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Review

Key Roles for Landscape Ecology in Transformative Agriculture Using Aotearoa—New Zealand as a Case Example

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Received: 5 April 2020; Accepted: 8 May 2020; Published: 11 May 2020

Abstract: Aotearoa—New Zealand (NZ) is internationally renowned for picturesque landscapes and agricultural products. Agricultural intensification has been economically beneficial to NZ but has implications for its clean green image. Contaminated waterways, high carbon emissions, and extensive soil erosion demonstrate the downside of high stocking rates and land clearing. Transformative farming systems are required to address the challenge of balancing production with the environment. Whilst navigating through the process of change, farmers need to be supported to make informed decisions at the farm and landscape scale. Landscape ecology (LE) is ideally positioned to inform the development of future farming landscapes and provide a scientific context to the criteria against which land-related information can be evaluated. However, to do this effectively, LE needs to demonstrate that it can link theory with practice. Using NZ as a case example, this paper discusses the key roles for LE in future farming systems. It looks at the way LE can help quantify the state of the landscape, provide support towards the co-creation of alternative futures, and assist with the inclusion of land-related information into design and planning to ensure mitigation and adaption responses assist in the transformation of farming systems for sustainable outcomes.

Keywords: future farming systems; sustainable landscapes; landscape planning; environmental challenges; transdisciplinary

1. Introduction

Globally, agriculture finds itself on the brink of transformation. Agriculture needs to respond with immediate action to the current global environmental challenges like climate change and issues of contamination from intensively managed land. It also needs to be capable of feeding an increasing world population [1]. Reformation in terms of agricultural practice is also on the cards due to the increasing availability of new technological advancements applicable to farming systems and the changes in consumer preferences towards food products that have greater ethical and environmental credentials [2]. These challenges and pressures will likely result in a contemporary revolution for agriculture in which farming practices and systems move to a different paradigm. The imminent implications and consequences of which will mean landscapes, and the communities residing in them, will face outcomes and situations that have never been experienced before.

Aotearoa-New Zealand (NZ) is a nation that relies heavily on its tourism as well as its agricultural exports (beef, lamb, and dairy products). To balance the demands from both sectors, NZ is becoming increasingly aware of its need to change some farming practices and demonstrate its sustainable farming systems on a global platform. NZ prides itself on its picturesque landscapes, which are a drawcard for many of its international visitors. During 2019, international visitor arrivals to NZ were in the order of approximately 3.9 million [3]. With a population of only approximately 4.9 million [4], tourist numbers considerably bolster the spending capacity of residents and therefore have a significant economic impact in NZ. To attract tourists, NZ is very proficient at marketing the connection to nature that is part of its production cycle, especially that associated with its creation of meat products (e.g., the current "Taste Pure Nature" Campaign) [5]. This 'natural' image has been shown to have considerable market value overseas [6]. With heightened environmental concerns coming to the forefront of global consumer behaviour, NZ is grappling with the challenges of maintaining its status as a great primary producing nation and one of landscapes that are environmentally healthy. As a result, NZ wants to position itself as a leader in the global agricultural sector by demonstrating 'gold standard' environmental practice. However, knowing exactly what to do to have the best outcomes is currently difficult for farmers who are presented with lots of reasons to change their practices but not much information on the best way to change to have the biggest environmental impact whilst maintaining a viable livelihood.

Landscape ecology (LE) has a long association with agriculture and farming systems through its early focus on landscape pattern, habitat fragmentation, and the impact on biodiversity caused by productive and human-modified landscapes [7,8] However, the focus of LE research to date, especially in NZ, has largely been one of considering LE in terms of biodiversity loss, habitat fragmentation, restoration of natural systems, and trying to improve degraded landscapes and enhancing conservation outcomes at the landscape scale [9–11]. There is little evidence to date to demonstrate the potential LE has in NZ to work alongside farmers towards future farm system design. There appears to be untapped potential for a role in creating both sustainable production systems and sustainable local landscapes. This means appropriately advising farmers on how to improve production outcomes for their farms as well as environmental ones.

The holistic and transdisciplinary nature of landscape ecological science positions it well to not only address the environmental challenges facing the broader landscape but also to contribute to production issues by providing advice on how to plan, design, modify and develop new landscapes (both at the farm and wider landscape or catchment scale) with best environmental, and livelihood outcomes in mind. However, despite LE theory having been developed and extensively discussed over the last 20–30 years, it has not had the on-ground impact that it perhaps would have been expected to have [12].

This paper builds on the work of Opdam et al. [12] that makes recommendations for how LE can become 'a science for action' at the local landscape scale. Their narrative intended to "reinvigorate and refocus the aim of landscape ecology towards cooperative knowledge production in order to better integrate landscape science into local practice and to adjust scientific methods to better support actions at the local level" [12] (pg. 1444). Given that individual farm systems operate at a local level but collectively have significant broad landscape impacts, this call for action is particularly important to guide the research agenda for LE in the context of farm systems. This paper also expands on ideas developed 20 years ago by Meurk and Swaffield [13] around sustainable agriculture in New Zealand. In doing this, the paper reflects on the position of LE in NZ in terms of being able to effectively demonstrate its practicality as an applied science with local impact and direct relevance to NZ farmers and the challenges that that farmers face around landscape sustainability in the 21st century.

This paper uses NZ as a case example, to explore how the science of LE can capitalise on its potential to work closely with, and appropriately inform, an agricultural sector facing difficult challenges and radical change. The most significant challenge for agriculture being an ability to increase food production in the face of market and climatic variability whilst reducing environmental impact. The paper first provides the context for agricultural change by describing the main issues facing agriculture globally and in NZ. It then goes on to identify some key roles for LE, and recommends some priorities that should be addressed to help make LE science more useful for farmers. Finally, whilst reflecting on progress to date, the paper presents advice that can contribute to a LE research agenda that can support farming systems and rural communities through the transformative change that is required to address the challenges they face.

2. The Need for Agricultural Change

2.1. The Global Situation

McCalla [14] stated that agriculture globally would face three challenges in the 21st century. These challenges are: i) food security, ii) poverty reduction, and iii) sustainable natural resource management. However, facing challenges is not something new for the agriculture sector. The challenge of increasing production has proved to be something that agriculture has been able to respond to. In the past, the ability to keep pace with a growing population has included expansion of production onto 'new' land, technological advancements, and policy incentives [14]. Agricultural production more than tripled between 1960 and 2015 as a result of these responses [15]. However, 21st-century challenges for agriculture look likely to be more difficult to address than the ones that came before because individual issues are compounded. Challenges now include addressing wicked problems like being able to cope with an expected global population increase to almost 10 billion people by 2050 [15,16]; the impacts of climate change; and economic growth in low and middle-income countries that is likely to facilitate the transition in these countries to a diet consisting of more meat, fruit, and vegetables [2,15]. All these challenges will put increasing pressure on the world's natural resource base [15]. The ability to adequately address the issues associated with food security and environmental concern will require the creation of sustainable farming systems that can double their production whilst maintaining environmental integrity [14]. Farming systems will also need to have the ability to adapt to and mitigate impacts of climatic variability of unknown quantity and severity. For this to happen, there is a lot of pressure on farmers to make the right choices for their businesses, in terms of both production and the environment [2]. As custodians of the land, the role of farmers and their land use will become increasingly more important as they attempt to increase production whilst curtailing their own environmental footprint [2]. Farmers will also have to work for the greater good by putting in place strategies around carbon sequestration that can help to mitigate carbon emissions at both the global and national level [2]. Ensuring that farmers get the best advice possible to assist them to make the optimum decisions will be crucial for the sustainability of their livelihoods and the environment.

2.2. The Situation in Aotearoa—New Zealand

Aotearoa - New Zealand (NZ) covers a landmass of 268, 021 km^2 (26.8 million hectares) [17]. It comprises of 3 main islands – North Island, South Island, and Stewart Islands plus some smaller islands including the Chatham Islands. The main islands are located geographically between a latitude of 34 and 47S and a longitude of 166 to 179E and from the very top to bottom NZ covers approximately 1600 km and is 450 km wide at its widest point [18]. Most of the population of NZ is focused around major population centres (e.g., Auckland, the biggest city in NZ, had a population of 1.657 million in 2017, and the next biggest and capital city of Wellington had just under 500,000), leaving approximately 78% of the total area of NZ described as having "no inhabitants recorded per square kilometer" [19], demonstrating the rural and remote nature of much of the country.

The landscapes of NZ have many famous tourist destinations. Tourism currently contributes approximately 20% of foreign exchange earnings [20], making it NZ's biggest export industry. The financial injection tourism provides to the economy consists of a direct annual contribution to GDP of $16.2 billion, or 5.8% of GDP [20], and a further indirect contribution of $11.2 billion, another 4% of GDP [19]. Despite being worth less than tourism, agriculture is also hugely important to the NZ economy. The benefit of agriculture to the NZ economy consists of an annual contribution of around $11 billion, approximately 4% of gross domestic product (GDP) [21], with the dairy sector contributing 3.5% or $7.8 billion to NZ's total GDP [22].

Farming dominates the land use of NZ, with 45.3% of the total land area of NZ (i.e., 12.1 million ha) being utilised for agriculture or horticulture and 7.8 million ha of this farmland being grassland [23] (see Table 1 summarising the proportions of the major land uses in NZ). Livestock farming dominates agricultural land use, with sheep and beef farming occupying approximately 32% of land and dairying nearly 10% [20]. As of June 2019, NZ farmed 10.3 million cattle (3.9 million beef cattle and 6.4 million dairy cattle) and NZ farmed 26.7 million sheep [24]. In comparison, less than 0.5% of NZ's total land area is under fruit and berry production and 0.3% was used for growing vegetables [23].

Table 1. The proportion of the New Zealand (NZ) total land area occupied by major land use types (This work is based on/includes Stats NZ's data which are licensed by Stats NZ for reuse under the Creative Commons Attribution 4.0 International licence [23]).

Major Land Use Type	Proportion of NZ Total Land Area
Agriculture	45%
Conservation	32%
Forestry	8%
Urban	0.8%

Compared with neighbouring Australia, NZ has a relatively recent history of human settlement. The Polynesians who developed the Māori culture first settled NZ about 750 years ago, with European settlers arriving nearly 200 years ago. Impacts on biodiversity and land cover change started with early Māori deforestation but the expansion of the European settler population had the most significant impact on land use and land cover change, as they cleared the landscape to make way for more intensive agricultural production. By 2016, 55,473 farm holdings were recorded in NZ with an average size of 252 ha [25]. Since European settlement, the rural landscape has largely been dominated by the 'family farm' [26].

Despite NZ farming mostly being undertaken by farmers of European settler origin, the contribution of Māori agriculture to the farming economy is significant. About 5% of the total land area of NZ is Māori land. Of this, a total of 49.5% is administered by *ahu whenua* trusts (a land trust that promotes the use and administration of one or more Māori land blocks) [27] and 13.7% by Māori incorporations [28]. Most of the incorporations and a big share of the *ahu whenua* trusts have interests in agriculture. In 2016, 450,600 ha of land was categorised as being Māori farms used for primary production and of this, nearly half the total was under grassland or pasture (218,000 ha), followed by forest plantation (at 110,400 ha), bush and scrub (at 75,400 ha), and horticulture (at 2700 ha) [29]. Agriculture is estimated to account for about 20% of Māori authority enterprises [29]. In early 2000 more than 15% of NZ sheep and beef exports came from Māori farming interests [28]. The Treaty of Waitangi *Te Tiriti o Waitangi* signed in 1840 between the British Crown and Māori chiefs also plays a significant role in influencing land use and land rights in NZ [30].

The policy context for agriculture in NZ is presented in Swaffield [31]. In terms of land use change, significant events to drive change over the last 50 years include Britain entering the European Union in 1973, which affected the market for meat, wool, and dairy produce, and agricultural subsidies being removed in 1984, which has meant that agriculture has since operated under a free market system where consumer demand and markets started to drive agriculture change. The population of NZ has been steadily rising, with the resident population increasing from 3.5 million in 1991 to its near 5 million today [4]. During this time on-ground, observed changes to the land system have been recorded with a 10% increase in urban areas between 1996 and 2012 corresponding to a growing population and a 7% decrease in land used in agriculture production between the same time [21]. Between 2002 and 2016, there was also an approximate 20% decrease in land used for beef and sheep farming and during the same period there was a 40% increase in land used for dairy production [21] (see Figure 1 for change in land use during this time). However, despite less land being used for agriculture, there has been a continued intensification of farming with higher stocking rates on dairy farms over the last 15 years (the total number of dairy cattle increased 68.6%, from 3.84 million in 1994 to 6.47 million in 2017) [21]. The amount of nitrogen applied in fertiliser has also seen a more than a six-fold increase, with figures going from 59,000 tonnes in 1990, to 429,000 tonnes in 2015 [21].

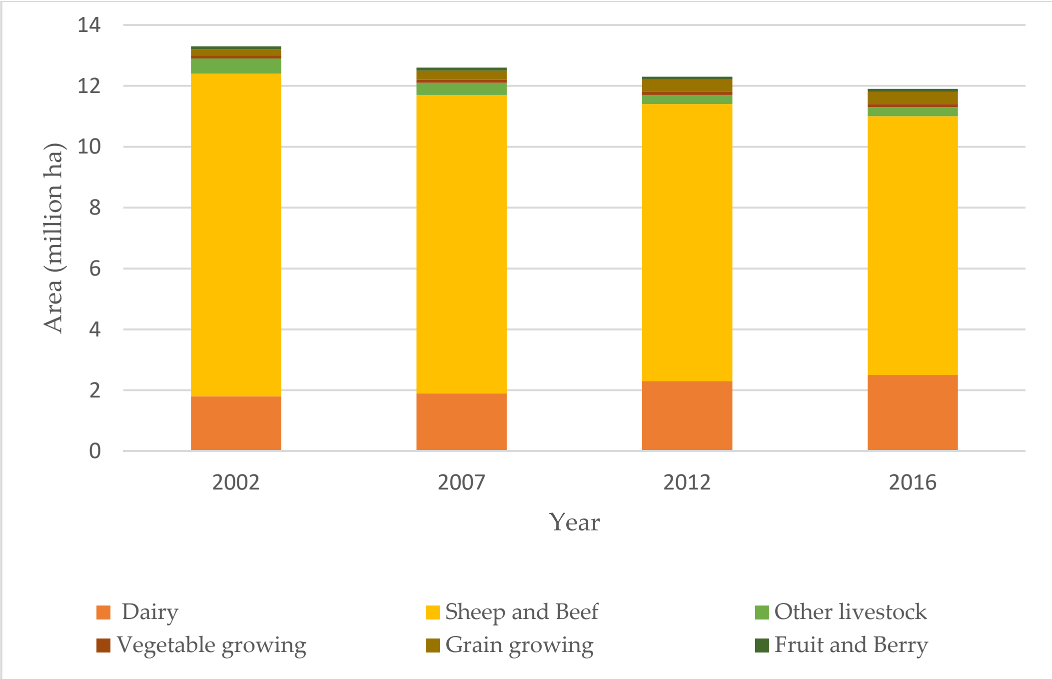

Figure 1. Area covered by main agricultural and horticultural land use types in NZ during 2002–2016 (This work is based on/includes Stats NZ's data which are licensed by Stats NZ for reuse under the Creative Commons Attribution 4.0 International licence [23].

When marketing NZ overseas, Tourism New Zealand has used the "100% Pure New Zealand" campaign since 1999 to deliver the 'story of NZ' to overseas consumers, the travel industry, and the media. This is a story of landscapes and a range of visitor activities and experiences that are unique to NZ [32]. This story is similarly replicated in the marketing campaign for Beef and Lamb NZ, which utilises the phrase "Taste Pure Nature" attached to its grass-fed meat products [33]. Although not intentionally focusing on the environment, by creating an image of "100% Pure" and "Pure Nature", NZ inadvertently lays claim to considerable environmental credentials, which may be in question given the country is currently facing many environmental challenges. Of note are issues associated with water quality (nitrate leaching from agricultural soils was estimated to have increased 29% percent between 1990 and 2012) [34] and erosion (the modelled rate of soil erosion is 720 tonnes per square kilometre per year) [35]. Increased erosion and soil loss (44% of soil lost per year from exotic grasslands) also increases the concentration of sediment in rivers, lakes, and coastal environments [21].

Another key environmental challenge faced in NZ includes the large-scale land clearance that has occurred to make way for agriculture. NZ is now in a situation where only 26% of its native forest remain, mostly in hilly and mountainous areas and less than half of the land area of NZ today is covered in some form of indigenous vegetation [36]. Whilst approximately 32% of the total land area is classed as having protected area status [23,36], just 10% of wetlands remain [35]. Added to this, 40% of the land cover of NZ is now under exotic pasture and exotic forest covers 8% of the land area [35] (see Figure 2 for a breakdown of the share of NZ total land by land cover [23]). With degraded ecosystem services provided by the fragmented native vegetation that remains, it is no surprise that nearly 80% of land vertebrates are now classified as threatened or at risk of extinction [37].

An intensive agriculture industry also has implications for emissions. The per-person rate of greenhouse gas (GHG) emissions is one of the highest for an industrialised country. This is in a country where 85% of electricity production comes from renewable sources, primarily from hydroelectric schemes [38]. Most emissions in 2017 were reported to have come from livestock and road transport with agriculture and livestock producing about half of NZ's total GHG emissions (see Figure 3) and of the 80,873 kilo-tonnes of greenhouse gases produced, most were methane and nitrous oxide (see Figure 4) [39].

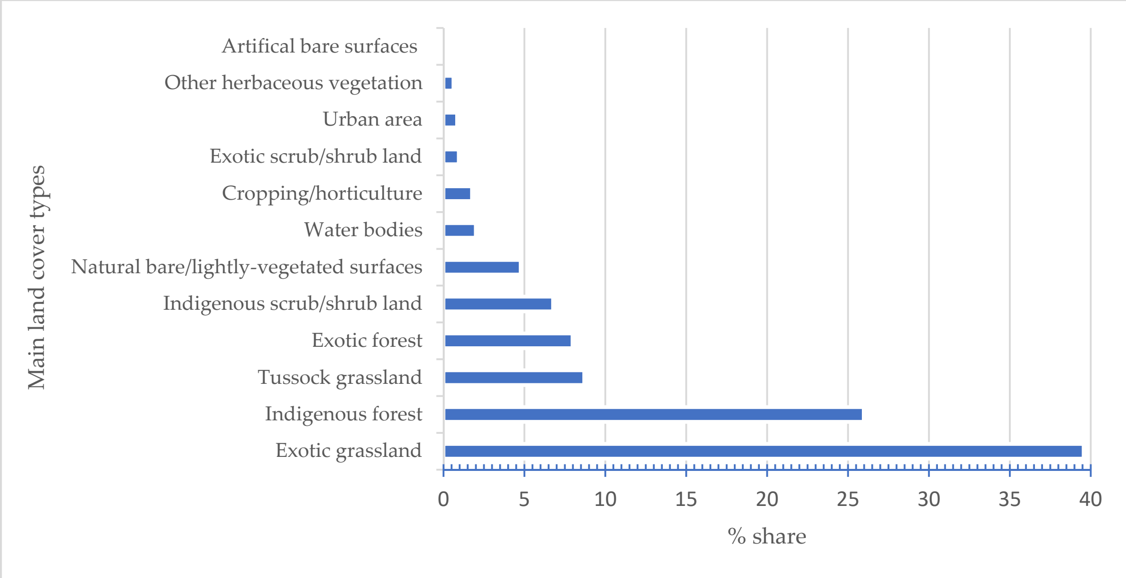

Figure 2. The percentage share of NZ total land area by main land cover types in 2012. (This work is based on/includes Stats NZ's data which are licensed by Stats NZ for reuse under the Creative Commons Attribution 4.0 International licence [21]).

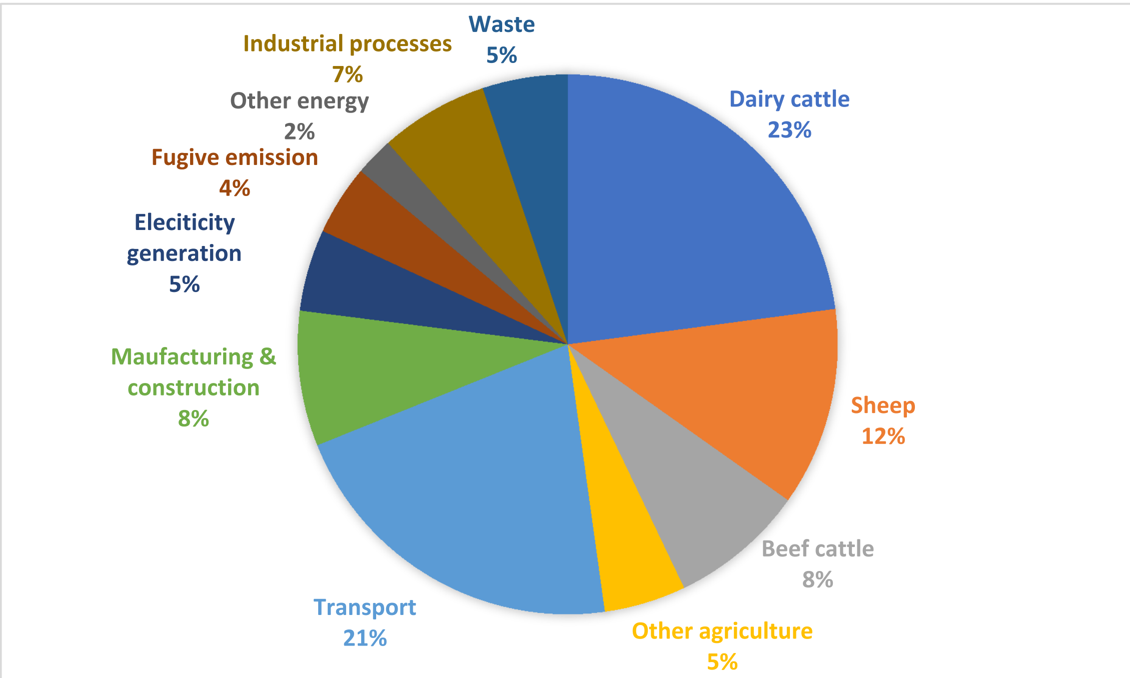

Figure 3. Breakdown of contributing sources of greenhouse gas (GHG) emissions in NZ (This work uses material sourced from the Ministry for the Environment, Stats NZ, and data providers, which is licensed by the Ministry for the Environment and Stats NZ for re-use under the Creative Commons Attribution 3.0 New Zealand licence. [39]).

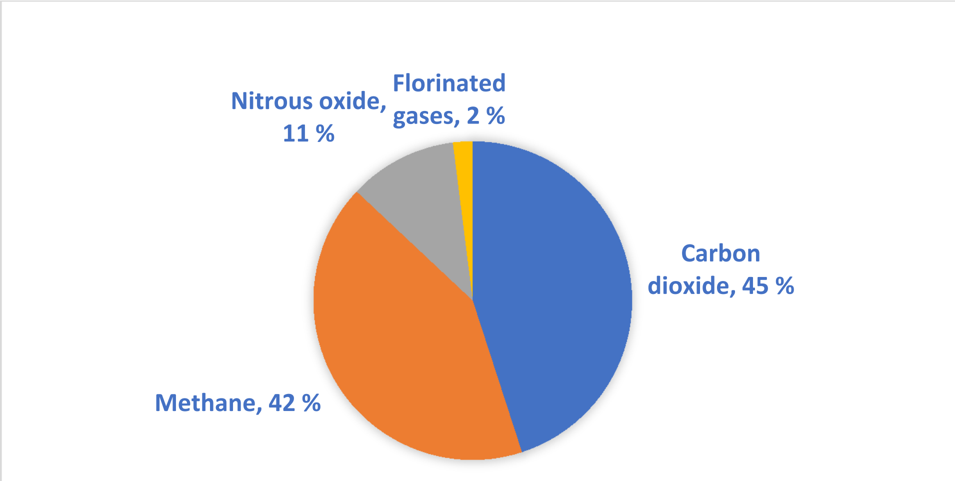

Figure 4. Percentage gas contribution to gross GHG emissions in 2017 (This work uses material sourced from the Ministry for the Environment, Stats NZ, and data providers, which is licensed by the Ministry for the Environment and Stats NZ for re-use under the Creative Commons Attribution 3.0 New Zealand licence [39]).

In 2016, livestock digestion was responsible for 82% of all methane emissions, whilst 94% of all nitrous oxide emissions were from agricultural soils, mainly from the urine and dung of grazing animals. In comparison, carbon dioxide emissions in 2017 were mainly attributed to having come from using fossil fuels in road transport and manufacturing [39]. Even though total agricultural emissions have increased by nearly 14% since 1990, efforts have been made by NZ farmers to reduce emissions and absolute emissions from the beef and sheep sector have been declining over the last 20 years and in 2017 were 30% below 1990 levels [39]. However, the 90% increase in the dairy herd, and a 650% increase in fertiliser use since 1990, has had a significant impact on GHG emissions [39], so considerable work still needs to be done to meet GHG targets. Under the Paris Agreement, NZ agreed to reduce its greenhouse gas emissions by 30% below 2005 levels by 2030 [40]. Recently (November 2019) the NZ government passed climate change legislation with bipartisan support to create a framework for NZ to develop climate change policies to meet targets agreed under the Paris Agreement. The resultant *Climate Change Response (Zero Carbon) Amendment Act 2019* aims to "reduce all GHGs (except methane) to net zero by 2050" and to "reduce emission of biogenic methane within the range of 24–47% below 2017 levels by 2050 including to 10% below 2017 by 2030" [41] and to enable NZ to prepare for and adapt to the effects of climate change [42,43]. This poses a big challenge to farming in NZ as each farm will need to be able to determine current emissions and come up with farm-specific plans that can demonstrate a reduction in emissions via a change in practice and management regimes.

Given the related nature of many of the environmental challenges facing agriculture, a holistic approach to farm management is required which addresses all issues (water quality, erosion, loss of biodiversity and ecosystem services, and GHG emissions). To addresses these challenges, farmers will need to be better at capturing and quantifying data relating to on-farm emissions and understanding approaches that can help to mitigate emissions. To date, accurate baseline monitoring data is limited with some modelling and farm management systems such as Overseer FM [44] being heavily relied upon to quantify emissions but their accuracy is dependent on what data are available. Overseer FM is currently used to generate models based on stock numbers and soil data that are based on broad-scale landscape monitoring. The outputs from which are being used to advise the process of creating farm environment plans with regulation determined under the *Resource Management Act 1991* (RMA 1991) [45] and jurisdictional control of Regional Councils. The creation of farm environmental is increasingly being used as a management approach for environmental sustainability in NZ but with limited fine-scale data, the ability of these to give accurate paddock-scale information is constrained.

More accurate and frequent data capture and modelling approaches will be required to improve modelling capability and to assist with better farm decision making into the future.

Another important challenge facing agriculture in NZ is that due to its free-market economy, it is under a great deal of pressure to respond to trends both domestically and from its global markets without buffering from government intervention. The most recent of these pressures that is currently recognised to be influencing the future development of NZ agriculture is an enhanced environmental consciousness as well as changing consumer views and preferences towards environmental sustainability and measurement of environmental effects and impacts from farming. This means that there are increasing consumer demands around the consideration of ethical production, environmental effects, and provenance/traceability. There are also faster mechanisms by which to spread and communicate these views e.g., via social media and internet-based news stories, meaning they can have a powerful influence both regionally and globally. The recent increase in urban land use and the rising urban versus rural population is also having a significant impact on expectations around farming. It has been noted that as the urban population grows, there is an increasing urban–rural divide when it comes to understanding agricultural production and the ethics around the use of animals as a food source as more people lose their connection to the land and become disconnected with where food comes from [2]. This is contributing to a demand for higher ethical standards around animal welfare and some change in consumer preferences. To maintain its market position, NZ agriculture must be suitably equipped to respond to these pressures and changing consumer trends. The result of a survey of key export consumers revealed that the NZ clean green image has "a significant export value" and that the environmental image of NZ is important to its goods and services in the international marketplace [6] (pg. 4). This means that the environmental credentials of NZ are vital not only for the sustainability of landscapes but also from a marketing perspective.

Other pressures being placed on NZ agriculture come from recent trends in transformational science associated with developments in genomics, and alternative proteins [2]. The changes that these are likely to make to farming and to the meat industry will no doubt impact further on consumer demand into the future. NZ meat consumption has already decreased by 57% in the last 10 years [2] and the rise of the "flexitarian" diet is becoming more evident in NZ and overseas [46]. A recent report commissioned by Beef and Lamb NZ showed that alternative proteins were likely to increasingly compete with meat, which has implications for NZ agriculture especially in the next five years, by which time alternative meat burgers are expected to be mainstream [46].

Other trends set to impact on agriculture include a rise in precision and digital agriculture. Developments and expansion in the uptake of on-farm technology to improve production are likely to lead agriculture into a new revolution [2]. Precision agriculture offers the ability to irrigate and apply chemicals with far greater accuracy and where they are needed most. Increasingly, farm machinery is supplied with onboard sensors that can provide spatial and temporal data useful for determining production [47]. Precision agriculture also offers opportunities for more sustainable management of inputs and thus has potential implications for more effective environmental management [2,47].

There is also a growing need to adapt and respond to a changing global climate. Climate change has the potential to bring about change that is to the detriment of some forms of agriculture in NZ whilst others might be provided new opportunities, with climate influencing where and what things will be able to be grown and produced into the future [41]. It is important to note that these trends and challenges are interlinked and interdependent and therefore are likely to compound each other and have multiple and far-reaching impacts. Farmers, therefore, need to be equipped with knowledge, tools, and approaches that are able to respond to these.

In summary, the challenges that NZ farming systems face are around i) ensuring sustainable production which will involve reducing nitrate emissions, reducing the loss of sediment into river systems and reducing GHG emissions especially methane; ii) dealing with the impacts of climate change which could prove to have both positive and negative consequence for NZ agriculture; iii) responding to an increasing disconnect between a growing urban population and the rural one and changes to consumer requirements along with the increasing need to demonstrate a social licence to operate; iv) increasing agricultural production to feed a growing global and domestic population and v) responding to a digital farming revolution. The implications for farmers associated with these challenges are that they will need to make different farm management decisions, with changes to land use being inevitable. Business decisions for the future will need to not only be based on profit and livelihood considerations but also on environmental outcomes. Overall, the new end goal for a sustainable future agriculture industry needs to be "maximising productivity within environmental constraints" [2] (page 26). As NZ farmers grapple with this, they are caught up in the dilemma of responding to open market agendas that push them to intensify to meet consumer demand and the need to meet sustainability agendas and preserve NZ's unique environmental integrity. Farmers will need access to the best information and relevant science to assist them to make informed decisions and to help them to navigate through the necessary transformation.

3. Landscape Ecology and Farming Systems

3.1. An Overview of Landscape Ecology in An Agricultural Context

Landscape ecology (LE) can be seen to be a science that is still relatively in its adolescence. It is characterised as a science that since its relatively recent inception in the mid-20th century has primarily focused on landscape structure, function and change [7]. Its main emphasis has been on the "spatial heterogeneity and pattern", "how to characterise pattern", "where pattern comes from", "why pattern matters", and "how pattern change over time" [48] (pg. 1170). However, the scientific theory behind LE has been evolving. Recent years have seen a change to the paradigm it represents with a move towards a stronger emphasis on socio-economic elements of landscapes. There is now a greater understanding of human nature relationships and a recognised need to quantify landscape/ecosystem service provision from an anthropogenic as well as environmental perspective [49].

Early roles for LE were largely concerned with focusing on conservation, restoration, and trying to improve degraded landscapes with biodiversity in mind [6]. Within this the links between LE and farm biodiversity are long-established. The relationship between habitat fragmentation and agriculture has been studied and reported [50], and literature can be found calling for an increased provision of habitat and connectivity in amongst a matrix of agricultural landscapes [51]. LE has also been discussed in terms of the role it can play in agroecosystem management [52]. In this context, LE can be seen as having a role to play in recognising and supporting regulatory landscape services like soil fertility and pollination that will ultimately impact on the biophysical capacity of the farm system. It is also seen to be considering the spatial arrangement and makeup of landscape features that support ecological systems separate to the farm. The credentials of LE towards informing the preservation and restoration of ecological integrity and biodiversity in the farm setting are widely acknowledged. An example of this type of application is demonstrated in recent research by Ekroos et al. [53]. They illustrate a role for LE in establishing an ecological focus over parts of the farm through the application of "greening" measures, where the specific placement of these measures across the landscape can enhance potential benefits to birds.

In recent times, LE has seen a shift in its predominant focus. The focus has moved from one of improved management strategies to facilitate the preservation of important landscape pattern and process [54–57] towards a stronger emphasis on the role of LE in landscape sustainability. This has resulted in LE increasingly incorporating planning and design as important considerations in its theory [48,58]. Within this is a stronger focus on the socio-economic aspects of landscapes and on the importance of livelihoods, value, and culture in framing future landscape systems. Associated with this is a recognition of the crucial role of community participation in problem-solving [48,59]. Applying this new holistic paradigm for LE [48] has great applicability to assist farmers who require socio-economic considerations in their decision making in order to develop sustainable landscapes and farming systems of the future. There is increasing debate on how LE can be integrated with current thinking related to on-farm system management and the need to consider landscape-scale functioning to assist in the development of more sustainable agriculture [60,61], presenting more opportunity for greater expansion into this area.

Despite having great potential to be applied in agricultural planning, LE has not had much opportunity to work in a more constructive sense and play a role in creating future farm landscapes. It has also had sparse practical flow through to on-ground farm planning and management and links between landscape science and farm system design are limited [62,63]. However, taking a landscape ecological approach to the integrated analysis of landscape function has the potential to help provide farmers and land managers with approaches, information, and important knowledge that can guide future management strategies and assist in land use decision making [64]. In this paper, I argue that landscape ecologists should be exploiting this potential and striving to assist farmers in places like NZ as they plan their future farm systems.

3.2. Landscape Ecology and Farming Systems in NZ

The idea that there is a role for LE in assisting farming systems to work towards more sustainable agriculture in NZ is not new. Twenty years ago, Meurk and Swaffield [13] made recommendations around a landscape ecological framework for the regeneration of indigenous vegetation in rural NZ, aspects of which were also discussed at the International Association of Landscape Ecology (IALE) World Congress in 1999. Meurk and Swaffield [13] stated that nature conservation and agri-business should not be seen as separate to each other, as they had been become viewed in association with the agricultural landscape in NZ. They suggested an alternative future vision for NZ agricultural landscapes where ecological integrity was reinstated via regeneration of indigenous vegetation within an exotic matrix. This is in keeping with the idea that the more a landscape resembles its natural state and maintains some key landscape features of importance, the more likely it is to have resilience and greater functionality, which ultimately assists with its sustainability [65]. Their vision promoted the establishment of landscape elements which enabled the integration of production and conservation. In this vision, they suggested creating a matrix of indigenous species along edge features that create functional elements like riparian systems and road verges. They also suggested having areas made up of predominantly indigenous species that could be useful for both production and functional purposes [13]. Theirs was an integrated vision in which natural processes and communities provide the underlying framework for the landscape rather than intensive agriculture dominating the landscape [13]. These ideas were expanded upon by Swaffield [26]. He argued for a strategy to create a long-term matrix of sustainable and self-regenerating ecosystems within which productive land uses can be undertaken. He suggested an 80:20 target i.e., for every 80 ha of production at least 20 ha should be allocated to regenerative functions such as biodiversity, riparian margins for water quality, shelter, and carbon sequestration. These sorts of ideas are becoming much more widely debated in the realm of regenerative and restorative farming [66–68].

Fundamental to a landscape ecological approach and the ideas put forward by Meurk and Swaffield [13] is a recognition of the interrelationships between landscape elements and how these interrelationships affect landscape function. The relationship between landscape structure and process/functioning is one that has received considerable attention in LE worldwide with the notion that patchiness in the landscapes is a way to help mitigate dysfunctional effects of intensive production [69]. Ideas put forward by Meurk and Swaffield [13], which focus on creating integrated landscapes, with a patchwork of landscape elements consisting of natural features and native species co-existing in unison with production in the landscape, is one of encouraging multifunctionality. The idea of creating multifunctional landscapes by applying LE principles has been widely discussed [70–73] and there is great potential to consider this more strongly in the planning and design of future farming systems especially in response to some of the challenges facing NZ [63].

Concerning the challenges faced by NZ agriculture, Swaffield [26] felt that a new vision for rural NZ was needed. That is one that could respond to some of the 21st century's greatest global challenges around the environment and sustainability and one that was developed with bottom-up considerations. He stated that being able to take this vision to reality required more integrated research, greater enhanced modelling of ecological processes within multifunctional landscapes, and the development of guidelines that could help to determine optimum locations where landscape reconstruction would be beneficial for the overall functioning of the landscape [26]. Thus, greater 'whole of landscape' thinking is necessary, and the redesign of rural landscapes is required to be able to transition from a divided landscape (production and environment as separate considerations) to an integrated one (where production and environment are equal and considered in unison) [26].

3.3. Landscape Ecology and Agroecology

During the late 20th and early 21st centuries, agroecological theory has developed in parallel to LE. Agroecology (AE) has been a term and a consideration that has increasingly been applied over the last 30 years [74]. It arose within the discipline of agriculture out of a need to address some of the growing concerns around intensification and the environmental impacts that result from a heavy production focused land management system. Recognising the importance of the whole agroecosystem, AE has been described as an integrative study that takes a holistic approach to look at the ecology of food systems [75]. It is an approach that works towards ecological, economic, and social sustainability considering the processes involved in food systems from farm gate to the plate [76]. Like LE, AE has evolved, in more recent years, to focus more heavily on transdisciplinary approaches, participation, and change-oriented research [74,76]. Differences between LE and AE have been described as relating to the scale of investigation associated with the management unit i.e., AE has tended to focus at the finer resolution of the farm or field scale (the ecosystems in which farm services are delivered) whilst LE has largely looked at the broader landscape or catchment scale [77] of which farm systems are just a part.

Since farm systems have been described as integrated components of rural landscapes [78], both AE and LE have been evolving to consider integrated models and approaches that help to understand and manage human-dominated landscapes [79]. Fundamental to agroecological thinking is the importance of a certain structure on-farm which can maintain key functionality that can play a part in overall sustainability. Gliessman [65] (page 300), in line with some of the arguments of Meurk and Swaffield [13], stated that "the greater the structural and functional similarity of an agroecosystem to the natural ecosystems in its biogeographic region, the greater the likelihood that the agroecosystem will be sustainable".

Dalgaard [78] (page 8) when discussing landscape agroecology stated "The ecological, economic, wildlife and visual functions of landscapes within modern society are determined by processes that operate over a range of scales in space and time. Integrating knowledge of these processes into tools that can be used by people who have stewardship over the land, such as farmers and regulators, requires an interdisciplinary approach. Such an approach demands significant effort as it must work against the trend of specialisation and fragmentation of knowledge that has occurred over the recent centuries. It also requires, substantial technical developments, relating to data collection from disparate sources, data manipulation, and integration of information about the multiple landscape functions". This statement recognises the need to preserve important landscape functioning in the farm context. It also emphasises the lack of collaboration and tools required for the collection of useful information that is important to progress the application of AE approaches for more sustainable agriculture. Dalgaard [78] also acknowledged the need for greater work across disciplines to pull together knowledge and approaches to develop new strategies for farm and landscape management. Even though as far back as 1992, Flora [80] recognised that sustainable agriculture required transdisciplinary teams which included farmers working together to address research priorities, there is still a need for more cross-disciplinary collaboration to address knowledge gaps. The call for greater farmer-researcher partnerships, as they strive to balance environmental outcomes, agricultural production farm profit, and community wellbeing, is still very valid today. Similarly, the fact that limiting uptake of practice change was put down to there being a lack of good indicators of sustainability [78].

Whilst more sustainable on-farm management is important for individual farms, just preserving or improving within farm ecosystem processes and functioning will have limited benefit for the wider landscape unless other farms adopt similar strategies. Collaboration on strategies and group action to improve functioning across a broader landscape will be more effective in having much more far-reaching and beneficial environmental outcomes that individual activity. Given the similarity of interest and focus between LE and AE and the requirement for landscape sustainability to incorporate across-scale activity, it would seem sensible for greater collaboration and integration of ideas not just between farmers but also between disciplines as they work towards addressing the gaps in research and application required for more sustainable future farming systems. An ideal platform for this being through concepts of designing and managing multifunctional landscapes [77] where landscape consideration is given at both the farm and catchment scale.

The merger of the disciplines of AE and LE has been described by the term agro-landscape ecology which has been mooted for some time [81–83] but with growing farm-based challenges, the integration of agro-landscape ecology into addressing problems through farm environment planning appears to be coming increasingly more relevant and important. A stronger integration of concepts and theories and scales of operation presents an excellent opportunity to expand the application of LE and to bring a more scientific context to both farm and catchment scale planning processes currently being undertaken in places like NZ. This is becoming increasingly more relevant in NZ as farmers are joining forces to create community catchment management groups and are reaching out to scientists to provide both relevant farm and catchment scale advice. Greater integration of AE and LE science make both disciplines better placed to aid farm decision making. Bringing together the combined thinking from both AE and LE has the potential to ensure greater on-ground benefits across scales. Working with colleagues in AE can help landscape ecologists to determine what good indicators of agricultural sustainability might look like and how to measure and quantify effectively on-ground farm-scale change that has beneficial environmental outcomes at both the farm and landscape scale. Greater collaboration between AE and LE also has the potential to enable scientists within the field of LE to obtain a clearer understanding of a farm system issues and considerations that can help to make them become a more effective advisory and supportive science towards transformative agricultural change.

LE is increasingly being recognised as an important framework capable of assisting in the planning and design of future landscapes [72,84–87]. In this context, LE has an important role to play in providing appropriate tools, approaches and frameworks that can facilitate the planning, design, and advice required to help work towards the creation of future farming systems that meet societal needs, respond to the environmental challenges and that can sit within sustainable landscapes. Despite its obvious potential in this area, LE has only recently started to be practically applied in this context to a NZ setting [62,63].

4. Identifying Future Key Roles for Landscape Ecology that Can Help Progress Sustainable Agriculture

4.1. Key Roles

4.1.1. An Informing and Decision-Making Science

Recognising some unrealised potential for LE to date, one of its key roles for future farming systems is that of placing itself at the forefront of being an informing science around landscape sustainability. It needs to provide the scientific context for informed farm and catchment decision making, whilst acknowledging the increasing recognition in the farming sector of the importance of AE and regenerative agriculture. This means that LE needs to demonstrate its ability to 'value add' to agroecological studies through a collaboration that clearly illustrates the importance of landscape and catchment scale studies for farm system sustainability.

In helping to work towards sustainability of farm systems, LE has an important role to play in helping with the definition of land use optimisation. By informing the pattern of land use and making suggestions around the allocation and reallocation of land, it is possible for LE to help to create multifunctional agricultural landscapes that have sustainability in mind. To do this effectively, LE needs to demonstrate its ability to quantify information relating to process and function. LE also needs to provide advice around the management of landscapes to preserve important landscape services and functioning on-farm and across the broader landscape. This means helping to create models and strategies that define important landscape characteristics that need to be maintained and preserved, as well as being able to provide advice around the positioning of introduced landscape features that could assist with sustainability. A good example of this for NZ could be around identifying key locations for reconstructed wetlands (as mentioned previously, NZ currently has a situation where 90% of its wetlands have been drained with significant impact on nutrient flows into river systems [35]). Reconstructed wetlands can put back into the landscape important functionality that can improve environmental outcomes by reducing the loss of nitrates from intensive farming practices like dairy farming that cause considerable pollution of rivers [2,21].

LE also has a key role to play in being able to easily incorporate the scientific evaluation of land-related information into design, planning, and decision making through helping to provide a scientific context to the criteria against which land-related information can be evaluated for sustainability decision making. This will be vital for informed planning and design of future agricultural landscapes capable of providing appropriate mitigation and adaptation responses to some of the biggest environmental challenges. LE should be ideally positioned to guide process informed and value influenced planning and design within a theoretic framework guided by LE principles to assist with more holistic farm environmental planning. Linked to this is the potential for LE to assist with the creation of spatial decision support tools. Suggested approaches include the application of a spatial decision support framework using approaches that can build on important LE concepts and design agendas in a spatial planning context to work towards the creation of multifunctional landscapes [63,88].

Geodesign [89–91] offers a framework for smart planning in a spatial environment that enables the analysis of multiple data layers so that planning proposals can be evaluated, and new scenarios tested. This type of approach paves the way for an integrated holistic approach to farm and landscape planning which is vitally needed in NZ [62,63]. Such a framework can provide a basis under which it is possible to analyse the impacts of on-farm land use change prior to a change being implemented. This type of modelling approach can help to integrate concepts of ecosystem/landscape services into farm and landscape-scale planning by incorporating information on functioning as an important data layer used in the model. The model created in a geodesign framework can help to spatially visualise patterns of land use and land cover that enable important landscape functions (economic and environmental) to operate side by side. The generation of future alternative scenarios for farm system management enables farmers to see and contribute towards the development of visualisations of what sustainable utilisation of the landscape might look like both on their farm and in the surrounding landscape. It can also allow them to subsequently evaluate the economic feasibility of different scenarios. Generating scenarios that suggest optimal sustainable land use could contribute towards designing an appropriate future landscape pattern that is based on process and economic analysis and the idea of creating multifunctional landscapes at the farm and landscape/catchment scale.

4.1.2. Tools and Techniques for Farmers

Change to land use and farming systems is inevitable but knowing what practice change is best, with environmental and business sustainability in mind, and therefore how to change, is crucial if farmers are to have optimum (livelihood and environmental) outcomes. This is where LE has a potentially pivotal role to play. It can position itself to provide valuable advice to farmers and land management policymakers in terms of the 'what' and 'how' when it comes to creating healthy and sustainable landscapes. Fundamental to fulfilling this role, especially in countries like NZ that face challenges of demonstrating their environmental sustainability, will be the ability to assist farmers through their transformation by providing the necessary tools and techniques. These will be needed to quantify the current state of landscape and audit environmental sustainability (at both the farm and landscape scale) so baseline data can be established, and on-going monitoring achieved. Often there is little baseline data from which to start monitoring. A lack of good baseline data makes it difficult to quantify changes that might occur or have occurred due to improved practice. This is a problem facing on-farm climate change mitigation responses in NZ as good current baseline data on GHG emissions at the farm-scale are currently not available, yet farmers have only a few years to demonstrate beneficial change. The provision of baseline data provides an opportunity for LE to offer better mechanisms to capture the landscape situation for baseline assessments and approaches to monitor change as 'best practice' activity is undertaken.

In NZ tools like Overseer FM [44] have become standard to assist in recommendations around nitrate emissions. This is because tools like this give a measure and a figure that farmers can work within an ongoing capacity to address their land management challenges. Overseer FM is currently being expanded to have more GHG emission monitoring capability which will widen its application to assist farm decision-making LE has the potential to provide similar quantification and measurement capability through the many metrics that have been applied to quantify pattern and process. Aspinall and Pearson [92] outline a suite of indicators and metrics based on the assessment of landscape characteristics that have been used in LE research and can be applied to quantify catchment condition and how it changes over time, many of which could equally be applied at the farm scale. However, despite the extensive application of LE metrics, there has been criticism about their ability to adequately quantify the links between pattern and process and the sensitivity of some processes to structural changes to the landscape [93–95]. The scale of the data used and the scale at which analysis is conducted are also fundamentally important to the reliability of the results. This is a challenge for places like NZ where mostly only broad-scale data exists, with only a small number of farms having fine-scale soil data available.

LE research agendas need to take note that work is still required to develop innovative mechanisms to help to capture the current landscape situation at an appropriate scale and to quantify what is happening on the ground in a relevant form by farmers and also their regulators (e.g., Regional Councils in NZ). This is important if LE is going to be able to proactively provide the necessary tools and techniques for application at the farm scale. It also important to allow farmers and regulators to appropriately monitor change as land use and agricultural practice changes occur. Measures and tools that are only capable of being used by scientists or are at too broad a scale will have limited application in on-ground farm system management situations. Ease of use and capability that is tailored to farm system applications and solutions is of utmost importance in demonstrating relevance to both regulators and farmers. Greater engagement and collaboration around tool and indicator development will help to develop approaches to make LE a more actionable science [12].

LE also needs to consider further work on determining and quantifying landscape/ecosystem services present in agricultural landscapes [96] and how these change over time. Recent research by Dominati et al. states that "the supply of multiple ecosystem services from farmland and agroecosystems and trade-offs between service remains under-researched" [61] (pg. 704). They feel that this impacts on the ability to determine how well farm systems can achieve environmental sustainability outcomes whilst maintaining economic profitability. This means that more work is needed to determine how multifunctionality aspirations within farm systems can work alongside farm profitability goals for mutually beneficial outcomes [61]. As a result, there appears to be a role for LE to work more closely with AE to contribute towards developing better solutions towards more effective monitoring and evaluation of functioning and processes on agricultural land using appropriate indicators and measures.

Techniques need to be developed that can monitor the condition of processes and how this relates to function [64]. In line with recognised LE principles, it is important that these techniques should be able to adequately and easily capture information relating to state (condition), trend (changes across space and time), and function (stability, resilience, and sensitivity) at appropriate scales. Where possible, these need to be simple measures that represent key components of the system and have meaning beyond the attributes that are directly measured. For ease of capture, many of these indicators need to be capable of measurement from on-ground and remote sensing data sources and be spatially and temporally explicit offering opportunities to link to data capture for precision agriculture. It is also important that scenarios be developed for increasing functionality and that these can also be related to measures associated with raising profit. This is important to adequately understand the impacts of increasing landscape services and functioning on a farm and determining the relevance of actions that increase landscape functioning for long term farm and environmental sustainability.

4.1.3. Integrating Value and Cultural Perspectives into Landscape Analysis and Decision Making

Recognising values and cultural perspectives as well as landscape functioning is important for landscape management and therefore sustainable farming systems [59,97–100] so as to ensure the creation of future landscapes that can adequately support a diversity of values. This means that it is crucial that LE has mechanisms that consider the value of production from an economic and livelihood context and can incorporate key stakeholder involvement in processes to advise on the make-up of future farming systems. In doing this, LE needs to draw on its strength as a transdisciplinary science and put greater emphasis on developing the support mechanisms required for transdisciplinary approaches to problem-solving in an on-ground capacity. This means that there is an essential role for LE to be able to guide the effective on-ground application of real transdisciplinary projects that bring together a variety of stakeholders and recognise different values, beliefs, and perspectives. However, LE still needs to rise to the challenge laid down by Wu and Hobbs, Opdam et al., and Swaffield [12,98,101] around integrating science and practical application and outreach. This means that landscape ecologists should also be striving towards making LE a facilitating discipline i.e., one that takes the initiative to bring together other science disciplines with key stakeholders to work to generate solutions to some of the complex issues facing farming systems and is not afraid to promote bottom-up stakeholder-led research.

LE also has a key role to play in recognising culture as an important aspect of landscape management [100]. In places like NZ not enough attention to date has been paid to Māori perspectives and relationships between people and landscapes and what this can bring to future farmsystem design. Māori relations with landscapes are expressed through *kaitiakitanga. Kaitiakitanga* is a Māori term that encompasses guardianship and stewardship for the environment. This includes the responsibility to ensure sustainable harvest and fair distribution of resources. Incorporating *kaitiakitanga* into cultural functional assessment and an appreciation of value will help to derive a more broadly integrated stewardship focused approach to land management that is likely to provide for generational sustainability. Other important environmental concepts in Māori culture include *Ki uta ki tai*, which is a Māori whole-of-landscape approach similar to the concept of integrated catchment management that looks at resources and ecosystems from the mountains to the sea; *Te Ao Turoa* which is an intergenerational concept of resource sustainability; and *Whakapapa* which is concerned with the connection, lineage, or genealogy between humans and ecosystems and all flora and fauna [102]. Māori seek to understand the total environment or whole system and its connections through *whakapapa*, meaning that this perspective towards human and environment interactions is holistic and integrated [102]. An example of where Māori cultural perspectives are being integrated into NZ primary production has come from the recent (December 2019) launch of the vision for future NZ Primary Industries 'Fit for a better world' by the Primary Sector Council which centres on the Māori concept of *Taiao* which emphasises "respect for and harmony with the natural world" [103]. These concepts and perspectives are very much in line with LE thinking, so NZ is in the unique and exciting position of being able to capitalise on its Māori cultural heritage and the values and perspectives it can encourage in order to direct future sustainability. Landscape ecologists in NZ have the potential to help to bring these to the forefront to be implemented in helping to determine farm system change.

4.2. Past Impediments to LE Uptake and What Can Be Done to Improve This?

Given that LE has such an evident role to play in assisting in the environmental management of agricultural landscapes, it seems obvious to ask why we have not up to now seen a far greater integration of LE principles and practices into the management of current farming systems? And why in particular, we still have work to do on sustainable farm systems in NZ given that landscape ecologists like Meurk and Swaffield [13] were giving advice 20 years ago on how to create more multifunctional and sustainable farm landscapes. To answer this, several potential reasons can be identified. Acknowledging and recognising limitations can be useful for the future implementation of LE in the agricultural context. The reasons appear to be largely related to an ongoing disconnect between science, policy, and practice [12,98,104].

LE has shown its strength in providing good quality research on the theory of landscape management but regrettably, there has not been much flow through to practical on-ground application relevant to farm management. In 1997, Hobbs [104] concurred with this statement when he reported that LE did not at the time truly meet the criterion of being an applied science. More recently, in 2013, Opdam et al. [12] questioned LE's on-ground applicability. They highlighted the need for LE to deal more effectively with the science-policy gaps. Opdam et al. [12] also pointed out that many papers published in the journal *Landscape Ecology* are analytical in approach. The shortfalls associated with a lack of public involvement in the co-production of science-based solutions were also demonstrated in Seppelt et al. [49] in regard to research on ecosystem services. In 2002, Wu and Hobbs [98] highlighted the reasons that limit LE's applicability as being issues of integration between basic research, applications, and outreach and communication with the public and decision-makers. LE appears to be still struggling to address key issues around integration and outreach which would make it more applied and landscape ecologists still do not seem to have adequately addressed these challenges. Work is still required to make LE more applicable to on-ground action [105]. This means that despite prompting by leading landscape ecologists LE has stayed very in a much more theoretical and scientific realm rather than a practical context. To address some of the shortfalls, Opdam et al. [12] highlighted the need for additional topics of investigation in LE. The topics for further research looked at 'the local landscape as a boundary object that builds communication among disciplines and between science and local communities', 'iterative and collaborative methods for generating transdisciplinary approaches to sustainable change' and 'the effect of scientific knowledge and tools on local landscape policy and landscape change' [12]. Given the lack of follow up commentary in the LE literature that adequately addresses these topics of investigation, it appears that LE is still struggling to effectively address these topics in a research capacity. The result being that these challenges for LE could be equally listed on a research agenda today.

Some of the disconnect between science and practice is evident through the fact that to date the theoretical concepts and methods have not transitioned well into useful and practical tools and techniques for non-scientists. These are approaches that can help farmers and policymakers to compose better-informed decisions through capturing good monitoring data and translating it into useful information that can guide practice change and thus assist with environmental management at the farm and catchment scale [98]. Another potential problem has been the lack of relevant information made available in a manner that can be digested by farmers and policymakers. Most LE research is presented in journal format restricting its readability by land managers. There is also an inability to be able to adequately relate 'the cause to effect' when it comes to issues on the ground [2], which is crucial to demonstrate the overall worth of approaches for any farmer-based change. An inability to do this restricts a farmer's ability to make good decisions and practice change based on a knowledge that certain practices will cause problems whilst others will help. Also, the advances in science have helped us know more about the problem but are failing to suggest appropriate mitigation responses that can clearly demonstrate the cause and effect relationships to farmers. So suggested change to practice cannot always be definitively related to better environmental outcomes.

The receptiveness of farmers will also influence the uptake of science-based solutions. The factors that influence the decision-making processes of farmers are complex. Failure to adequately contemplate worldviews of farmers and livelihood considerations are also significant in terms of uptake of scientifically based approaches to landscape management. Suggesting landscape options that are not financially viable for farmers is not going to facilitate uptake as fundamentally farmers must maintain livelihoods and lifestyles for themselves and their families. A lack of political will to drive a pro-environmental agenda in many first world countries also has implications for implementation of on-farm landscape sustainability responses especially when the emphasis is placed on maintaining production without risking economic impact.

Both Hobbs [104] and Opdam et al. [12] said that if landscape ecology was to be more widely applied in a practical sense it would require increased engagement with policy and management when it comes to future landscape design strategies and approaches particularly at the local scale. It is evident that LE has come a long way in the last 30 years and progress has been made but more work is needed if LE is to have a bigger impact in helping to design future farming landscapes. More directed effort is needed to make a coherent link between science, policy, and practice [58] and to help to remove some of the barriers which have prevented the adoption of LE to real-world problems [105].

4.3. Understanding Farmer Behaviour and Motivations and Their Role in Changing Farming Systems

As noted above, a key problem for LE is linking the science to practice and recognising the role of the farmer in the implementation of science-based solutions. With increasing pressure on farmers to change practices for greater environmental outcomes, it is vital that the science that advocates for change can understand the constraints on farmers as well as their motivators and drivers that will encourage behaviour change. A report that was undertaken by AgFirst (Independent Agriculture and Horticulture Consultant Network) on farming decision making in NZ about climate change action discusses farmer behaviour and response to change in detail [106]. This report states that being able to understand farmer change and their ability to change practice and uptake new innovations and technologies as part of new farming systems requires recognition of i) "farmer awareness of the innovation"; ii) "ease of trialling an innovation on-farm"; iii) the "perception that an innovation is worth trialling"; and iv) "the value of the innovation in achieving the farmers' objectives" [106]. These recommendations have been substantiated by research findings from Pannell et al. [107], who looked at the adoption of conservation practices by farmers in Australia. He found that innovations were most likely to be adopted when they could demonstrate "high relative advantage" i.e., benefit returned from innovation over current practice, and when they were readily "triable" on-farm. The AgFirst report also stated that other important aspects of an innovation that interact with farmer decision making include i) "compatibility" i.e., degree to which the innovation is comparable with current farm system; ii) "complexity" i.e., the perceived difficulty to understand or implement the innovation; and iii) "observability" i.e., the visibility of the results of the change [106]. This means that action to bring about change needs to focus on increasing awareness and understanding, highlighting the advantages of mitigating impacts, emphasising the compatibility, encouraging and making trialability easier, and making the significance of change more obvious.

Other social factors that need to be considered when it comes to farmer behaviour change and uptake of new ideas include i) at the individual level considerations like time availability, level of education, approach to risk, advice sought and from whom, as well as personal and family circumstances [106–108]; and ii) at the wider social level, they include considering that farming is a socio-cultural practice i.e., it is a way of life and that the notion of sustainability for most farmers means staying on-farm rather than having environmental outcomes [106–108]. It is also important to consider that not all farmers are the same i.e., that the farming community is very socially diverse [108]. Also, that farmers might not distinguish environmental issues from other farm management issues, and that farmers often create their own knowledge through experience and that their key source of information is other farmers [108]. This means that effective extension requires an understanding of the worldview of the farmer. Further complicating this for NZ is the challenge of bringing together worldviews of Pakhea farmers (of European descent) and Māori farmers, plus the worldview of other migrant farmers.

The review that was undertaken by Journeaux et al. [106] also revealed that extension promoting change needs to emphasise the need to provide whole farm system-level solutions to the farmer so any change that is to be promoted needs to be explained within the context of the system as a whole. Making things difficult for farmers is the shift in farming focus i.e., from a system concerned with development and production to one of production within environmental constraints. Whilst the public perception of farm sustainability tends to focus on environmental sustainability, farmers who grapple with the concept of sustainability are required to consider both economic and environmental implications of their actions, and these can often conflict with each other.

If LE is to be useful to farmers, it is important that it recognises farmer's needs and aspirations and recognises that farmers need to be better supported to make informed farm and landscape-scale management decisions. To better support change in agricultural practice, LE research agendas need to focus on transdisciplinary and collaborative approaches that have a greater emphasis on understanding markets and consumer preferences and demand. Also important to individual farmer adoption of changes to their practices is having access to useful and relevant information and advice that is easy to collect, understandable, and implementable by the farmer himself. Overall, it is paramount to recognise that when considering or instigating farmer change there are lots of legitimate reasons for non-adoption of change and generally farmers need to feel valued as they embark on their transformation journey [106].

4.4. The Way Forward

As we face increasing environmental challenges around intensive agricultural production, population rises and the potential for natural disasters to occur more frequently and with unprecedented consequences, the science to support agricultural sustainability needs to deal with unpredictable situations and be able to move quickly [2]. To address these challenges, it is becoming increasingly more important to find solutions that look not only at the farm but also beyond the farm i.e., to consider the broader landscape mosaic of which the farm is a part. By working more closely with AE, LE can prove itself as a science to guide and inform farm and landscape decision making for more sustainable landscape management both in NZ and elsewhere at scales that are relevant. However, to do this effectively, it must be able to link to policy and practice and understand farmer needs and aspirations. To ensure this occurs, it is important that stakeholders become more involved in landscape research and that they participate from the inception of future farm systems and landscape planning and design processes. With wide-ranging participation, a transdisciplinary approach that can link the latest analysis and monitoring tools and techniques with LE theory and spatially informed design principles, will have the ability to suggest a recommended spatial structure and function for farm systems that can help with problem-solving [64]. Working with, and embracing, cultural values like *kaitaikitanga* presents an excellent opportunity for NZ agriculture to capitalise on Māori values, using this important sense of stewardship towards the land when developing strategies for future farming systems in NZ to ensure long term sustainability.

A good example of an application that effectively makes the link between science and practice in an agricultural context and addressed the issue of how to bring about farm-scale change is reported in Bohnet et al. [109]. This is a useful illustrative example of a transdisciplinary LE-focused collaborative project which was undertaken between scientists and graziers in North Queensland, Australia. The study looked at grazier change in relation to sediment and nutrient flow into the Great Barrier Reef and identified broad types of farmers within the study. These types were identified as "traditionalists", "diversifiers", and "innovators" [109]. Understanding the values and motivations underlying the types of farmer was shown to have an impact in terms of on-ground action. This study demonstrates that land management strategies are the result of an interaction between how farmers view their land, their experiences, their knowledge, their values, their motivations and their socio-economic situation [109]. Understanding what provides the context for farmer decision making is important when attempting to effectively link science and practice. As Leopold [110] (page 263) said in 1939 – "*the landscape of any farm is the owner's portrait of himself*". Therefore, it is crucial to understand farmers and their individual and collective worldviews when trying to change land management practice. Simply applying 'a one rule fits all' approach will not work [109]. This means that LE needs to be better at recognising and dealing with stakeholder differences.

It is crucial to understand that a sustainable future for farming systems will consist of considering the range of values that agricultural landscapes have to offer and managing them in a different way. This means treating landscapes as being 'healthy', 'attractive', and productive' and places were people and nature are capable of thriving and prospering alongside each other [111]. It is also important to recognise that agricultural landscapes need to support 'profitable enterprises', and 'vibrant communities', as well as being in good physical condition [112]. In order to achieve this, a changing approach to agribusiness is required and a shared vision needs to be built collaboratively with farmers whilst developing the important mechanisms to achieve the vision. LE with its ability to be 'more than just another discipline' has the opportunity to rise to the challenges laid down. It can cross the boundaries of other more traditional disciplines to view land management issues from a more holistic context that considers social and natural sciences [113]. This means that LE can work to stimulate the integration of a variety of disciplines to solve problems. To do this well will require capitalising on its transdisciplinary nature and being a facilitator of science to help drive the sustainability agenda. It also means guiding the effective on-ground application of projects and approaches that bring together a variety of stakeholders. It also means recognising different values, beliefs, and perspectives, as well as working more readily with colleagues in AE to jointly advance the knowledge, science, and application of sustainable solutions for future farming systems.

From a practical sense, LE science also needs to back up the facilitation role it can provide by offering better mechanisms to practically capture and quantify the current landscape situation and monitor change as land use and practice changes occur. This, as discussed above, will require the development of tools and indicators that can help with understanding landscape processes especially tools that evaluate ecosystem and landscape services and monitoring if a situation is deteriorating or improving. This will also require supporting mechanisms that enable the incorporation of relevant science into design, planning, and decision making. This is vital for informed planning and design of future landscapes to provide appropriate mitigation and adaptation responses. If LE can do this, it has great potential to make a strong contribution to the development of future farming systems.

5. Conclusions

Landscape ecologists to date have been responsible for developing some excellent science and theories which have the potential to help agriculture respond to future challenges and play some key roles in the management and design of future sustainable farming systems. However, as Flora [80] (page 38) said "*sustainable agriculture is as much a process as an endpoint*". So despite the fact that LE has always had on-ground relevance and strong applicability to heavily modified and agricultural landscapes, more work needs to be done on the "process"' of helping farmers to transition to more sustainable enterprises. This will require ensuring that the current science and methods are more frequently applied to practical farm management situations so what we already know in LE is taken out of the 'ivory tower' and becomes more widely recognised as a practical tool for farm sustainability rather than a theoretical construct. This means increasingly focusing on bridging the divide between science and practice and working more closely with the farming related community.

It is also important that landscape ecologists rise to the challenge of directing future research agendas towards developing LE-informed practices and techniques that are relevant and easy to apply for those engaging in on-ground landscape management. Above all, LE needs to demonstrate that it can be more practically applied to farmers and farming systems for both business and environmental sustainability. This will potentially mean engaging with the relevant stakeholders to undertake more 'bottom-up' research. In doing this, an area of focus for LE should be to provide easy to use tools and techniques for quantifying the state of the environment at the farm and landscape scale that can be integrated into business management systems to advise around holistic farm sustainability. Capturing good baseline data is fundamental to determining what is happening on the ground and what happens in response to practice change. So, LE also needs to focus on providing measures that relate landscape pattern/cover to ecosystem services/landscape functioning as well as providing ongoing monitoring tools to evaluate on-ground activity. Monitoring approaches that reflect pattern, process, and change relevant to farm systems need to be further developed and innovative ways to analyse monitoring data captured through farming mechanisms such as precision agriculture practices need to be explored for their use towards determining environmental outcomes as well as production outcomes. After data acquisition, LE needs to demonstrate an ability to turn relevant spatial and temporal data into useful information for decision support and be able to actively contribute towards generating adaptive management advice and planning techniques to assist in the creation of multifunctional landscapes. LE also has an important role to play in contributing towards the generation of spatial decision support tools to assist planning (scenario and visualisation) at the farm and landscape scale that combine concepts and theory of LE framed within the context of business support systems. This is particularly important for places like NZ, which has an intensive agriculture industry backed up by a strong rural-based economy and population and an important tourism industry.

With a strong desire to maintain their place in the global tourism and food markets, NZ needs to demonstrate its environmental credentials and the idea that "Pure NZ" and "Taste Nature" are a reality and reflected in landscape management, not just marking campaigns. This means that NZ farmers need to increasingly factor more integrated ways to manage the land into their business management approaches. These are approaches that work in association with nature to reduce emissions and maintain healthy landscapes and waterways. For farmers searching for answers on how best to do this, LE is ideally positioned to work with them to develop future farming systems. These systems can be not only multifunctional and environmentally healthy, but also work towards creating sustainable business enterprises that are capable of increasing productivity outcomes to the point required to bolster farming livelihoods and to feed a growing global population. There is plenty of good science out there within the disciplines of both LE and AE and extensive knowledge amongst farmers about their farm systems. Collaboration and the co-production of integrated interventions and solutions that plan and design future farm systems with people and the environment in mind appears to be the best way forward for achieving sustainable agricultural production, both in NZ and globally.

Funding: This research received no external funding.

Acknowledgments: Acknowledgement is given to Massey University for supporting this research. I would also like to thank the valuable advice given by 3 anonymous reviewers that helped to improve this manuscript and Julian Gorman for comments on earlier versions of the paper.

Conflicts of Interest: The author declares no conflict of interest.

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