Efficacy of the Ecosystem Services Approach in Transitioning to Regenerative Agriculture in Australia

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Abstract

Conventional agriculture is implemented across approximately 75 per cent of the world's agricultural land and has been linked to climate change and biodiversity loss. In contrast, regenerative agriculture focuses on practices that build soil fertility and improve ecosystem functioning to mitigate climate change and increase biodiversity. This review assesses how the regenerative practice of crop diversification influences soil fertility and crop productivity, pest control, water quality and climate-change mitigation. I take an Ecosystem Services Approach to assessing crop diversification, which is a form of natural resource management that considers the relationship between human and environmental needs. These ecosystem services are analysed within the Australian context to determine both current issues and potential opportunities in Australian agriculture. This review reveals that current methods of agriculture in Australia could be improved, and crop diversification offers a key opportunity for helping Australia ensure food security under future climate change. Further research on interspecies interactions is required to help classify the specific crops that provide beneficial ecosystem services in Australia.

Keywords: Crop diversification, soil fertility and climate-change mitigation, microbial diversity, ecosystem services in Australia, regenerative agriculture, Australian agriculture

Introduction

Conventional agricultural practices include some of the most globally dominant methods of producing food, fuel and fibre (Lacanne and Lundgren, 2018). These practices include simple monocultures, soil tillage and artificial chemical use (Giller *et al.*, 1997; Lacanne and Lundgren, 2018; Tilman *et al.*, 2011). However, these practices have been linked to climate change, water pollution (Robertson *et al.*, 2014), soil loss (Tsiafouli *et al.*, 2015) and biodiversity loss (Newbold *et al.*, 2015). The following paragraphs highlight some of the key negative outcomes of conventional agriculture.

In conventional agriculture, a row crop system is used, which involves sowing fields with either just one species (the cash crop) or a simple two-crop rotation (Robertson *et al.*, 2014, Tiemann *et al.*, 2015). Because of the lack of plant diversity, root systems in these fields are simplified (Liang *et al.*, 2016). In addition, the nutrients available to microbes in these soils is significantly reduced in chemical complexity and available carbon, and this decreases microbial diversity and activity within the soils (Liang *et al.*, 2016, Rhodes, 2017). Because microbes are key in the formation and maintenance of fertile soils, conventional farms must rely on artificial fertilisers to maintain high yields when the soils' microbial diversity is depleted (Rhodes, 2017).

Farming with conventional agricultural methods requires an over-reliance on artificial chemicals (Rhodes, 2017). Because landscape diversity is often reduced in agricultural settings, natural predators of common agricultural pests are often absent due to the inability of these homogenous landscapes to support complex food webs (Gardiner *et al.*, 2009). For example, aphids are a common agricultural pest that can be naturally controlled by planting wildflowers that attract ladybirds, which are a natural predator of aphids (Ammann *et* *al.*, 2020; Sutter *et al.*, 2018). In simplified agricultural landscapes, natural predators of pests become less abundant as the habitat provides fewer 'safe havens' or refugia for insect predators to evade predation from birds and other predators, and this results in decreased prey diversity (Robertson *et al.*, 2014; Rusch *et al.*, 2016). As a result, conventional farms must rely on pesticides and insecticides that not only kill the pests but also leach into the soil, killing soil microbes and further reducing the functioning of the soil (Rhodes, 2017).

Because the complexity of root systems in conventional agriculture is reduced, microbial activity within soils is diminished (Poeplau and Don, 2015). Decreased activity results in the creation of fewer air pockets through which water can flow (Balota *et al.*, 2014; Poeplau and Don, 2015), which reduces the soils' capacity to hold water (Bodner *et al.*, 2015). This results in over-watering, which decreases the soils' stability and leads to high amounts of nutrient losses through run-off and evaporation (Bodner *et al.*, 2015). Because of an over-reliance on artificial chemicals, run-off from conventional fields is often toxic to nearby waterways and has been found to leach into groundwater supplies (Srivastav, 2020). This presents a critical issue for human health, with findings that artificial chemical run-off can result in the presence of chemicals in drinking water, which have the potential to cause cancer (Srivastav, 2020).

Methods employed under conventional agriculture drive greenhouse gas emissions (Rhodes, 2017). The conversion of natural land to land managed under conventional agriculture depletes the soil by between 60 to 75 per cent of soil organic carbon (Lal, 2004). This is because intensive agricultural practices decrease soil biodiversity (Giller *et al.*, 1997; McDaniel *et al.*, 2014; Tiemann *et al.*, 2015; Tsiafouli *et al.*, 2015). This loss of biodiversity impacts several functions, including nutrient cycling and carbon sequestration (Tiemann *et al.*, 2015; Swift *et al.*, 2004; Tsiafouli *et al.*, 2015; Wagg *et al.*, 2014). Carbon sequestration, which is the removal of carbon from the atmospheric carbon pool and its subsequent incorporation into the soil carbon pool, is facilitated by microbial activity (Figure 1; Balota *et al.*, 2014). Soil microbes produce both polysaccharides and glomalin (Balota *et al.*, 2014). Together, these organic substances facilitate the formation of soil aggregates which drive soil stability; an important component in the ability of soils to hold carbon (Balota *et al.*, 2014). Because conventional agriculture depletes microbial diversity, its ability to sequester carbon is greatly reduced (Poeplau and Don, 2015).

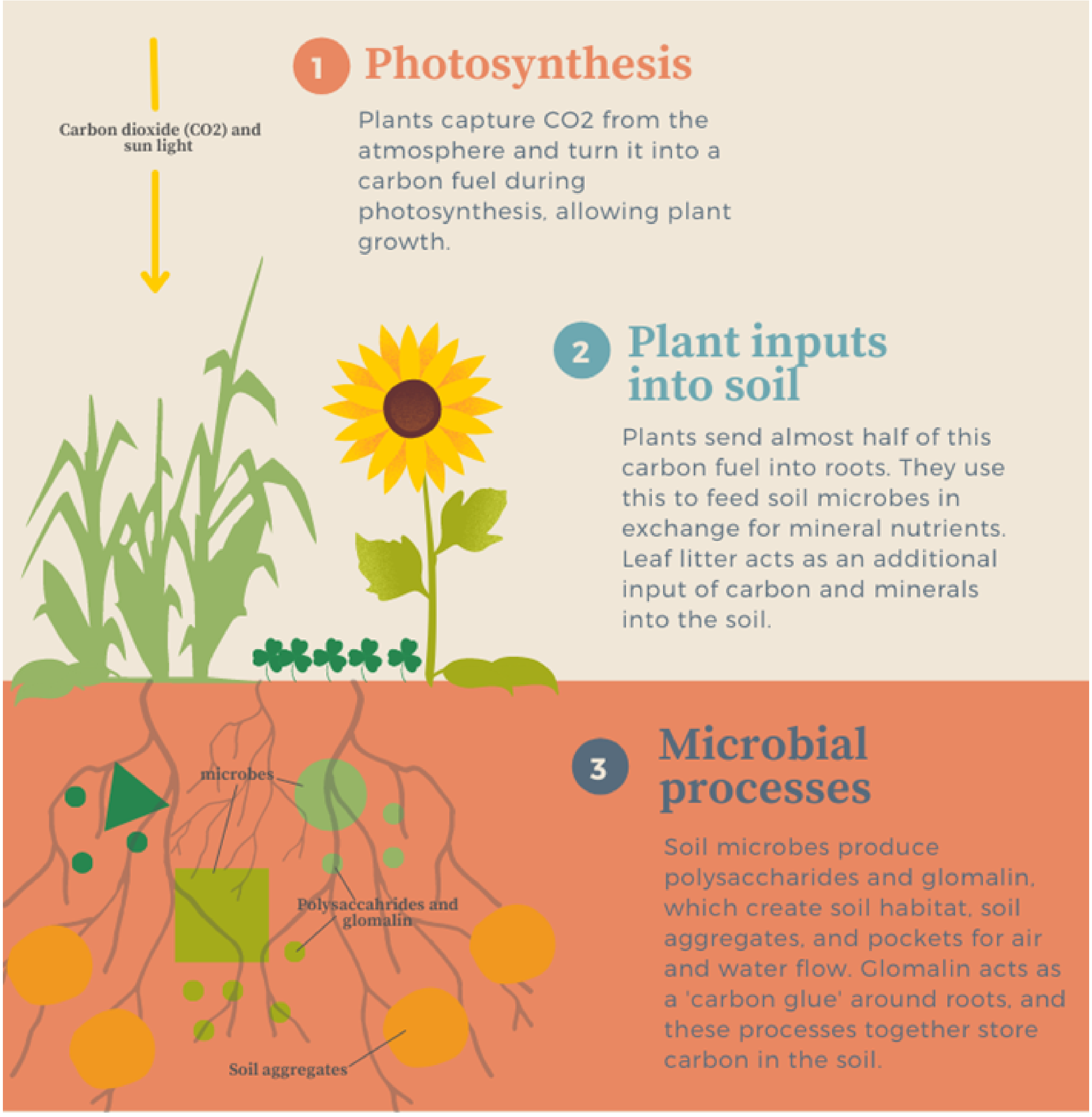

Figure 1: Diagram illustrating a simplified explanation of carbon sequestration. Different shapes indicate different species of microbes and the organic substances they produce. Depictions are a symbolic representation of described processes.

As the global population grows, and climate change intensifies, techniques that feed the world sustainably will become increasingly important (Poeplau and Don, 2015). Regenerative agriculture is a method of food production that focuses on the promotion of soil fertility, biodiversity and climate-change mitigation without negatively impacting yields (Lacanne and Lundgren, 2018). Because regenerative agriculture includes such a broad array of farming methods, we will focus here on crop diversification as a method of regenerative agriculture (Figure 2).

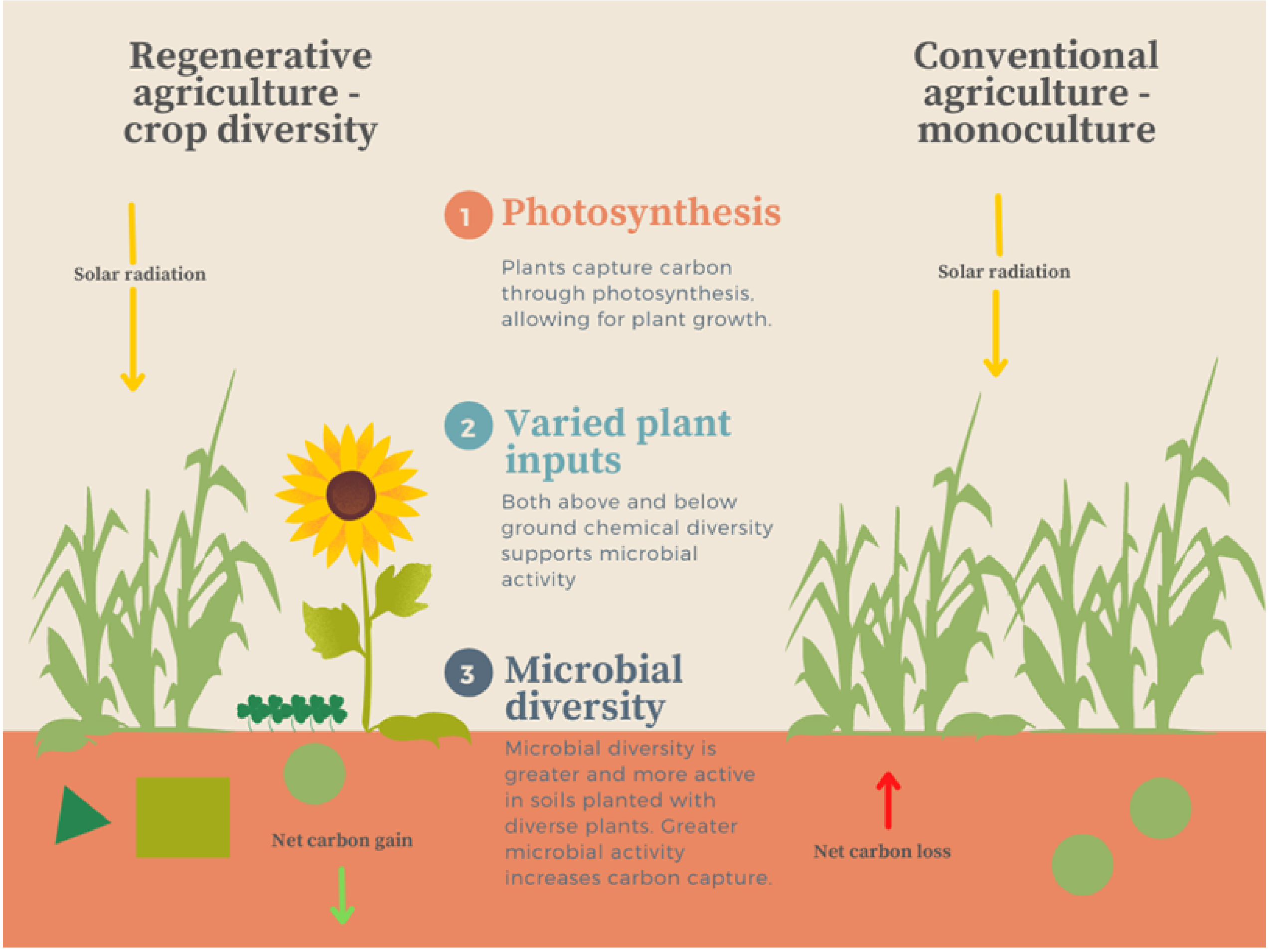

Figure 2: Diagram illustrating a comparison of crop diversity in conventional and regenerative methods of agriculture. Different shapes indicate different species of microbes. Depictions are a symbolic representation of described processes.

Crop diversity in this paper refers to both genotypic and phenotypic variance within and between species in an agricultural ecosystem (Falco and Zoupanidou, 2017). The practice of crop diversification moves away from the simple one- or two-crop rotations of conventional agriculture (Robertson *et al.*, 2014). By doing so, crop diversification promotes the inclusion and close monitoring of functionally diverse crops, which provide a number of ecosystem services (Robertson *et al.*, 2014). The elements of crop diversification and the ecosystem services that they provide are explored in more detail in the following section.

Following the next section exploring crop diversification and ecosystem services, I will then assess the current state of agriculture in Australia. This assessment reveals some issues in Australia's current agricultural methods. I then suggest some solutions to these issues by highlighting how crop diversification will benefit Australia specifically. I conclude by identifying the roadblocks currently preventing a transition to regenerative agriculture and offer some solutions at both a local and a global scale.

Research on implementing crop diversification through an Ecosystem Services Approach (ESA) has been conducted (Robertson *et al.*, 2014; Swift *et al.*, 2004). However, an analysis of existing and potential implementation of such an approach in an Australian context is currently absent from the literature. The potential environmental and societal benefits of such implementation may be of vital importance to ensuring food production in Australia during future climate change.

An introduction to ecosystem services

An ESA is a form of management and decision making that considers both human and environmental needs, and the relationship between the two (Martin-Ortega *et al.*, 2015). This is achieved by assessing management options to determine the most sustainable ways to manage Earth's resources. Ecosystems provide society with four key ecosystem services (Matson *et al.*, 1997; Swift *et al.*, 2004). These include provisioning, cultural, regulating and supporting services (Figure 3).

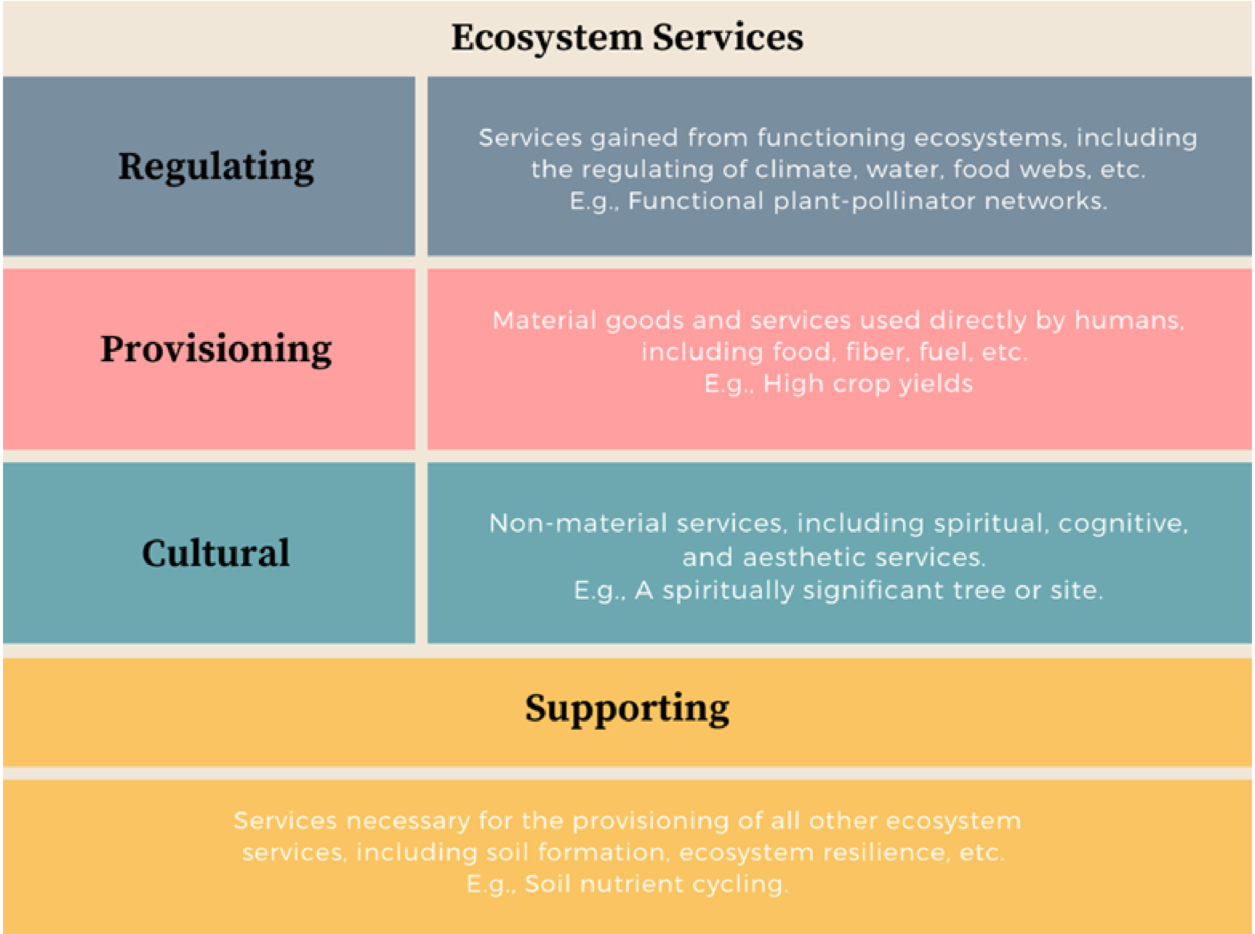

Figure 3: Definitions and examples of the four ecosystem services, as described in Abson and Termansen (2011).

Biodiversity plays a key role in facilitating these services because different species provide alternative functions (Swift *et al.*, 2004). In conventional agriculture, systems are simplified to enhance management efficiency and meet market demands (Swift *et al.*, 2004). This simplification reduces functional groups and overall ecosystem functionality (Wagg *et al.*, 2014). An ESA considers both environmental and societal demands in an economic framework (Martin-Ortega *et al.*, 2015). This involves the valuing of ecosystem services as 'natural capital' so that they can be considered along with other commodities in an economic market. The value that we put on these four ecosystem services can be defined in several ways, including intrinsic value, utilitarian value, bequest value and functional value (Figure 4) (Swift *et al.*, 2004). Intrinsic values are those that ecosystems give in and of themselves, whether that be an ethical, cultural or aesthetic value – such as the beauty of a clean river (Raymond *et al.*, 2009). Utilitarian value is the value that ecosystem services give in a commercial or subsistence sense, such as increased crop production (Lamarque *et al.*, 2011). Bequest value is the value that ecosystem services give to future human generations, such as climate-change mitigation (Raymond *et al.*, 2009). Intrinsic, utilitarian and bequest values can all be classified as anthropocentric, as they all focus on the benefits nature gives to humans (Swift *et al.*, 2004). Functional value, on the other hand, focuses on services that maintain the structure and integrity of ecological systems, such as the persistence of a pollinator species (Swift *et al.*, 2004).

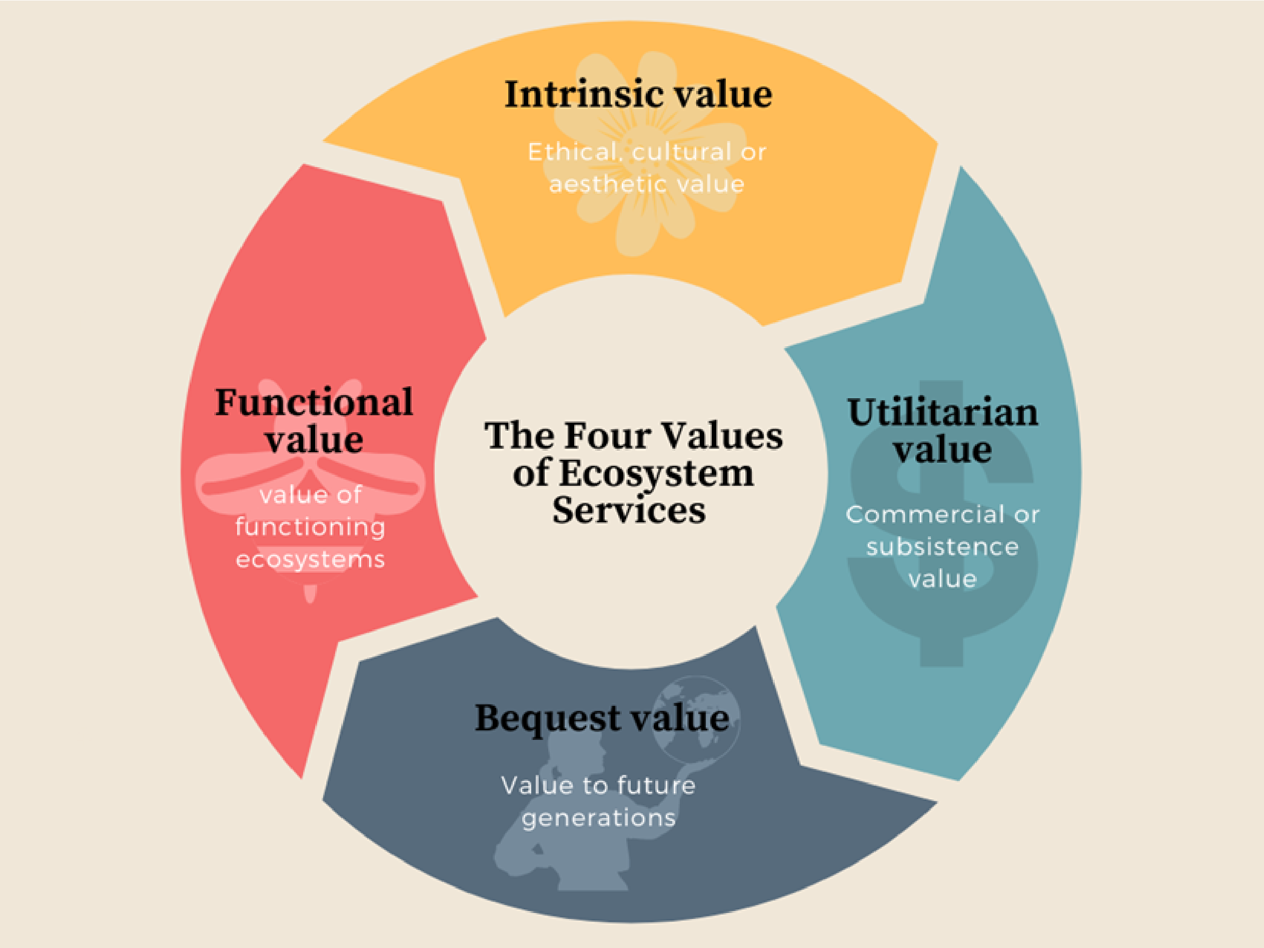

Figure 4: Chart showing the four ways of valuing ecosystem services.

In the following paragraphs, we will explore the key aspects of crop diversification, the value they provide and how they relate to the four ecosystem services.

Increased soil fertility and crop yields

In contrast to the simple one- or two-species row crop rotations in conventional agriculture (Liang *et al.*, 2016), crop diversification involves the mindful coupling of a variety of plants in rotations to increase the complexity of the soil habitat. This improved soil habitat results from the presence of more diverse root systems, which increases the available niches in the rhizosphere (Tiemann *et al.*, 2015). Diverse crop rotations have been evidenced to increase the biomass of soil microbes by an average of 21 per cent (McDaniel *et al.*, 2014). Increased microbial activity drives the formation of soil aggregates, which promotes soil stability (Balota *et al.*, 2014). This in turn increases the ability of the soil to support crops (Tiemann *et al.*, 2015). Therefore, yields in regenerative fields tend to be either similar to or higher than in conventional row crop rotations (Drinkwater *et al.*, 1998). A 30-year comparative study comparing plots farmed with conventional methods with those farmed with regenerative agriculture found that, although yields were similar in both systems, regenerative farms outperformed conventional ones in times of drought (Rhodes, 2017). Regenerative systems also used 45 per cent less energy overall than conventional systems, making the profit per unit of crop greater in regenerative than in conventional agriculture (Rhodes, 2017).

Therefore, crop diversification offers provisioning services by increasing crop yields, which provides utilitarian value to humanity by increasing our ability to feed a growing population. In addition, crop diversification provides supporting services by increasing soil fertility naturally – rather than through the use of artificial fertilisers – with soil fertility then providing a range of other benefits, including increased yields, increased soil stability, increased microbial activity, and so on. Crop diversification can, therefore, be valued for its bequest value, as fertile soils are vital to the survival of future generations.

Biocontrol: a natural pest control method

The complex food webs needed to provide biocontrol depend greatly on habitat complexity, habitat quality and dispersal capabilities of resident biota (Gardiner *et al.*, 2009). Habitat heterogeneity is of vital importance to ecosystem functioning. It provides resident biota with key habitats and refugia that are essential to the trophic functioning of an ecosystem (Robertson *et al.*, 2014). In agricultural ecosystems, crop diversity provides a 'biocontrol' mechanism for unwanted pests, reducing the need for harmful chemicals such as pesticides and insecticides (Gardiner *et al.*, 2009). In contrast to conventional agriculture, crop diversification therefore provides a diverse range of habitats that can support natural pest predators and increase prey diversity, supporting a more complex food web which helps farmers naturally deal with pests (Robertson *et al.*, 2014). Increasing plant diversity is also positively associated with increased floral richness, which is key to supporting a diverse community of pollinator species (Orford *et al.*, 2016). For example, a study by Woodcock *et al.* (2014), investigating whether the addition of florally diverse seed mixtures to agricultural fields increased insect pollinator diversity over a four-year period, found that the abundance and species richness of pollinators correlated with increased flowering resources (Woodcock *et al.*, 2014). This highlights the importance of floral diversity in maintaining pollination services in agricultural fields. Pollinators tend to differ in their floral preferences, and so a diverse array of flowering plants will attract a variety of pollinator species with temporally different pollinating cycles (Kremen *et al.*, 2007). This may allow farmers to maintain pollination productivity year-round.

Both pollination and biocontrol can be considered provisioning services as they provide humans with a zero-cost method of controlling pests and weeds. They therefore provide utilitarian value as they reduce costs for farmers by decreasing their reliance on costly pesticides. They also provide regulating services through increasing the heterogeneity of a landscape that regulates food webs and trophic dynamics. This service can be valued as a functional value as it maintains ecosystem functioning.

Improved water quality

Crop diversification promotes diverse microbial communities, which has been linked to increased levels of soil organic matter (Tiemann *et al.*, 2015). Soil organic matter plays a vital role in water storage (Hudson, 1994). In Rawls *et al.* (2003), the amount of water available to plants was positively associated with increases in organic matter content. This suggests a positive relationship between organic carbon content of soil and water retention (Rawls *et al.*, 2003). Having soils that can retain water is of vital importance in agricultural systems as, without this water retention capacity, crops will need significantly more irrigation to grow. Not only is this costly but it also puts future generations at risk by over-using current water supplies, as well as increasing top soil erosion, the contamination of nearby water bodies, and an increase in the risk of landslides (Datta *et al.*, 2017). In addition, deep-rooted crops improve the efficiency of water retention by improving both soil structure and increasing carbon retention (Kell, 2011). Therefore, having a diverse range of root types, including deep and shallow roots, decreases the need for over-irrigation in agricultural systems. Having a diverse range of root types will also be beneficial for taking advantage of varying levels of precipitation. This is because increasing crop diversity promotes a more diverse range of root types within the soil profile, which may promote the temporal functionality of agricultural ecosystems (Bodner *et al.*, 2015). For example, plants with deep roots are effective under moderate temperatures and precipitation rates, whereas plants with shallow roots are more effective under limited precipitation (Srinivasarao *et al.*, 2016). Considering future climate variability, farmers must maintain diverse crops that can provide effective water retention under varying levels of temperature and precipitation.

The presence of 'blue spaces' (whether that be a lake, waterfall, stream, etc.) has been found to be beneficial to human health and emotional wellbeing (Völker and Kistemann, 2011). This makes the regulation of irrigation and run-off from agricultural fields a cultural service that provides intrinsic value. In addition, the lack of over-watering needed under crop diversification provides utilitarian and bequest value as not only does it currently save farmers expenses, but it also ensures fresh-water supply for future generations.

Carbon sequestration

In contrast to conventional agriculture, which turns the soil into a carbon source, regenerative agriculture transforms the soil into a carbon sink, thus fully utilising the soil carbon pool (Liang *et al.*, 2016). This is important as the soil pool can hold double the amount of carbon than the atmospheric pool (Balser, 2005). As discussed earlier, soil microbes are the key to driving carbon sequestration in soils. By having a diverse array of crops, farmers can increase soil microbial activity as these diverse crops provide an array of root types and chemical inputs that support more complex soil microbial communities (Liang *et al.*, 2016; Rhodes, 2017). In addition, high plant diversity increases soil organic matter accumulation over relatively short time frames (Fornara and Tilman, 2008). This is likely due to the increased production of root biomass and plant residue, which is then incorporated as soil organic matter and builds the soil carbon pool (Fornara and Tilman, 2008).

The maintenance of natural carbon cycles under regenerative agriculture is an example of a regulating service as it regulates the natural flow of nutrients in an ecosystem. Carbon sequestration provides a great deal of bequest value as it ensures that atmospheric carbon is maintained at healthy levels for future generations.

Crop diversification in Australia: Applying an Ecosystem Services Approach

The current state of agriculture in Australia

Despite the benefits of regenerative agriculture, a proportion of Australian farmers still manage their land with damaging conventional agricultural methods (Conacher and Conacher, 1998; Wood *et al.*, 2006). For instance, in north-east Victoria, 80 per cent of the farmed area is dominated by just one variety of canola (Agribusiness View, 2019). In addition, wheat crops occupied a harvesting area of approximately 13 million hectares in Australia in 2018, an increase of approximately 7.5 million hectares since 1940 (Kirkegaard and Rees, 2019). Australia is also reliant on artificial fertilisers and pesticides, with total agricultural chemical sales in Australia amounting to AU$40 million a year (Nash *et al.*, 2019). This suggests that biological pest management and soil health are not always maintained. The current state of agriculture in Australia is also threatening future climate vulnerability, with an estimated 50 per cent of the original soil carbon stocks in Australia having been lost due to intensive agriculture practices (Richardson *et al.*, 2019).

Australia has, however, been working towards a more environmentally focused model of agriculture. The Carbon Farming Futures programme was implemented by the Australian Government between 2012 and 2017 (Department of Agriculture and Water Resources, 2016). It focused on adapting agricultural practices to climate change, while simultaneously improving farm profitability and productivity (Department of Agriculture and Water Resources, 2016). The project focused on research into livestock grazing, manure management and tillage techniques. Little focus was given to crop diversification, and there was no mention of ecosystem services. However, the report does identify that climate change will bring new opportunities for farmers, including 'new crop types and varieties' (Department of Agriculture and Water Resources, 2016). The Carbon Farming Futures programme was originally allocated $348 million, but a change in government policy led to a 40 per cent reduction in funding (Grosvenor Management Consulting, 2017). This reduction prevented the gathering of detailed information regarding the adoption of identified beneficial practices by Australian farmers (Grosvenor Management Consulting, 2017). This is particularly concerning when considering that the success of the programme relies heavily on the adoption of these practices. Feedback surveys collected at the end of the Extension and Outreach project identified that many participants still felt there was a disconnect between policy, available technologies and research (Grosvenor Management Consulting, 2017). Participants noted that this disconnect limits the ability to change farmers' attitudes and decreases farmer participation in schemes (Grosvenor Management Consulting, 2017).

How crop diversification will benefit Australia: Taking an Ecosystem Services Approach

In relation to the previously mentioned example outlined in Rhodes (2017) regarding the ability of regenerative agriculture to maintain yields during periods of drought, diverse crop communities have also been evidenced to produce yields at a more stable rate over time (Prieto *et al.*, 2015). In addition, they have been found to show increased resilience to climate change compared to simplified agricultural communities (Isbell *et al.*, 2017). Therefore, crop diversification may help to guarantee yields in arid and extreme environments within Australia. This is particularly important given predictions that climate change will increase the intensiveness of drought and uncertainty within the Australian agricultural sector (Department of Agriculture, Water and the Environment, 2019a).

Pollinators have been evidenced to be in decline globally, which has significant implications for the pollination of agriculturally important crops (Ghazoul, 2005). This is also the case in Australia, with insect pollinators being crucial to the functioning of the Australian agricultural sector (Cunningham *et al.*, 2002). As discussed earlier, the application of pesticides is a key driver of insect pollinator declines (Cunningham *et al.*, 2002). Crop diversification, which involves a move away from these pesticides by enhancing plant-pollinator networks, offers a solution to this issue by providing an unpaid and reliable pollination service to Australian farmers.

Australia is known for its extremely variable climate and high drought risk. This makes the Australian agricultural industry particularly vulnerable to declines and high variability in yields and profit. For example, in a study of several shires in north-eastern Australia, it was found that many of the centrally located shires showed aggregated soil water recharge values as low as 10 per cent in 2006 during an El Niño year (Stone and Potgieter, 2008). Australian agricultural soils would therefore benefit greatly from crop diversification, which restores the soils' capacity to hold water.

Australia's greenhouse gas emissions are higher than the OECD average, with it seeming unlikely that they will meet the Paris Agreement reduction targets by 2030 (Ivanovski and Awaworyi Churchill, 2020). In addition, most of Australia's nitrous oxide emissions, which is a potent greenhouse gas, are derived from the agricultural sector (Ivanovski and Awaworyi Churchill, 2020). Crop diversification, therefore, presents Australia with a key opportunity to reduce its emissions while simultaneously improving the health of ecosystems. For example, Australian pastures that are adopting techniques such as crop rotations are seeing a carbon accumulation rate of approximately 0.5mg carbon/ha/year (Richardson *et al.*, 2019). This highlights the climate-mitigation potential that crop diversification has in Australia.

How might Australia be able to transition to regenerative agriculture?

Despite the variety of funding and awareness programmes that the Australian Government has implemented over the past few decades, a smooth transition to regenerative agriculture has been lacking. Changes in government policy and support have continually altered incentives for farmers and delayed the ability of farmers to undergo meaningful transitions (Kingwell *et al.*, 2019). This may suggest the need for a more consistent and well-rounded management scheme in the agricultural sector. In addition, the current budget allocation of $1 billion to the National Landcare Program is insufficient when one considers the $3 billion farmers invest annually in natural resource management (Williams, 2019). A transition to regenerative methods is also haltered by its controversial nature. Alannah MacTiernan, Western Australian Minister for Agriculture and Food, highlights this controversy when she talks about bringing prominent regenerative farmer David Marsh to talk at a 2018 meeting with the Department of Primary Industries and Regional Development:

> I proposed to our agricultural people here, the Department of Primary Industry, that we bring him [David Marsh] over and we bring all our ag. [agricultural] people around and let him [...] talk [...] And there was deep concern about this, because this [...] was seen as something that would generate a lot of hostility from a lot of farmers.
> — (ABC, 2020)

Others believe that regenerative agriculture is just another marketing scheme. For example, Victorian red meat producer Georgina Gubbins claims that regenerative agriculture is a term that has at times been used to capitalise on the vulnerable (Whetham, 2020). Issuing products, such as common organic fertilisers, under this term to vulnerable farmers may exploit them by providing an apparent solution with no scientific backing. Gubbins argues that studies on regenerative agriculture are not extensive enough in Australia, and predominately consist of interviews with graziers who had hit a crisis point and needed to adopt regenerative methods as a way out (Whetham, 2020). To overcome the barriers to regenerative agriculture, the following points should be considered, which will be outlined in further detail below:

Creating a platform across which farmers and governments can interact and develop a system of valuation for the various ecosystem services produced across differing spatial scales.

The development of agricultural policies that reduce incentives for monocultures and other conventional techniques, and promote funding for transitioning to regenerative methods.

The development of novel methods of valuing ecosystem services in the global market, which will require action at the international level.

The value of crop diversity will vary at different scales. At the plot level, farmers may maintain crop diversification only for those services that provide utilitarian value and maximise the profit of their farm. At the landscape level, having local farms that maintain diverse crops may decrease pollutant run-off into government-managed waterways. Therefore, the local government may value crop diversification intrinsically for its aesthetic value and for keeping residents happy (Swift *et al.*, 2004). Providing advice to policymakers to help Australian farmers transition to regenerative agriculture must therefore look at multiple scales. It is vital to consider the farmers involved within landscapes, and how their management strategies may have a cumulative effect on landscape processes (Swift *et al.*, 2004). Crop diversity must be maintained not only within-farms but also between-farms in a landscape. This suggests the need for a platform so that farmers and governments can interact and develop a system of valuation and maintenance that is considerate of ecosystem services across spatial scales.

Agricultural policies that promote diversification by reducing incentives for monocultures will be crucial in transitioning away from conventional farming (Falco and Zoupanidou, 2017). Monocultures are only viable if farmers have access to risk-buffering mechanisms such as agricultural subsidies or insurance schemes. This is due to their degrading nature and inability to support ecosystem services (Swift *et al.*, 2004). Although it will be more economically viable in the long term, crop diversification will require substantial initial investment (Isbell *et al.*, 2017). This will include ensuring farmers have access to appropriate harvesting equipment, a diverse range of seeds, and the knowledge to implement these practices effectively (Swift *et al.*, 2004). The Australian Government's website on crops partitions the website into four key crops; cotton, rice, sugar and wheat (Department of Agriculture, Water and the Environment, 2019b). Based on the results of this literature review, which highlight the benefits of crop diversification, I recommend that each of these sections contain information on companion species that can be planted with each main crop, along with the ecosystem services associated with implementing these crop combinations. It is vital to make these recommendations region-specific (e.g., temperate, tropical, etc.), as different ecosystems will show varied responses to different crop combinations. Implementing an ESA when transitioning to practices of crop diversification will be costly. It is therefore important that several funding mechanisms be established. For example, Carbon Eight is a not-for-profit organisation whose goal is 'To transition Aussie farmers to regenerative agriculture and support them to rebuild the carbon in their soil from 1% to 8%' (Carbon Eight, 2020b). They use the profits from donations to educate farmers on how to increase soil carbon content and provide them with tools to transition to regenerative practices (Carbon Eight, 2020a; 2020b).

The above two points highlight action that can be taken at the local and national scale to increase the uptake of regenerative agriculture in Australia. However, to fully transition to regenerative methods, there must be a shift in the global economic market so that the value of ecosystem services can be suitably realised and valued appropriately. It has been suggested that placing monetary values on natural phenomena commodifies nature (Robertson *et al.*, 2014). In addition, a reliance on market-based instruments is the main driving factor explaining the current degraded state of the environment (Gómez-Baggethun and Ruiz-Pérez, 2011). This suggests that the commodification of ecosystem services may be counterproductive in a pursuit towards biodiversity conservation and ecosystem functioning (Gómez-Baggethun and Ruiz-Pérez, 2011). However, valuing something does not necessarily mean we are commodifying it (Robert, 2006). For instance, we may need to shift away from monetary methods of valuation to truly appreciate the benefits of crop diversification. For example, bequest value may be hard to measure in market terms due to its temporal nature and the vulnerability of the economic market to fluctuations over time. Therefore, novel methods of valuing must be developed and integrated into the global economic market to achieve a sustainable transition to regenerative agricultural practices.

Conclusion

Crop diversification can provide the Australian agricultural sector with four key ecosystem services: increased soil fertility and crop yields, biocontrol, increased water quality and reduced greenhouse gas emissions. These services will increase Australia's ability to manage climate change and maintain secure food supplies into the future. Interspecies interactions should be further researched to develop a classification system that links specific crops with specific ecosystem services. To shift towards crop diversification practices in Australia, numerous economic and cultural challenges must be overcome. These include but are not limited to: How do we transition away from the low-cost, high-profit mentality of capitalism without completely changing how society operates? Who is responsible for funding the transition to sustainable methods of food production? How do we ensure that farmers understand their role as environmental stewards? And how do we effectively quantify which services and values correlate to which practices in a given context? These questions must be answered to ensure a sustainable and ethical transition to regenerative agriculture.

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List of figures

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Glossary

Anthropocentric: A view that humans are of central importance.

Biocontrol: Controlling pests through the use of biological mechanisms.

Biota: The plant and animal life of a particular locality.

Crop diversification: The agriculture practice of increasing the biodiversity of a system of crops by including a variety of different species within an agricultural landscape..

Carbon sequestration: The removal of carbon from the atmospheric carbon pool and its subsequent incorporation into the soil carbon pool.

Ecosystem Services Approach (ESA): An approach to environmental policy and management that considers the value of natural systems in an economic and social sense to drive decision making, rather than relying on any ethical debates around humanity's obligations to preserve the environment..

Genotype/genotypic: An organism's complete set of genes.

Glomalin: A glycoprotein (which is a carbohydrate linked to a protein) produced by arbuscular mycorrhizal fungi which are present in soil and in the roots of plants..

Habitat heterogeneity: Unevenness of features in a habitat.

Interspecies interactions: Interactions between individuals of different species.

Monoculture: A single crop cultivation.

Phenotype/phenotypic: An organism's expressible traits.

Polysaccharide: A carbohydrate.

Refugia: An area that provides refuge for individuals during unfavourable conditions.

Rhizosphere: The section of the soil that is in direct influence of plant roots.

Soil organic matter: The component of the soil consisting of biological matter.

Trophic functioning: The functioning of a food web.

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