farm? For example, government support groups (LandCare), neighbourhood groups, NGO organisations, co-operatives (SSK). Yes No

If no, why?

____

____

____

If yes, which groups and why do you belong to each group? What kind of support do they provide?

____

____

____

____

6.2. Are there any associations that provide access to climate information and strategic support? Yes No

Do you find this information valuable – why or why not?

____

____

____

____

6.3. What support services would you find useful as a farmer that do not exist or that are difficult to access in your area?

____

____

____

____

7. Records:

Do you have any records from your farm you would be willing to share? Yes No

Examples: rainfall, temperature, crop yields, crop types, tide levels in the river, water quality measurements, salt levels in the ground, changing weather patterns, etc.

8. Recommendations

Would you be able to recommend any other farmers in the area that might also be willing to talk to us?

APPENDIX 1B: ETHICS APPROVAL

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

Faculty of Science
University of Cape Town
RONDEBOSCH 7701 South Africa
E-mail: richard.hill@uct.ac.za
Telephone: + 27 21 650 2786
Fax: + 27 21 650 3456

26 May 2015

Ms Catherine Ward
Department of Biological Sciences

Coping with global change in social-ecological systems of the southern Cape, with focus on farming communities

Dear Ms Catherine Ward

I am pleased to inform you that the Faculty of Science Research Ethics Committee has approved the above-named application for research ethics clearance, subject to the conditions listed below. You are required to:

- Implement the measures described in your application to ensure that the process of your research is ethically sound;
- Uphold ethical principles throughout all stages of the research, responding appropriately to unanticipated issues: please contact me if you need advice on ethical issues that arise; and
- Ensure that informed consent to carry out the interviews is obtained in written form.

Your approval code is: FSREC 20– 2015

I wish you success in your research.

Yours sincerely

RCHill

Dr Richard Hill
Chair: Faculty of Science Research Ethics Committee

Cc: Prof Astrid Jarre, Supervisor

APPENDIX 1C: FEEDBACK PAMPHLETS

FARMING AND CLIMATE VARIABILITY

SCIFR

Catherine D. Ward

University of Cape Town

Department of Biological Sciences
Marine Ecology & Fisheries Research Group

+27 (0)82 643 5824

+27 (0)21 650 5454

catherine.d.ward@gmail.com

www.eafsa.uct.ac.za

SARChI MARINE ECOLOGY & FISHERIES

FARMING IN THE SOUTHERN CAPE

Local climate impacts have numerous implications for the future development of South Africa, and require a deeper understanding into the dynamics around such environmental changes within the complex realm of social-ecological systems.

Given the high environmental variability in systems such as the southern Benguela and southern Cape, there is a need to understand the local context and 'on-the-ground' experiences of resident communities, such as farmers, to contribute to the understanding of social-ecological systems under global change.

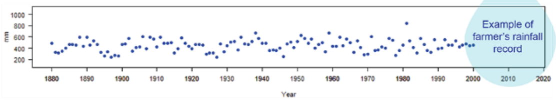
This research examined local agricultural perspectives by surveying southern Cape farmers and built in terrestrial scientific data through looking at local climate in relation to farming perspectives. Observations on terrestrial rainfall and temperatures were collected through interviews with 50 farmers, along with shared rainfall records from 13 farming families and ten official weather stations in the area.

Research area: Focused on farming communities based in or adjacent to the Duiwenhoks and Goukou catchment areas located in South Africa's southern Cape coastal region

RAINFALL

Farmers stressed that rainfall was highly variable in the research area as a whole, with no distinct trends over time.

Analysed rainfall data were highly variable, mirroring farmers' observations that rainfall did not have any clear trends over time.



Rainfall patterns in vlakte areas were observed to have shifted from a typical winter regime into a more varied pattern, where the onset of traditional rainfall periods were perceived to have shifted to a later time. For example, crop farmers located on the vlakte areas noted that their planting season had shifted to a later time – rather than planting crops during the onset of traditional seasonal rainfall in early autumn like their parents or grandparents, planting tended to take place in late autumn.

Analysis of rainfall data also showed that when the traditional planting season was compared to the new planting season in terms of rainfall, indicating that the onset of the typical autumn rainfall season had shifted to a month later over the past decade.

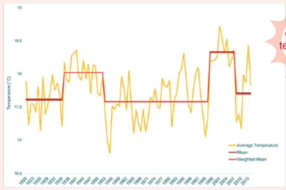
Across the research area, farmers observed an increase in intense rainfall events and prolonged dry spells, describing these events as becoming more severe and occurring more regularly, when compared to past experience. Long-term farming families observed that rainfall patterns had shifted from (winter) periods of soft, drizzle rain from over 50 years ago to more extreme rainfall events that happen over shorter periods of time.

Rainfall data from the research area indicated a significant increase in extremely dry months over the past few decades in the western and central research areas, while the eastern extent indicated a decrease in drier months across the time periods.

TEMPERATURE

The majority farmers did not observe any noticeable or enduring changes in temperature patterns.

Details and timescales regarding participants' observations on temperature and wind were less descriptive when compared to rainfall. None of the surveyed farmers kept long-term temperature records. Some livestock farmers noted that extreme temperatures (more 'very hot' days) had impacted their lambs in recent years.



Temperature data from the southern Cape investigated here were highly variable over time, indicating more complexity on smaller scales. Temperature time series did display periods of consistent warm or cool periods over time, which interestingly overlaid between coastal and inland observation stations. There was a consistent warm period between the mid-1930s to mid-1950s, followed by a cooler period, then a consistent warm period from late 1990s to mid-2000s, followed by a cooler period after 2006.

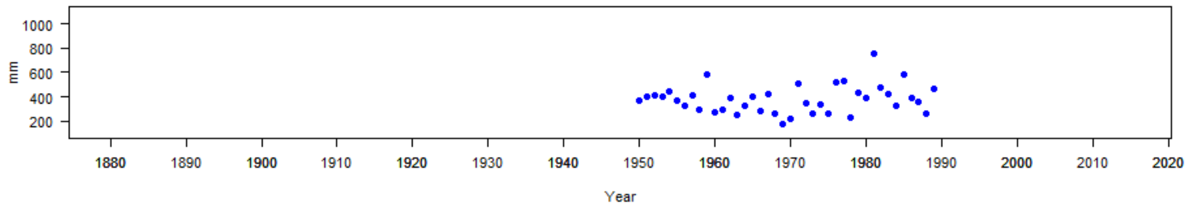
CLIMATE STRESSORS

Climate variability featured as a stressor for farmers where participants noted that increased extremes had negative consequences, such as big flooding events that result in erosion and loss of topsoil. Prolonged dry periods also placed additional stress on farming activities and water availability, where (for example) livestock farmers had to increase financial expenditure to buy in animal feed due to the lack of pasture. Climate variability was viewed by many participants as a stressor that aggravated existing challenges of farming, and worked in concert with other stressors within a complex social-ecological system. Linked to increased climate variability, water availability was also highlighted as a key stressor by farmers. Changes in rainfall patterns over time, increased anthropogenic demand, degradation of catchment areas through invasive plants and policy changes can be viewed as interacting stressors that result in limited water availability for different user groups, such as farmers.

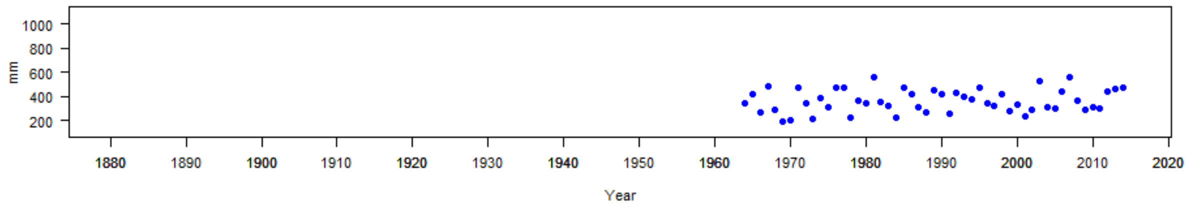
Climate knowledges of farmers were often contextualised from a multigenerational perspective, where current generations drew on observations passed down through previous generations and evolved their knowledge bases accordingly. This deep-seated understanding of climate through generations of experimentation provided valuable narratives on past patterns of local ecosystems.

APPENDIX 2A: ANNUAL RAINFALL TIME SERIES

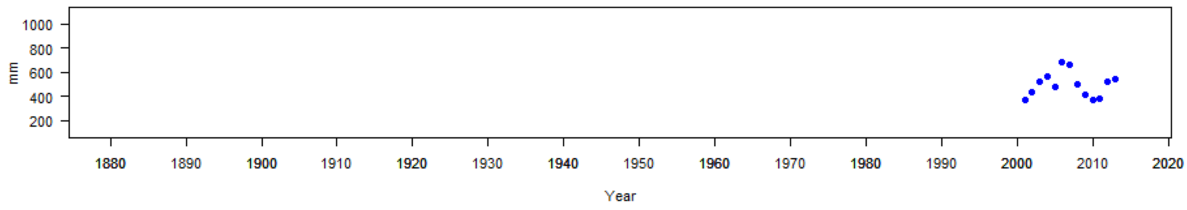
Farm 1



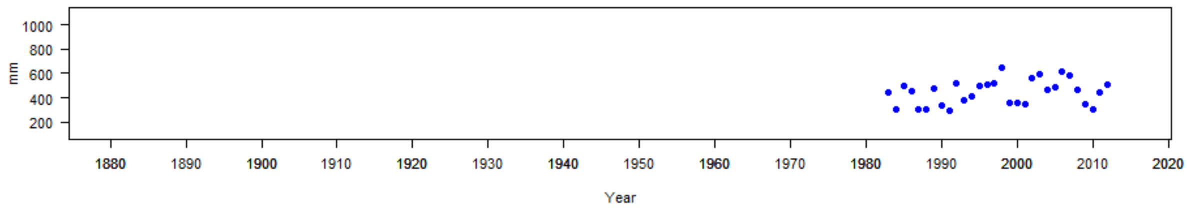
Farm 2



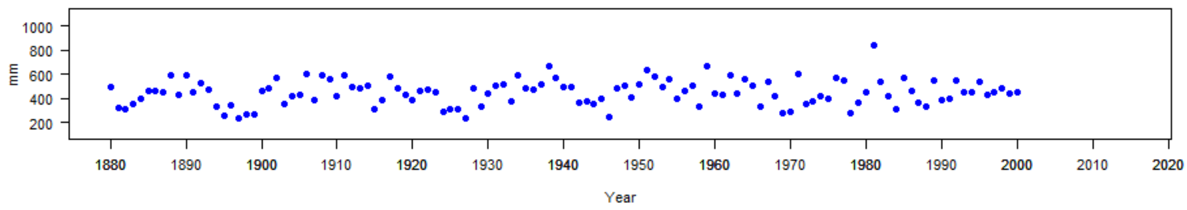
Farm 3



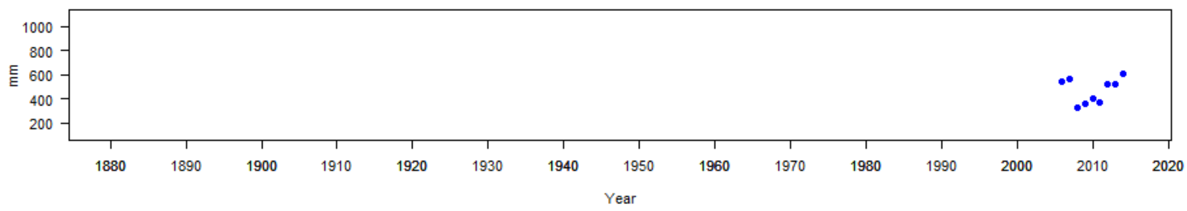
Farm 4



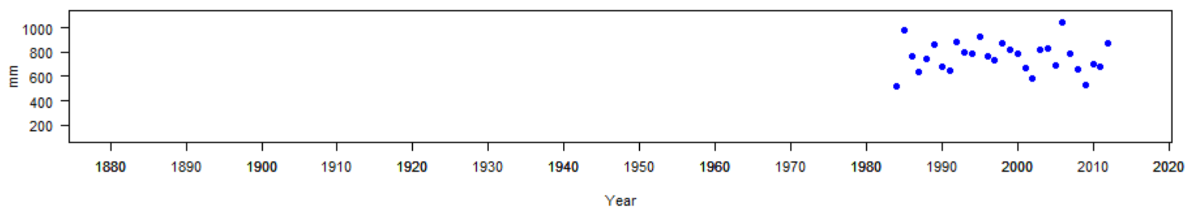
Farm 5



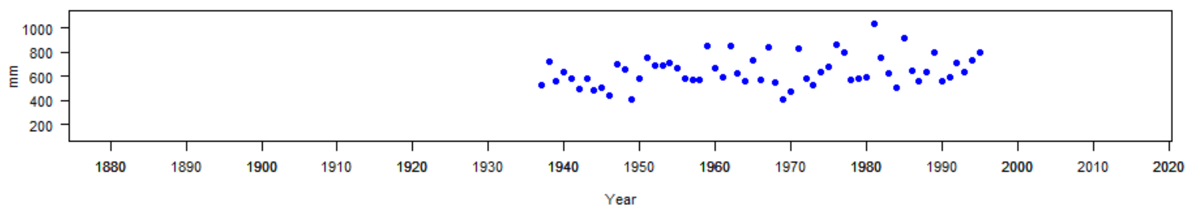
Farm 6



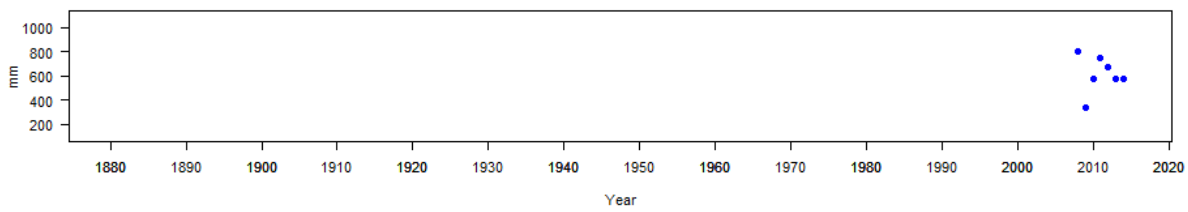
Farm 7



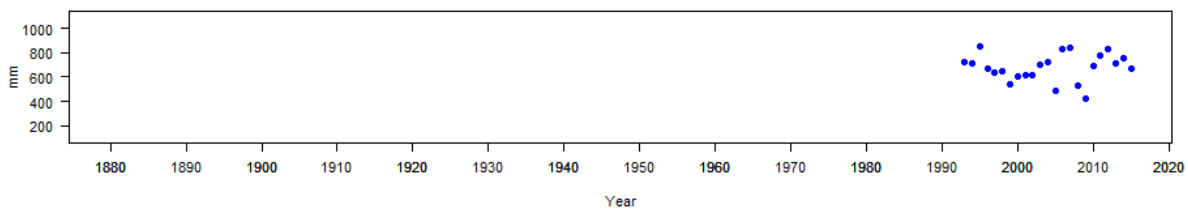
Farm 8



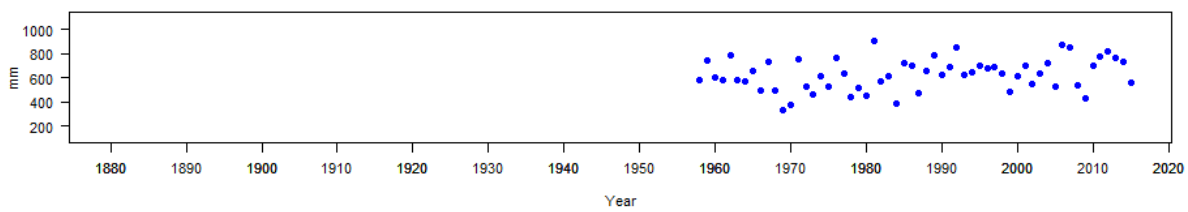
Farm 9



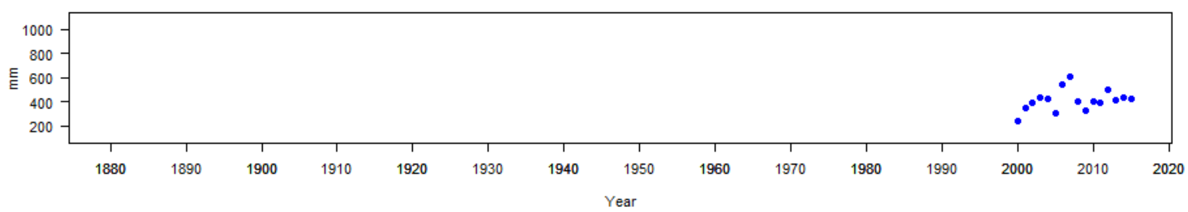
Farm 10



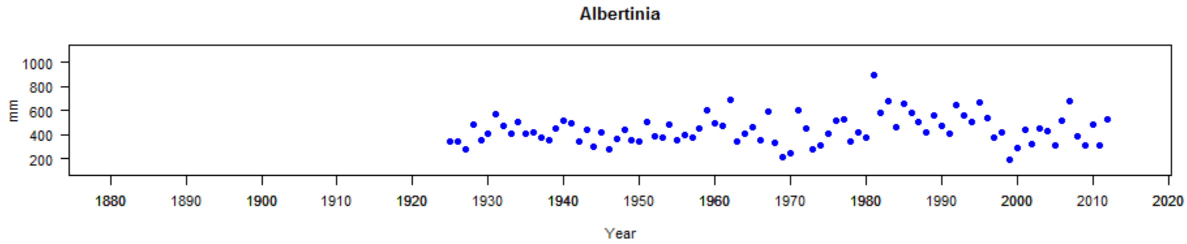
Farm 11

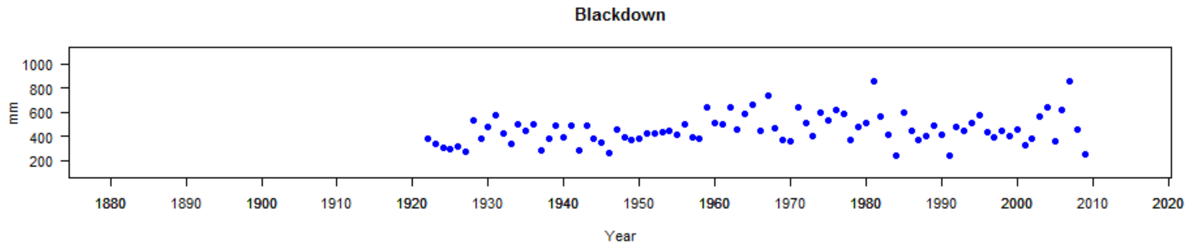


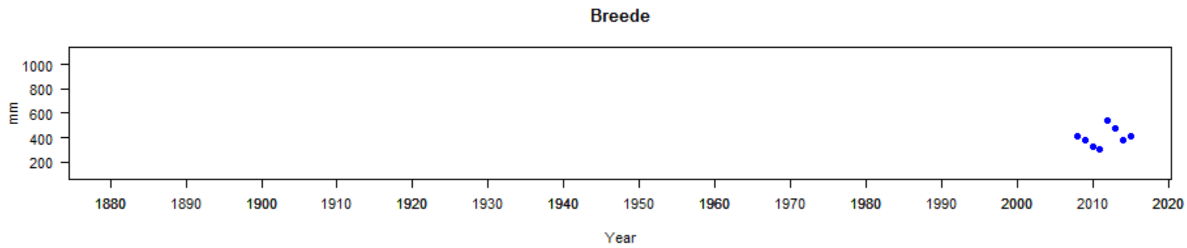
Farm 12

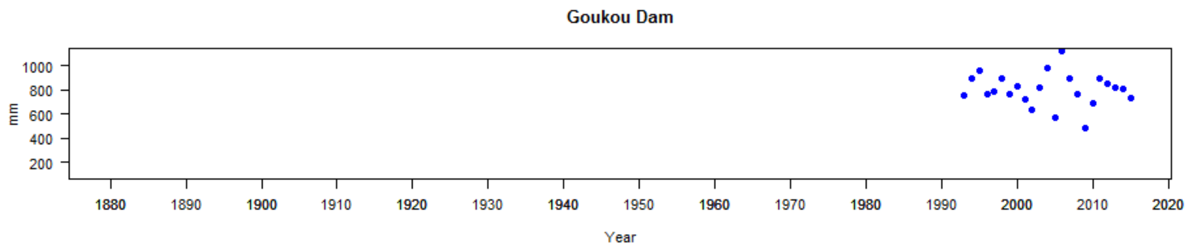


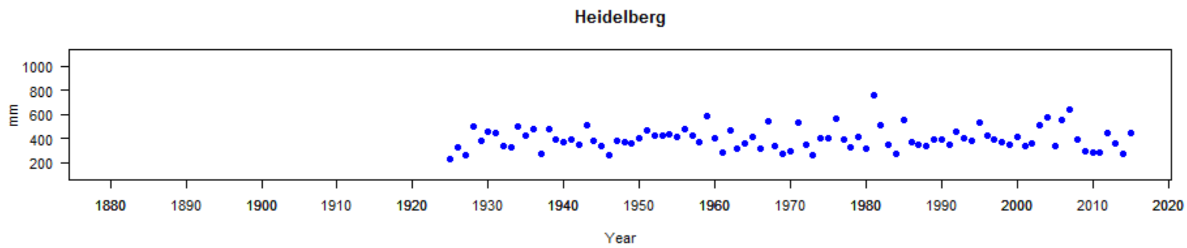

Farm 13
mm
1000
800
600
400
200
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020
Year


Albertinia
mm
1000
800
600
400
200
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020
Year

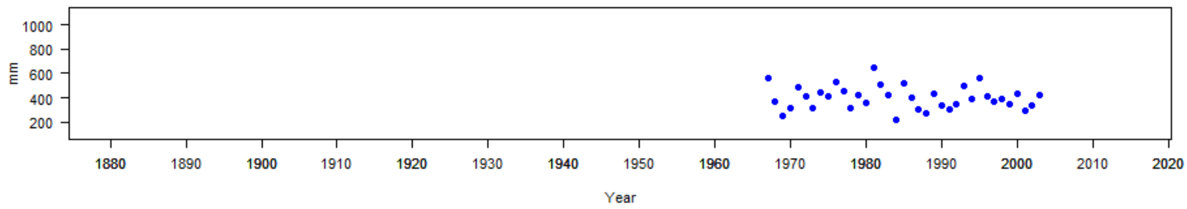

Blackdown
mm
1000
800
600
400
200
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020
Year


Breede
mm
1000
800
600
400
200
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020
Year

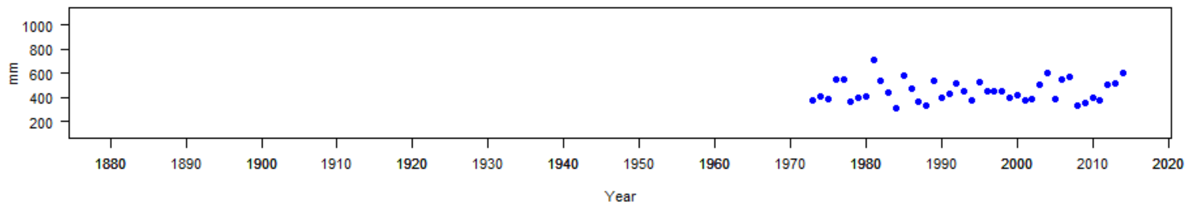

Goukou Dam
mm
1000
800
600
400
200
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020
Year


Heidelberg
mm
1000
800
600
400
200
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020
Year

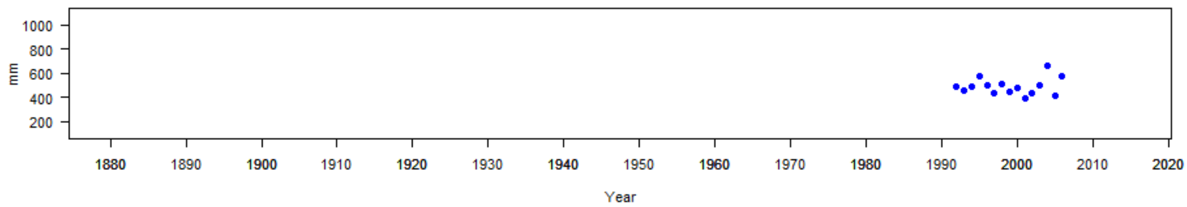
Mon Desir



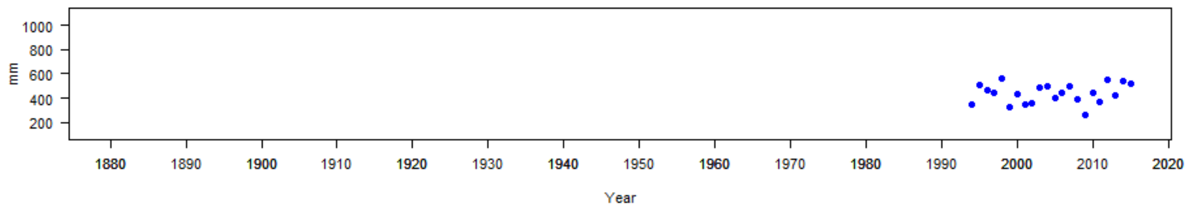
Riversdale ARC



Riversdale

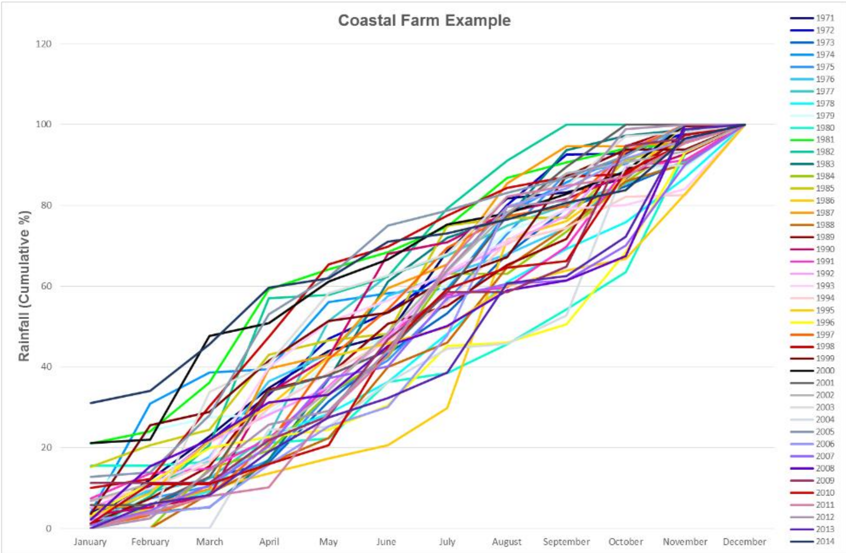


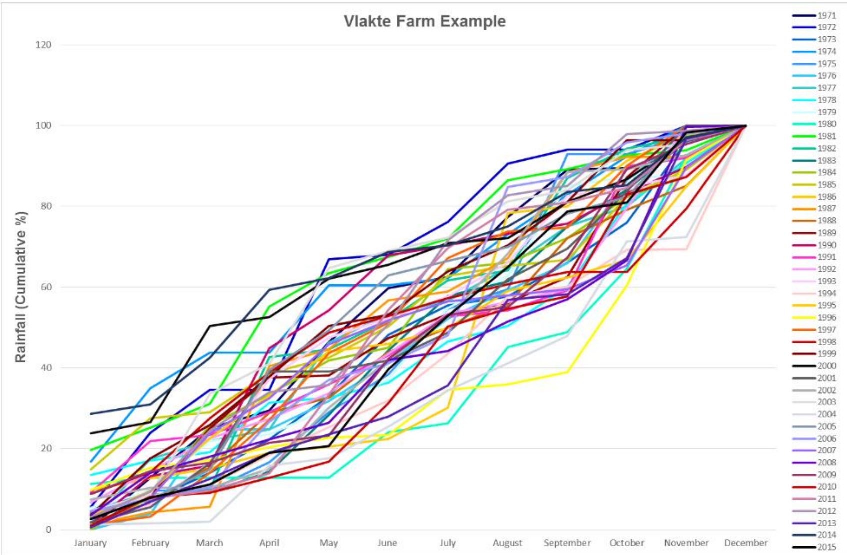
Still Bay

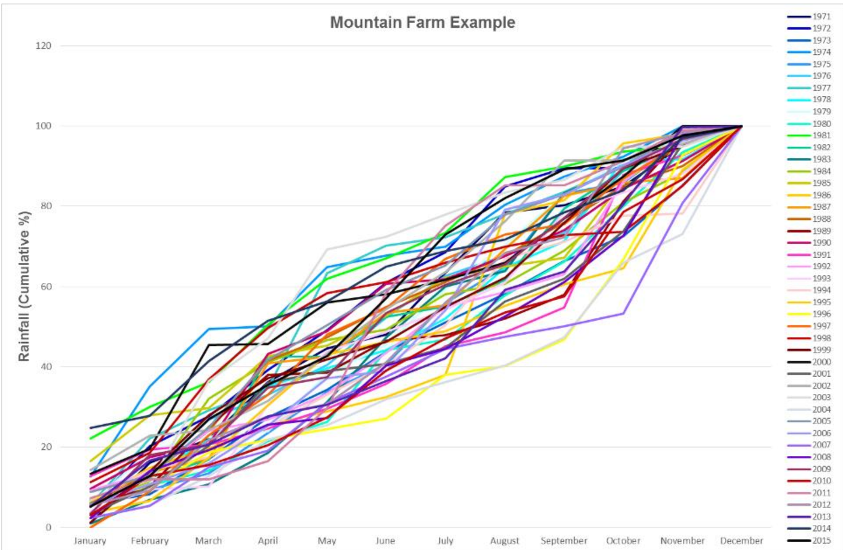


Witsand

APPENDIX 2B: EXAMPLES OF CUMULATIVE RAINFALL IN AREAS







APPENDIX 2C: RAINFALL AMONALIES

Coastal farm example:

```
Residuals:
Min             1Q              Median          3Q              Max
-149.822        -79.134         -1.272          67.734          207.127

Coefficients:
            Estimate Std.       Error           t value         Pr(>|t|)
(Intercept) -1956.0240          1790.9343       -1.092          0.28
Year        0.9834              0.9004          1.092           0.28

Residual standard error: 94.65 on 49 degrees of freedom
Multiple R-squared: 0.02377,   Adjusted R-squared: 0.003844
F-statistic: 1.193 on 1 and 49 DF, p-value: 0.2801
```

Vlakte farm example:

```
Residuals:
Min             1Q              Median          3Q              Max
-204.49         -78.77          -3.23           65.17           378.44

Coefficients:
            Estimate Std.       Error           t value         Pr(>|t|)
(Intercept) -649.2067           529.4732        -1.226          0.223
Year        0.3346              0.2729          1.226           0.223

Residual standard error: 104.8 on 119 degrees of freedom
Multiple R-squared: 0.01247,   Adjusted R-squared: 0.004176
F-statistic: 1.503 on 1 and 119 DF, p-value: 0.2226
```

Mountain farm example:

```
Residuals:
Min             1Q              Median          3Q              Max
-255.47         -98.00          8.72            73.54           284.53

Coefficients:
            Estimate Std.       Error           t value         Pr(>|t|)
(Intercept) -4097.0608          1985.1959       -2.064          0.0437 *
Year        2.0625              0.9993          2.064           0.0437 *

Significance codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 127.4 on 56 degrees of freedom
Multiple R-squared: 0.07069,   Adjusted R-squared: 0.05409
F-statistic:  4.26 on 1 and 56 DF, p-value: 0.04367
```

APPENDIX 2D: RAINFALL IN CATCHMENT LOCATIONS

Variances:

Catchment location:	Rainfall:
Duiwenhoks/Breede	12605.12
Goukou	28264.91
Goukou/Gouritz	23359.62

Levene's Test for Homogeneity of Variance:

centre = median

Df	F value	Pr(>F)
2	7.7258	0.0004852 ***

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Kruskal-Wallis rank sum test:

Kruskal-Wallis chi-squared = 75.2975, df = 2, p-value < 2.2e-16

Multiple comparison test after Kruskal-Wallis
p.value: 0.05

Duiwenhoks/Breede vs Goukou comparison:

Observed difference	critical difference	difference
167.80057	47.36417	TRUE

Duiwenhoks/Breede vs Goukou/Gouritz comparison:

Observed difference	critical difference	difference
166.70172	57.74726	TRUE

Goukou/Gouritz vs Goukou comparison:

Observed difference	critical difference	difference
1.09885	44.93389	FALSE

APPENDIX 2E: RAINFALL IN CATCHMENT LOCATIONS

(EXCLUDING MOUNTAIN AREAS)

Variances:

Catchment location:	Rainfall:
Duiwenhoks/Breede	12605.12
Goukou	11269.51
Goukou/Gouritz	11725.37

Levene's Test for Homogeneity of Variance:

centre = median

Df	F value	Pr(>F)
2	0.4642	0.629

Kruskal-Wallis rank sum test:

Kruskal-Wallis chi-squared = 26.796, df = 2, p-value = 1.518e-06

Multiple comparison test after Kruskal-Wallis
p.value: 0.05

Duiwenhoks/Breede vs Goukou comparison:

Observed difference	critical difference	difference
74.43579	34.42519	TRUE

Duiwenhoks/Breede vs Goukou/Gouritz comparison:

Observed difference	critical difference	difference
53.38974	47.98032	TRUE

Goukou/Gouritz vs Goukou comparison:

Observed difference	critical difference	difference
21.04606	42.24970	FALSE

APPENDIX 2F: RAINFALL IN AREAS

Variances:

Catchment location:	Rainfall:
Coastal	12701.21
Vlakte	11445.40
Mountain	20105.29

Levene's Test for Homogeneity of Variance:

centre = median

Df	F value	Pr(>F)
2	10.643	2.854e-05 ***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Kruskal-Wallis rank sum test:

Kruskal-Wallis chi-squared = 285.0399, df = 2, p-value < 2.2e-16

Multiple comparison test after Kruskal-Wallis
p.value: 0.05

Coastal vs Vlakte comparison:

Observed difference	critical difference	difference
61.92908	44.79247	TRUE

Coastal vs Mountain comparison:

Observed difference	critical difference	difference
300.85518	48.42558	TRUE

Mountain vs Vlakte comparison:

Observed difference	critical difference	difference
238.92610	39.86415	TRUE

APPENDIX 2G: INDIVIDUAL PLACE PERDENTAGE & FREQUENCY TABLES

PERCENTAGE

Farm 1: Coastal Duiwenhoks/Breede			
	< 10mm	75th percentile	95th percentile
Period 1 (1950-1981)	22%	24%	4%
Period 2 (1982-1989)	20%	29%	8%
Period 3			
Period 4			

Farm 2: Coastal Duiwenhoks/Breede			
	< 10mm	75th percentile	95th percentile
Period 1 (1964-1981)	22%	24%	4%
Period 2 (1982-1995)	20%	24%	5%
Period 3 (1996-2007)	27%	22%	5%
Period 4 (2008-2014)	30%	32%	6%

Farm 3: Coastal Duiwenhoks/Breede			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2			
Period 3 (2001-2007)	8%	27%	5%
Period 4 (2008-2013)	13%	22%	4%

Farm 4: Coastal Goukou			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2 (1983-1995)	18%	20%	2%
Period 3 (1996-2007)	17%	30%	8%
Period 4 (2008-2012)	18%	23%	5%

Farm 6: Vlakte Goukou			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2			
Period 3 (2006-2007)	3%	27%	7%
Period 4 (2008-2014)	10%	25%	5%

Farm 7: Mountain Goukou			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2 (1984-1995)	3%	25%	4%
Period 3 (1996-2007)	4%	26%	6%
Period 4 (2008-2012)	7%	22%	5%

Farm 8: Mountain Goukou			
	< 10mm	75th percentile	95th percentile
Period 1 (1937-1981)	6%	24%	4%
Period 2 (1982-1995)	4%	27%	7%
Period 3			
Period 4			

Farm 9: Mountain Goukou			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2			
Period 3			
Period 4 (2008-2014)	11%	25%	5%

FREQUENCIES

Farm 1: Coastal Breede			
	< 10mm	75th percentile	95th percentile
Period 1 (1950-1981)	83	92	16
Period 2 (1982-1989)	19	28	8
Period 3			
Period 4			

Farm 2: Coastal Duiwenhoks/Breede			
	< 10mm	75th percentile	95th percentile
Period 1 (1964-1981)	48	51	9
Period 2 (1982-1995)	34	41	9
Period 3 (1996-2007)	39	32	7
Period 4 (2008-2014)	25	27	5

Farm 3: Coastal Duiwenhoks/Breede			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2			
Period 3 (2001-2007)	7	23	4
Period 4 (2008-2013)	9	16	3

Farm 4: Coastal Goukou			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2 (1983-1995)	28	31	3
Period 3 (1996-2007)	24	43	12
Period 4 (2008-2012)	11	14	3

Farm 6: Vlakte Goukou			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2			
Period 3 (2006-2007)	1	8	2
Period 4 (2008-2014)	8	21	4

Farm 7: Mountain Goukou			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2 (1984-1995)	5	36	6
Period 3 (1996-2007)	6	38	8
Period 4 (2008-2012)	4	13	3

Farm 8: Mountain Goukou			
	< 10mm	75th percentile	95th percentile
Period 1 (1937-1981)	30	131	24
Period 2 (1982-1995)	7	45	11
Period 3			
Period 4			

Farm 9: Mountain Goukou			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2			
Period 3			
Period 4 (2008-2014)	9	21	4

Farm 10: Mountain Goukou/Gouritz			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2 (1993-1995)	3%	33%	6%
Period 3 (1996-2007)	2%	22%	4%
Period 4 (2008-2015)	6%	25%	5%

Farm 10: Mountain Goukou/Gouritz			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2 (1993-1995)	1	12	2
Period 3 (1996-2007)	3	32	6
Period 4 (2008-2015)	6	24	5

Farm 11: Mountain Goukou/Gouritz			
	< 10mm	75th percentile	95th percentile
Period 1 (1958-1981)	8%	24%	2%
Period 2 (1982-1995)	7%	25%	5%
Period 3 (1996-2007)	7%	27%	8%
Period 4 (2008-2015)	5%	26%	7%

Farm 11: Mountain Goukou/Gouritz			
	< 10mm	75th percentile	95th percentile
Period 1 (1958-1981)	23	68	6
Period 2 (1982-1995)	12	42	9
Period 3 (1996-2007)	9	35	10
Period 4 (2008-2015)	5	25	7

Farm 12: Vlakte Goukou/Gouritz			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2			
Period 3 (2000-2007)	19%	23%	3%
Period 4 (2008-2015)	26%	26%	6%

Farm 12: Vlakte Goukou/Gouritz			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2			
Period 3 (2000-2007)	18	22	3
Period 4 (2008-2015)	25	25	6

Farm 13: Vlakte Goukou/Gouritz			
	< 10mm	75th percentile	95th percentile
Period 1 (1971-1981)	22%	22%	4%
Period 2 (1982-1995)	18%	24%	5%
Period 3 (1996-2007)	20%	22%	6%
Period 4 (2008-2015)	18%	30%	5%

Farm 13: Vlakte Goukou/Gouritz			
	< 10mm	75th percentile	95th percentile
Period 1 (1971-1981)	29	29	5
Period 2 (1982-1995)	31	41	9
Period 3 (1996-2007)	29	32	8
Period 4 (2008-2015)	17	29	5

Albertinia SAWS: Vlakte Goukou/Gouritz			
	< 10mm	75th percentile	95th percentile
Period 1 (1925-1981)	21%	24%	4%
Period 2 (1982-1995)	9%	32%	7%
Period 3 (1996-2007)	24%	24%	6%
Period 4 (2008-2012)	33%	22%	8%

Albertinia SAWS: Vlakte Goukou/Gouritz			
	< 10mm	75th percentile	95th percentile
Period 1 (1925-1981)	144	163	26
Period 2 (1982-1995)	15	53	12
Period 3 (1996-2007)	35	34	9
Period 4 (2008-2012)	20	13	5

Riversdale SAWS: Vlakte Goukou			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2 (1992-1995)	6%	23%	3%
Period 3 (1996-2006)	7%	23%	5%
Period 4			

Riversdale SAWS: Vlakte Goukou			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2 (1992-1995)	2	8	1
Period 3 (1996-2006)	9	31	7
Period 4			

Still Bay SAWS: Coastal Goukou			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2 (1994-1995)	17%	25%	4%
Period 3 (1996-2007)	6%	23%	3%
Period 4 (2008-2015)	13%	27%	6%

Still Bay SAWS: Coastal Goukou			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2 (1994-1995)	4	6	1
Period 3 (1996-2007)	9	33	5
Period 4 (2008-2015)	12	26	6

Blackdown SAWS: Mountain Duiwenhoks/Breede			
	< 10mm	75th percentile	95th percentile
Period 1 (1922-1981)	15%	27%	4%
Period 2 (1982-1995)	13%	21%	7%
Period 3 (1996-2007)	14%	23%	6%
Period 4 (2008-2009)	29%	8%	4%

Blackdown SAWS: Mountain Duiwenhoks/Breede			
	< 10mm	75th percentile	95th percentile
Period 1 (1922-1981)	108	193	32
Period 2 (1982-1995)	22	35	11
Period 3 (1996-2007)	20	33	8
Period 4 (2008-2009)	7	2	1

MD SAWS: Vlakte Duiwenhoks/Breede			
	< 10mm	75th percentile	95th percentile
Period 1 (1967-1981)	11%	29%	4%
Period 2 (1982-1995)	23%	23%	7%
Period 3 (1996-2003)	18%	20%	4%
Period 4			

Blackdown SAWS: Vlakte Duiwenhoks/Breede			
	< 10mm	75th percentile	95th percentile
Period 1 (1967-1981)	20	52	7
Period 2 (1982-1995)	38	39	11
Period 3 (1996-2003)	17	19	4
Period 4			

Heidelberg: Vlakte Duiwenhoks/Breede			
	< 10mm	75th percentile	95th percentile
Period 1 (1925-1981)	20%	26%	5%
Period 2 (1982-1995)	15%	21%	6%
Period 3 (1996-2007)	13%	26%	6%
Period 4 (2008-2015)	26%	23%	5%

Heidelberg: Vlakte Duiwenhoks/Breede			
	< 10mm	75th percentile	95th percentile
Period 1 (1925-1981)	137	178	31
Period 2 (1982-1995)	26	36	10
Period 3 (1996-2007)	18	37	8
Period 4 (2008-2015)	24	21	5

Breede SAWS: Coastal Duiwenhoks/Breede			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2			
Period 3			
Period 4 (2008-2015)	19%	24%	4%

Breede SAWS: Coastal Duiwenhoks/Breede			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2			
Period 3			
Period 4 (2008-2015)	18	23	4

Witsand SAWS: Coastal Duiwenhoks/Breede			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2 (1986-1995)	29%	28%	4%
Period 3 (1996-2007)	31%	22%	6%
Period 4			

Witsand SAWS: Coastal Duiwenhoks/Breede			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2 (1986-1995)	35	33	5
Period 3 (1996-2007)	45	31	8
Period 4			

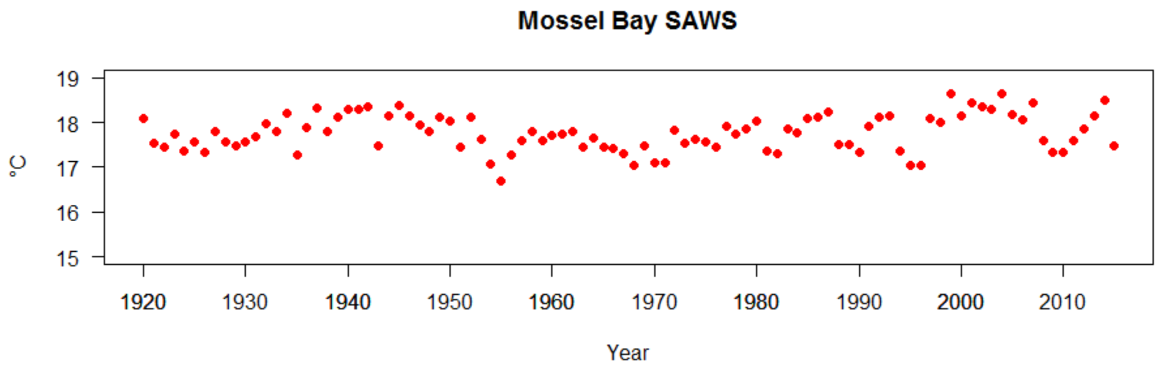
Goukou Dam: Mountain Goukou			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2 (1993-1995)	0%	31%	6%
Period 3 (1996-2007)	2%	24%	5%
Period 4 (2008-2015)	2%	24%	4%

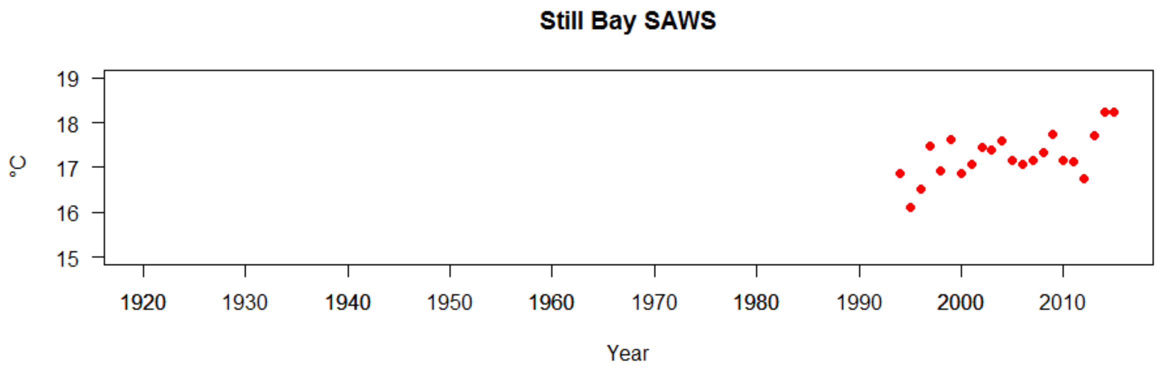
Goukou Dam: Mountain Goukou			
	< 10mm	75th percentile	95th percentile
Period 1			
Period 2 (1993-1995)	0	11	2
Period 3 (1996-2007)	3	35	7
Period 4 (2008-2015)	2	23	4

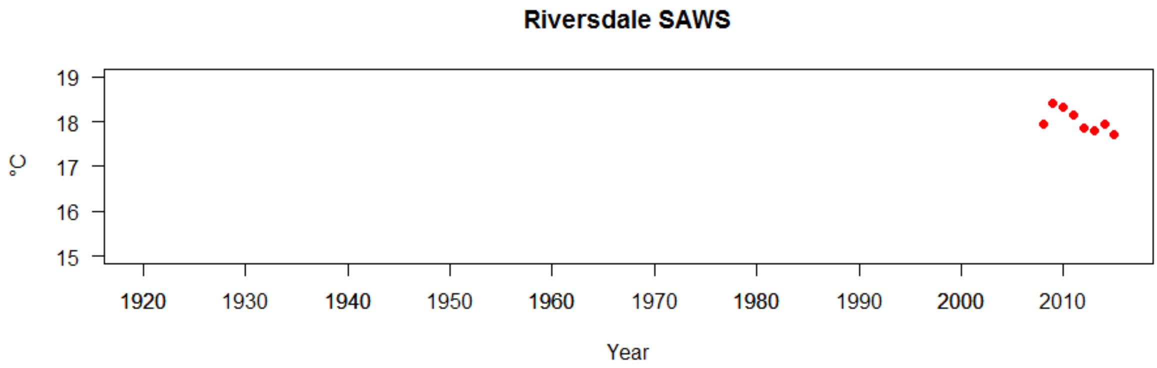
Riversdale ARC: Vlakte Goukou			
	< 10mm	75th percentile	95th percentile
Period 1 (1973-1981)	9%	23%	4%
Period 2 (1982-1995)	10%	23%	6%
Period 3 (1996-2007)	9%	26%	6%
Period 4 (2008-2014)	10%	26%	4%

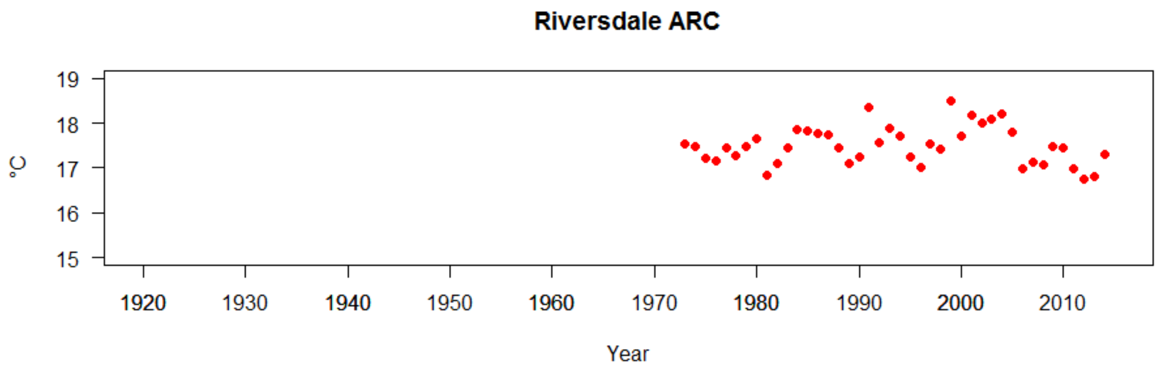
Riversdale ARC: Vlakte Goukou			
	< 10mm	75th percentile	95th percentile
Period 1 (1973-1981)	10	25	4
Period 2 (1982-1995)	17	39	10
Period 3 (1996-2007)	13	38	8
Period 4 (2008-2014)	8	22	3

APPENDIX 2H: TEMPERATURE TIME SERIES







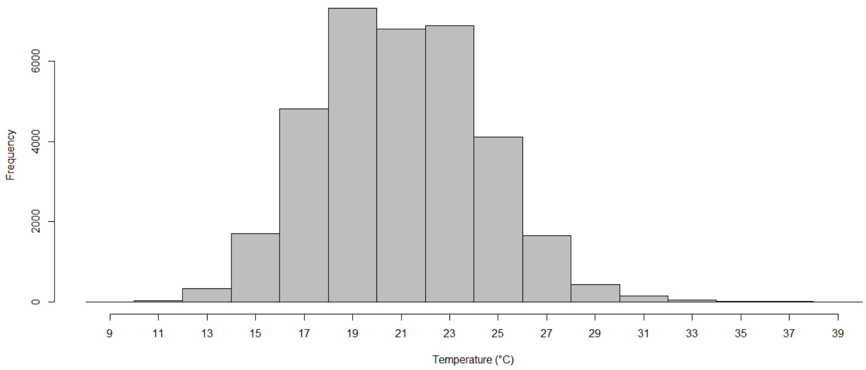


APPENDIX 2I: SUMMARY STATISTICS FOR TEMPERATURE

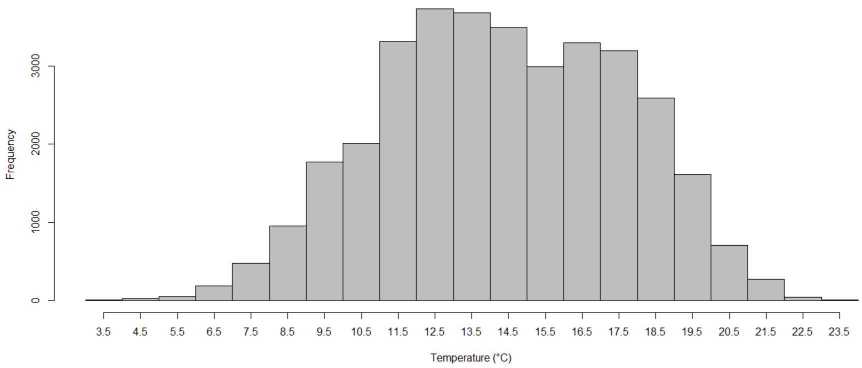
Mossel Bay:

Maximum		Minimum		Average	
Min.	8.70	Min.	3.30	Min.	6.95
1st Qu.	18.50	1st Qu.	12.00	1st Qu.	15.45
Median	21.00	Median	14.40	Median	17.75
Mean	21.06	Mean	14.42	Mean	17.74
3rd Qu.	23.40	3rd Qu.	17.00	3rd Qu.	20.05
Max.	40.00	Max.	23.60	Max.	31.65

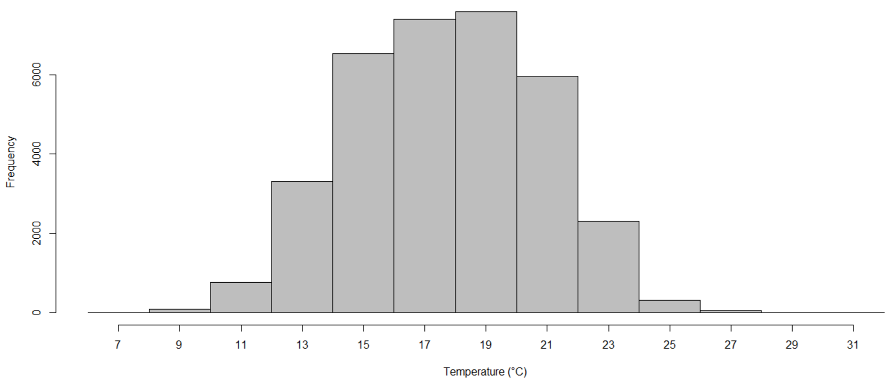
Maximum:



Minimum:



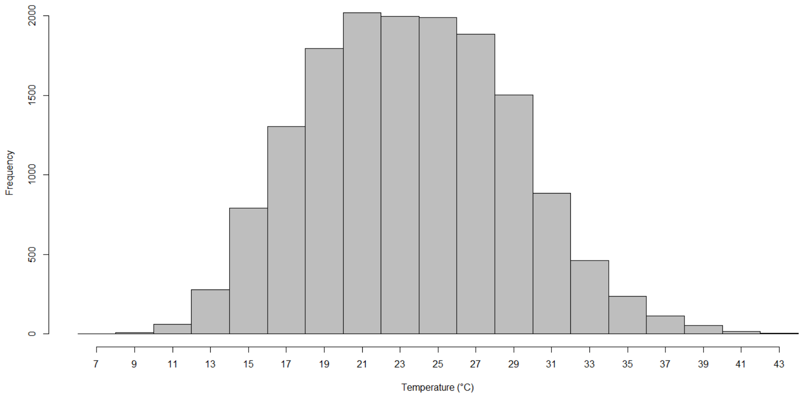
Average:



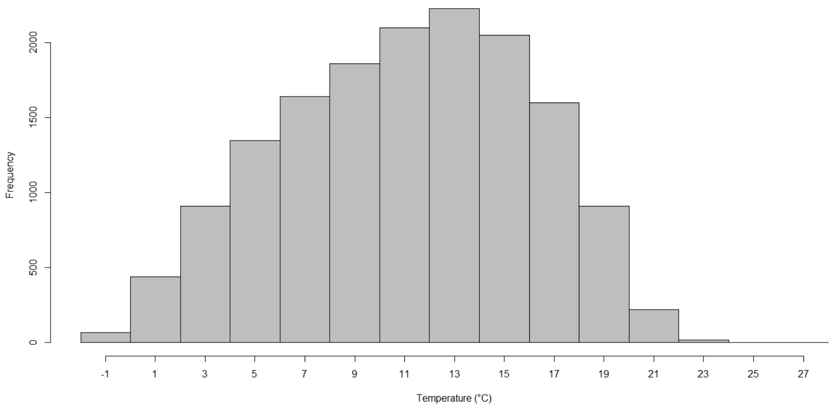
Riversdale:

	Maximum	Minimum	Average
Min.	6.98	-2.0	6.00
1st Qu.	19.70	7.5	13.85
Median	23.50	11.5	17.50
Mean	21.06	11.2	17.45
3rd Qu.	27.50	15.0	20.95
Max.	43.59	27.0	31.65

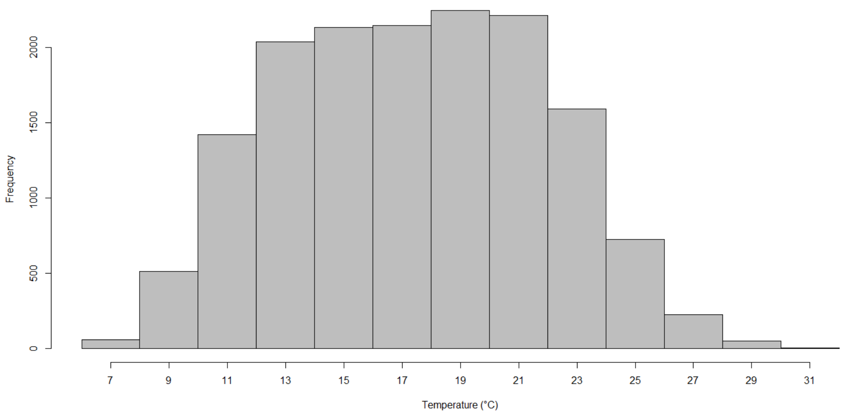
Maximum:



Minimum:



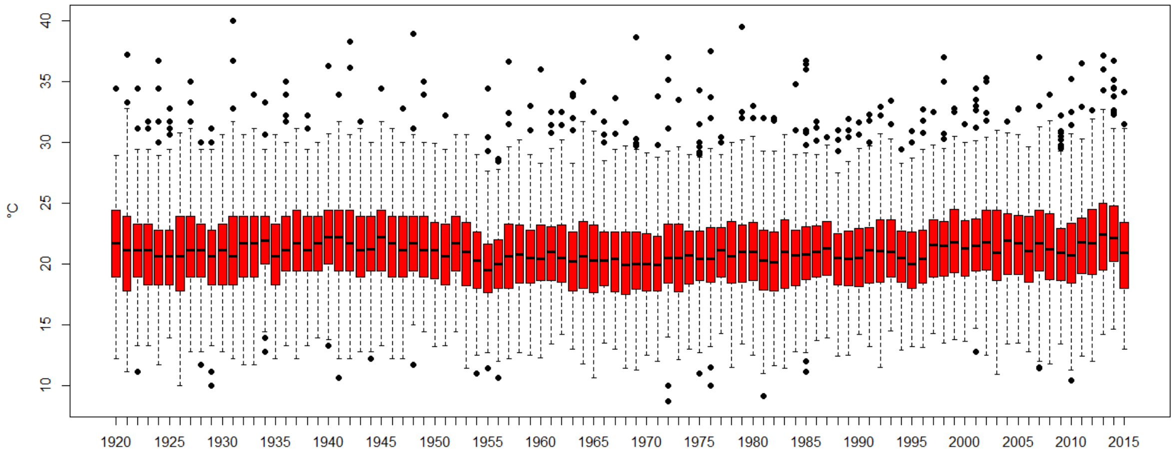
Average:



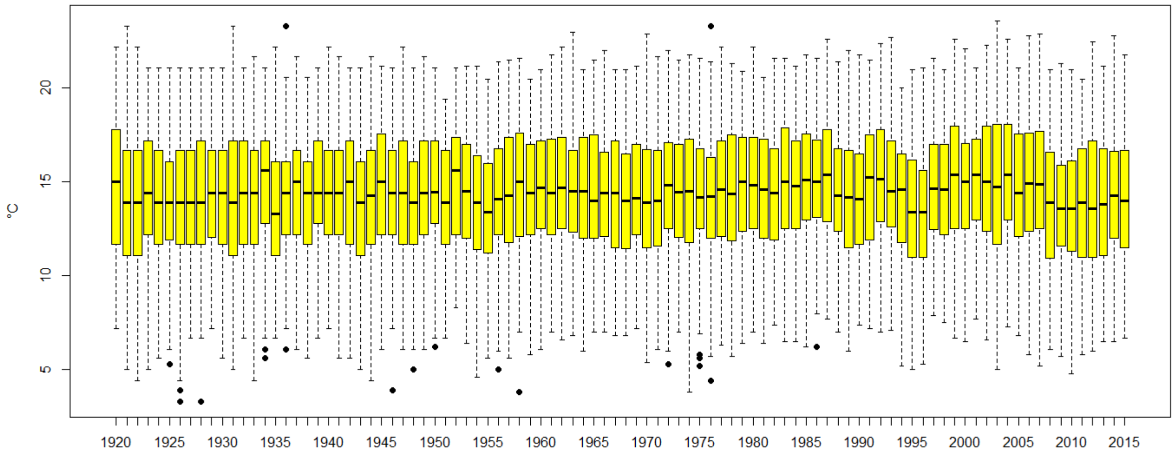
APPENDIX 2J: MAXIMUM AND MINIMUM TEMPERATURE BOXPLOTS

Mossel Bay:

Maximum:

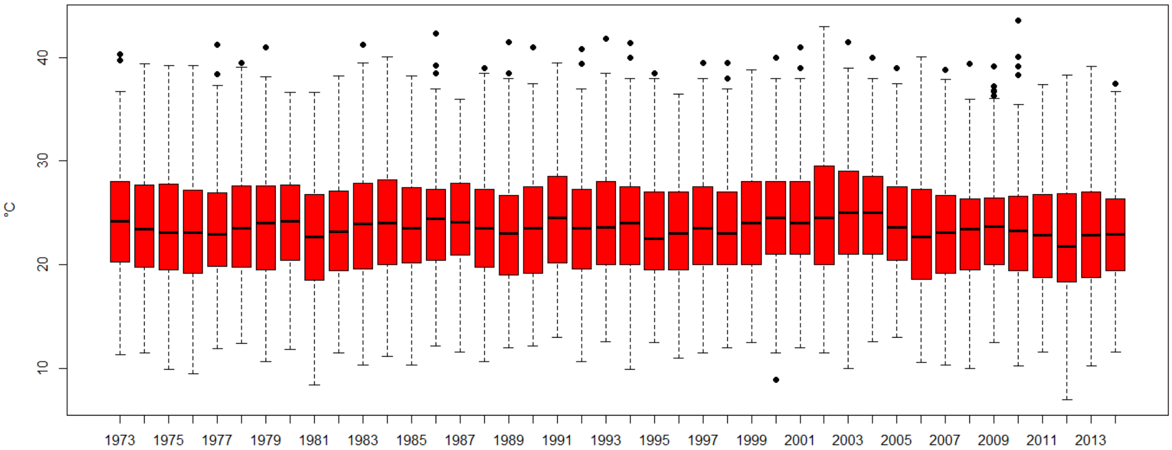


Minimum:

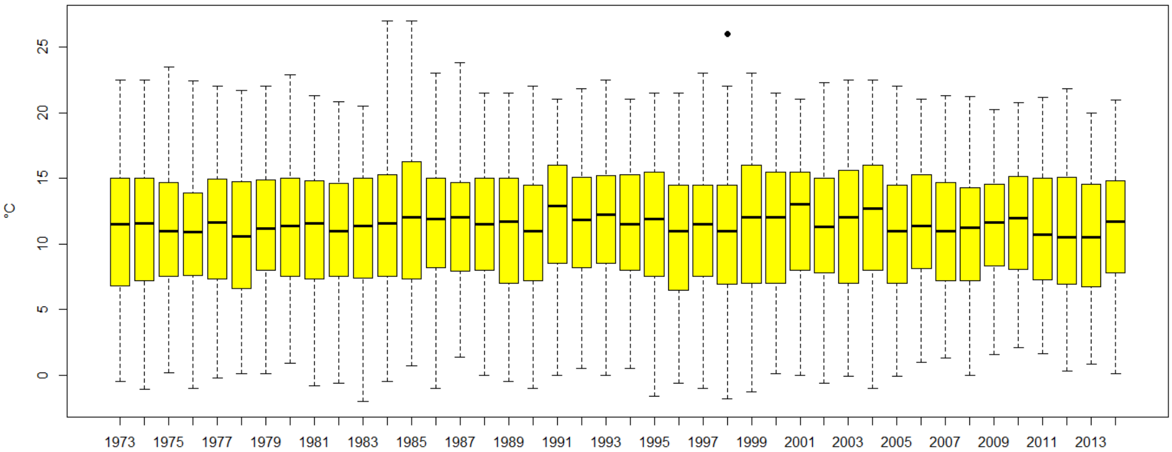


Riversdale:

Maximum:



Minimum:



APPENDIX 2K: TEMPERATURE AMONALIES

Mossel Bay SAWS:

Residuals:

Min	1Q	Median	3Q	Max
-1.06264	-0.29661	0.00062	0.31649	0.80685

Coefficients:

	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	-3.959201	2.922323	-1.355	0.179
Year	0.002012	0.001485	1.355	0.179

Residual standard error: 0.4032 on 94 degrees of freedom
Multiple R-squared: 0.01916, Adjusted R-squared: 0.008722
F-statistic: 1.836 on 1 and 94 DF, p-value: 0.1787

Riversdale ARC:

Residuals:

Min	1Q	Median	3Q	Max
-0.69987	-0.32344	-0.04762	0.26480	1.00343

Coefficients:

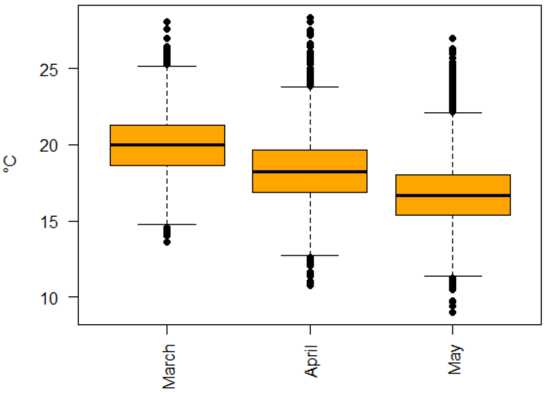
	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	3.710856	10.799421	0.344	0.733
Year	-0.001861	0.005417	-0.344	0.733

Residual standard error: 0.4255 on 40 degrees of freedom
Multiple R-squared: 0.002943, Adjusted R-squared: -0.02198
F-statistic: 0.1181 on 1 and 40 DF, p-value: 0.7329

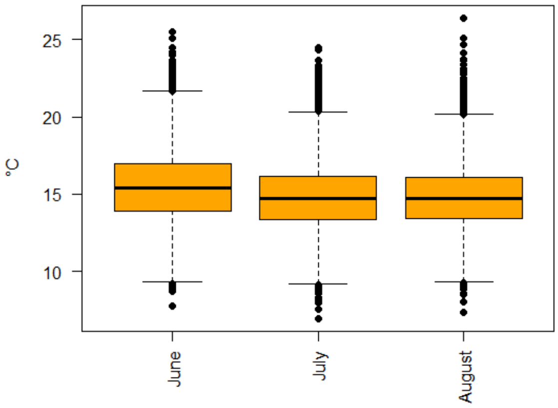
APPENDIX 2L: TEMPERATURE SEASONALITY

Mossel Bay:

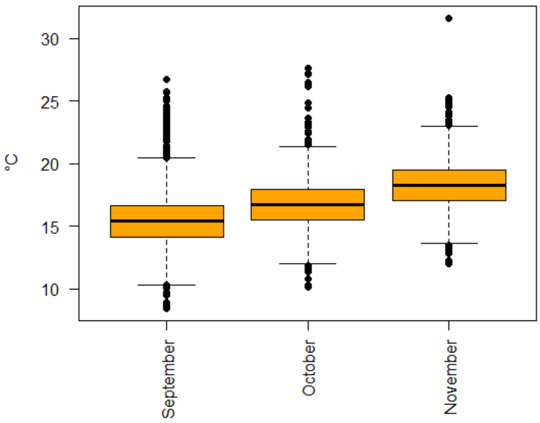
Autumn



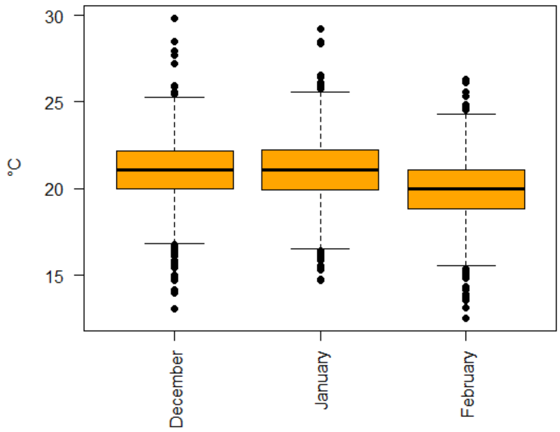
Winter



Spring

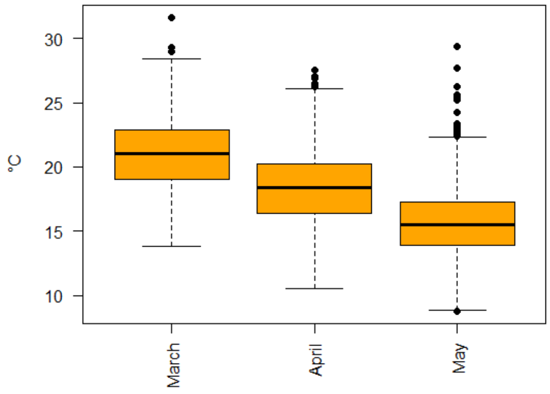


Summer

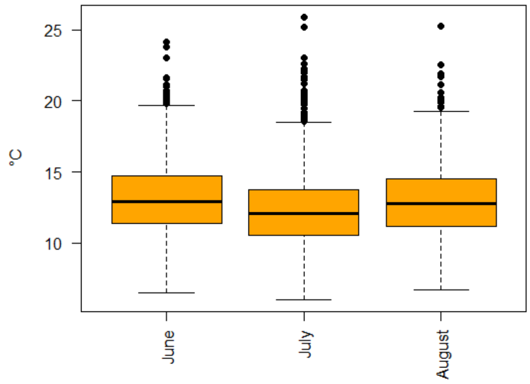


Riversdale:

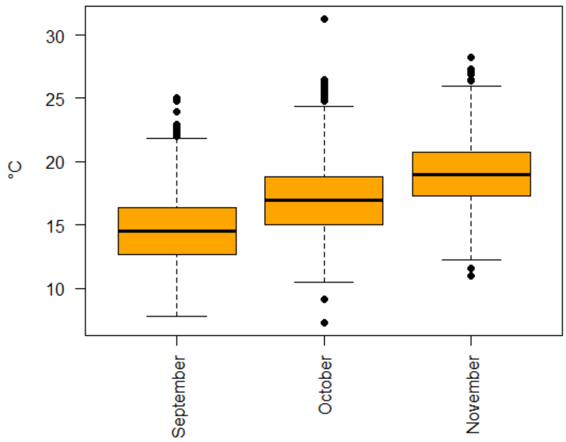
Autumn



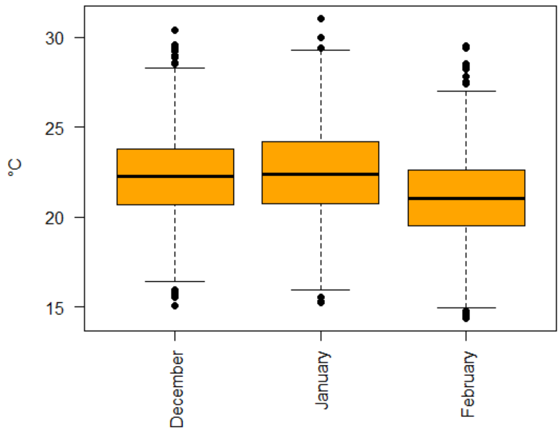
Winter



Spring



Summer



APPENDIX 3A: NEAR-SHORE EXTREME WIND DAYS

Witsand:

Autumn

```
Residuals:
Min          1Q           Median       3Q           Max
-6.0186      -2.3032      0.0412       2.3848       5.7267

Coefficients:
             Estimate Std.  Error            t value   Pr(>|t|)
(Intercept)  -238.4184      194.0306         -1.229             0.232
Year         0.1248         0.0968           1.289              0.211

Residual standard error: 3.283 on 22 degrees of freedom
Multiple R-squared: 0.07023, Adjusted R-squared: 0.02797
F-statistic: 1.662 on 1 and 22 DF, p-value: 0.2107
```

Winter

```
Residuals:
Min          1Q           Median       3Q           Max
-6.958       -3.603       -1.710       3.980        10.793

Coefficients:
             Estimate Std.  Error            t value   Pr(>|t|)
(Intercept) 187.24884       306.06095        0.612     0.547
Year        -0.08348        0.15269   -0.547           0.590

Residual standard error: 5.178 on 22 degrees of freedom
Multiple R-squared: 0.0134,  Adjusted R-squared: -0.03144
F-statistic: 0.2989 on 1 and 22 DF, p-value: 0.5901
```

Spring

```
Residuals:
Min          1Q           Median       3Q           Max
-11.8065     -2.7174      -0.5239      2.5565       11.7587

Coefficients:
            Estimate Std.   Error            t value   Pr(>|t|)
(Intercept) 245.3457        309.1548         0.794     0.436
Year        -0.1130         0.1542    -0.733           0.471

Residual standard error: 5.23 on 22 degrees of freedom
Multiple R-squared: 0.02384, Adjusted R-squared: -0.02053
F-statistic: 0.5372 on 1 and 22 DF, p-value: 0.4713
```

Summer

```
Residuals:
Min          1Q           Median       3Q           Max
-5.3953      -2.9170      0.3676       2.7727       4.4625

Coefficients:
             Estimate Std.  Error            t value   Pr(>|t|)
(Intercept)  -81.18182      205.89501        -0.394             0.697
Year          0.04743       0.10274          0.462     0.649

Residual standard error: 3.268 on 21 degrees of freedom
Multiple R-squared: 0.01005, Adjusted R-squared: -0.03709
F-statistic: 0.2131 on 1 and 21 DF, p-value: 0.6491
```

Still Bay:

Autumn

Residuals:

Min	1Q	Median	3Q	Max
-5.700	-2.675	-0.075	2.475	6.350

Coefficients:

	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	-87.1000	201.5377	-0.432	0.670
Year	0.0500	0.1005	0.497	0.624

Residual standard error: 3.41 on 22 degrees of freedom
Multiple R-squared: 0.01112, Adjusted R-squared: -0.03383
F-statistic: 0.2473 on 1 and 22 DF, p-value: 0.6239

Winter

Residuals:

Min	1Q	Median	3Q	Max
-10.118	-3.422	-1.525	4.764	12.011

Coefficients:

	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	-6.63522	365.76702	-0.018	0.986
Year	0.01435	0.18247	0.079	0.938

Residual standard error: 6.188 on 22 degrees of freedom
Multiple R-squared: 0.000281, Adjusted R-squared: -0.04516
F-statistic: 0.006183 on 1 and 22 DF, p-value: 0.938

Spring

Residuals:

Min	1Q	Median	3Q	Max
-11.9983	-1.9809	-0.9722	1.2517	8.0296

Coefficients:

	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	1.403e+01	2.829e+02	0.050	0.961
Year	3.478e-03	1.411e-01	0.025	0.981

Residual standard error: 4.786 on 22 degrees of freedom
Multiple R-squared: 2.761e-05, Adjusted R-squared: -0.04543
F-statistic: 0.0006073 on 1 and 22 DF, p-value: 0.9806

Summer

Residuals:

Min	1Q	Median	3Q	Max
-7.0020	-2.8676	0.7115	2.2801	6.1354

Coefficients:

	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	-272.6996	215.1165	-1.268	0.219
Year	0.1433	0.1073	1.335	0.196

Residual standard error: 3.415 on 21 degrees of freedom
Multiple R-squared: 0.07821, Adjusted R-squared: 0.03431
F-statistic: 1.782 on 1 and 21 DF, p-value: 0.1962

Mossel Bay:

Autumn

Residuals:

Min	1Q	Median	3Q	Max
-3.4946	-1.7083	-0.4155	1.7242	3.3936

Coefficients:

	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	-193.37710	130.21029	-1.485	0.152
Year	0.09870	0.06496	1.519	0.143

Residual standard error: 2.203 on 22 degrees of freedom
Multiple R-squared: 0.09497, Adjusted R-squared: 0.05383
F-statistic: 2.308 on 1 and 22 DF, p-value: 0.1429

Winter

Residuals:

Min	1Q	Median	3Q	Max
-5.0328	-3.0055	-0.7688	2.7178	11.5307

Coefficients:

	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	-207.2103	250.8649	-0.826	0.418
Year	0.1091	0.1252	0.872	0.393

Residual standard error: 4.244 on 22 degrees of freedom
Multiple R-squared: 0.03341, Adjusted R-squared: -0.01053
F-statistic: 0.7604 on 1 and 22 DF, p-value: 0.3926

Spring

Residuals:

Min	1Q	Median	3Q	Max
-4.7736	-2.3636	0.4403	2.3512	4.9394

Coefficients:

	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	-135.26290	164.06494	-0.824	0.419
Year	0.07130	0.08185	0.871	0.393

Residual standard error: 2.776 on 22 degrees of freedom
Multiple R-squared: 0.03335, Adjusted R-squared: -0.01059
F-statistic: 0.759 on 1 and 22 DF, p-value: 0.3931

Summer

Residuals:

Min	1Q	Median	3Q	Max
-2.4632	-1.4580	-0.7931	1.5978	3.6485

Coefficients:

	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	114.87229	134.06345	0.857	0.402
Year	-0.05584	0.06686	-0.835	0.414

Residual standard error: 1.855 on 19 degrees of freedom
Multiple R-squared: 0.03541, Adjusted R-squared: -0.01536
F-statistic: 0.6975 on 1 and 19 DF, p-value: 0.414

APPENDIX 3B: OFF-SHORE EXTREME WIND DAYS

AUSTRAL SUMMER (ONLY)

30 km off-shore:

Witsand

```
Residuals:
Min          1Q          Median      3Q          Max
-12.5652     -4.3636     0.6364      3.2381      11.4368

Coefficients:
             Estimate Std.  Error       t value     Pr(>|t|)
(Intercept)  -370.4427      393.0062    -0.943      0.357
Year         0.1996         0.1961      1.018       0.320

Residual standard error: 6.239 on 21 degrees of freedom
Multiple R-squared: 0.04701,   Adjusted R-squared: 0.001632
F-statistic: 1.036 on 1 and 21 DF, p-value: 0.3203
```

Still Bay

```
Residuals:
Min          1Q          Median      3Q          Max
-16.4783     -2.9506     -0.4506     5.1107      9.9051

Coefficients:
             Estimate Std.  Error       t value     Pr(>|t|)
(Intercept)  -382.4111      394.3637    -0.970      0.343
Year         0.2055         0.1968      1.044       0.308

Residual standard error: 6.26 on 21 degrees of freedom
Multiple R-squared: 0.04938,   Adjusted R-squared: 0.004113
F-statistic: 1.091 on 1 and 21 DF, p-value: 0.3082
```

Mossel Bay

```
Residuals:
Min          1Q          Median      3Q          Max
-12.6957     -4.2441     0.4585      3.2757      11.2470

Coefficients:
             Estimate Std.  Error       t value     Pr(>|t|)
(Intercept)  -394.0751      389.6948    -1.011      0.323
Year         0.2115         0.1945      1.087       0.289

Residual standard error: 6.186 on 21 degrees of freedom
Multiple R-squared: 0.05331,   Adjusted R-squared: 0.008229
F-statistic: 1.183 on 1 and 21 DF, p-value: 0.2892
```

50 km off-shore:

Witsand

```
Residuals:
Min           1Q            Median        3Q            Max
-14.7826      -3.3631       0.1462        4.5208        10.0563

Coefficients:
             Estimate Std.  Error         t value       Pr(>|t|)
(Intercept)  -434.5731      400.6284      -1.085        0.290
Year         0.2322         0.1999        1.162         0.258

Residual standard error: 6.36 on 21 degrees of freedom
Multiple R-squared: 0.06037,  Adjusted R-squared: 0.01563
F-statistic: 1.349 on 1 and 21 DF, p-value: 0.2584
```

Still Bay

```
Residuals:
Min           1Q            Median        3Q            Max
-13.4348      -3.6462       -0.6126       4.4091        9.0316

Coefficients:
             Estimate Std.  Error         t value       Pr(>|t|)
(Intercept)  -325.0079      356.7902      -0.911        0.373
Year         0.1779         0.1780        0.999         0.329

Residual standard error: 5.664 on 21 degrees of freedom
Multiple R-squared: 0.04537,  Adjusted R-squared: -8.802e-05
F-statistic: 0.9981 on 1 and 21 DF, p-value: 0.3292
```

Mossel Bay

```
Residuals:
Min           1Q            Median        3Q            Max
-14.7826      -3.3631       0.1462        4.5208        10.0563

Coefficients:
             Estimate Std.  Error         t value       Pr(>|t|)
(Intercept)  -434.5731      400.6284      -1.085        0.290
Year         0.2322         0.1999        1.162         0.258

Residual standard error: 6.36 on 21 degrees of freedom
Multiple R-squared: 0.06037,  Adjusted R-squared: 0.01563
F-statistic: 1.349 on 1 and 21 DF, p-value: 0.2584
```

Aggregate scatterometer:

Residuals:

Min	1Q	Median	3Q	Max
-12.874	-4.476	-0.284	4.934	10.345

Coefficients:

	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	-769.5212	476.4087	-1.615	0.123
Year	0.3974	0.2378	1.671	0.111

Residual standard error: 6.6 on 19 degrees of freedom
Multiple R-squared: 0.1281, Adjusted R-squared: 0.08222
F-statistic: 2.792 on 1 and 19 DF, p-value: 0.1111

NCEP-DOE:

Residuals:

Min	1Q	Median	3Q	Max
-12.3152	-4.2294	-0.6554	4.6641	14.0251

Coefficients:

	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	-1088.3913	470.7609	-2.312	0.0322 *
Year	0.5532	0.2350	2.354	0.0295 *

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 6.522 on 19 degrees of freedom
Multiple R-squared: 0.2258, Adjusted R-squared: 0.185
F-statistic: 5.541 on 1 and 19 DF, p-value: 0.02949

APPENDIX 3C: REGIME SHIFTS FOR MEAN

NCEP-DOE:

Season	Number of regimes	Period of regimes	Mean average wind speed per period
Annual U Wind	3	1992/1993 2013/2014	1.6 0.8 0.4
Annual V Wind	3	1996/1997 2009/2010	0.5 0.2 0.8
Austral Summer U Wind	3	1992/1993 2006/2007	-0.01 -0.9 -1.8
Asutral Summer V Wind	2	2011/2012	1.9 2.4
Austral Winter U Wind	2	2011/2012	2.9 3.8
Austral Winter V Wind	3	1995/1996 2009/2010	-0.9 -1.4 -0.7
Winter U Wind	3	1993/1994 ——	3.3 4.1 5.2
Winter V Wind	3	1998/1999 2009/2010	-1.6 -2.2 -1.3
Spring U Wind	2	2013/2014	0.7 -2.2
Spring V Wind	3	1996/1997 2005/2006	1.3 0.9 1.5

Aggregate scatterometer:

Season	Number of regimes	Period of regimes	Mean average wind speed per period
Annual U Wind	2	2013/2014	1.4 0.8
Annual V Wind	1	——	1.2
Austral Summer U Wind	2	2006/2007	-0.1 -0.5
Asutral Summer V Wind	2	2008/2009	2.2 1.8
Austral Winter U Wind	2	2014/2015	3.0 2.1
Austral Winter V Wind	1	——	0.3

Winter U Wind	2	2014/2015	4.0 2.8
Winter V Wind	2	2010/2011	-0.3 0.2
Spring U Wind	2	2013/2014	1.4 0.3
Spring V Wind	2	2015/2016	1.7 1.9

Witsand:

Season	Number of regimes	Period of regimes	Mean average wind speed per period
Annual U Wind	2	2013/2014	0.7 -0.04
Annual V Wind	2	2006/2007	2.3 1.9
Austral Summer U Wind	2	2006/2007	-0.8 -1.4
Asutral Summer V Wind	3	2005/2006 2014/2015	3.9 3.3 3.1
Austral Winter U Wind	2	2014/2015	2.4 1.3
Austral Winter V Wind	1	——	0.7
Winter U Wind	2	2014/2015	3.3 2.0
Winter V Wind	2	2014/2015	0.02 0.5
Spring U Wind	2	2013/2014	0.8 -0.6
Spring V Wind	2	2007/2008	3.1 2.5

Mossel Bay:

Season	Number of regimes	Period of regimes	Mean average wind speed per period
Annual U Wind	2	2013/2014	1.0 0.6
Annual V Wind	2	2006/2007	1.4 0.9
Austral Summer U Wind	2	2006/2007	-0.1 -0.4
Asutral Summer V Wind	3	2005/2006 2013/2014	2.6 1.8 2.0
Austral Winter U Wind	2	2014/2015	2.3 1.6
Austral Winter V Wind	1	——	0.2
Winter U Wind	2	2014/2015	2.9 2.1
Winter V Wind	2	2014/2015	-0.3 0.08
Spring U Wind	2	2013/2014	1.0 0.2
Spring V Wind	2	2007/2008	2.0 1.4

APPENDIX 3D: REGIME SHIFTS FOR VARIANCE

NCEP-DOE:

Season	Number of regimes	Period of regimes	Variability per period
Annual U Wind	3	1987/1988 2006/2007	5.4 7.6 10.9
Annual V Wind	1	——	3.5
Austral Summer U Wind	2	1989/1990	3.6 2.5
Asutral Summer V Wind	1	——	0.4
Austral Winter U Wind	3	1988/1989 2013/2014	3.3 4.4 13.2
Austral Winter V Wind	2	2010/2011	1.8 1.3
Summer U Wind	1	——	2.9
Summer V Wind	2	2013/2014	0.3 0.6
Autumn U Wind	2	2014/2015	6.8 14.5
Autumn V Wind	1	——	2.4
Winter U Wind	2	2013/2014	2.7 12.1
Winter V Wind	1	——	1.3
Spring U Wind	2	2011/2012	4.9 13.3
Spring V Wind	1	——	1.4

Aggregate scatterometer:

Season	Number of regimes	Period of regimes	Variability per period
Annual U Wind	2	2011/2012	5.7 7.5
Annual V Wind	2	2008/2009	1.6 0.9
Austral Summer U Wind	1	——	2.4
Asutral Summer V Wind	2	2012/2013	0.2 0.1
Austral Winter U Wind	2	2002/2003	5.1 3.2
Austral Winter V Wind	2	2001/2002	0.9 0.5
Summer U Wind	1	——	2.1
Summer V Wind	1	——	0.1
Autumn U Wind	2	2015/2016	4.6 0.8
Autumn V Wind	1	——	0.9
Winter U Wind	1	——	2.4
Winter V Wind	2	2008/2009	0.6 0.2
Spring U Wind	1	——	4.4
Spring V Wind	1	——	0.6

Witsand:

Season	Number of regimes	Period of regimes	Variability per period
Annual U Wind	2	2012/2013	5.7 7.4
Annual V Wind	3	2001/2002 2014/2015	3.7 2.7 1.4
Austral Summer U Wind	1	——	2.3
Asutral Summer V Wind	1	——	0.3

Austral Winter U Wind	2	2002/2003	4.7 3.0
Austral Winter V Wind	3	2001/2002 2011/2012	1.7 1.1 0.7
Summer U Wind	1	——	1.8
Summer V Wind	1	——	0.1
Autumn U Wind	2	2014/2015	4.2 5.0
Autumn V Wind	2	2015/2016	2.1 0.8
Winter U Wind	1	——	2.2
Winter V Wind	2	2001/2002	0.9 0.3
Spring U Wind	1	——	4.2
Spring V Wind	1	——	1.3

Mossel Bay:

Season	Number of regimes	Period of regimes	Variability per period
Annual U Wind	2	2011/2012	3.1 4.4
Annual V Wind	3	2000/2001 2008/2009	2.2 1.6 1.0
Austral Summer U Wind	1	——	1.2
Asutral Summer V Wind	2	2010/2011	0.3 1.8
Austral Winter U Wind	3	2002/2003 2014/2015	2.5 1.8 0.7
Austral Winter V Wind	2	2001/2002	1.0 0.5
Summer U Wind	1	——	1.0
Summer V Wind	1	——	01

Autumn U Wind	3	2002/2003 2015/2016	3.0 1.8 0.5
Autumn V Wind	2	2010/2011	1.1 0.6
Winter U Wind	1	——	1.3
Winter V Wind	2	2008/2009	0.6 0.1
Spring U Wind	1	——	2.3
Spring V Wind	1	——	0.6