The Potential of Biomimicry to Describe and Extend Regenerative Australian Agriculture

by

Sophie Moss

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Candidate's Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge, it contains no material previously published or written by another person, except where due reference is made in the text.

Sophie Moss Date: 6/11/2018

“Imitation is not just the sincerest form of flattery **-** *it's the sincerest form of learning.”*

George Bernard Shaw

Abstract

Australia's methods of food production require reform. Concern over the environmentally harmful and self-undermining nature of existing productionist, industrial agriculture has sparked interest in 'regenerative' approaches to food production. Regenerative strategies aim to decrease agrochemical inputs and negative environmental impacts, through building agroecosystems' capacity to provide ecosystem services. However, these methods are not widespread. This is in part due to the disconnect between agricultural research and practice, which has led to the lack of an accessible framework to transfer regenerative theory and practice between ecologically different areas, thus, inhibiting the adoption of successful practices into mainstream agriculture. This thesis used qualitative methods to assess the potential for biomimicry to provide this framework. Regenerative farmers and academics were interviewed to determine firstly, whether biomimicry and associated biomimetic methods were perceived to be consistent with regenerative practices. Secondly, how effectively these systems and methods function in the Australian landscape, and lastly, what insights biomimicry may have into extending regenerative Australian agriculture.

This study found that systems using regenerative strategies were perceived to maintain higher productivity in a more sustainable manner than industrial systems, under Australia's highly variable rainfall, making them well suited to the Australian landscape. Regenerative practices were perceived to be more productive in the long term, due to their better performance in sub-optimal conditions. Most participants believed regenerative agricultural practices were consistent with biomimicry. Insights into how biomimicry could be used to extend existing Australian agricultural strategies to improve their long-term sustainability and productivity were gained. These included expanding the spatial scale over which Australian agriculture is managed and adopting key functional elements from locally adapted ecosystems for long-term survival. The implications of this study are that biomimicry has potential to act as a holistic, accessible, and transferrable framework from which to cultivate participatory research into further development and wider adoption of regenerative practices in Australian agriculture. Further participatory research is recommended into a representative assessment of farmers' perceptions of how natural ecosystems achieve goals relevant to agriculture, and how these could be feasibly translated into management. The current approach to drought subsidies is perceived as unfair by regenerative managers and future work should focus on creating policies that assist rather than disincentivise the uptake of regenerative practices. Australian agriculture could also benefit from further case-study based research into local adaptations of natural ecosystems, and their effectiveness in an agricultural context. Particularly strategies associated with improved water management will be advantageous applications of agricultural biomimicry in Australia's variable climate.

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As George Bernard Shaw said, mimicry is the deepest form of learning. There are many words and voices that aren’t my own in the pages to follow. I would like to thank all of my participants for giving your time, enthusiasm and knowledge. This year has been a steep learning curve, and I have loved every bit of it, but the best part was sitting down to talk with such interesting people.

To my family. Without your indoctrination, support, and long distance encouragement I wouldn’t be here. Thank you Thomas, for putting up with me not being home, Mum, for your intellectualism, and Dad, for the time you came home and told me about that radio talk you listened to, about a cool thing called biomimicry.

Table of Contents

List of Figures

List of Tables

List of Boxes

List of acronyms and abbreviations

ANU	Australian National University
WOPR	Whole of paddock rehabilitation

Glossary and Terms

In this thesis, people who might conventionally be referred to as researchers are referred to as **academics** or **academic researchers.** The methods of this research separated participants into two categories: farmers and academics, aiming for equal representation of both. It could be argued that this is a false distinction. Many agroecological academics have their own farming enterprises, likewise many farmers study agronomy or agroecology academically. The reason that I have not used the less ambiguous term of 'researcher' instead of academic, is that both groups undertake their own research within different frameworks of knowledge creation and experimentation. Thus I wanted to avoid the implication that farmers were not researchers.

Agroecology is the application of ecological concepts and principles to the design and management of sustainable agroecosystems (Altieri, 1983). **Agroecosystems** are agricultural systems (ie, a farm).

Biology and **ecology** in relation to biomimicry I have treated as one. Biomimetic literature mainly uses the term 'biological solutions', whose principles it aims to emulate. However in mimicry at a system scale, 'ecological solutions' are probably a more accurate term. Here I have generally used the word biological, in accordance with the literary representation of biomimicry, as a term that encompasses forms, processes *and* systems. Thus, the reader should note that what might be conceptualised as *ecological* solutions can be represented as *system-scale biological* solutions.

Biomimicry refers to the emulation of natural forms, processes and ecosystems to create more sustainable design (Benyus, 1997). **Forms** are structures or shapes, **processes** can be chemical or physical pathways through which forms are built or degraded, or systems maintained, and **systems** are webs of interacting elements, which function as a whole. Systems can range from the scale of a cell, to an ecosystem.

Broadacre farming, refers to large scale cropping or grazing on extensive areas of land (ie, not in glasshouses) (OECD, 2000)

Country is an Australianism and roughly equates to the way "land" is used. The way it is used in this thesis includes the land and all living things on it.

The definition of **ecosystem services** is controversial (Fisher *et al.*, 2009), however here they are defined as "the conditions and processes through which natural ecosystems and the species that make them up, sustain and fulfil human life" (Daily, 1997).

Efficiency is the ratio of outputs to inputs. Eg, high efficiency means lower inputs for higher outputs.

Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life (Clay, 2002).

Neoliberalism describes an ideology that views the free market as an enabler of individual autonomy, and efficient economic outcomes. The market should be free from government and institutional interventions (Western *et al.*, 2007).

A **paradigm** is a set of assumptions from which new knowledge is generated, it is a world view which influences how things are thought about, and how decisions are made (Lawrence *et al.*, 2013).

Participatory research is defined as a collective, self-reflective process undertaken by researchers and participants to understand and improve on the practices in which they participate (Baum *et al.*, 2006). Often referred to as "participatory action research", the reflective process is linked to action.

Productivist and **productionist** refer to the same concept, although here productionist is preferred, and refers to the paradigm as described in *Food Wars* (Heasman and Lang, 2015).

Productivity is a measure of kilograms of product (eg wool or grain) per hectare. This can be over long timescales of decades or centuries, or shorter ones of a year or season.

Regenerative agricultural practices or **regenerative agricultural strategies** in this thesis are defined broadly as any practices or strategies that decrease reliance on external inputs, minimise negative environmental impacts and attempt to regenerate ecosystem function. A **regenerative system** comprises a number of practices or strategies.

Chapter 1: Introduction

1.1 Background

Humanity's food systems are struggling. The human population is booming, and by 2050 it is estimated that we will have approximately 9 billion mouths to feed (Godfray *et al.*, 2010). Currently a quarter of all food produced is wasted (Holt-Giménez *et al.*, 2012), one in nine people are undernourished, and this proportion is increasing (FAO *et al.*, 2018). Current methods of food production are causing extensive environmental degradation, which has and will continue to reduce our capacity to produce food (Hooke *et al.*, 2012). This is an especially urgent matter in Australia, which is predicted to be one of the countries worst affected by climate change (Gunasekera *et al.*, 2007). Thus, addressing declining agricultural productivity cannot be delayed.

In the context of a growing population, and the ongoing struggle to achieve global food security in the face of climate change, we cannot afford methods of food production that undermine themselves, which is why it is crucial to investigate agricultural methods which can meet our food production needs and simultaneously support the ecosystem services they rely on (Tscharntke *et al.*, 2012). Within a capitalist framework that fails to prioritise long-term food security, the competing goals of food production and holistic ecosystem service conservation has become an intractable compromise (Lawrence *et al.*, 2013). How to simultaneously feed a growing population and reduce the environmental impact of our agricultural systems within an economically oriented paradigm remains one of our greatest challenges (Hobbs *et al.*, 2008).

Regenerative agriculture is an approach that aims to maintain and restore ecosystem services while meeting food production needs. It limits reliance on synthetic fertilisers, pesticides, fossil fuels and other external inputs by facilitating ecosystem services to perform functions such as fertilising, water retention, nutrient cycling, and pest control. Despite the uptake of regenerative practices by many Australian farmers (Massy, 2017), industrial, chemical based agriculture still dominates. However, with climate change expected to exert increasing, synergistic pressures on Australian agriculture, we must cultivate systems that will be resilient in the face of increased frequency and severity of droughts, high rainfall events, and shifts in pest and disease distributions. Crucial to the development, adoption and assessment of these practices are frameworks that are easily understood and operable by all stakeholders, from farmers to academics (Howden *et al.*, 2007). There is a gap in the provision of such frameworks, a gap which biomimicry may be able to address (explained in detail in section 3.7).

1.2 Models of sustainability

Agroecological measures of sustainability centre on the concept of sustainable yield: the condition of being able to harvest biomass from a system in perpetuity because the ability of the system to renew itself or be renewed is not compromised (Gliessman, 2006). However, in ecological systems, parameters and conditions change through space and time, making practices that were previously operating within one system's limits no longer sustainable. Thus this definition places the proof of sustainability in the future; in "perpetuity" (Gliessman, 2006: 124).

While the future is the ultimate measure of sustainability, the past provides a model for it. Natural ecosystems achieve sustainability within changing conditions and parameters and have done so for billions of years. The ecosystems we study now are 'living definitions' of sustainability; models from which we can learn methods of managing agroecological systems successfully in the long term. Biomimicry is the emulation of natural forms, processes and systems to create more sustainable design. There is evidence to suggest that this concept not only describes existing regenerative practices but could also provide tools for regenerative management and act as a framework from which to develop agricultural strategies better suited to survival on the Australian landscape.

Biomimicry is a rapidly growing field however its expansion has largely taken place in materials science, chemistry and engineering (Kennedy *et al.*, 2015). We are well practiced at mimicking nature's forms (structures and shapes) and processes (chemical, or biophysical pathways) for more efficient and sustainable human designs, but there has been considerably less focus on the mimicry of natural systems. It is at a systems scale that agriculture is struggling to balance biotic productivity and sustainability, a struggle which natural ecosystems have been optimising solutions to for over 3.8 billion years (Baumeister, 2014; Benyus, 1997). This is a key trade-off in the struggle to achieve productive and sustainable agriculture. If using nature as a model has been so successful at inspiring efficient and sustainable designs at the scale of forms and processes, can it provide a model for sustainable systems? More specifically agriculture?

1.3 Aims

This gap within a gap is where this thesis sits. This study aimed to determine whether there is theoretical and practical merit to the application of biomimicry in Australian agriculture. To do this the study aimed to first establish how regenerative practices were perceived to affect agricultural productivity and sustainability on the Australian landscape. Secondly it aimed to assess whether leaders in regenerative agriculture viewed regenerative practices as continuous with biomimicry. Lastly, this study aimed to discover what biomimetic agricultural practices might look like, and their perceived impacts.

Given the novelty of this application, this study used qualitative research methods to assess its potential through interviews with leaders in regenerative agriculture. People researching and practicing regenerative agriculture are the vanguard of this movement. As such, if they perceive biomimicry as unlikely to contribute to regenerative Australian agriculture, there is little chance that others will take a more positive view.

1.4 Research questions

This study asks: Does biomimicry have the potential to describe and extend regenerative Australian agriculture? To answer this question three sub-questions were devised:

1) How are regenerative management strategies perceived to balance agricultural productivity and sustainability on the Australian landscape?
2) Are current regenerative management strategies consistent with the concept of biomimicry?
3) Can biomimicry be used to extend current Australian agriculture, and what impacts might this have on productivity and sustainability?

1.5 Scope

This thesis will focus on the potential of biomimicry to inform the sustainable *production* of food. There is no doubt that food availability is not the only aspect of our modern food systems that needs reform (Holt-Giménez *et al.*, 2012; Ingram, 2011; Parfitt *et al.*, 2010). However, our food productive capacity is declining, and cannot be assumed to remain constant (Gunasekera *et al.*, 2007). Climate change poses still further challenges to food supply (Rosenzweig *et al.*, 2001).

Thus although there is no doubt that in order to achieve global food security we must reform our whole food system, this thesis determines the capacity of a knowledge framework to address unsustainable production. It does not test the actual effectiveness of the regenerative practices discussed, only their perceived effectiveness through qualitative data. There is no doubt that this is an important aspect, however given the uncertainty of the applicability of biomimicry to Australian agriculture, this thesis is a pilot study to determine whether it is a solution worth pursuing more quantitatively, based on the opinions of leaders in regenerative agriculture.

1.6 Thesis Overview

This thesis is an assessment of the potential of biomimicry to provide a theoretical and practical framework to describe and extend regenerative agriculture.

Chapter two provides some background knowledge on farming in Australia and introduces concepts that are built on in later discussion chapters. **Chapter three** reviews the relevant literature on food systems and paradigms, the emergence of regenerative agriculture, and biomimicry. **Chapter four** outlines the research design and qualitative methods used. Presentation and discussion of the results occurs in the following three chapters. Moving from present to future: **chapter five** discusses perceptions on how current Australian regenerative strategies balance productivity and sustainability, with a focus on drought; **chapter six** presents the perceived relationship of these practices to biomimicry; and **chapter seven** discusses insights gained into how biomimicry can extend regenerative agriculture in Australia, and the potential effects of biomimetic strategies on the sustainability and productivity of future Australian agriculture. **Chapter eight** summarises the research findings and implications of the study, and highlights directions for future research.

Chapter 2: Background information

This chapter introduces concepts necessary to understand later chapters. It begins by discussing how ecosystem services and biodiversity differ between natural and agricultural systems, and how this affects resilience. It then provides some context on drought in Australia, and the Australian government's policies relating to it. It concludes with the increasingly apparent need for resilient agroecosystems and proactive policies which respond to crises by preventing further crises.

2.1 An introduction to ecosystem services, biodiversity, and resilience

A common way of conceptualising how humans interact with and benefit from ecosystems (including agroecosystems) is the concept of services that ecosystems provide to humans. These can be subdivided into 4 broad categories: provisioning, regulating, cultural and supporting services (table 2.1).

Table 2.1: Definitions and examples of ecosystem services (Alcamo, 2003)

Ecosystem service	**Examples**
Provisioning services	Environmental products used directly by humans eg. fresh water, wood, fibre and food.
Regulating services	Benefits humans receive from environmental regulation of key processes, eg. carbon sequestration, disease control, and flood mitigation.
Cultural services	Non-material benefits, eg. spiritual, educational and aesthetic benefits.
Supporting services	Underpin the capacity of these systems to provide services eg. nutrient cycling, soil formation and primary productivity.

There are many critiques of the ecosystem services framework (Schröter *et al.*, 2014; Gómez-Baggethun and Ruiz-Pérez, 2011). However, in comparing natural and agricultural systems, it provides a useful measure.

Ecosystem services are often directly dependent on biodiversity (Isbell *et al.*, 2015; Gamfeldt *et al.*, 2013; Balvanera *et al.*, 2013; Loreau, 2010). In natural ecosystems, species diversity and niche partitioning over evolutionary time increase resource use efficiency at the community level (Oehri *et al.*, 2017; Esser *et al.*, 2005; Chase and Leibold, 2002). "Nature abhors a vacuum" and an empty resource niche will be filled because it offers opportunities for reduced competition (Lloyd-Smith, 2013; Brown, 1994). This process, driven by natural selection, results in natural ecosystems which optimise resource use and provide holistic ecosystem services.

Natural ecosystems also often exhibit ‘functional redundancy’, meaning more than one species fills the same functional role in a system, resulting in greater resilience. These ‘extra’ species aren’t necessarily needed for the system to function. However, they make the system less vulnerable to collapse, because a functional role is less likely to be lost when conditions change (Laliberte *et al.*, 2010). This has implications for resilience. Resilience is defined as “the capacity of a system to persist or maintain function in the face of exogenous disturbance” (Hodgson *et al.*, 2015: 5). The biodiversity, redundancy, and holistic ecosystem service provision within natural ecosystems, results in greater resilience to pressures, such as drought.

Contrariwise, agroecosystems are inherently simplified, and therefore less resilient (Altieri *et al.*, 2015). Agricultural systems concentrate resources on a few species suitable for utilisation by humans. Hence humans reduce the system’s total diversity to increase the percentage of diversity that is useful to humans. This includes removing other elements that would reduce the amount humans get out of the system, either because these elements predate on or compete with species of interest. As a result, agroecosystems are simplified versions of diverse natural ecosystems. The simplification of agricultural ecosystems and resulting reduced ecosystem service provision results in lowered resilience to pressures (Altieri *et al.*, 2015; Walker *et al.*, 2004). When a pressure is applied, the system is more vulnerable to losing its capacity to persist and function (Laliberte *et al.*, 2010).

2.2 Farming in Australia

Reduced resilience creates vulnerabilities that are acutely felt in a country like Australia, which has the most variable climate in the world (Heberger, 2012). Agriculture in this uncertain climate is challenging, and agricultural systems are frequently exposed to extreme pressure. Figure 2.1 shows southern Australia’s extreme variability in rainfall. This area is located below South Australia’s northern border, and contains Australia’s most intensive agricultural areas (Angus and Grace, 2017). In 2018, the year this research was conducted, the average autumn rainfall, crucial for the southern cropping season, was 44% (57mm) lower than average (see figures 2.1, and 2.2).

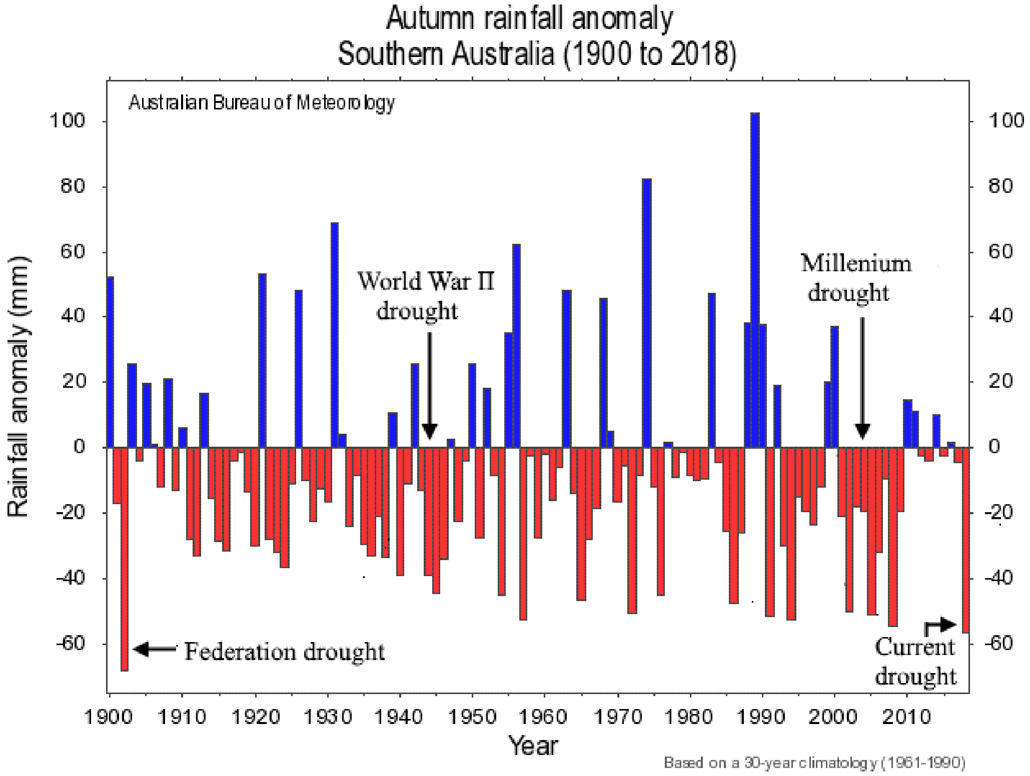

Figure 2.1: Southern Australia autumn rainfall anomaly (difference to the mean) between 1900-2018, indicating well-known droughts (Bureau of Meteorology, 2018b).

Drought is a common occurrence on the Australian landscape as evidenced by the red in figure 2.1. The effects can be financially, biophysically and psychologically catastrophic for farmers. Australian farmers have higher levels of suicide and mental illnesses compared with rural non-farmers and the general population (Judd *et al.*, 2006; Alston, 2012). In drought, issues such as depression, relationship breakdowns, risk of domestic violence and suicide are exacerbated (Hall and Scheltens, 2005). The current drought has yielded news coverage of farmers' difficulty in sourcing feed interstate, with the price of hay increasing by 460% (Neales, 2018), and rural towns on emergency water restrictions to extend their water supply beyond a few months (Upper Hunter Shire Council, 2018).

Drought is a norm in Australia, however it is treated as an anomaly both by policy and agroecological systems. Botterill (2003) describes the history of Australian government responses to drought as neoliberal and ad hoc. To help farmers weather the climatic variability of the Australian landscape, the Australian government provides emergency financial subsidies to struggling farmers in drought. Additionally, farmers are encouraged to manage their own production risks with little assistance (Lawrence *et al.*, 2013). More detail on the specific subsidies provided in the 2018 drought is in appendix 2.

Through this neoliberal lens Australian agriculture is viewed as a mechanistic economic system. Drought is reduced to a period of low income, to which the solution is money. This is a problematic approach considering the increasing stress that drought, pests and heavy rainfall are predicted to have on Australian agriculture in the future (Rosenzweig *et al.*, 2001) which will result in an increasing need for emergency financial relief. Continuous external assistance creates further need for external assistance, and erodes the system's capacity to self-regulate in crisis and remain stable (Senge, 1991). According to MacRae *et al.* (1990), problems with agricultural systems that are not self-regulating include: increased vulnerability to disruption of food supply, costly energy inefficiency, less nutritious food and a leaky local economy due to the cost of external inputs.

This is not to say that emergency assistance is not important. However, subsidies should be coupled with addressing systemic flaws that result in a need to provide emergency relief. If we wish to cultivate resilient agricultural systems that do not periodically collapse and require financial aid in drought, then we need to treat agroecosystems not as mechanistic economic systems but as living systems, that can cultivate resilience in their design.

2.3 Cultivating resilience

With Australia's extreme climatic variability and the combined effects of climate change and land degradation, resilient agroecosystems will become increasingly important to the survival of Australian agriculture (Lin, 2011). In the future, Australia is expected to experience more extreme weather events, including more prolonged and intense droughts, and more heavy rainfall in summer and autumn (Stokes and Howden, 2010; Mpelasoka *et al.*, 2008; Rosenzweig *et al.*, 2001). Australian agroecosystems will be put under severe and synergistic pressures, and resilience will be a key determinant in which agricultural strategies can survive (Lin, 2011).

If we are to adapt proactively, not only subsidise reactively, we must address the systemic issues that lead to vulnerable food systems, and cultivate stable, resilient agricultural systems which are more robust in all conditions and especially less vulnerable to crises in drought. This will only become increasingly important as our agricultural systems must withstand increasing pressures. This thesis builds on the already significant body of knowledge on regenerative agriculture, to work towards the achievement of widespread Australian agricultural practices that can supply food in perpetuity.

2018 was a particularly interesting time to be undertaking this study (figure 2.2). The recent drought revealed the latent vulnerability and resilience of the different management systems represented in the following chapters.

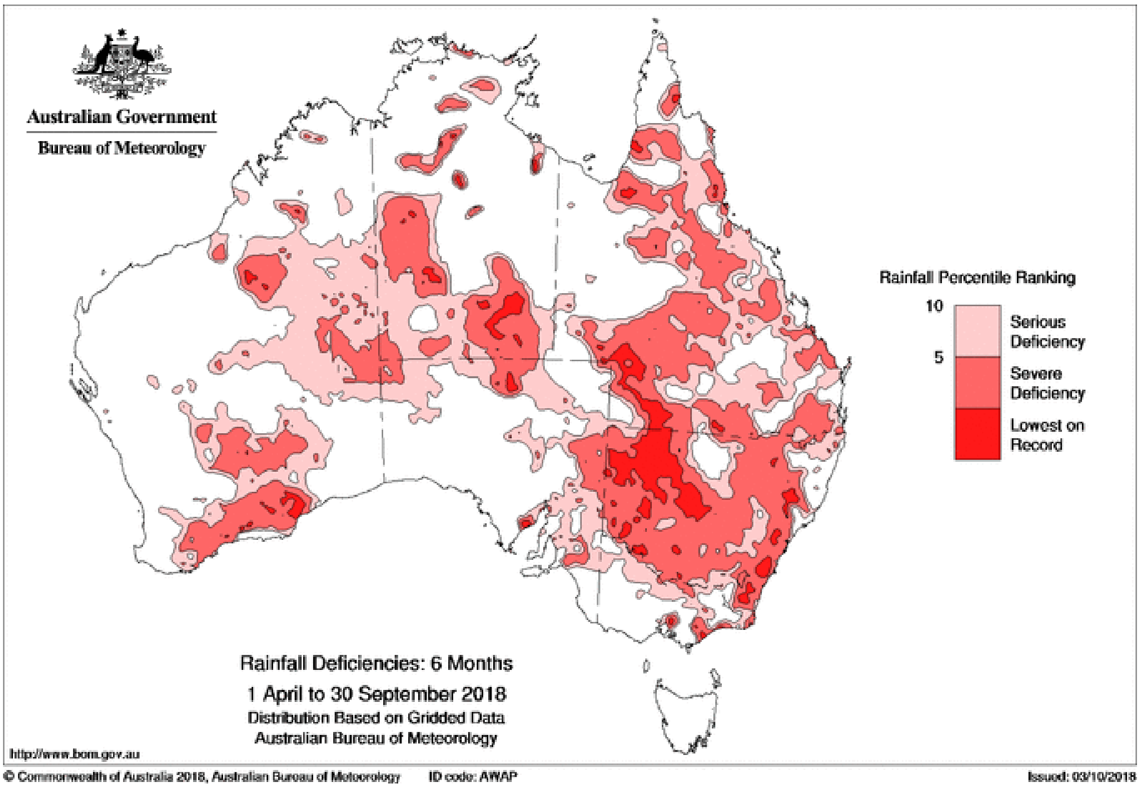

Figure 2.2: The backdrop to this study: Australia's recent rainfall deficiencies over 6 months from April 1st to September 30th 2018 (Bureau of Meteorology, 2018a)

Chapter 3: Literature review

Current food systems, particularly our methods of production need reform. Productionist, industrial approaches to farming are causing degradation of ecosystem services which is in turn jeopardising future food security. An integrated approach to food production is needed, requiring conservation of ecosystem services both on and off-farm.

A growing body of literature has demonstrated that regenerative strategies are agricultural alternatives which not only cultivate ecosystem services, but are also more productive and profitable in the long term in comparison to industrial methods. Despite this, industrial methods still dominate, due to the disconnect between academic regenerative research and its uptake by farmers, as well as the lack of a generalisable framework that allows for systematic adaptation of practices to locally specific conditions.

The overarching themes of many ‘nature inspired’ regenerative, sustainable, and alternative agricultural practices, shows strong parallels between regenerative practices and the concept of biomimicry. If biomimicry is recognised as consistent with regenerative agricultural practices then it holds potential as an accessible framework from which to develop, communicate, and transfer strategies between ecologically different areas for the regeneration of Australian agriculture, from the bottom up.

3.1 Food security: learning to farm without harming

There is strong evidence to suggest that our entire food system needs reform (Ingram, 2011), however, its foundation–food production—is becoming increasingly insecure. The effects of unsustainable management are resulting in a shrinking capacity to produce food. Roughly 43% of the earth’s terrestrial vegetated surface now has diminished capacity to supply benefits for humans, and agricultural activities account for most of this degradation (Hooke *et al.*, 2012; Butler *et al.*, 2007; Daily, 1995). Fischer *et al.* (2002:6) states “there is no way we can meet food security and poverty concerns without first addressing the issues of sustainable agricultural and rural development.” These concerns need to be tackled synergistically, however addressing unsustainable agricultural production cannot be delayed.

Industrial agriculture, informed by the neoliberal ‘productionist’ paradigm is the dominant method of food production in Australia. Paradigms are a set of assumptions; a framework from which new knowledge is generated, and decisions made. Heasman and Lang (2015) define the dominant food systems paradigm as productionist. This paradigm is characterised by an increasing pressure to intensify production on farms, made possible by the inputs of agrochemicals, the dominance of fewer, larger farms, and increased reliance on mechanisation and fossil fuels. The productionist paradigm has shaped an agricultural science that measures its success by increased food output. Industrial agricultural strategies have become the economically rational, most widespread methods of producing food. Industrial agriculture is characterised by high yielding, hybrid crop varieties, grown as large-scale monocultures, with a reliance on heavy machinery and high chemical inputs, including synthetic fertiliser and frequent pesticide applications (Fess and Benedito, 2018).

These industrial agricultural methods are strongly implicated in the destruction of Australian ecosystems (Hobbs, 1998; Sattler and Creighton, 2002). Australia has experienced some of the highest extinction rates worldwide (Woinarski *et al.*, 2015), and of the 35 globally recognised biodiversity hotspots, where high proportions of endemic species are under extreme threat, two are in Australian agricultural areas (Hopper *et al.*, 2016).

There is overwhelming empirical evidence that Australia's current agricultural methods are self-undermining and unsustainable. The erosion of biodiversity created by agricultural activities degrades ecosystem functioning and compromises the services these ecosystems provide, including services that agricultural systems rely on directly, such as pollination, carbon sequestration and pest regulation (Midgley, 2012). Pervasive issues such as soil erosion, secondary salinization, and threats to long-term water supply are the result of agricultural management that does not maintain these ecosystem services (Weis, 2010). Based on current trends, the neoliberal, productionist paradigm cannot provide the long-term solutions required to safeguard future food security (Heasman and Lang, 2015; Cocklin *et al.*, 2006).

The self-undermining nature of industrial agricultural production places food security in a vulnerable position (Deutsch *et al.*, 2013; Foley *et al.*, 2011), particularly in Australia (Gunasekera *et al.*, 2007). If the world continues to use current methods of food production, by 2050 the combined effects of climate change and eventual land degradation are expected to decrease food production by over 40% per capita (Kendall and Pimentel, 1994). Furthermore, Australia is projected to be one of the countries worst affected by climate change and land degradation, with our agricultural exports projected to decline by 11-63% by 2030 (Gunasekera *et al.*, 2007).

Therefore, ability for productionist, industrial systems to continue to meet food production needs is in doubt, due to the conflict inherent in their methods of production. Modern Australian agriculture relies on ecosystem services which its continued expansion is undermining (Power, 2010; Tscharntke *et al.*, 2012:286; Foley *et al.*, 2011; Deutsch *et al.*, 2013). We must develop new agricultural strategies that resolve this internal conflict (Altieri *et al.*, 2015).

Tscharntke *et al.* (2012) argues that linking the goals of biodiversity conservation and hunger reduction requires integrated solutions, which current agricultural methods have failed to provide. In order to achieve global food security without undermining the ecosystem services we depend on, we must develop an approach to both agriculture and ecosystem service conservation where neither system undermines the other (Howitt, 2002). There are new paradigms emerging which offer methods of production that are not internally contradictory.

3.2 New paradigms

Heasman and Lang (2015) describe how humanity has reached a critical juncture in its relationship to food supply, where new paradigms are struggling for dominance over the productionist paradigm. They describe a new ecologically integrated paradigm, which moves away from dependence on high inputs, instead seeking ecological solutions to the problems presented in managing food production. Shifting toward more information-intensive rather than energy-intensive farming. However, the assumptions, values and measures of the productionist paradigm underlie the entire food system and internally reinforce the paradigm’s dominance, making it difficult for alternative paradigms to gain a foothold in mainstream agriculture (Massy, 2017; Heasman and Lang, 2015). ‘Alternative’ methods that fit under this new paradigm are broadly summarised below.

3.3 Regenerative agriculture

Alternative ecological strategies to industrial agriculture seek to achieve food production goals while maintaining or regenerating ecological services. Examples of such strategies include integrated pest and nutrient management systems, organic farming, permaculture, agroforestry and many more (Vandermeer, 1995; Altieri, 1983). Facilitating and using ecological processes through strategies such as polycultures, multi-species crop rotations, crop diversification, and organic soil amendments, allows alternative agricultural practices to eliminate industrial fertilisers and pesticides and thus reduce external energy input (Pimentel *et al.*, 2005a; Liebman and Davis, 2000). Many Australian farmers are becoming interested in these more sustainable alternatives (Massy, 2017).

There is evidence to suggest that Australian farmers are increasingly using “regenerative” agricultural management (Massy, 2017), however there is currently no uniformly recognised definition of regenerative agriculture (Elevitch *et al.*, 2018). The term “regenerative” rather than “sustainable” is preferred in this context because it connotes management that more than sustains the ecological functions necessary for food production, and recognises the need to actively re-build (often degraded) agricultural systems towards full-health in order to benefit from their services. Jeffery (2017) defines regenerative agriculture as:

> the application of techniques which seek to restore landscape function and deliver outcomes that include sustainable production, an improved natural resource base, healthy nutrient cycling, increased biodiversity and resilience to change.

This can include many types of sustainable agriculture mentioned previously. Many regenerative biophysical strategies come down to reducing reliance on external inputs such as synthetic fertiliser and pesticides, that is, regenerative systems can be defined as any systems that are “semi-closed” (Pearson, 2007). Some examples of regenerative practices are given in table 3.1.

Table 3.1: Examples of regenerative agricultural practices from Soils for Life case studies (Outcomes Australia, 2012)

System element regenerated	**Practices**
Soil	Restoring natural nutrient cycles through composting, and cultivating soil biology, especially mycorrhizal fungi. This can involve limiting soil disturbance, chemical fertilisers and bio-cides.
Water	Adjusting stocking rates to maintain ground cover and plant litter. Slowing water flow through creeks, in many cases using leaky weirs in creeklines.
Vegetation	Creating shelter belts of trees. Establishing and maintaining perennial pastures. Implementing planned grazing, which utilises stock to cultivate diversity and resilience of vegetation.

In this thesis I use the term regenerative in its broadest sense to refer to any strategies that decrease reliance on external inputs, minimise negative environmental impacts and attempt to regenerate ecosystem function. This deliberately broad interpretation encompasses a variety of sustainable agricultural strategies, as well as strategies that may be adopted by more industrial farmers, allowing for people who don’t necessarily identify as regenerative farmers to use regenerative strategies.

3.4 Productivity vs sustainability: a time dependent trade-off

In optimal conditions, over shorter timeframes, regenerative systems are less productive when compared to industrial agriculture, in kilograms of product per hectare (Seufert *et al.*, 2012; Pimentel *et al.*, 2005a; Stanhill, 1990). This has led to the widespread belief in an unavoidable trade-off between productivity and sustainability in agricultural systems (Grau *et al.*, 2013;

DeFries *et al.*, 2004; Raudsepp-Hearne *et al.*, 2010). This belief has propagated because many studies comparing regenerative and industrial systems are short-term (Müller *et al.*, 2010; Badgley *et al.*, 2007). Due to the nature of funding and qualification durations, environmental research projects typically run within a period of three years, leading to a lack of scientific knowledge over longer timescales (Müller *et al.*, 2010). This knowledge is critical to making informed decisions about urgent long-term issues such as sustainable land management and food security (Müller *et al.*, 2010).

This bias in scientific practice means that while many studies endorse industrial methods as better for short term productivity, we are not considering their long-term productivity through the near-optimal and sub-optimal conditions that happen in reality, when deciding which systems optimise productivity. Productionist science is focused on creating systems that maximise agricultural output under near-optimal conditions (supplied by industrial inputs) at the cost of their ability to cope in sub-optimal conditions (Lotter *et al.*, 2003). That is, they follow a 'boom and bust' approach to productivity. Contrariwise, regenerative systems can be characterised as 'risk averse'. Many studies have shown that regeneratively managed farms have lower long-term yield variability and excel in water and climate stress in comparison to industrially managed systems, in some cases outperforming them by up to 70-90% in drought (Lotter *et al.*, 2003; Laliberte *et al.*, 2010). Therefore, regenerative systems sacrifice high yields in favourable conditions for resilience in unfavourable conditions, while industrial systems are designed to maximise productivity in favourable conditions, and are more vulnerable to severe reductions in productivity in unfavourable times.

This has implications for how the long-term productivity of these two systems play out on the Australian landscape, where sub-optimal conditions happen frequently (chapter 2). Relevant agricultural research must run long enough to observe the response and recovery of agricultural systems to extreme events, such as drought and high intensity rainfall, which can cause extensive losses in vulnerable agricultural systems, affecting their overall productivity. Unfortunately there are no long-term comparable studies in Australia. However, farms using regenerative strategies in other countries have demonstrated higher long-term productivity than industrial farms (Pimentel *et al.*, 2005a; Lotter *et al.*, 2003; Pimentel and Patzek, 2005; Delate *et al.*, 2003; Smolik *et al.*, 1995). Thus there is substantial evidence to suggest that regenerative systems would also have higher productivity in Australia over longer timescales.

3.5 Why aren't regenerative practices more widespread in Australia?

There are substantial practical benefits to regenerative agriculture, however their lack of uptake indicates the strength of the dominant paradigm over land management decisions (Massy, 2017). In addition to the long-term productivity of regenerative systems, they have been found to be more profitable, due to low input costs and access to niche markets (Reganold and Wachter, 2016; Crowder and Reganold, 2015; Pimentel *et al.*, 2005b; Smolik *et al.*, 1995). However, there are practical barriers to their adoption. Due to the well-documented slump in productivity in the changeover from industrial to regenerative methods, they generally have to be in place for a number of years before they can start to compete economically with conventional agriculture (Pimentel *et al.*, 2005b; Martini *et al.*, 2004). Given that the uptake of innovative agricultural practices is primarily motivated by commercial reasons rather than environmental benefits (Kabii and Horwitz, 2006; Langholz *et al.*, 2000), this initial economic disadvantage is a substantial barrier to adoption of regenerative practices. Although, extensive evidence showing regenerative strategies have greater long-term productivity and profitability, suggests that the barriers to their uptake may be more ideological (Massy, 2017).

An important barrier to the spread of regenerative agriculture starts with a disconnect between academic researchers and farmers (Röling and Pretty, 1997). This disconnect between where regenerative practices are studied and developed 'academically' and where they are practiced results in academic research focusing on 'bundles' of regenerative strategies that are only beneficial under certain conditions: the conditions of the researchers rather than those of the farmers who are expected to adopt them.

Regenerative practices tend to be highly site specific, to optimise their productivity and sustainability outcomes (Gomiero *et al.*, 2011; Pacini *et al.*, 2003). However with no systematic framework for adaptation, this specificity results in a lack of generalisable principles, that can be taken and applied to other areas (Rodriguez *et al.*, 2009). Prescribed bundles of strategies that come out of academic research are difficult for farmers to adapt to suit the ecological specificities of their farms, involving trial, error and uncertainty (Rodriguez *et al.*, 2009; Röling and Pretty, 1997; McKenzie, 2013), and there is no accompanying systematic framework that facilitates the adaptation of regenerative practices to a different set of ecological and biophysical requirements on another farm. Thus the trial error and experimentation that farmers must undertake to implement regenerative practices almost *de novo*, is a substantial barrier to their wider adoption (McKenzie, 2013; Rodriguez *et al.*, 2009; Vanclay, 2004). Stuart (2014:7) describes the importance of collaboration as "farmers and environmentalists need each other…when they fight, they both lose, and so do the rest of us."

To address this barrier to the uptake of regenerative strategies, firstly, a more participatory approach to developing these strategies is needed, where knowledge is no longer perceived as a one-way transfer from researchers to practitioners (Pretty, 1995; Röling and Pretty, 1997). Participatory research is a collective, self-reflective process undertaken by researchers and participants to understand and improve on the practices in which they participate (Baum *et al.*, 2006). It is a form of research that is intrinsically linked to action, and its findings are more likely to be implemented due to the participation of stakeholders in the process (Bruges and Smith, 2008; Chambers and Pretty, 1993). Farmers create their own knowledge. It is not something transferred to them by scientists or agricultural extension officers (Vanclay, 2004). Thus, prescriptive bundles of regenerative practices that don't make sense in farmers' worldviews, or that don't suit their landscape without significant experimentation are unlikely to be adopted (Reij and Waters-Bayer, 2014; Vanclay, 2004). To address the crucial barrier to regenerative practices being accepted into mainstream agriculture we must facilitate a participatory discourse between farmers and academic researchers in a manner that is accessible to both (Jeffery, 2017; Bruges and Smith, 2008).

Secondly, a substantial barrier to the uptake of regenerative strategies is that there is no holistic and accessible framework recognised to encompass these strategies. Regenerative agriculture is difficult and controversial to define (Elevitch *et al.*, 2018). There is no simple and systematic framework that can enable easy assessment or translation of regenerative strategies between farmers in ecologically and biophysically different areas (Elevitch *et al.*, 2018), making them difficult to communicate. Regenerative and sustainable strategies are packaged as 'bundles' of practices that are adopted on a trial and error basis, with Australian farmers often feeling like they have no-one to follow (McKenzie, 2013). The most recent State of The Environment report reiterated the fragmented nature of Australia's attempts to achieve more sustainable agricultural management. (Jackson *et al.*, 2017). A single holistic framework that can encompass and communicate the underlying themes of regenerative practices and how they can be adapted by individual farmers would assist in the dissemination of regenerative strategies (Howden *et al.*, 2007).

Thus, two key requirements to addressing this barrier to the wider adoption of regenerative agriculture have emerged:

- Agricultural research must be done collaboratively with farmers and academic researchers. These groups are working toward the same goal, but would be more likely to succeed when working together.
- We need a holistic knowledge framework that allows for regenerative strategies to be generalisable to ecologically different areas, but that also allows for systematic adaptation of general practices to the biophysical and ecological conditions of a specific farm.

Thus, an accessible knowledge framework that is understood by all stakeholders, which encompasses existing regenerative practices and facilitates the systematic adaptation of these practices on a farm level is needed. Such a framework would enable researchers and farmers to co-create agricultural knowledge that is both theory and practice driven, and thus more likely to be adopted. Biomimicry may have the potential to provide this framework.

3.6 A unifying framework?

Much of the literature around regenerative and otherwise branded forms of sustainable agriculture has overarching themes of being ‘nature inspired’. Regenerative strategies are often characterised as ‘working with nature, rather than against it (Jordan, 1998), as approaches that ‘look to natural ecosystems’ and ‘nature’s wisdom’ (Massy, 2017). The rotational grazing strategy devised by Allan Savory was based on the observation of wild herds of African animals being moved around by predators, so that grazing pressure was intense and localised but only for short periods—an ecological reality to which the grasses adapted (Hoffman and Cowling, 2003; Savory, 2013). Peter Andrews’s natural sequence farming came from an understanding of how natural hydrological and biogeochemical cycles can restore ecosystem functions (Norris and Andrews, 2010). Permaculture is defined as “Consciously designed landscapes that mimic the patterns and relationships found in nature” (Holmgren, 2007). The single thread that runs through all these practices is that they are deliberately or unintentionally mimicking the way that natural systems solve the same problems agriculture faces. The practice of learning from and mimicking nature is called biomimicry (Baumeister, 2014). By recognising biomimicry as a single overarching framework for existing regenerative agricultural strategies, biomimicry has the potential to be an accessible, unifying framework that can facilitate the adoption and adaptation of practices between fams.

3.7 Biomimicry

> If the history of earth was compressed into a year, humans would appear in the last 15 minutes, and recent industrial progress in the last minute (Hwang *et al.*, 2015).

Box 1: A brief history of human existence

Biomimicry is the emulation of natural forms, processes and ecosystems to create more sustainable design, and it is based on the notion that the problems we are solving are not new (Baumeister, 2014). We are still figuring out how to use less energy to do more, how to build reliable structures with cheap and abundant materials, how to maximise production sustainably. The natural world as we see it today is the culmination of 3.8 billion years of tried and tested solutions to the problems faced by living within earth’s operating conditions. In the organisms and ecosystems around us, the principles of co-existance over billions of years are manifested (Box 1). Using these forms, processes and systems as a model for developing sustainable designs represents a fundamental scientific shift from learning about nature to learning from nature (Baumeister, 2014).

Janine Benyus, a well-known biomimetic who has brought biomimicry into mainstream science with her (1997) book and the foundation of the Biomimicry Institute, describes biomimicry as:

> Learning to live gracefully on this planet by consciously emulating life's genius. It's not really technology or biology; it's the technology of biology. It's making a fibre like a spider, or lassoing the sun's energy like a leaf. (Baumeister, 2014).

The term "biomimetics" originated in biophysics in 1957, and its applications have since proliferated largely in mimicry of natural forms and processes, by chemists, engineers, and material scientists due to the efficiency, sustainability and reliability achieved by mimicking the key principles of these natural designs (Hwang *et al.*, 2015; Lepora *et al.*, 2013; Bensaude-Vincent *et al.*, 2002). There has been a fivefold increase in biomimicry patents, scholarly articles and research grants since 2000 (Kennedy *et al.*, 2015), and biomimicry could account for $1.6 trillion of global economic output by 2030 (Kennedy *et al.*, 2015). Nature has had 3.8 billion years over which to refine designs that are more reliable, energy efficient, and environmentally 'cleaner' than modern human technology (Bogatyrev and Bogatyreva, 2009).

The natural world has a huge number of models to inspire more efficient and sustainable designs. Box 1 and figure 3.2 show some solutions whose principles have been used to improve on human designs.

Ridges on shark skin induces vortices which significantly reduce drag. Bechert *et al.* (2000) describes how it has been used on the hulls of sailing boats, as well as on aircraft, resulting in a drag reduction of 5-10%. For competition sailing, the use of biomimetic shark ridges has since been banned.

The leaves of plants in dark tropical understories have anti-reflective surfaces to assist in light capture (Lee, 1986). This was engineered into a polythene sheet attached to the glass surface of a solar panel, making the panels 10% better at capturing light through mimicry of this survival strategy (Vincent *et al.*, 2006).

The observation that the leaves of lotus flowers are always clean, despite their muddy surrounds led to the development of 'Lotusan', a self-cleaning paint which has been able to dramatically reduce cleaning expenses on high rise buildings (Barthlott and Neinhuis, 1997).

Box 2: Some commercialised examples of biomimicry

This proliferation of biomimetic applications shows that the emulation of biological *forms* and *processes* in these contexts can provide humans with more sustainable, energy efficient and economically advantageous designs. The comparatively unexplored area is whether this holds true for natural *systems,* which have received far less attention. Can natural systems inform the design of more sustainable, energy efficient and economically advantageous manmade systems? And could systems biomimicry hold the solution to more sustainable agricultural ecosystems?

Figure 3.1: Biological analogues to design problems, from left to right: lotus flower, antireflective *Selaginella willdenowii*, and shark skin under an electron microscope.

3.7.1 Systems biomimicry

> So in natural science, it is the composite thing, the thing as a whole which primarily concerns us, not just the materials of it, which are not found apart from the thing itself.
>
> Aristotle from (Altieri, 1983)

The biomimetic applications discussed thus far, and which dominate biomimetic literature are examples of imitating isolated designs. This is known as 'reductionist' biomimicry, and doesn't necessarily guarantee sustainable outcomes, because of its selective use of biological principles (Reap *et al*., 2005; Volstad and Boks, 2012). For instance, despite the improvement in the solar panel's efficiency by adding an antireflective component, it is still constructed from metals that were acquired through environmentally harmful means, and which the natural leaf had no need of. If we want to achieve not only the efficiency of nature's forms but also the sustainability of nature's systems, then we need to look to larger scales of mimicry.

There are fair objections to using nature as a model for efficiency, and many argue that nature's solutions are only 'good enough' (Volstad and Boks, 2012). Nature often has less efficient solutions than human technology, due to evolutionary constraints. For instance, it has been said that "nature abhors waste" (Kennedy, 2012), despite the resource and energetic inefficiency of a deciduous tree which sheds leaves in the autumn only to undergo the expensive process of growing them anew in spring.

However, this judgement comes from applying a reductionist lens. In isolation we fail to see the system of which that design is a part. The fallen leaves form a layer of insulation for the tree's roots, keeping them warmer throughout the winter (Heinrich, 1987). Not only the tree but other organisms benefit from this, organisms which play their part in the tree's ecosystem (Heinrich, 1987). Some of them assisting in cycling the nutrients from those leaves back into the soil, to be used again by the same tree or other younger trees which will succeed the original when it dies.

This is the scale of sustainability humans struggle to achieve. We need to adopt a wider lens that allows us to see the bigger picture, and the interdependencies of designs, both biological and manmade. Learning to live as sustainably as other organisms in the biosphere, is something we can only learn from natural systems.

Nature doesn't evolve isolated solutions to problems. Biological solutions show "how seemingly isolated design, is in fact, linked to larger and larger systems" (Baumeister, 2014:32). Designs cannot be seen as independent, and our designs—like nature's—must acknowledge their own interdependencies to be sustainable. This is 'holistic' biomimicry. In contrast to reductionist biomimicry, holistic biomimicry takes into account the whole design and, complete life-cycle of each aspect, and how they are integrated as part of a larger system (Volstad and Boks, 2012). These levels of biomimicry are represented in figure 3.2.

Figure 3.2 exemplifies how knowledge of form, process and system can inform sustainable design. The structure of a tree distributes stress, and the fractal-like arrangement of branches dampens force from wind, and is an efficient structure for transporting substances to and from leaves, while maximising sunlight capture (Rian and Sassone, 2014). The tree is constructed largely from 'cheap' abundant elements (carbon, hydrogen, oxygen), from which the tree is synthesised under biological conditions, yet achieves remarkable strength for its weight (Vogel, 2000). The example given in the diagram illustrates the biosynthesis of lignin with different properties, which can be manufactured in varying ratios, as needed from existing pathways, enzymes, and materials (Abreu *et al.*, 2009). The system represents the relationship of the tree with its environment: succession, degradation, transpiration, precipitation, the role it plays in the system it is a part of, the elements it is dependent on, and which depend on it. This scale of systems biomimicry is highly relevant to regenerative agriculture.

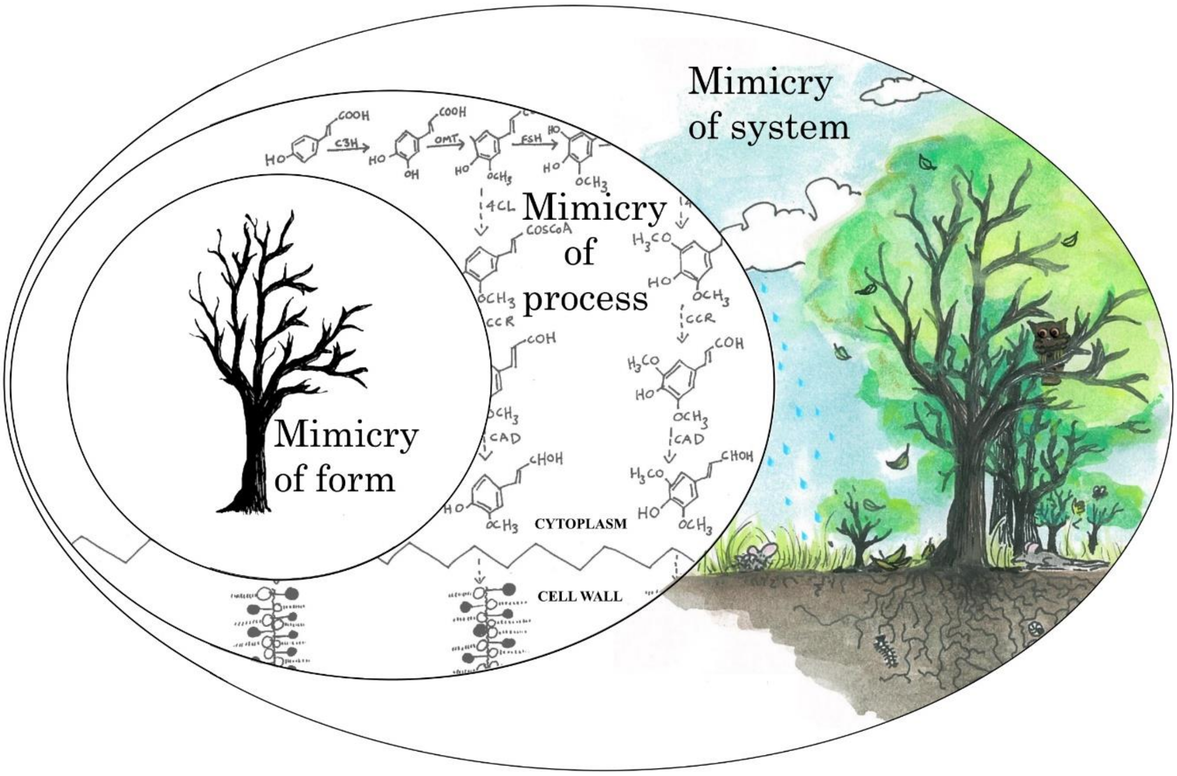

Figure 3.2: Levels of biomimicry

3.7.2 Shifting from energy-intensive to information-intensive systems

Industrial agroecosystems are undesirably energy intensive, requiring constant inputs to maintain productivity, particularly in extreme conditions, while in contrast natural ecosystems are self-organising and resilient to perturbations. When analysing the way in which both nature and human technology solve problems, Vincent *et al.* (2006) found that where human-made solutions tend to use energy to solve problems, biology solves the same problems using information and structure (i.e. design). Our current land management and agricultural systems conform to this high energy pattern. Industrial agriculture is energy intensive, largely due to fertiliser and pesticide use (Pimentel *et al.*, 2005a; Dalgaard *et al.*, 2001). However natural systems have different ways of solving these same problems. Pests are controlled biologically, niche separation allows for diversity and patterns of distribution that confer resilience against pests and competitors, and cultivate ecosystem services. Nutrients are often cycled within the same system, rather than in the extractive, linear fashion of industrial agriculture, requiring large inputs of synthetic fertiliser. Thus, the design of biological systems allow them to achieve the same goals that human agriculture maintains using energy. Current forms of regenerative agriculture attempt to leverage *parts* of these biological processes. Correspondingly, organic cropping—for example—uses only two-thirds of the energy of conventional cropping (Pimentel *et al.*, 2005a). This is largely because these regenerative systems eliminate the need for energy intensive fertilisers, instead using strategies such as nitrogen fixing legumes or cattle rotations (Pimentel *et al.*, 2005a).

Natural Australian ecosystems are the ideal systems to model agricultural sustainability on. Learning how Australian ecosystems survive long-term climate variability while maximising biotic activity, through design rather than high energy inputs, has the potential to inform more sustainable and productive agriculture in the long term.

3.7.3 Biomimetic agriculture

> Agriculture cannot survive long at the expense of natural systems that support it and provide it with models… We can build one system only within another. We can have agriculture only within nature, and culture only within agriculture. At certain critical points these systems have to conform with one another or destroy one another.
>
> -Wendell Berry 'The Unsettling of America'

There is little research on how agroecosystems can be sustainably designed using principles of systems biomimicry. Applications are being investigated in North America, where the potential for agriculture that mimics principles of prairie grasslands is being explored (Crews, 2016). In the North American landscape, prairies create and maintain ecosystem functioning and ecosystem services rather than degrading them. These reference systems may help design sustainable biomimetic agriculture in landscapes where prairies naturally dominate (Crews, 2016). Regenerative agriculture currently utilises bundles of practices which mimic *parts* of natural ecosystems. However, biomimicry has the potential to provide a framework to model regenerative agricultural practices more holistically and develop strategies specific to the Australian landscape.

This thesis sought to determine whether biomimicry has the potential to describe and extend regenerative agricultural strategies in Australia.

- To safeguard future food security we must have methods of food production that do not undermine their own capacity to produce food.
- To achieve this, ecosystem service provision both on and off-farm is needed.
- Regenerative strategies have emerged as agricultural practices that cultivate ecosystem services, and are more productive and profitable in the long term in comparison to industrial methods.
- Despite this, industrial methods still dominate, due to the disconnect between academic regenerative research and the implementation of these practices by farmers, as well as the lack of a generalisable framework that allows for systematic adaptation of practices to locally specific conditions.
- Biomimicry has parallels with current regenerative strategies and may be able to provide management tools within an accessible framework to facilitate the co-creation of agricultural knowledge that is both theory and practice driven, and grounded in ecological reality.
- Mimicry of natural systems is a comparatively unexplored area of biomimicry, however it is highly relevant to agriculture, and its potential applications are being investigated in other countries.
- This thesis sought to determine whether biomimicry has the potential to describe and extend regenerative agricultural strategies in Australia.

Box 3: Literature review key points

Chapter 4: Research design and methods

As a study of potential, the research methods were designed to ascertain if there is theoretical and practical merit to the application of biomimicry in Australian agriculture.

4.1 Research questions

To determine whether biomimicry has the potential to describe and extend regenerative agricultural management strategies in Australia, it is important to critically examine existing practices. Firstly, this study aimed to establish how regenerative practices were perceived to affect agricultural productivity and sustainability on the Australian landscape. Secondly it aimed to assess whether leaders in regenerative agriculture viewed regenerative practices as consistent with biomimicry. Lastly, this study aimed to discover what biomimetic agricultural practices might be, and their perceived impacts.

From these central aims, three research sub-questions were developed:

1) How are regenerative management strategies perceived to balance agricultural productivity and sustainability in the Australian landscape?
2) Are current regenerative management strategies consistent with the concept of biomimicry?
3) How can biomimicry be used to extend current Australian agriculture, and what impacts might this have on productivity and sustainability?

4.2 Data collection

To answer these questions, this thesis used qualitative methods involving semi-structured interviews with farmers and academics. This method allowed for in-depth analysis of participants' perceptions of regenerative practices and biomimicry. As a study of potential, this depth of analysis was important, to capture the reasons and experiences behind the views of participants, and their contextual underpinnings.

Face-to-face interviews were held in a university or public space, or at farmers' properties depending on the participant's preference, for a duration of approximately one hour. Interviews were recorded with the consent of participants. The interviews were transcribed in a summarised form and sent to participants for transparency and to confirm the accuracy of the recorded information.

The limitations of using qualitative methods, is that the findings of this research are less generalisable. The knowledge yielded in these interviews, is from a specific sub-set, in a relatively small geographical area, and cannot be claimed to be representative of farmers and academics in general. However, as a pilot study of potential, representative data was less important than having an in-depth understanding of the reasons and contextual experiences of people practicing and researching regenerative agriculture. More representative and quantitative studies are left for future research should this study indicate that this is an avenue worth pursuing.

4.2.1 Interview questions

Interview questions were developed to answer the research questions and to confirm that the problem framing was accurate according to the participants. Farmers and academics were asked questions that targeted the same information but the questions were framed differently for each demographic. For instance, where a farmer was asked "Do you feel that you have had to sacrifice productivity for sustainability or vice versa?" an academic was asked "Do you think that sustainable agricultural production has to involve a trade-off between productivity and sustainability?", so that the questions were framed appropriately according to the participant's relevant experience. A list of interview questions for both demographics are in appendix 1. In accordance with the semi-structured format of the interview, if participants raised additional relevant points, follow up questions were asked.

When assessing the potential for biomimicry to inform sustainable agriculture, the questions asked targeted the *concept* of biomimicry rather than the term. Rather than asking whether farmers saw their practices as biomimetic, they were asked whether they saw their farm as more closely resembling a natural system, or whether they viewed their management practices as mimicking natural ecological processes. This removed definitional confusion around preconceptions of biomimicry, and enabled participants unfamiliar with the term to engage with the questions.

4.2.2 Participants

Interviews were conducted with six regenerative farmers and six agroecology academics. These participants are leaders in the practice and theory of alternative and regenerative agriculture, and if this group of people didn't believe that biomimetic agriculture had benefits for Australian agriculture, then it would be unlikely that others would have a more positive view. The research was approved by the Australian National University (ANU) Human Research Ethics Committee (protocol number: 2018/230).

Local academics with expertise in agroecology were identified through publications and academic networks. All academics interviewed were from the Fenner School of Environment Society at the ANU, in various academic positions. Regenerative farmers were identified through the Soils for Life case studies (Outcomes Australia, 2012), which contained a register of nearby farmers undertaking regenerative practices. The farmers were from a mixture of backgrounds, types of sustainable practices, and farming enterprises. Most were family run farms except for one farm manager. The farmers were all involved in grazing of sheep and/or cattle, with some also undertaking cropping and other enterprises. Identified participants were contacted via email. All participants agreed to be identified and more participant information can be found in tables 4.1 and 4.2.

Snowballing; a form of purposive sampling, whereby respondents use their social networks to recommend potential participants, enabled relevant academics and farmers other than those initially identified to be included (Mack *et al.*, 2005). This included local farmers who were considered to use regenerative practices but who had not participated in the Soils for Life publication, and academics with relevant expertise but less public profiles.

For qualitative studies involving interview data, within a homogeneous group, data saturation tends to occur at twelve participants, and no new information is gained by increasing the sample size (Guest *et al.*, 2006). As farmers and agroecologists were potentially distinct groups, as interviews progressed the data was monitored for a point approaching saturation. The repetition of certain ideas and concepts in interviews suggested that the data had achieved a level of saturation and the participant size was limited to twelve.

For the sake of practicality participants were selected from the Australian Capital Region (ACR), including Canberra and the surrounding NSW region shown in figure 4.1. This landscape is dominated by cropping, sheep and cattle grazing on improved and unimproved native perennial grasslands (Porter *et al.*, 2014), rainfall is highly variable (Murphy and Timbal, 2008), and the region has a lower agricultural output compared to other productive lands globally (Sheng *et al.*, 2015; Porter *et al.*, 2014).

The chosen participants and study area has implications for how this study may apply to other areas. Strategies for sustainable agricultural management that achieve yields perceived to be high or acceptable by ACR land managers may be perceived as less productive than conventional agriculture if used in other more productive areas, where yields are usually higher. The ACR also has highly variable yields dependent on rainfall (Porter *et al.*, 2014). As agricultural strategies that conserve ecosystem services are generally more resilient and stable (chapter 2), ACR land managers may place higher value on strategies that buffer the effects of environmental variability. The management practices may also be skewed towards a representation of strategies that are useful for sheep and cattle enterprises, given the participant demographic.

Table 4.1: Participating academics

Transcript number	**Name**	**Primary research areas**
1	David Freudenberger	Ecological restoration, mine site rehabilitation, impact of feral herbivores.
2	Saul Cunningham	Agricultural landscapes, crop pollination, conservation biology, applied ecology.
4	David Dumaresq	Sustainable farming systems, transdisciplinary environmental studies, environmental philosophy.
5	Brian Walker	Resilience of social-ecological systems and ecosystem dynamics.
7	Craig Strong	Land capability and soil degradation, soil biology, natural resource management, atmospheric aerosols.
12	Matt Colloff	Environmental science, management and policy, adaptation to climate change, ecosystem ecology, functional ecology of floodplains and wetlands, integration science and decision making, systematics and biogeography, conservation science.

Table 4.2: Participating farmers

Transcript and property number	**Name**	**Farming enterprise**
3	Charlie Maslin	Sheep and cattle.
6	Bill Daly	Cereals, legumes, canola sheep and cattle (breeders).
8	Bron and Matt Ryan	Wheat, canola, sheep and cattle (traders).
9	Jane and Dave Hewlett	Sheep.
10	Charlie Massy	Sheep, sometimes cattle.
11	Michael Fitzgerald	Poultry egg enterprise, cattle, pigs, goats.

4.3 Data analysis

This study used thematic analysis, which involved summarising and coding the transcribed data into broad themes relevant to the research questions, and analysing the opinions and perspectives that emerged under each theme to draw conclusions and identify trends in perceptions of management strategies. This ensured systematic and transparent analysis of interview data (Miles and Huberman, 1994).

Where opinions were converted into Likert data for simplified quantifiable comparison between groups, participants were classified as ‘strongly agreed’ if they used decisive language such as “absolutely” or “definitely” in their answer or presented only an opinion in agreement. Opinions were classified as ‘agreed’, if participants, seemed less certain or discussed reasons for disagreement, but on balance agreed. Opinions were classified as neutral, if participants were indecisive, or had an alternative interpretation of the question—placing their answer outside of the framework with which they could be said to agree or disagree. The criteria for ‘strongly disagreed’ and ‘disagreed’ are the inverse of those described for ‘strongly agreed’ and agreed’.

The themes that arose through the analysis of interview data are discussed in the following chapter based on their relevance to the research questions and whether they were raised by multiple participants, as highly relevant.

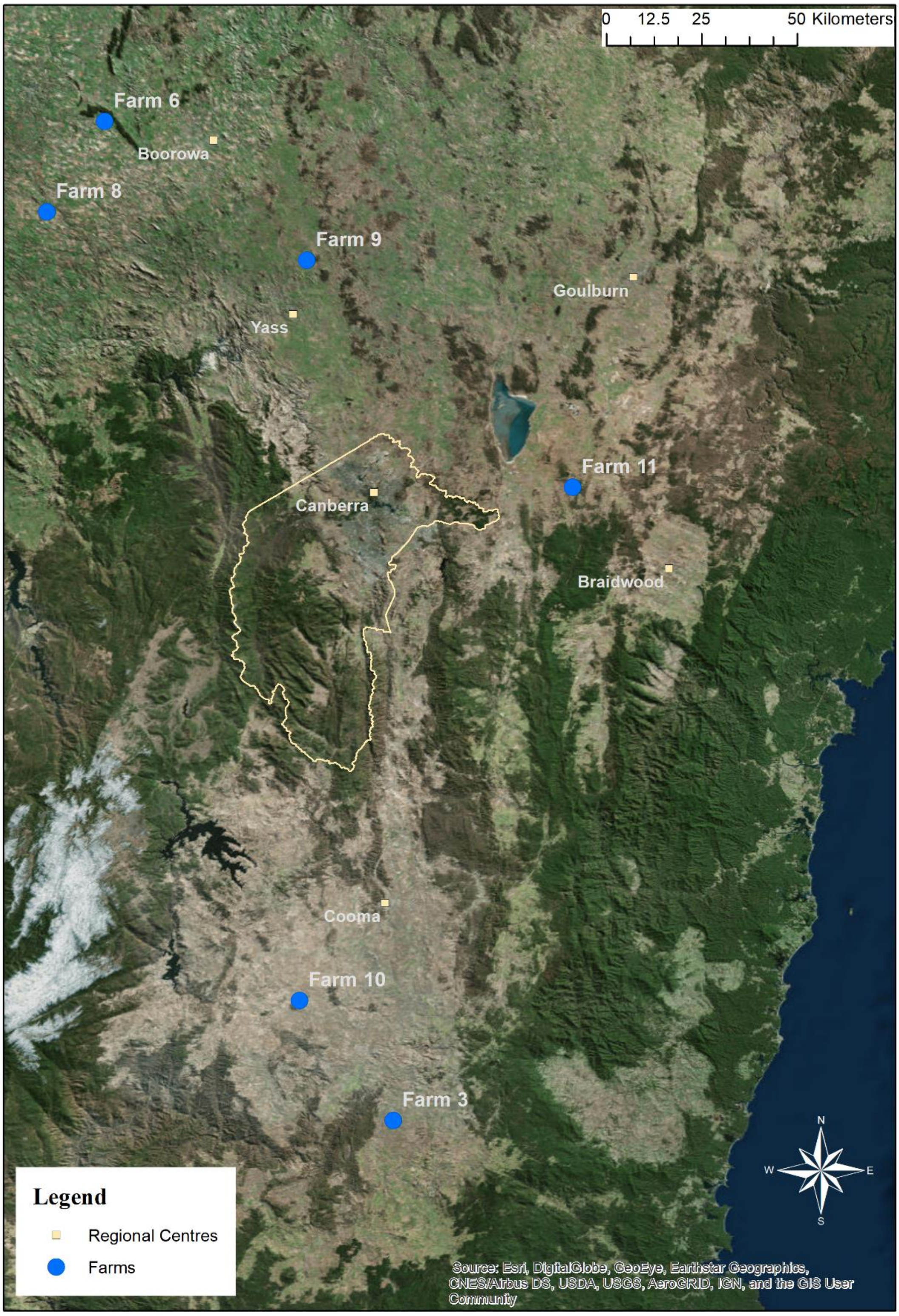

Figure 4.1: Locations of participating farmers' properties within the ACR. Farms are labelled according to corresponding transcript number. The yellow outline indicates the border between the Australian Capital Territory and New South Wales.

Chapter 5: Productivity and sustainability of regenerative practices on the Australian landscape

This section addresses how regenerative management strategies were perceived to balance agricultural productivity and sustainability on the Australian landscape. This was particularly topical considering the drought that coincided with the interviews, exposing the latent vulnerability and resilience, that industrial and regenerative systems were perceived to have respectively. Unlike industrial strategies, regenerative strategies were perceived to have sustainable, lowered but continued production throughout a drought. The productivity of industrial systems in drought was perceived to be lower, and more environmentally harmful.

5.1 A positive note on sustainability

Many farmers using regenerative strategies reported unexpected benefits relating to increased biodiversity such as increased frog life in creeks (T3), platypodes appearing (T11), more small birds in paddocks and tree belts (T9), the presence of threatened bird species, increases in insects and biological control of pests (T10). Whilst these are only briefly mentioned here, this finding is supportive of substantive literature demonstrating regenerative agricultural strategies are more beneficial for sustainability and biodiversity conservation goals compared with industrial agriculture (Massy, 2017; García-Orenes *et al.*, 2012; Pimentel *et al.*, 2005a; Tilman *et al.*, 2002).

5.2 Management, sustainability and productivity

Productionist agriculture focuses on maximising productivity assuming conditions are favourable, and it maintains conditions close to optimal through high inputs. However, some conditions are beyond its control. In Australian systems in particular, 'droughts and flooding rains' are the norm, and thus resilience in the face of sub-optimal and extreme conditions was perceived as a crucial element of systems that are productive in the long term. Risk is the likelihood of an event occurring and vulnerability is the severity of the event's impact should it occur. Climate variability has equal risk for all agricultural systems, however, regenerative systems were perceived to be less vulnerable to it.

> I know people who are still going down the high fertiliser and pasture improvement route. Their productivity is higher than ours, but when a dry time comes they don't back off the accelerator with the stock numbers. Most keep the stock on and keep feeding, in these times their productivity and production of their land drops off, so it depends how much time you spend on good seas and how much time you spend in dry times. *Farmer* (T3)

This exemplifies the perceived importance of regenerative agricultural systems that can continue to sustainably produce food in dry times.

5.2.1 Interactions between drought and management

While drought is a low rainfall phenomenon, management was perceived to have a significant influence on its severity of impact. In the quotation below a sheep farmer noted the importance of management on the effects of drought.

> The later you go into a drought, the quicker you'll come out…Some places will come out [of drought] quicker because they got rid of sheep, and looked after the place so that you can come out of it quickly." *Farmer* (T9)

This quotation exemplifies that while all Australian agriculture is at risk of drought, not all systems of management are equally vulnerable to it. That is, a farm can receive low rainfall and not experience the financial and biophysical catastrophes of farmers requiring emergency relief. A recurring theme that emerged in over half the interviews (four academics, three farmers) is that regenerative and sustainable systems experience drought less severely, because of practices that encourage water infiltration and improve water availability for plant use. These findings are supportive of previous literature (van Dijk *et al.*, 2013). The perceived management strategies and mechanisms behind this are laid out in the following sections.

The feed-feedback loop

Many complex factors determine farmers' decision to destock or attempt to carry stock through a drought by supplementary feeding (such as whether they carried breeding stock or how large their feed reserves were), however the typified view of participants is presented here. When farmers were asked how they were coping in drought, the measure they often gave was how much feed they'd bought. This is a key aspect of the cycle that is referred to here as the feed-feedback loop.

This feedback loop describes the difference between the balancing effects of regenerative management in drought, which perceived ground cover as a fixed parameter, and the reinforcing effects of industrial management, which perceived stock as a fixed parameter. In drought, industrial management was perceived to spiral into a reinforcing feedback loop of degradation, which decreased productivity, profitability and sustainability. Contrariwise, regenerative management was perceived to buffer the effects of drought on the farm, resulting in better profitability, productivity and sustainability.

The distinction perceived between regenerative and industrial farmers can be summarised as each set of strategies viewing different aspects of their system as fixed. Regenerative farmers perceived ground cover as a fixed parameter and adjusted their management of stock numbers to suit ground cover. Whereas industrial farmers were perceived to view their stock numbers as fixed, and to adjust their feed to maintain stocking rates.

Regenerative strategies allowed available ground cover to dictate stock numbers. In a drought when there was less ground cover, they reduced their stock, decreasing compaction, aiding water infiltration, so any rain that fell would have a greater impact on regenerating ground cover. This creates a balancing, negative feedback loop, helping them to maintain productivity and profitability through a drought, whereby decreasing stock leads to a decreasing need to decrease stock. The following quotation is an academic describing a regenerative farmer's property.

> It's a real bad drought now, and he's taken a lot of his stock off. The soil is still covered by a high density of rooted grasses and litter and that means infiltration will occur. So whatever rain does come it's going to go in. And looking at his neighbour's property, its bare soil, it's just going to run off. The inherent productivity of his property is higher, because he's capturing all the rain, and it's as simple as that. The rain's going in not running off, and in a water limited system, what does that tell you? Straight away that it's a better way of doing things. *Academic* (T5)

This exemplifies the balancing effect of regenerative strategies in drought. Contrariwise, when there was less ground cover available in drought, industrial farmers buy in feed to maintain stocking numbers. This creates a reinforcing positive feedback loop whereby buying in feed and keeping stock "walking around on dry, crap country" (T8) leads to compaction, inhibiting water infiltration, decreasing water available to plants, further reducing ground cover, decreasing the ability of the land to recover when rain fell, and increasing the costs of maintaining stock by creating further need to buy feed.

It should also be noted that as regenerative strategies dictate matching stock to feed, these farmers perceived they bought less or no feed in comparison to industrial managers, meaning that they also had lower costs in a drought. Profitability is mentioned further in section 5.2.6. These two typified management approaches that emerged are summarised in table 5.1.

Table 5.1: Comparison of typified regenerative and industrial management decisions in drought

	Regenerative management	**Industrial management**
Management response to a decrease in ground cover.	Reduce stock numbers.	Buy feed to maintain stock numbers.
Effect of management response on water infiltration.	Increases water infiltration	Decreases water infiltration
Impact on country.	Positive. The improved water infiltration means that the country recovers quickly when rain falls, and regenerative farmers “come out of drought” faster.	Negative. The reduced water infiltration and larger stock numbers result in compaction, the country takes longer to recover, and the effects of drought last longer.
Cost of maintaining stock.	Low. Stock are feeding on ground cover	High. Stock are feeding on bought supplementary feed.

A similar feedback loop is described by Hamza and Anderson (2005) which incorporated other factors that result in compaction of the soil. A participant also mentioned work by a previous honours student, who reported similar findings:

> He found that there are a group of farmers, didn’t matter if they were conventional or organic, who had taken an approach to farming summed up as “not being greedy”, it was about knowing the capacity of the land and not to push it too hard. As the season gets worse you pull back. Don’t overinvest in new machinery, don’t go into large debt, if you start to run out of feed you destock, don’t buy feed, that’s the way you’ll go bankrupt really fast. This group of farmers were in fine shape in the height of the millennial drought. They weren’t on welfare, they weren’t getting divorced or committing suicide, they weren’t in debt. This was in a maelstrom of chaos around them. *Academic* (T4)

This sums up the resilience of regenerative strategies in comparison to industrial practices. Regenerative strategies prioritised sustainability, keeping the country in a good condition to respond to rainfall. This created a balancing feedback loop enabling these systems to continue producing despite low rainfall, and to come out of drought quicker. This outcome hinges on a flexible approach to grazing, which is discussed in section 6.2. Stock numbers have a direct impact on vegetation which is a key parameter manipulated by regenerative managers. The use of vegetation to achieve resilient agroecosystems is outlined in the following sections.

5.2.2 Vegetation management to achieve resilience in droughts…

The presence of vegetation was perceived to be a vital part of regenerative approaches to maximising water availability. This regenerative farmer described the importance of vegetation and its perceived effects on the availability of water.

> What I notice now with tree breaks and ground cover… plants transpiring, putting water up, along with the bacterial micro-particles which is what forms rain…having ground cover and every morning having dew or frost or even fog condensing, the small water cycle is probably adding about 10 or 12 inches [of rainfall equivalent] a year. *Farmer* (T10)

This quotation demonstrates that vegetation was perceived to have a significant impact on available water. The concept of the 'small water cycle' of repeated evaporation and precipitation over land, appears relatively underdeveloped in the literature, but is estimated to make up a significant (<50%) proportion of rainwater (Kravčík *et al.*, 2007). Kravčík *et al.* (2007) identifies functional plant cover as playing a crucial role in the small water cycle, and agricultural activities that disrupt vegetation cover can deleteriously affect its function, reducing available water. Micro-climates created by greater vegetation cover can also improve the water use efficiency of plants. Meaning with more vegetation, plants produce more biomass per unit of water (Wallace, 2000).

The effects of vegetation cover and other ecological modifications on microclimate and water availability is an area of regenerative agriculture that merits future research. In particular it has value for Australian agriculture given its water-limited nature, and that "anything to improve the ability of water to infiltrate is going to improve profitability" (T3). Quantifying how regenerative strategies maximise their water use efficiency and availability ecologically, could help more farmers improve their utilisation of water, and thus their productivity and sustainability through drought.

5.2.3 …and flooding rains

Regenerative strategies were perceived to be advantageous in high rainfall events. Farmers believed that "high input wouldn't be able to retain as much [soil]" (T3) in times of high rainfall. This viewpoint was echoed by another farmer:

> We had a six inch rain. Down the road on the same country—this guy had been an industrial, traditional grazer—his country at 2 inches [of rain] was running red. The soil was already moving. That was because he set stocked his country, there looked to be some cover but it was probably 50% bare, and compacted soils. The rain stopped about 24 hours later. I went for a walk as it was easing, and our steep country was trickling clear water. *Farmer* (T10)

This quotation indicates the ability of regenerative strategies to limit soil loss in high rainfall events, as exemplified by the trickling of clear rather than muddied water in comparison to his industrial neighbour who after 2 inches of rain was losing soil with the water runoff. This was attributed to higher vegetation cover in regenerative systems and is supported by extensive literature on the ability of regenerative practices to retain more soil and nutrients, and prevent erosion (García-Orenes *et al.*, 2012; Montgomery, 2007; Pimentel *et al.*, 2005a). A participant also expressed that if Australia's climate is going to become more variable and extreme rainfall events more common, then ability to retain soil and water from high rainfall events will be highly valued (T3). The resilience of regenerative systems to short term climate variability is recognised to be an advantage to future climate change (Vignola *et al.*, 2015; Altieri and Koohafkan, 2008). This advantage may become increasingly important in a changing climate. Regardless, retaining water, and increasing feed are desirable for any farming system.

5.2.4 Government subsidies: supporting the unsustainable farmer.

A topic mentioned by many participants (three academics, two farmers) was how government subsidies during drought disadvantages sustainable managers. This was an especially topical issue given the government announcement on 30th July 2018 of a $500 million emergency drought relief package (additional information included in appendix 2).

As discussed in relation to the feed-feedback loop (5.2.2), a key regenerative strategy was matching stocking numbers to available feed. However, "Being conservative with stock numbers has a cost." (T3), and farmers expressed that regenerative strategies often meant that they were less productive in 'good years' than industrially managed farms.

> Every year I take a financial penalty because I could have run an extra 10% of stock and eaten that grass and sold it and taken the cash. But I've put that feed away so in the bad time I've got something to do to feed back and sustain my level of income or reduce the losses. *Farmer* (T8)

An academic also summarised the sentiments of participants toward government drought subsidies, saying that sustainable managers who get less profits in good years and who do well enough to not need drought relief in the bad years are never compensated. The agricultural systems which put pressure on external systems to subsidise them in drought are those that are rewarded, rather than strategies which reduce their vulnerability to such events. This was perceived as unfair by regenerative farmers.

> The system that they're using now in the drought is supporting the unsustainable farmer. It's heartbreaking for those people on the news but it's just as heartbreaking for us knowing that we're not going to see a dime because this is how we manage our property. *Farmer's partner* (T8)

The unfair and unsustainable repercussions of these subsidies were echoed by another farmer, who stated: “All we’re doing is propping up a broken system” (T10).

> I think one of the fundamental problems in our agricultural system is that people get paid for doing the same wrong thing, it’s not that they shouldn’t get help, but they should get help to change, not help not to change. *Academic* (T5)

This quotation details how drought relief payments were perceived to support unsustainable industrial management strategies and thus in the long term financially disadvantage farmers who were using regenerative strategies. Furthermore, academics pointed towards the government drought subsidies as an indication of a lack of social sustainability, and understanding of regenerative agriculture in Australia.

> Most of Australian agriculture is not sustainable at the collective social level if we are not capable of learning that we are in large scale climate variability, always have been, and there will be intense dry periods regularly… there is zero social and policy understanding of what sustainable agriculture might be. *Academic* (T4)

The importance of social sustainability manifested in policy was emphasised by another academic.

> Do we really want to keep going through a system where we support farmers in times of emergency in order to keep them on the land, in order to keep doing practices which are business as usual, when what we could be doing is saying how do you start to drought proof your farm? How do you start to make your production systems more sustainable? *Academic* (T12)

Participant perceptions show that agricultural management strategies do not act in isolation, they are subject to social and political factors. The need for a wider understanding of regenerative strategies in Australia, and for a shift in policy assistance from emergency relief in drought to systemically addressing agriculture’s vulnerability to drought, is a crucial aspect for more sustainable Australian agriculture.

5.2.5 Profitability

Half the participants (3 farmers, 3 academics) noted that more regenerative strategies could be more profitable even if they were equally or less productive than industrial agriculture. This was because of their reliance on ecosystem services rather than expensive inputs such as synthetic fertilisers. A farmer noted that his profits were now higher and more consistent, since adopting regenerative practices, and that he had reduced the amount of time spent on stock work by 40% by having fewer, larger mobs of sheep (T3).

> Where regenerative agriculture is more resilient and profitable is because your input costs are slashed so you're not dependent on the high industrial expense of chemicals, fertilisers, fuels *Farmer* (T10)

The above quotation exemplifies the use of "free" ecosystem services as opposed to high industrial inputs and was echoed by another academic.

> So he's more profitable because his input costs are low. You can balance profitability through economic means and through use of ecosystem services. *Academic* (T12)

This increase in profitability from low inputs supports findings in the literature (Reganold and Wachter, 2016; Bragg *et al.*, 2005; Reganold *et al.*, 2001). Meaning regenerative farmers can be more economically resilient to drought. Harris (2007), characterized a debt spiral, whereby farmers using less expensive inputs (ie, ecosystem services) were able to avoid spiralling into debt during drought, leading to greater resilience, both biophysically and economically. Thus by valuing ecosystem services other than production, regenerative farmers are decreasing their own costs, and providing regulating, supporting and cultural services for themselves and others.

5.3 Long-term productivity

Participants believed regenerative agricultural strategies overall would increase productivity in the long term in comparison to an industrial system (2 farmers, 3 academics). A farmer noted that "We probably haven't increased our productivity in the short term but we probably will in the long term." (T11). An academic echoed that "I think it would increase productivity over time…There's evidence for that." (T5). These perspectives align with long-term studies in the literature which show that agricultural systems using regenerative strategies can outperform industrial systems in the long term but less commonly in the short term (Reganold and Wachter, 2016; Crowder and Reganold, 2015; Pimentel *et al.*, 2005b; Smolik *et al.*, 1995). Many participants did not conceptualise productivity as maximising output per hectare in a single year.

> Issues with conventional agriculture is its definition of productivity. Modern ag[riculture] is fixated on yield. Kilograms per hectare. This is exactly the wrong measurement. We should be focusing and redefining what we mean by productivity with a temporal scale of decades. *Academic* (T1)

This long-term conceptualisation of productivity aligns with the other outcomes described. When trying to maximise productivity in the long term, production in drought becomes important given the reality that Australian agricultural systems exist in long-term climate variability. In addition to not degrading the land and reducing production over time, these factors meant that regenerative agriculture was perceived as more productive over longer timescales.

5.4 Summary

In drought, regenerative systems were perceived to maintain higher productivity than industrial systems in a more sustainable manner. This resilience to both high and low extremes of rainfall was controlled through vegetation cover, which stocking rates were managed around. Despite the long-term benefits that regenerative strategies were perceived to have on productivity, government subsidies were perceived to have a negative effect on their profitability—as they only benefited industrial methods which collapsed in drought. With this aside, regenerative strategies were perceived to be more profitable through their use of 'free' ecosystem services, small input costs, and were more productive in the long term.

Chapter 6: Are regenerative practices perceived as biomimetic?

This section addresses whether current Australian regenerative strategies were perceived to be consistent with the concept of biomimicry. It qualifies reasons why most participants believed this was true, and presents flexible rotational grazing as a specific practice identified as biomimetic. It addresses objections raised to the majority narrative.

6.1 The majority narrative

The majority of participants (5 farmers, 4 academics) agreed or strongly agreed that current regenerative or sustainable practices mimicked ecological processes that occurred in natural systems, or that their farm more closely resembled a 'natural' system after implementing sustainable management strategies.

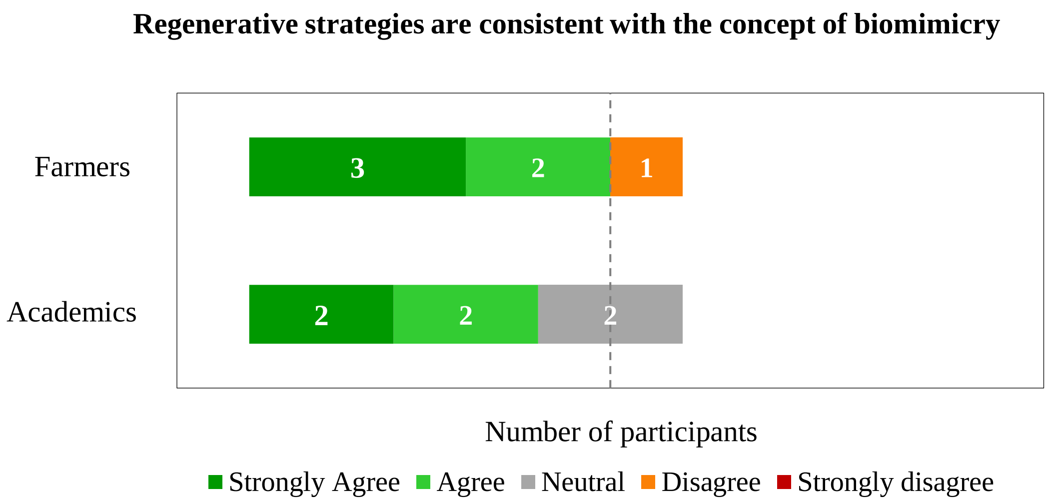

Figure 6.1: Participants' perspectives on whether regenerative strategies are consistent with the concept of biomimicry. Numbers in white indicate the number of participants who held this view.

Figure 5.1 shows participants' perceptions of regenerative practices on the Likert scale. It shows that compared to academics, more farmers agreed that their sustainable practices were consistent with the concept of biomimicry and their opinions were more polarised, however the significance of this difference cannot be reliably determined.

In response to whether they thought their management strategies mimicked natural ecological processes, a farmer stated "As best as we can, we try to mimic those systems and still be commercially viable." (T11). Another example of a farmer who agreed with this, said "That's the whole idea. That's the aim. I'm not saying it does. If we were doing it completely, we'd be reforested right back to where it was in 1788" (T10). These quotations characterise the majority view, that regenerative practices were consistent with mimicry of natural systems. Below is a photo of the sign from one of the farms visited, which shows their management philosophy of 'following nature'.

Figure 6.2: The sign at the entrance to one of the farms visited expresses their principle of following nature.

The perspectives of academics similarly aligned. Below an academic described why he believed practices that focus on being successful in the long term tend to be biomimetic, by accident or intention.

> You'll find that implementing natural ecosystem processes in the form of regenerative agriculture will produce a system in the long term that will actually emulate a lot of a natural ecosystem, even if you didn't look at a natural ecosystem to copy it. Even if you just let 100 farms go through the process of being selected, the ones that survived after 50 years of continuous agriculture—without help—would look more like the properties of a natural ecosystem than anything else. *Academic* (T5)

He describes how through natural selection pressures, farms with management that mimicked strategies already selected as successful, over evolutionary time in that location, would survive in the long term. Because regenerative systems are more focused on long-term production they resemble systems that have evolved for long-term survival. The quotation also highlights this academic's belief that intentionality was not a requisite for mimicry which will be discussed further in section 6.3.2. Another academic echoed the implication that designing systems for long-term survival means results in similar outcomes to evolutionary processes.

> If we take evolutionary biology seriously, the implication of that is that any landscape that is co-evolved, has co-evolved to maximise chances of biotic activity occurring, that is, every niche will be filled eventually. One can argue that across evolutionary time a co-evolved landscape will be the most productive that it can be. This might actually set us an outer limit on what the long-term limit on any agriculture is. *Academic* (T4)

The above academic believed that a natural system could be the most biotically productive in the long term. And that the biotic productivity of natural ecosystems might be the maximum that broadacre agroecosystems can achieve over long timescales, implying that biomimietic agriculture could be advantageous to long-term productivity.

6.2 Biomimetic grazing

Participants were asked to identify specific strategies or practices that they perceived as consistent with the concept of biomimicry. A strategy worth highlighting is flexible rotational grazing, which was identified as a biomimetic strategy by five farmers. In particular it was noted that rotational grazing alone is not biomimetic, rather it was a mindset of responding appropriately to changing conditions.

> Meeting your feed peaks and troughs, because in a natural environment nomadic animals roam to food and water, and that can only be good for the ground. *Farmer* (T8)

The above quotation illustrates why farmers perceived this strategy as biomimetic. Farmers highlighted that matching stocking rates to available ground cover had to be a flexible process—ie, not rigid rotational/cell grazing—because of constantly changing conditions.

> Don't say "They're eating grass that's fine". We know the grass has changed, at the moment we've only had 6.5 inches of rain over 8-9 months of the year, and we got most of that in February, so things aren't going to be the same. *Farmer* (T6)

The practice of matching stocking numbers to available feed as conditions change, avoids the positive feedback loop involved in buying feed (section 5.2.2), and was identified by one farmer as "the key to the bulk of –even our environmental –sustainability" (T8).

> We do the same thing all the time but we also do something different all the time, what we do all the time is re-assess. If somethings worked, we'll say,

> that worked let's give it a go, or these are the reasons why it worked, and that's not going to work this time. *Farmer's partner* (T8)

The importance of continual re-assessment of changing conditions was echoed by another farmer who stressed the importance of "always assessing what your grass, animals and landscape are doing. Making that decision consciously rather than just out of habit…" (T11). For many farmers these flexible land management strategies were informed by a broader philosophy of "letting the land dictate to me rather than me dictate to it" (T3). An academic repeated that flexibility of management was a key characteristic of regenerative agricultural practices—that a management practice in isolation is not necessarily regenerative but rather its method of application is what makes it so.

> [conventional agriculture] saying "I think the animals would be better off in that pasture there because it is producing—" whereas regenerative agriculture people are looking at the process and would move them to a place because that's going to be best for infiltration, or ecosystem function. It might not be as good for the animals but its best for the ecosystem… pure rotational grazing by itself in a strict way is not helping to get an understanding of the ecosystem processes that are underlying. *Academic* (T5)

Thus the most common regenerative practice that was considered biomimetic between the participants interviewed is not a practice, but rather the constant changing of management to suit conditions. This is an inherently biomimetic mindset, because in natural ecosystems population sizes change, with animals migrating in response to patterns of resource availability. For instance many farmers noted they were being "absolutely hammered by kangaroos" (T8) because the kangaroos had moved from the drier areas, to places of comparative resource abundance. This small but consistent observation provided a stark contrast between the scale at which both industrial and regenerative agriculture is operating and the scale at which the Australian biota has evolved to respond to drought. This is discussed further in section 7.1.

6.3 Counterarguments

Despite the majority view that biomimicry is consistent with regenerative practices, for this study—as a study of potential—it is important to examine the outliers.

6.3.1 Improved pastures

The farmer who disagreed (figure 5.4), disagreed that all his farming practices were biomimetic, because he had improved and altered his pastures, taking them further away from a natural system. However he viewed the whole of paddock rehabilitation (WOPR) he had undertaken as mimicking natural ecosystem processes, and attributed an increase in lamb survival to it (T9).

6.3.2 Intentionality

Of the two academics who were classified as neutral, one believed sometimes sustainable practices did mimic ecosystem processes but that this was not necessarily intentional. This introduces an element of intentionality to how we define biomimicry. Does mimicking natural ecosystem processes have to be intentional to be classified as biomimetic? Benyus (1997) defines biomimicry as the “conscious emulation of life’s genius”, making the conscious decision to mimic biological solutions a crucial part of the definition. However, the question is a philosophical one. An academic provided an example of industrial farmers using organic, ecological pest control, rather than chemical pest control because they were cheaper than pesticides (T4). This takes their agricultural system a step closer to a natural system, however, this convergence was not a conscious emulation of nature. Nature itself evolves biological solutions through the trial and error process of mutation and natural selection. The question of whether intention or outcome is more important cannot be decided here. This same teleological problem underlies regenerative agriculture. Regeneration can be achieved through both intentional and non-intentional means. For instance stopping harm to the environment and allowing nature to regenerate itself, as well as active strategies which assist natural regeneration processes.

6.3.3 Mimicry vs utilisation

There were some important alternative interpretations of biomimicry, involving the distinction between “mimicking” ecological processes, and “utilising” or “enabling” them. Two participants interpreted regenerative agriculture as the latter. They defined their understanding of agriculture as utilizing ecosystem processes, or in the case of regenerative agriculture, enabling them to a greater extent than their non-regenerative counterparts. When asked whether sustainable agricultural management strategies mimicked natural ecosystem processes, one academic responded:

> *All* agriculture uses natural ecosystem processes. It cannot work without them. Even hydroponics in a city basement still uses the gaseous composition of the atmosphere. *Academic* (T4)

A different response was given by another participant who was familiar with biomimicry. Their answers to previous questions indicated that they believed their sustainable practices were consistent with the *concept* of biomimicry, thus in accordance with the criteria on the Likert graph they were classified as in agreement, however they explicitly stated that they didn’t consider biomimicry to align exactly with regenerative agriculture.

> It’s not so much biomimicry—Nature can’t mimic itself. It’s [Regenerative agriculture is] enabling natural processes to work again rather than simplifying and dominating… My interpretation of true regenerative

> ag[riculture] is empowering self-organisation, and empowering nature's function. The word biomimicry means mimicking nature. It's not just mimicking nature, its enabling nature to function properly like she's designed to. *Farmer* (T10)

Both viewpoints raise interesting objections about the ability of biomimicry to encapsulate regenerative agriculture. It raises a distinction between 'utilising' and 'mimicking' natural ecosystem processes. The difference—I believe—hinges on whether we assess farm management practices at a system or process scale.

An agroecosystem is made up of processes, some of which are natural or 'self-organising', and others which are performed by humans. The processes that humans undertake (eg. tractor tilling) can often be functionally replaced by a natural process, for instance, permaculture makes use of tilling animals like fowl (Lee, 2004). Instances of replacing human activities with natural processes are a biomimetic grey area. Some argue that this process is *bio-utilisation*, rather than biomimicry, as it involves taking advantage of the placement of a natural process rather than mimicking key principles of that process (Baumeister, 2014). Therefore, individual processes are arguably not biomimetic. However I suggest that facilitating these processes has implications for system scale mimicry.

If we view a farm as a system where the manager chooses which natural processes to suppress, and which to facilitate, the selection of processes becomes meaningful at a system level. Agricultural systems can't be completely self-organising, that is, they can't enable all natural processes "otherwise we'd be reforested" (T10). Regenerative agriculture currently gives little guidance as to how much self-organisation is optimal for production and ecosystem service provision. However, this study suggests that current practices are consistent with biomimicry at a *system scale*. The decision to enable selected processes are made in accordance with making the farm function more like a natural ecosystem on a system scale. Most farmers believed their farms had become more like a natural system after implementing regenerative strategies (T3, T6, T10, T11). This system scale mimicry—by facilitating *key* processes—confers system scale properties such as resilience. Thus, biomimicry in agriculture entails process scale utilisation and system scale mimicry. This is expanded on in section 7.2.

6.4 Summary

Regenerative strategies were largely perceived as consistent with the concept of biomimicry. Flexible rotational grazing emerged as a strategy that was identified by farmers as biomimetic. Objections to biomimicry being consistent with regenerative agriculture were raised on the basis that some management decisions took the farm further away from a natural system, that regenerative strategies did not always intentionally mimic nature, and that they enabled natural ecological processes rather than mimicked them.

Chapter 7: Insights into how biomimicry can extend regenerative Australian agriculture

The perspectives and insights gained in this study, highlight areas where biomimicry could extend and provide benefits for Australian agriculture, including perceived effects that biomimetic strategies might have on productivity and sustainability, and the necessity of biomimetic agriculture.

7.1 Discrepancy in spatial scales

The framework that biomimicry provides shows that there is a discrepancy between the spatial scales at which the Australian biota operates in long-term climate variability, and the scale at which current regenerative agriculture operates. For instance, in drought kangaroos migrate away from dry areas where there is less feed into better watered areas (Moloney and Hearne, 2009). Farmers who were not as severely affected by the drought observed large numbers of kangaroos on their properties (section 6.2), in some cases up to ten times the usual (T8). This response exemplifies the larger scale at which the Australian biota has evolved to long-term climate variability. Agriculture doesn’t currently operate at this scale.

> The problem we face with a lot of agriculture is that we cut out the possibility of having dynamics at the upper scale in an ecological way, we’ve got a fenced off area and that’s it. *Academic* (T5)

Matching stocking rates to available feed partially mimics the reduced pressure from migrating animals in drought that would occur in the natural system, on a farm scale (section 6.2). However, if we take the assumption that natural ecosystems have evolved to maximise biotic activity, then agricultural systems could potentially maintain greater biotic activity in drought if it mimicked the way that natural ecosystems respond, by mimicking migratory behaviours on a larger scale.

An academic described the way some Australian agroecosystems did achieve mimicry at a larger scale (T5), claiming some Queensland farmers had long-standing relationships, whereby when there was a drought in one area, a farmer would send his cattle up to another farm where they had more rain that year, and vice versa. This social arrangement over a long timescale was approximating the scale at which the natural Australian system operates.

> The value of this is that it’s getting back to the way that system functions. That system functions at a spatial scale this big with a distribution of rain over decades, and how you make this [agricultural] system compatible with that scale is very difficult if you’ve just got this little bit, and you have to keep the

> animals there all the time. That's not the scale at which the system evolved. *Academic* (T5)

Biomimicry at larger scales may make our agricultural systems more resilient in drought and more productive in the long term.

7.2 Key elements of mimicry

Participants stressed that biomimetic agricultural systems had to strategically mimic natural ecosystem *functions*. Elements that are essential to the function and the potential of natural ecosystems to function, were perceived to be the elements that agriculture must mimic.

> Because you can't go back to completely natural, because you can't do agriculture there…you want to look at…what are the essential ecosystem processes that enable the potential of the system to remain, and the potential of the system is nutrients, water, soil base and depth, as long as that's there you can regenerate the system again. *Academic* (T5)

This academic emphasised that complete mimicry wasn't helpful for agriculture but mimicry of key elements to achieve system functionality, and the potential of the system to regenerate is required for sustainability. Another academic qualified that agriculture must mimic ecosystem function, to be sustainable.

> All natural systems have 3 basic functions… you can break it down into structural, compositional and functional components. Agriculture *has to* mimic natural ecosystem functions. Fundamentally, agricultural systems require water infiltration, nutrient cycling and soil retention. *Academic* (T1)

They believed that mimicking ecosystem function was possible through cultivating elements of the system's structure and composition.

> We need elements of the same structure and composition of a natural ecosystem to achieve the same functions as a natural ecosystems. At the scale of the production unit…a paddock or field. *Academic* (T1)

The emphasis on scaling this to the production unit is an important dimension of biomimicry. That is- intensive agricultural systems and distant conservation estates were not perceived to conserve ecosystem services at a small enough scale to be biomimetic. This begs the question of at what scale should we mimic and to what extent, without sacrificing the goals of an agricultural landscape? This is a key question that we need to answer to strategically and optimally design biomimetic agriculture. To answer it, we may be able to transfer some knowledge from the field of restoration ecology.

> The acid test of our understanding is not whether we can take ecosystems to bits on paper, however scientifically, but whether we can put them together in practice and make them work. (Bradshaw, 1996)

Bradshaw was talking about restoration, not agriculture. However, the principles of restoration ecology may be relevant to determining biomimetic agricultural strategies. Farmers noted a need to adapt general regenerative practices to their farm, for them to be effective. Other participants stressed the location specific nature of sustainable practices. “[Sustainability] means binding in place as well as time.” (T4). Ecosystems have many characteristics in common with each other but are also locally adapted; they follow generalist rules—for instance increasing water infiltration with increasing ground cover—that apply to most natural ecosystems, and they also have adaptations to local constraints. For instance, vegetation community structures adapted to soil types (Gondwana Link Ltd, 2014). Thus, natural systems adapted to biophysical, landscape constraints indicate what strategies are required for the survival of a functional community, at a system scale in that location. These act as reference ecosystems to capture a local understanding of how communities survive and function in the landscape. Restoration ecologists use reference systems to identify key functional elements, and regenerate functional sustainable ecosystems (Yates *et al.*, 2000; Hobbs and O'connor, 1999). These methods of ‘putting together ecosystems’ are transferrable to developing locally adapted biomimetic agricultural strategies, in addition to generalist regenerative strategies that are currently used.

7.3 Speculative outcomes: the sustainability and productivity of biomimetic agriculture

All academics agreed that using biomimetic principles in agriculture could improve agricultural sustainability “almost by definition” (T2). However, there were varied opinions on how following biomimetic principles in agriculture would affect productivity.

Three academics noted that mimicking natural systems was likely to have a negative effect on productivity in the short term and a positive effect in the long term (T2, T5, T4). If we are mimicking what in the long term has proved to be the most biotically productive system for that particular place, then in the long term this would outproduce systems that may be productive in the short-term but which collapse when conditions are sub-optimal.

> One only has to go to a travelling stock reserve on the Monaro, look at ground cover, how well they respond in harsh season, and know that in the long term they are out-producing exotic pastures. They are the closest things that we have around here to co-evolved grasslands. They are evolved to long-term climate variability. And will outperform in the long term any exotic pasture. *Academic* (T4)

This quotation shows how long-term productive systems were viewed to closely resemble the ecosystem native to that area. These sentiments were echoed by the following academic who believed that more resilient and natural systems were in the long term more productive, than those which collapsed and had to be propped up.

> I think the cost of high production in the short term is reflected much later on in lowered production and deep collapses, unless you're bailed out. *Academic* (T5)

These observations indicate that biomimetic principles can create long-term productive systems because they are inspired by the longest surviving biotically productive systems. The long-term benefits of strategies which cultivate ecological processes are supported by the literature, because for the longest running field trials, agricultural systems that could be classified as biomimetic outperform industrial systems over time (Pimentel *et al.*, 2005b; Pimentel and Patzek, 2005; Delate *et al.*, 2003; Lotter *et al.*, 2003; Smolik *et al.*, 1995). That is, when one starts to build time into the definition of productivity then "productivity would slowly converge towards sustainability" (T2) and more closely resemble a natural system in that space, because that is the optimally productive system over evolutionary time.

7.4 The importance of learning from nature

Some participants expressed that mimicking natural systems in Australian agriculture was not only beneficial but necessary for the survival of Australian agriculture.

> Understanding how "natural systems" work is absolutely fundamental to then understanding how agriculture has to work for the next 10 000 years. We have discovered key principles of how natural systems work, that we need to try to mimic in agriculture. *Academic* (T1)

This academic highlighted the importance of applying what we understand to be the key elements of natural systems to agriculture to ensure its sustainability. The academic (below) believed this was particularly crucial from a water supply perspective, due to the increasing pressures on water supplies in drought, which is recognised as a chief concern for future agriculture (Pearson, 2007).

> So if we don't start learning from nature about how you put trees back in the landscape, how insects and other organisms create macro pores in the soil that allow for water infiltration… then we're going to be in serious trouble. *Academic* (T12)

These quotations exemplify the strong potential that biomimicry was perceived to have for Australian agriculture. They have indicated additional strategies we can learn from natural systems to extend regenerative Australian agriculture.

7.5 Summary

Adopting a biomimetic framework for Australian agriculture was perceived as having the potential to improve the sustainability and long-term productivity of Australian agriculture. Insights into how this can be done include expanding the spatial scale over which Australian agriculture is done, and emulating key elements of natural ecosystems to achieve their locally adapted advantages to long-term survival within landscape constraints. Using these strategies was perceived by some as not only beneficial but necessary for the survival of Australian agriculture.

Chapter 8: Conclusion

This study set out to answer whether biomimicry had the potential to describe and extend regenerative Australian agricultural practices, through three key sub-questions.

Firstly, this study aimed to establish how regenerative practices were perceived to affect agricultural productivity and sustainability on the Australian landscape. Farmers and academics believed that these strategies were well suited to the variability of the Australian landscape and able to maintain higher productivity than industrial systems in a more sustainable manner during extreme low and high rainfall events. These practices were perceived to be more productive in the long term and largely more profitable due to lower input costs.

Secondly it aimed to assess whether leaders in regenerative agriculture viewed regenerative practices as consistent with biomimicry. It found that the regenerative farmers and academics interviewed largely believed regenerative practices to be consistent with biomimicry. However, existing strategies within this sample were limited to biomimicry at a farm scale.

Lastly, this study aimed to glean insights into how biomimicry might extend regenerative agriculture in Australia and what the perceived impacts of this might be. Insights included: expanding the spatial scale over which Australian agriculture is managed, and adopting key elements from locally adapted ecosystems for long-term survival. It was believed that the use of biomimetic practices in Australian agriculture would be beneficial to sustainability and long-term productivity.

8.1 Implications

This study has demonstrated that biomimicry does have the potential to describe and extend regenerative Australian agriculture. Biomimicry is also a framework that has promise for being both accessible to all stakeholders and transferrable between ecologically different areas, which were areas in current regenerative agriculture shown to be a significant barrier to their adoption into mainstream agriculture.

Perhaps one of the most powerful implications of this study is that every participant had a conceptualisation of how nature works and how these principles relate to management. This holds promise for biomimicry as an accessible framework for bottom-up assessment and development of regenerative strategies. Unlike “regenerative” and “sustainable”, “biomimietic” gives land managers not only the goal of regeneration or sustainability, but a method to achieve it, using an analogy that they are likely to already understand. Biomimicry is a framework that can facilitate the systematic assessment, adaptation and transfer of practices between ecologically different areas, based on local reference ecosystems. Thus it is a generalisable framework and provides a model for optimised, locally specific solutions. The potential accessibility of biomimicry as a framework for both academics and farmers, as well as its potential for ecological specificity demonstrated in this study means biomimicry could be the foundation for a more participatory approach to land management.

In his report to the Prime Minister, the Honourable Michael Jeffery, former Governor General of Australia and National Soil Advocate recommended:

> Establish a long-term, perhaps permanent, soil, water, vegetation and agricultural knowledge program that encourages collaboration between scientists and successful farmers to build knowledge, collate the evidence to support successes and improvements, provide improved extension services to share the information and promote the wider use of regenerative farming techniques. This will inform and educate a broad range of stakeholders about leading regenerative land management practices by expanding an initial 21 Soils for Life case studies which have proven the concept, to 100 best practice and innovative farm sites Australia wide. (Jeffery, 2017)

This thesis has preliminarily shown that biomimicry is a potential platform across which farmers and academics can collaborate to co-create knowledge that is theory and practice driven, and which can extend existing regenerative agricultural practices. This can lead to the development and refinement of agricultural strategies that are more productive and sustainable on the Australian landscape in the long term, and which are more likely to be used by land managers—something that scientists alone are struggling to achieve.

Biomimicry has the potential to make Australia's systems of production fit for the long-term climatic variability that this landscape will continue to experience. By mimicking principles of systems that have found successful solutions to long-term survival on this country, we can make our agricultural practices less vulnerable to collapse. This will only become increasingly important with a growing population, climate change and increasing land degradation (Gunasekera *et al.*, 2007; Rosenzweig *et al.*, 2001).

8.2 Recommendations and future research

More representative studies into how farmers perceive natural ecosystems to achieve goals relevant to agricultural management, and whether these might be viable strategies to incorporate into agricultural systems are recommended. This would provide more representative information into the accessibility of biomimicry and the practicality of its adoption.

This study has also shown that while emergency financial subsidies can temporarily alleviate stress on farmers, they are perceived as unfair by regenerative farmers, and economically disincentivise sustainable management. Rather than continuing to respond reactively in crises we need to proactively reduce the vulnerability of our agricultural systems to collapse, and create policies and financial assistance that facilitate sustainable management. Further research into economic and political strategies to incentivise sustainable agricultural management and provide "help to change, not help not to change" is recommended. This echoes the recommendations of Jeffery (2017), who advised that more funds should be put towards helping farmers adopt regenerative strategies.

Given droughts and high rainfall are significant challenges for Australian agriculture, developing effective and quantifiable biomimetic strategies based on locally adapted natural ecosystems has the potential to reduce the vulnerability of Australian farms to drought and other challenges such as water retention, erosion and nutrient loss. Research on a case study basis should be done into generalised and local adaptations of reference Australian ecosystems especially for water management. Further research should experimentally or observationally determine the effectiveness of these strategies translated to agricultural systems. This is crucial for developing strong evidence based biomimetic knowledge in agriculture.

As previously mentioned the framework of biomimicry lends itself to participatory research. Involving farmers as well as scientists and policy makers in this further research will be highly beneficial to not only the quality of the research but the potential impact of their findings.

Australian systems of production need reform, and the need to adapt our agricultural systems to climate change will only become more urgent. We are now at a critical juncture where we must decide how we want the future of food systems to be shaped (Heasman and Lang 2015). For future food security in the face of climate change, it is critical to create agricultural systems that are suited to Australia's ecological realities, and do not collapse periodically and require external help when subjected to pressure. Natural Australian ecosystems provide the ideal model for cultivating resilient internally regulated systems. Understanding and mimicking these systems can enable us to co-create and expand the theory and practice of regenerative agriculture.

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Appendix 1: Interview questions

Farmers

Definitions and problem framing check

1. What do you farm?
2. What does sustainability in a farm context mean to you? What does it entail?
3. What role do you think biodiversity plays in agricultural sustainability?

Main questions

4. What specific sustainable practices do you use? and where did they come from?
5. On your property was there a before/after you started using these techniques? Or have you always run the farm this way?
6. What made you change the way you manage your property?
7. Would you say any of your techniques are used by others or are widespread strategies? Why/why not do you think they are/aren't?
8. What barriers do sustainable farmers face when implementing these management strategies?
9. What would you say are the strongest benefits of implementing your sustainable farming techniques?
10. Do you see the strategies you use as mimicking the way that natural (ecological) systems work?
11. Do you think that by implementing your techniques, your farm more closely resembles a 'natural system'?
12. How do you see your strategies affecting the sustainability of the farm?
13. How do you see your management strategies affecting the productivity of the farm? (Productivity measure suggestions: amount and consistency)
14. How do you see your management practices affecting biodiversity?
15. Do you feel that you have had to sacrifice productivity for sustainability or vice versa?
16. Do you feel that you have had to sacrifice productivity for biodiversity conservation or vice versa?
17. How do you think the ecology/climate of your area impacts which practices you can use?

Academics

Definitions and problem framing check

1. What is your understanding of sustainability in agriculture? What do you think it entails?
2. What role do you think that biodiversity conservation plays in agricultural sustainability?
3. Do you think that sustainable agricultural production has to involve a trade-off between productivity and biodiversity conservation?
4. Do you think that sustainable agricultural production has to involve a trade-off between productivity and sustainability?

Main questions

5. Do you think that regenerative agriculture utilises management strategies which are similar to natural ecosystem processes? (for instance, strategies to achieve pest resilience or lower chemical inputs)
6. Do you think that by making agricultural systems mimic the way that natural ecosystems work, we can make agricultural systems more sustainable?
7. What impact do you think this would have on productivity?
8. Do you think that regenerative/sustainable/alternative agricultural strategies are widespread? (which ones?) why or why not?
9. What barriers to implementing sustainable/regenerative/alternative agricultural strategies do you know of?
10. Which aspects of natural systems do you think it would be most valuable to mimic in an agricultural system? Or which practices that you already know of do you think are the most successful (at achieving both productivity and sustainability outcomes)?
11. Do you know of any specific sustainable agricultural practices that you would say mimicked natural ecosystem processes?

IF YES:

12. Were they successful? (still being used? Did they achieve their sustainability outcomes?)
13. How did they affect the productivity of the farm or land in question?
14. How did these practices affect biodiversity conservation?

Appendix 2: 2018 drought subsidies

The NSW Government's $500 million Emergency Drought Relief Package was designed to help farmers manage the effects of the current drought (Department of Primary Industries, 2018). It included:

- $190 million for Drought Transport Subsidies;
- $100 million to cut the cost of farming by waiving fees and charges; and,
- $150 million to bolster the Farm Innovation Fund (FIF) infrastructure program.

As well as support for:

- Counselling and mental health;
- Critical services in regional communities including transporting water and drought related road upgrades and repairs; and,
- Animal welfare and stock disposal.

The total NSW Government Drought Assistance Package is now $1.1 Billion from when it was launched in 2015 with the $300 million Drought Strategy. The Drought Strategy aimed to focus on preparedness, improved decision making and targeted support for rural communities (Department of Primary Industries, 2018).