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INTRODUCTION

A Sustainability Crisis in World Agriculture

Producing food while maintaining biodiversity and ecosystem services is one of the greatest challenges facing humanity (Norgaard, 1987; Millennium Ecosystem Assessment, 2005; Schmitzberger *et al.,* 2005; Ehrlich, 2008). With more than 40% of the Earth's surface being used for agriculture (FAO, 2007), farmers and herders manage vast tracts of land and the natural resources within them, shaping ecosystems, habitats and landscapes (OECD, 2008). Farms are vital in securing human survival, both directly by producing food and fibre, and indirectly by producing amenities.

There is increasingly widespread concern that agriculture and the world food systems it supplies are not sustainable. The industrial revolution and associated access to fossil fuels, together with advances in medicine and efficient agricultural production triggered a geometric population increase. The global human population is projected to peak at approximately 9 billion by 2050, 3 billion greater than the present population. There is currently enough food to feed 12 billion people, and many predictions of the impact of climate change suggest that world food supplies will increase (Kaye-Blake et al., 2009). However, the distribution of this food is a crucial issue, and predictions often neglect to consider that much of the production in industrial scale agriculture and the world food systems it supplies are subsidised by inexpensive energy from fossil fuel, despite recent 'peak energy' projections asserting that supplies are already declining (Newman, 2008).

Moreover these predictions do not account for the fact climate change means production will be shift into areas which currently do not either produce food or do not have expertise in the new crops and therefore the transaction costs of developing an infrastructure around production is not being assessed. At least as important in the short term are the fluctuations in food prices caused by increased speculation in commodities, exasperated by the financial crisis. In addition, climate change is also predicted to lead to more extreme climate events, causing shortages of supply that will lead to price fluctuations. Such fluctuations can lead to humanitarian crises, as well as political instability. Changes in world food markets are also affected by international agricultural policies. For example, the way in which the introduction of subsidies for biofuels in the EU and the US has distorted world food market prices (Wreford et al., 2009).

Many farming practices negatively affect ecosystems both on- and off-farm, sometimes over large distances, through importing ecological subsidies (Moller *et al*., 2008c) and exporting pollution (Gordon *et al.*, 2008). The contribution of agriculture to global climate change through greenhouse gas emissions and heavy consumption of fossil fuels has led to calls for the transformation of agricultural production. Increased reliance of technology and aggregation of family farms into large corporate land holdings has triggered depopulation of rural areas in many developed nations. Consequent erosion of the vitality and resilience of rural communities threatens transition of farm ownership within families and transmission of local knowledge. Some agricultural sectors are experiencing a shortage of farm labour during intensive phases of crop rearing and harvest, and exploitation of itinerant labourers is considered unethical by an increasing body of consumers who demand food that has been grown sustainably in all environmental, economic and social dimensions.

Concern for the sustainability of agricultural systems at interlinked local, national and international levels is spreading well beyond an academic community of "whistle blowers" to become a well organised mainstream consumer and environmental movement. This trend is evidenced by a growing number of popular books, websites, films, newspaper, radio and television items about the agricultural sustainability crisis, food security and food sovereignty (e.g. Moore-Lappe and Lappe, 2003; Pollan, 2006; Nestle, 2007; Pollan, 2008; Richardson, 2009; Winne, 2009; Weber, 2009; Gottlieb and Anupama, 2010). There is a clear need for sound and accessible agricultural systems science to guide this growing popular movement for transitions to more sustainable and equitable food production.

The Importance of Agricultural Sustainability for New Zealand

New Zealand, more than most other developed country, relies heavily on the continuation of agriculture and associated supply chains to sell its products to distant markets. Over 57% of New Zealand's overseas export earnings come from agricultural produce, with an additional 13% from forestry and aquaculture[1]. Biological production dominates land use, engaging more than 60% of the country's surface area, particularly in low-altitude, warm and fertile sites where indigenous biodiversity once flourished (Perley *et al.* 2001, MacLeod *et al.* 2009). New Zealand has prospered over the past century from mass production of a small number of agricultural commodity products, which it was able to produce efficiently through increasingly intensive farming to supply markets in United Kingdom, Europe, North America, and, to a growing extent, Asia. However, this has also led to NZ falling down the OECD ranking as the income elasticity of demand for food has been less than one, meaning as

[1] MAF Situation and Outlook 2011 - http://www.maf.govt.nz/news-resources/statistics-forecasting/statistical-publications.aspx

countries grew richer, a lower proportion of their expenditure was on food, particularly raw commodities. Increasing globalization of food systems and markets has threatened New Zealand's historical position as a low cost supplier, and competition in the market has intensified. Therefore, for New Zealand to continue as a major commodity producer risks both declines in relative income but also greater competition from other countries, and loss of market share. In addition there is a growing awareness within New Zealand around the impacts of agriculture and farming, particularly on the environment. Therefore, for New Zealand to maintain or increase its income while meeting national demand, the attributes of food that consumers and communities demand and are willing to pay for must be carefully considered (Saunders *et al.* 2010).

These attributes, including the increasing consumer demand for 'ethical food' production, present significant challenges to the security of market access for New Zealand's agricultural products (Figure 1). Many of the pressures on agricultural sustainability identified overseas are also felt in New Zealand, together with uniquely

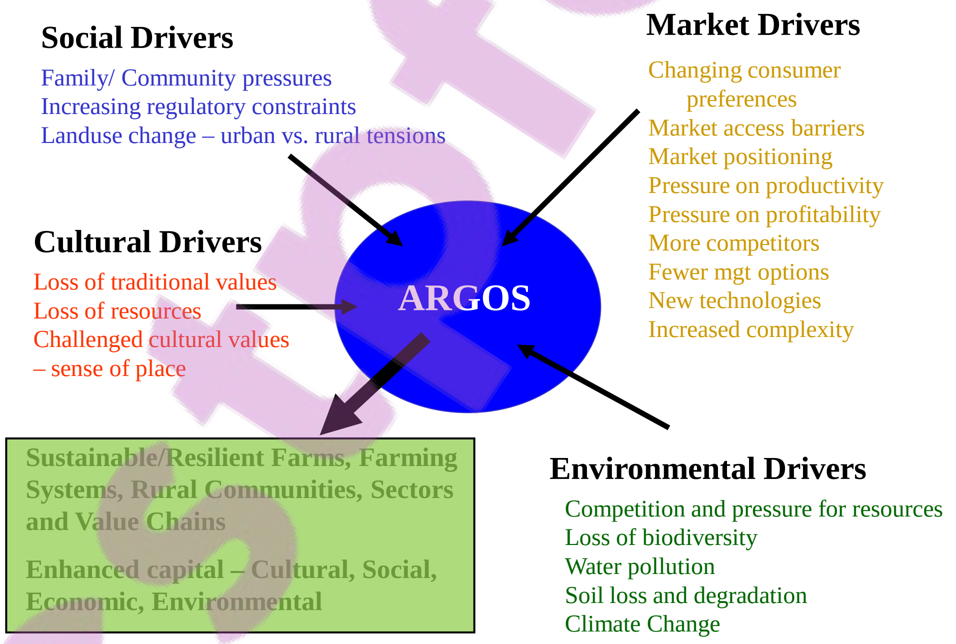

Figure 1. Some of the drivers and challenges to the resilience and sustainability of New Zealand Agriculture that led to the formation of the Agriculture Research Group On Sustainability (ARGOS) research programme.

New Zealand concerns for the cultural sustainability of Māori communities. Recent reviews have underscored the ways in which the accelerating rate of agricultural intensification in New Zealand may threaten both the environment and the sustainability of food production (Norton and Miller 2000, PCE 2004; MacLeod and Moller, 2006, Moller *et al.* 2008c). Despite the Parliamentary Commission for Environment's "*Growing For Good*?" analysis calling for a 'redesign' of New Zealand Agriculture in 2004 (PCE 2004), there has been no apparent progress or even suggested mechanism to trigger such a major transition.

The ARGOS Programme and its Goals

A group of researchers in New Zealand has been working together since 2001 to research a number of threats to the sustainability and resilience of New Zealand agriculture. Their longitudinal and transdisciplinary study of the sustainability of 108 horticultural and pastoral farming enterprises began in late 2003. The ARGOS group formed a collaborative entity linking two universities, three sectors, a consulting group and several smaller subcontractors, under the name The 'Agriculture Research Group on Sustainability' (ARGOS). The ARGOS group was successful in obtaining New Zealand government funding through the Foundation for Research Science and Technology to establish the first phase of a long term study of agricultural sustainability, with funding initially confirmed for the period 2003-2009 ('ARGOS1'), then extended until 2012 ('ARGOS2').

The overarching mission of ARGOS is ***to understand the enablers and barriers to the future sustainability and resilience of agriculture so as to enhance New Zealand's economic, social and environmental wellbeing*.**

This mission has been undertaken by implementing well-replicated and long-term research of whole working farms, across a continuum of agricultural land use intensification for nationally important agricultural sectors. ARGOS has designed and monitored key sustainability performance indicators, as well as examining the production and sustainability choices and actions of farming families, their rural communities, and wider industries. In our research programme, trends within world food systems are linked to opportunities to secure and grow market access for New Zealand's agricultural exports. In addition, we are researching the influence of New Zealand's broader society, environment and economy on the ability of farming families to maintain profitable, efficient, satisfying and environmentally friendly production. ARGOS is committed to a high level of dialogue and engagement with actual practitioners in farming sectors, both to inform research and as a means to encourage innovation and new insights that are practically grounded and likely to be applied.

ARGOS1 was designed after reviewing prior international attempts to study how 'sustainability dynamics' emerge through systems effects at the farm level. The result was a methodology that sought to understand farm-level dynamics as practiced by actual farmers (rather than in model farm, split farm or laboratory settings). These effects were examined over time, because systems-level interactions often involve an important temporal dimension. ARGOS1 took these approaches further than any previous farm-level study of sustainability anywhere in the world by using a sufficient number of farms to generate the statistical rigour necessary to inform debates that were previously limited to speculative analysis based on limited and unnatural cases. In addition ARGOS1 used a transdisciplinary approach to investigate social, economic and environmental dynamics emerging on farms – particularly as they interact with one another. The first main theme chosen to realise the mission of ARGOS was an exploration of the efficacy of alternative market accreditation pathways to sustainability. ARGOS2 has maintained this emphasis on market accreditation, while focusing specifically on the key factors involved in resilience to shocks, long-term drivers of change, and threats to sustainability.

The Historical Context for a New Zealand Agricultural Sustainability Study

The need for a more comprehensive and integrated research programme into agricultural sustainability in New Zealand was influenced by a number of local and international policy discussions. The most notable drivers operating in the longer-term political economy of New Zealand agriculture hinge around three key dynamics:

- Historical exploitation of land resources during colonial settlement. The arrival of European settlers in New Zealand triggered massive changes in the landscape ecology of New Zealand, with significant land clearance leading to the establishment of British-style family farms throughout New Zealand (see Pawson and Brooking 2002, and Brooking & Pawson 2010). This long-term colonial exploitation of land resources was accompanied by significant ecological disturbance, biodiversity and landscape impacts, social impacts, and (importantly for farmers) a series of crises in soil fertility that recurred over a number of decades leading up to WWII. This phase established the basis for long-term environmental instability in the farmed landscape in New Zealand, reinforcing the recent timeframe of land settlement and farming in the country. Throughout this process (and through to the present day), Māori land-users formed an interesting, but under-researched, site of farming that is potentially distinct from mainstream commercial farming in New Zealand.
- The post-WWII phase of land-use intensification based around new fertilisers and mechanised land clearance saw a significant increase in the amount of pasture as well as increasing intensity of stocking rates per hectare (see MacLeod and Moller 2006, Haggerty *et al.* 2009). This phase of intensification combined with highly beneficial market relations with the United Kingdom to

underwrite a period of sustained prosperity for New Zealand farming. This period was highly socially important, entrenching the notion that a set of productionist strategies could provide a model for successful agriculture in New Zealand.

- A major shock to this system came in 1973 when the United Kingdom joined the European Common Market and New Zealand lost privileged market access. The resulting decade of instability and crisis saw a range of government interventions to stabilise agriculture, and eventually culminated in the adoption of radical neoliberal reform across the whole New Zealand economy in 1984. At this time, all subsidies for New Zealand agriculture were removed as the State retreated from strategic management and regulation of agriculture with multiple consequences for farm operations and agricultural support systems (Macleod and Moller 2006, Haggerty *et al.* 2009). These events were followed by a period of structural and social crisis in New Zealand rural society, with agriculture only beginning to restabilise around new trade linkages and structures in the 1990s. The fundamental transition of New Zealand agriculture to its current reliance on market incentives alone to deliver sustainability and associated land care was more extreme than in Australia (Dibden et a. 2009). However, both countries stand alone as outliers in socio-political ideology within which market forces alone are expected to provide sustainability[2].

Prior research has identified two broad dynamics underpinning the rise of 'alternative' systems of agricultural management in the New Zealand context. Emergence of an organic agriculture movement in the 1930s in New Zealand, partly from the influence of academic dialogue with organic advocates in Britain, and partly in direct response to the soil crisis and DDT impacts then gripping New Zealand pastoral farming (Campbell and Fairweather 1998, Hunt 2004, Stuart and Campbell 2004). This early flourishing of organic agriculture peaked during WWII then declined after the war as a spirit of technological optimism took New Zealand agriculture in a more intensive direction.

The second dynamic influencing the emergence of alternative agriculture in New Zealand was the rise of new governance structures among export industries in the years of reconstruction of New Zealand agriculture following Neoliberal reform. This process initially took the form of corporate exporters fostering the development of certified organic produce for markets in Europe, Japan and the US. This was quickly

[2] We nevertheless caution that formal and detailed research may uncover important differences between Australia and New Zealand in policies, especially concerning regulation and subsidization for land care, drought relief etc. For example, Australia has an inspiring variety of governance institutions and assistance for farmers to allow forms of 'land sparing' and environmental care that are integrated with farm production (Bennett *et al.* 1995). Collectively these schemes double the area with some form of governance institution to protect biodiversity when added to the area in national parks in Australia.

followed by the introduction of quality assurance (QA) schemes deriving environmental qualities from the deployment of crop management techniques based on integrated pest management (IPM or IM) systems. The early innovators in these schemes were the kiwifruit and pipfruit industries, and retailer-driven QA schemes have since emerged as key gate-keeping mechanisms for protecting high-value markets. These QA schemes have become elaborated around a range of environmental and food safety criteria, and have come to constitute the main conduit to establishing more environmentally-friendly practices among food exporters.

The specific historical context of New Zealand considerably influenced the available options for study and longitudinal research design. At this time, commercial agriculture was, as throughout its history in New Zealand, strongly export focused, with the exportation of over 90% of commercially produced food, often to high-value markets, in which higher prices are paid for produce. Within export industries were groups of growers who had relatively recently adopted certified organic or IPM forms of crop management. Alongside these two new groups were long-term adherents to organic practices as well as the majority of pastoral farmers who had persisted with conventional production systems. With interest in the consequences of this earlier transition and restructuring of New Zealand agriculture, the ARGOS group sought to construct a longitudinal study to enable deeper and more integrated evaluation of the consequences of adopting new, more environmentally-oriented styles of production in what had hitherto been a largely productionist-style agricultural economy.

The Aims of this Working Paper

This working paper is intended to inform prospective collaborators about where ARGOS came from and why it was designed it the way it is. In addition, this overview is designed to help researchers and students involved in ARGOS to identify where best to focus their own research. Moreover, we hope to provide a broad-brush picture of ARGOS and its rationale to assist overseas teams contemplating similar endeavours. Finally, this paper seeks to critically reflect on the research already undertaken, and its design, allowing us to identify future research directions.

The following section describes the formation of the ARGOS team and the way it is administered. This is followed by an introduction to the design and methodology of the first phase of the ARGOS programme. The paper then details the elaboration of research design in-the-field over the first two years of the project's funded life. We then summarise the specific research strategies of the social, economic and environmental research teams and the initial challenges of attempting transdisciplinary dialogue. The discussion evaluates the strengths and limits of inference of the ARGOS research programme. Finally, a list of the written outputs from the programme until August 2010 is appended.

THE FORMATION OF THE ARGOS GROUP

The ARGOS programme bid emerged out of a number of different activities and processes:

- In March 2001, a steering group was established to investigate the potential for an integrated research programme into sustainable primary production. This group comprised: Prof Caroline Saunders (Lincoln University), Assoc. Prof John Fairweather (Lincoln University), Dr Hugh Campbell (University of Otago) and Mr Jon Manhire (AgriBusiness Development Group).
- In November 2001 a discussion paper by Fairweather and Campbell (2001) reported a literature review of international research into farms and orchards converting to sustainable production. In addition, the paper presented a brief research design for a possible longitudinal study of farms in New Zealand, capable of underpinning much of the research provision into key food export sectors in New Zealand.
- In September 2002, the steering group circulated a brief version of the research plan and visited people in three sectors as potential participants in such a study: Dairy, pipfruit and kiwifruit.
- A revised research plan was produced by Manhire *et al.* (2002). This plan outlined the methodology for a longitudinal study by incorporating the insights of the different industry groups interested in supporting the research. Dr Henrik Moller was invited to join the discussion and provide greater expertise on the environmental component of the eventual ARGOS bid.
- A full bid was submitted to the Foundation for Research, Science and Technology, gaining funding for the period October 2003-July 2009.

This steering group initially identified the following five needs for achieving a better understanding of agricultural sustainability:

- The need for more basic underpinning research to assist with technical challenges in new sustainable production systems
- The need for more whole-system rather than 'component' research
- The need for a more integrated research approach across research providers
- The need to better facilitate the uptake of new innovations in sustainable production
- The need to identify the key areas of comparative advantage and establish benchmark performance measures for new systems of production.

The research group took shape as a formal memorandum between the University of Otago, Lincoln University and the Agribusiness Group. The group also invited the local iwi, Ngāi Tahu, to join the agreement. The tribe deemed this unnecessary, as it already had a formal memorandum with the University of Otago. This MoU formed the basis of the governance structure of ARGOS, and a second tier of relationships was established through cross-employment of field staff between ARGOS and ZESPRI, a meat company, and Fonterra. To emphasise the intent of the ARGOS project to strongly engage with industry and other stakeholders, the project was administratively housed at The Agribusiness Group in Christchurch with Jon Manhire as Project Leader.

THE DESIGN OF THE ARGOS PROJECT

The main ARGOS null hypothesis

Our primary focus on alternative market accreditation pathways to sustainability led to the development of a primary over-arching null hypothesis of the ARGOS programme: *There are no differences between organic, integrated management and conventional farming in economic, environmental and social outcomes*.

The ARGOS programme was structured around testing this null hypothesis in a range of agricultural production sectors, utilising a transdisciplinary approach and a longitudinal design. The following sections describe the process of determining which agricultural sectors were most important to study, and how research 'panels'[3] were selected within each sector. This is followed by a detailed description of the specific features of the research design of the ARGOS programme.

Choice of New Zealand Agricultural Production Sectors for Study

The ARGOS steering group identified a strong need for study to be specific to particular production sectors to ensure that results could be produced that were relevant to end user needs, and to acknowledge that sector results would likely be sector-specific. Preliminary consultation and existing experience working with NZ primary industries suggested that specific sectoral strategies were having a strong effect on outcomes. Thus the design chose to work with the sectors as a key element of design rather than examine an NZ-wide engagement with all dominant land-uses within the context of government policy and general environmental regulation (Fairweather and Campbell 2001). We sought to balance the following in our choice of study sectors:

- Importance of the sector in terms of land coverage, number of farming families and financial contribution to the New Zealand economy[4]
- Studying sectors where most produce is exported
- Incorporating at least one example of horticulture
- Spanning a wide range of agricultural intensification
- Incorporating a Māori cultural dimension to support New Zealand's Treaty of Waitangi principles[5]

[3] 'Panel' emerged as our label for each group of farms within a given sector that were following a particular 'farming system' (i.e., organic, IM or conventional). Where a group of farms was being followed from the time of conversion to new alternative farming systems, the panel can more appropriately be referred to as a 'cohort' of farms (Fairweather *et al*., 2005).

[4] ARGOS sought to support the New Zealand government's high-level goal of generating wealth for New Zealand by reducing chemical inputs and enabling the development of safer, low impact, acceptable and more efficacious means of controlling diseases, animal and plant pests that threaten primary industries. In addition, ARGOS sought to enhance sustainable production sector environments through integrated approaches to their management, to ensure sustainability of production systems, and to develop innovative and novel production systems and technologies.

- Ensuring a wide geographic spread within New Zealand
- Involving sectors with active engagement with organic and other QA accreditation systems
- Targeting sectors with well-organised and cohesive industry facilitation and representation

Although the ARGOS programme was initially designed to examine four sectors of New Zealand Agriculture (dairy, sheep/beef, kiwifruit and pip fruit), it was initially deployed in only two sectors – kiwifruit and sheep/beef. This change resulted from the lower than expected total amount of funding, and the particularly strong industry support in these two sectors for the programme. In 2004 a decision was made to add the dairy sector to the programme. We also conducted case studies of 12 High Country farms, providing an examination of low-intensity farming. The Māori panel incorporates a wide variety of farming and related business enterprises, including a significant contribution of sheep/beef production in all seven of its case studies. Dairy was not included at the beginning of the ARGOS programme (October 2003) because the overall funding requested was reduced. However, supplementary funding from Fonterra enabled us to research 12 pairs of dairy farms since 2005, half of which were beginning conversion to organic production at that time. Dairy and sheep/beef farms produce the bulk of New Zealand's agricultural exports and dominate agricultural land use (Table 1). Kiwifruit is New Zealand's leading horticultural export and is actively facilitated by a 'single desk' exporting authority applying uniform and stringent QA systems.

Merino NZ Inc., a merino-growers industry group, was supportive of ARGOS's aim to provide independent and accurate information on High Country farms and their performance and impact on the environment. It was perceived that such information would be useful to support marketing as well as advocacy for the merino wool industry. For ARGOS, the high country panel provided a complementary case study of low intensity farming i.e.

- highly intensive agriculture on kiwifruit and dairy
- high to medium intensity farming on mixed cropping and sheep/beef farms on the Canterbury plains,
- medium intensity sheep/beef growing on rolling hill country of South Island
- low to medium intensity sheep/beef farming combined with a variety of other enterprises on Ngāi Tahu communal land holdings
- extreme low-input/low-output sheep/beef farming on High Country runs.

[5] Government research strategy in support of Treaty of Waitangi partnership has subsequently been packaged within '*Vision Mātauranga*' (MRST, 2005) to "unlock the innovation potential of Māori knowledge, resources and people to assist New Zealanders to create a better future". Most of the ARGOS research effort supports Vision Mātaruranga's objective for *Indigenous Innovation: Contributing to economic growth through distinctive Research and Development*. However the 'Sustainable Lifeways' and 'Ecosystems Management' approaches adopted by our Māori research objective also contribute strongly to Vision Mātauranga's second and third objectives: i.e. "*Taiao: Achieving environmental sustainability through iwi and hapū relationships with land and sea*" and "*Hauora/Oranga: Improving health and social wellbeing*".

Table 1: Recent New Zealand agricultural sector statistics for the sectors chosen by ARGOS as the main research focus.

	Kiwifruit[1]	Sheep/beef	Dairy
Land cover (ha)	12,525	9,966,592[2]	1,519,000[3]
Number of enterprises	2,711	29,241[4]	11,618[3]
Export Earnings 2010 ($ Billions)	$1.4	Lamb - $2.9 Beef - $2.0 Wool - $0.91	$13.2[4]

[1] For the year ending 31 March 2010. ZESPRI Annual Review 2009/10. http://www.zespri.com/about-zespri/zespri-business/investors.html
[2] Statistics New Zealand 2007 Census – includes ANZSIC classes AO141, 142, 144, 145
[3] New Zealand Dairy Statistics 2008-09. LIC & Dairy NZ. http://www.lic.co.nz/pdf/dairy_stats/DAIRY_STATISTICS_08-09.pdf
[4] Situation and Outlook for New Zealand Agriculture and Forestry (SONZAF) 2011. http://www.maf.govt.nz/agriculture/statistics-forecasting/international-trade.aspx
[5] Situation and Outlook for New Zealand Agriculture and Forestry. http://www.maf.govt.nz/mafnet/rural-nz/statistics-and-forecasts/sonzaf/2010/2010-sonzaf.pdf

Sheep/beef farming was depressed when ARGOS began, but has enjoyed stronger economic growth in the last three years. Beyond 2012, MAF predicts steady production growth in dairy and kiwifruit[6]. Together with a predicted depreciation in the NZ dollar, there is a strong forecast growth in export revenues from all of New Zealand's agricultural exports. Accordingly much of ARGOS's investment was and remains targeted to support national prosperity by supporting economically important agricultural sectors, and the most important sectors from a land cover standpoint. High Country and Māori (Ngāi Tahu) farming were prioritised because they are important for New Zealand's national and cultural identity.

Establishing the ARGOS research panels

In each sector, the key person in selecting suitable farms/orchards was the ARGOS field officer. This person visited a large number of potentially suitable farms and prepared dossiers on potential participants (and their relative positioning to other properties in order to form clusters). The representativeness of each potential participant was then considered and debated by the ARGOS Academic Research Committee. The key debates over representativeness revolved around the degree to which environmental similarities would drive the research design. These were balanced against the need to find households that were economically representative (in terms of financial flows, debt and ownership structure), were

[6] MAF Situation and Outlook 2011 - http://www.maf.govt.nz/news-resources/statistics-forecasting/statistical-publications.aspx

not socially atypical in terms of their wider panel's group of growers (although this was difficult to predict until later research had taken place), and who exhibited management characteristics that represented a range of farming approaches (i.e., we avoided only choosing the keenest participants). In sheep/beef, dairy, and kiwifruit, the location of organic farms typically dictated where a cluster was centred, because of the relatively small number of organic farms.

In the kiwifruit sector, after considerable consultation with ZESPRI, 12 clusters of kiwifruit orchards were identified (Table 2 and Figure 2). Due to the lack of converting organic orchards, the three panels were reconfigured to comprise: Existing organic (Hayward variety), existing IPM (Hayward) and KiwiGold IPM (using the gold variety). This was considered an interesting structure due to the industry perception that gold kiwifruit were produced in a more intensive system than usual for the Hayward variety. Panels were constructed through identification of a group of organic kiwifruit orchards, reflecting the perception by industry stakeholders that they were representative of the wider population of organic growers.

Table 2: Numbers of participating ARGOS farms.

	Conventional	New system	Established organic	Total
Kiwifruit	**12 KiwiGreen**	**12 Gold**	**12**	**36**
Dairy	**12**	**12 Entering organic**		**24**
Sheep/beef Lowland	**12**	**12 Integrated management**	**13**	**37**
High Country	**12 Various intensities**			**12**
Māori	**8 Initial case studies**			**8**

Once suitable organic orchards had been identified, a green and a gold orchard were identified in close proximity to the organic orchard. The overt intent of the clustering was to find orchards that inhabited the same soil type, microclimate and ecological surroundings. In some cases these clusters involved neighbouring orchards. Other cases required the clustering of orchards in reasonably close proximity. This process resulted in 12 clusters – fulfilling the expectations of the panel design. Ten of the twelve clusters were situated in New Zealand's premier kiwifruit growing province – the Bay of Plenty – with one situated in Northland and another in Nelson to provide some representation of outlying regions.

Selection of panels in the sheep/beef sector was more challenging, because of the small number of certified organic sheep/beef producers in the South Island of New Zealand. The panels in sheep/beef comprised: existing organic, integrated management and conventional (Figure 3). Due to the limited number of organic producers, it was difficult to obtain a broad selection of possible clusters from which the best 12 could be chosen (as was the pattern with kiwifruit). Key compromises were made, with at least two clusters involving farms that were in the same catchment, but without the tight geographical scope of the clusters that was achievable with kiwifruit. Another methodological concern was differentiating between integrated and conventional producers. The key industry stakeholder working with ARGOS had implemented a farm assurance programme recognising protocols for integrated management. However, this had not been occurring for long and integrated management clearly does not have the recognition or history evident in other sectors, such as kiwifruit. As such, there was some debate about whether the integrated farmers would end up being particularly different to conventional farmers.

The dairy sector provided the best opportunity for a before-after-controlled-impact (BACI) design. 12 farms that expressed an intention to convert to organic management were identified in the North Island (Figure 4). These were matched with 12 conventional dairy producers in close proximity. The dairy industry has no integrated management programme, so no third panel was possible. The BACI design was somewhat thwarted by the finding that a number of dairy farmers converting to organic production were not 'purely' conventional beforehand. To some extent, these farmers had already moved away from conventional farming in their approach to farming and/or their farm practice.

In terms of stability, it was important that the attrition rate of participating households should be kept to a minimum. This has largely been achieved through careful management of contact with the participating growers. Field officers mediate all contact between growers and researchers, and each research exercise is evaluated to gauge how many hours of participants' time is involved. The result has been good, with four growers dropping out of the study.

Over the next few years, two key tests of these panels took place concerning their stability and their representativeness. The key test of representativeness was the degree to which our 108 households represented views and behaviours that were typical of their wider social group. This question was addressed in a national survey of growers (which also went to all ARGOS households), enabling us to test the representativeness of responses to key questions between the ARGOS subgroup and wider populations. Fairweather *et al.* (2007a) reports that out of 145 questions, the ARGOS farmers' and growers' responses significantly differed on only three to 17 questions, depending on the management system and the sector.

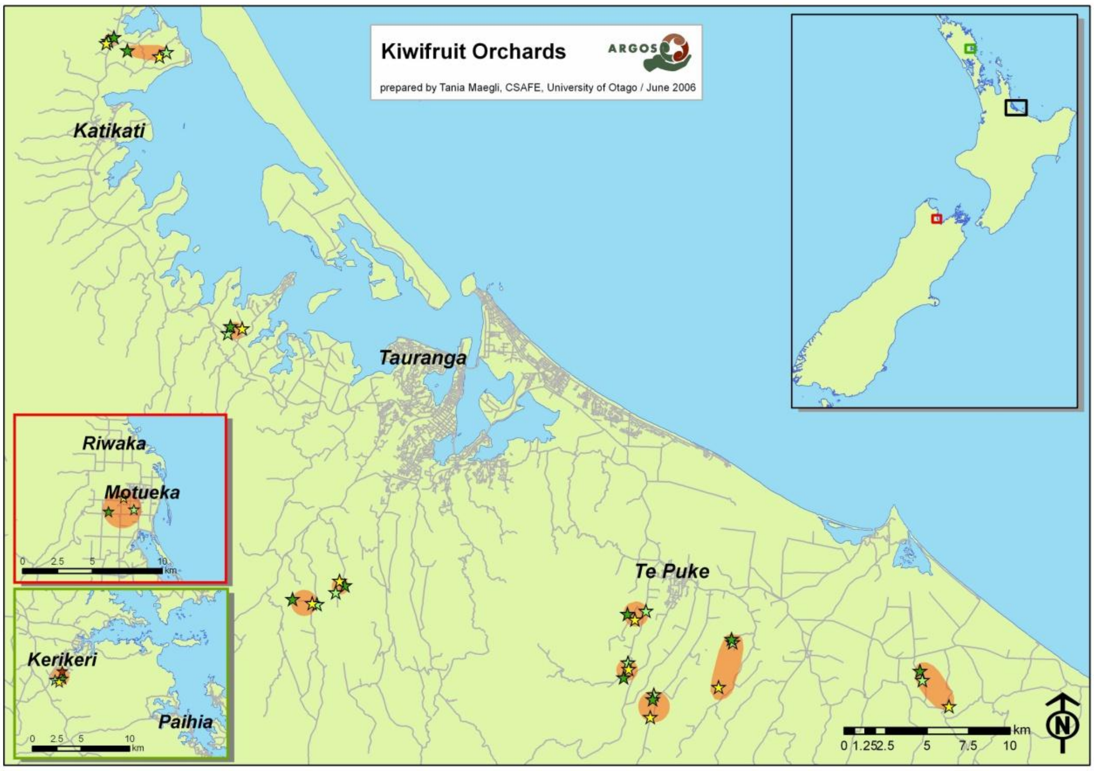

***Figure 2. Clusters of orchards selected for study in the kiwifruit secto*r**

While this panel structure lies at the heart of the ARGOS design, we reasoned that methodological strength would be created by incorporating other sectors and groups using a case study design. Accordingly, groups of High Country sheep farms, Māori land holdings and a sub-sample of one cluster of sheep/beef farms were selected for case study analysis.

High Country farmers were selected in consultation with Merino New Zealand Inc., a Merino industry research agency and project funder. Properties were selected to reflect the regional distribution of High Country farms as well as farm size. Because of the size of some of the farms (up to 45,000 Ha) and the lack of any significant differences between audit systems, only 12 farms were selected as case studies, rather than examining paired farms.

Māori participants for the *He Whenua Whakatipu* objective were selected by networking within Ngāi Tahu networks to identify whānau groups with aspirations for developing sustainable livelihoods on communally owned land (Reid, 2008; 2011). Eight groups were initially selected, but intensive and long-tern participation was maintained with 5 of them spread throughout Ngāi Tahu's *rohe* (tribal area). All included some component of sheep and beef raising, but a wide variety of enterprises (eg. ecotourism, horticulture with novel crops, beekeeping, educational centres) were integrated into the planning for sustainable livelihoods.

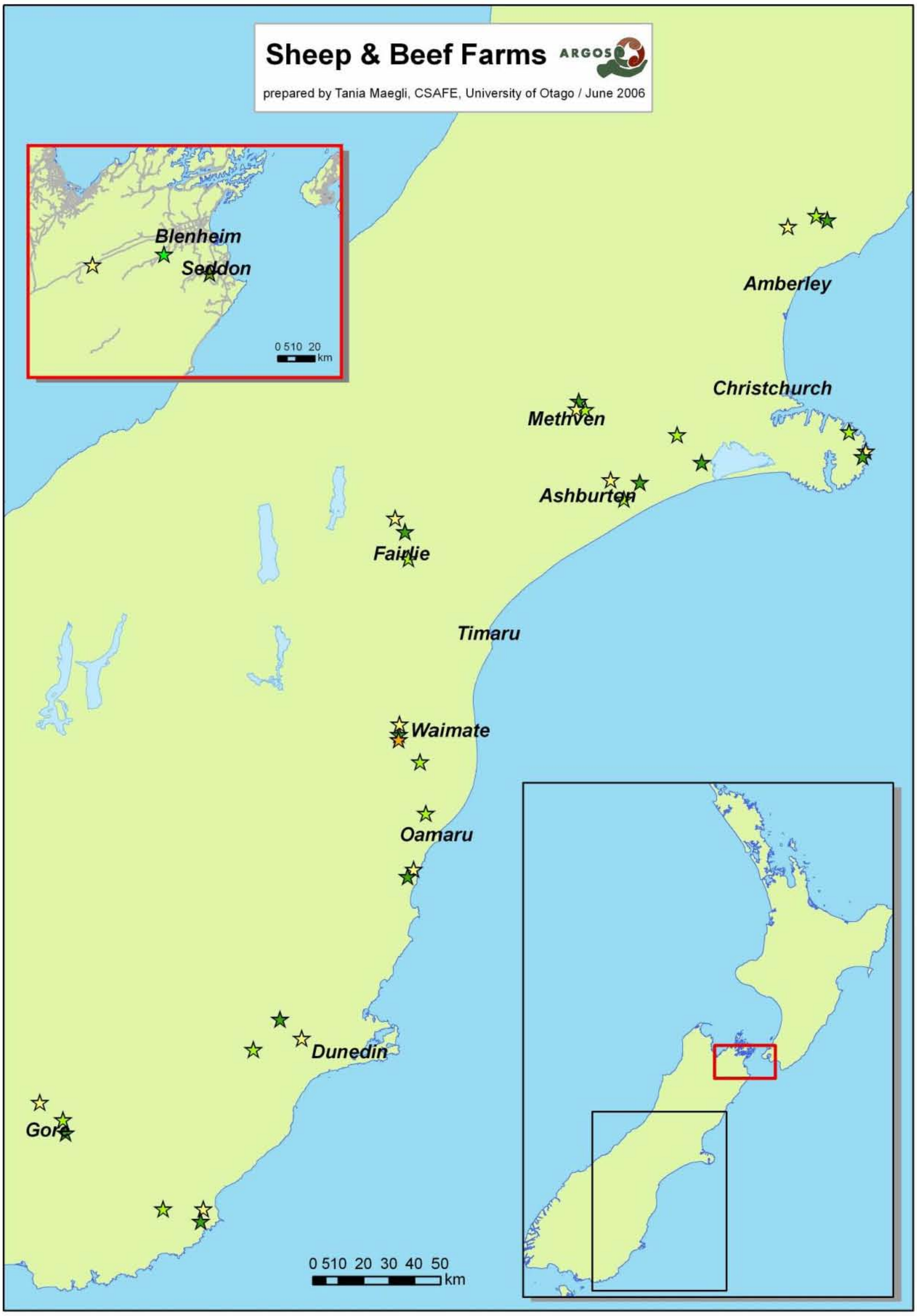

Figure 3. Farms selected for study in the sheep/beef sector

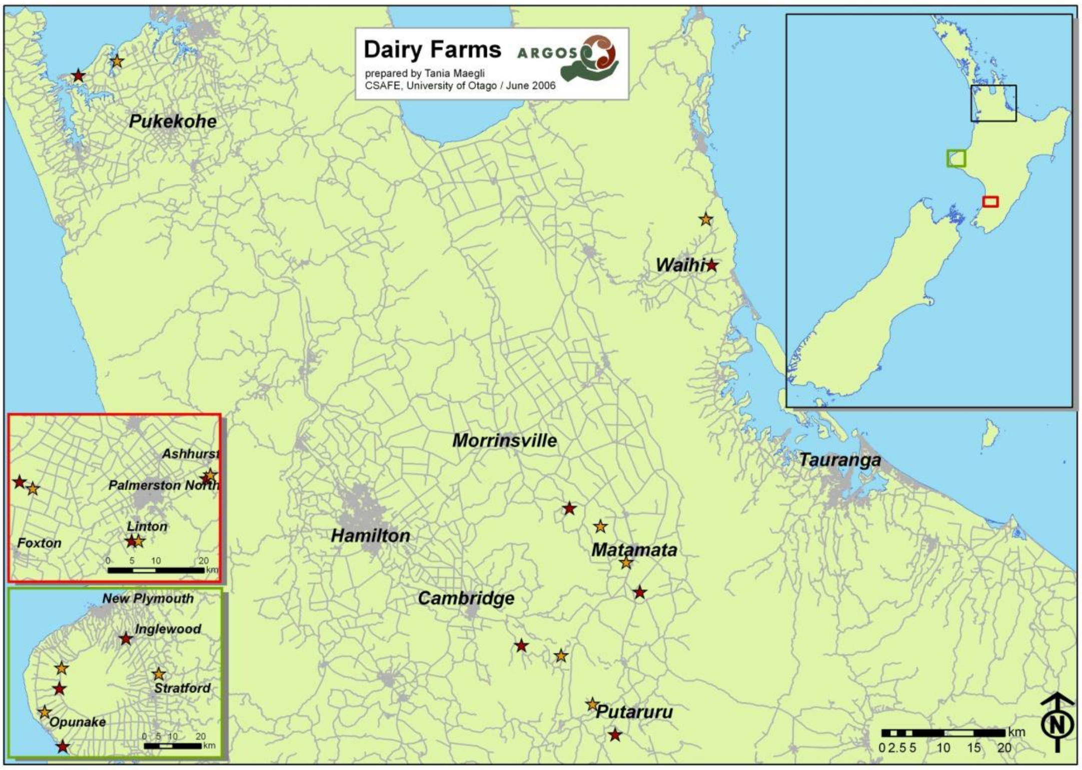

Figure 4. Farms selected for study in the dairy sector

The Need for a Systems and Transdisciplinary Approach

Part of the impetus to form the ARGOS group came from a review of government funding of research into sustainability, which identified separation between academic disciplines and separation of researchers from growers and industry as key problems for sustainability research. Indeed, many studies have addressed the challenge of identifying more environmentally friendly production methods, but their traditional focus on agronomic aspects of farming has come at the expense of studying the farm or farming system as a whole. The ARGOS group sought to re-integrate social, environmental and economic domains through dialogue with academics, farming consultants and advisors and farmers themselves.

While ARGOS expected to apply a variety of disciplines to guide agricultural sustainability, our team quickly became aware of recent calls for the importance of achieving 'transdisciplinarity', rather than merely 'multidisciplinarity'[7] (Fairweather and Moller, 2004; Moller, 2005). Compared to multidisciplinarity, transdisciplinarity requires a much more transformative, challenging and active engagement between the disciplines in which each discipline itself is changed in practice and understanding through its interaction and co-discovery with other academic disciplines and with other process professionals like farm consultants and farmers themselves (Moller *et al.,* 2008b; Aeberhard and Rist, 2009; Hunt *et al.,* 2010). The project was designed to operate across disciplines (and has subsequently engaged in an ongoing debate about the potential of transdisciplinary approaches). The second traditional separation mentioned above, between researchers and industry/growers, led ARGOS to develop a governance structure in which the project was administered and managed by a consulting group dedicated to developing sustainable agriculture, involving paid personnel from different industry sectors as field officers to work between growers and researchers. Each sector has a 'Sector Oversight Committee' comprised of senior industry figures and grower representatives. These committees were most active during the establishment and early stages of the project reviewing plans and results. The role of the Oversight Committee was to;

- Provide guidance/support on the direction of ARGOS research programme to ensure that it addresses:
    a. Targeted sector issues
    b. Stakeholder expectations – farmer/grower, industry
    c. Researcher expectations
- Provide guidance/support for the Field Research Manager
- Identify mechanisms to facilitate the use of the output of the project – identify opportunities and challengers
- Have a strategic and not operational focus

The structure of the ARGOS project was based around five objectives that reflected important primary disciplines (Farm Management, Social, Economics, Environment and Māori). These specialist disciplines were chosen as disciplines that traditionally contributed to land use sustainability assessments, and to ensure cultural safety and effectiveness.

A common feature of systems inquiries is a focus on linkage across a wide range of spatial and temporal scales, with particular emphasis on feedbacks between these hierarchical scales. The various ARGOS research disciplines focused on different scales, but collectively stretched from global to local scales that incorporated farm practice all the way to supermarket operators and consumers in the northern hemisphere. These types of world food system inquiries are sometimes referred to as a "gate to plate", "plough to plate", or "farm to fork" systems inquiries.

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[7] A related term is 'interdisciplinarity'. In our experience, interdisciplinarity and transdisciplinarity are used interchangeably by some researchers, but taken to mean quite different things by others. Many of the latter use interdisciplinary to refer to the meeting of different academic disciplines, and transdisciplinary to refer to the engagement between practitioners and academics in what some researchers have called 'soft-systems' approaches to problem solving. The latter is more challenging than the former, but is more likely to produce reliable and innovative new understandings of sustainability and how to achieve it.

Replication at the Whole Farm Level

A review of prior European research into the sustainability of different farming systems revealed the repeated use of three research designs (Fairweather and Campbell, 2001). The classic agricultural experimental approach was to treat plots of the same farms in ways that organic and conventional farmers would treat whole farms. In these studies, plot treatments were typically well-replicated within farms, but focused on small parts of farming systems in the normal reductionist approach of agricultural experiments. A second group of studies used 'split farm' trials within which experimental farms were split in half, with one side farmed organically, and the other farmed conventionally. Split-farm approaches are generally pseudo-replicated within each farm (there were no reported instances in which several such split-farm trials were studied in parallel to test whether observed differences in the focal farm recurred elsewhere). This pseudo-replication makes broader inference of comparisons between farming systems invalid in such designs. The experimental plot and split farm approaches are strong designs for exploring bio-physical processes on small spatial scales, but cannot be used to make inferences about whole-farm enterprise considerations or the different social orientations of the farmers. In short, these designs are unrealistic and artificial arenas that are unlikely to predict how real farms and farming families will choose to adopt new farming strategies, nor the consequences of doing so. The third approach of previous studies overseas was to match a conventional real whole farm with a paired (usually nearby) organic farm, then sequentially sample them to compare outcomes over a long time. Although this is the most realistic of all the designs, there were no examples of the approach being replicated at the matched-pairs level. Some general inferences about outcomes from organic and conventional farming can be made via meta-analysis of several such studies, such as that reported by Hole *et al.* (2005) describing environmental outcomes. However, such meta-analyses may lack power and a defined zone of inference when a mass of uncoordinated studies are pooled, all with different methodologies, foci, farming sectors and locations. In addition, few such meta-analyses have been published.

ARGOS has attempted to go further than all previous studies of alternative farming systems reviewed by Fairweather and Campbell (2001), by designing a co-ordinated and well-replicated study of real whole-farm enterprises that are either converting to, or continuing to apply, alternative farm management regimes in New Zealand. The expectation was that by studying real farming enterprises at the whole farm scale we would gain realism and relevance of findings in ways that may be critical for the uptake and transition of farming systems. However, by choosing to replicate at the whole farm level (each one of which will vary in terms of a huge number of farm management, social, economic and ecological details other than their chosen farm accreditation scheme), we lost considerable experimental and statistical 'control' on the comparisons between farming system panels. That is, what was gained in realism by taking a systems inquiry approach on each farm, was traded-off against reduced statistical power to detect differences. As such, the overall ARGOS programme design is best characterised as a quasi-experiment rather than formal agricultural experiment.

In the sections below, we describe the six main ways we reduced the loss of statistical and experimental power while retaining the benefits of realism and relevance: (i) maintaining a longitudinal design, (ii) using a clustered design, (iii) where possible using a before-after-control-impact study design to control for variation in starting conditions between farms when they entered alternative farming systems, (iv) measuring several ‘covariates’ of sustainability indicators in the hope that they can reduce unexplained variation in statistical models, (v) standardisation of methods across all farming sectors and panels, and (vi) employing a hierarchical and nested design that spans a deeper study of a few ARGOS farms, the main ARGOS panels, and national surveys of randomly selected farms.

Even though the primary unit of replication in the ARGOS study was the ‘whole farm’, all the researchers examined higher spatial scales beyond the farm boundaries, as is appropriate for a systems-level understanding, but each disciplinary team tended to emphasise different scales more or less than others (Table 3). Environmental research often focussed on individual ‘management units’ within each farm i.e. paddocks[8] (pastoral systems), or blocks and bays (kiwifruit) within each farm or orchard, and tended to emphasise national (biogeographical) features of New Zealand’s ecological systems. Māori research was generally more focussed on the local level, as is common in indigenous social-ecological systems research. Although a wide span of nested spatial scales was confronted by the ecologists (part of that discipline’s traditional emphasis on the importance of spatial variation), lack of resources prevented them from mounting concentrated research at the ecological landscape and regional scales. In the meantime ARGOS’s clustered farm design attempted to partition the effects of this important ecological landscape level to increase statistical power for farming systems level comparisons, but the nature of the landscape in each cluster was not investigated and treated much as a nuisance variable rather than a primary ecological driver of the differences observed between whole farms. It is hoped that future landscape and regional research can be enhanced to fill in this gap.

Table 3: Spatial scale emphases within ARGOS disciplinary research objectives. *The size of the symbol indicates the degree of research investment at that scale. Farm Management (Objective 1) focussed on delivery of the research programme and so is not considered a discipline in the same way as the others.*

	Economic	*Environment*	*Social*	*Māori*
Global	X	x	x	
National	x	X	X	X
Regional		x	x	X
Sector	X	X	X	X
Landscape		X		
Farm	X	X	X	X
Paddock		X		

[8] New Zealand farmers refer paddocks where European farmers normally refer to ‘fields’.

A Thirty-year Longitudinal Study

Design of a long-term study was important, particularly where conversions to new systems were being examined, because of the tendency for some effects to only emerge after a considerable length of time. Community and ecosystems ecology has repeatedly emphasized the way in which masses of 'indirect' and often weak interactions in a community foodweb eventually predominate over perturbation of the strong individual 'direct' ecological interactions (Yodzis, 1988)[9]. Some of the rapid and strong ecological transitions in species abundance seen soon after conversion to IM or organic agriculture may eventually slow, stop, reverse and eventually overshoot the starting abundance of the species before farm conversion occurred. There is no *a priori* way of predicting how long it will take for such turbulence following conversion to stabilize, so the only safe rule of thumb is to maintain any investigation of an ecological (and thus also any farm management experimental perturbation) for as long as practically possible (Raffaelli and Moller, 2000). Trend detection for some annual ecological or farm production outcomes (e.g. yield or bird abundance) relies on at least 6 years of annual sampling, and even then must have relatively little sampling uncertainty and minimal inter-annual variation for a steady trend to show. The prescribed 'conversion period' to organic farming formally takes three years, and it is desirable for ARGOS properties to be monitored into a 'mature' state. Organic farmers themselves report needing 5-8 years after taking on a farm before the soils are fully reconditioned to meet organic standards. Social changes can sometimes be very slow and unpredictable, just as economic indicators will fluctuate greatly from year to year in response to market or financial forces acting well beyond the farm level (Saunders, et al., 2009).

Although the initial funding allocation secured by ARGOS was for six years, ecological and sociological experience suggested that at least two and maybe three decades would be required for reliable inference. The research team was therefore confronted with a need to design a programme that delivered sufficient preliminary outcomes after six years to inspire the confidence of stakeholders and funders to re-invest for another six years after that, and so on. We predicted that the prospect of renewed funding on the promise of eventually establishing a powerful long-term database might be possible in the first refunding cycle, but then it would get more difficult to maintain the confidence of investors in the middle years, before eventually the power and usefulness of say 18 or 24 years of accumulated data would become self-evident. Our researchers have therefore confidently asserted that ARGOS was to be a thirty-year research programme and have designed it accordingly, while planning spurts of synthesis and recommendations that signal changes of gear or temporary emphasis within each six-year funding cycle.

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[9] For example imagine a simple food web in which a predator (A) eats a large number of two prey species (B and C), but B also competes with species C. If conversion to IM agriculture immediately triggers an increase in the abundance of A (perhaps reduced pesticide use allows more of the predators to survive to reproduce), one might expect the abundance of B and C to immediately fall because the direct effect of A's predation has been released. However if a decrease in B also releases competition of B on C, surprisingly the abundance of C may eventually rise compared to before conversion to IM. This compensatory rise in prey species C when its predator numbers are increased is a simple example of an "indirect effect". Imagine now the complexity and turbulence triggered by conversion to IM farming that might occur if there are scores of plants and animals connected by both direct and indirect interactions in a more realistic foodweb.

In any longitudinal study, the consequences of participant selection have significant implications that remain for the life of the project. Consequently, the first nine months of the ARGOS project were dedicated to negotiating an overall research design amongst participating researchers and choosing panels of participating farms/orchards in different primary production sectors. Several early prospective participants withdrew when confronted by the above challenges, or when other financial or research priorities intervened, but first trials of the main data streams were broadly in place within 1 – 1.5 years from inception of the study.

Maintenance of a long-term study is not only important because changes in social-ecological systems have no end-state and can sometimes be gradual, but is also crucial for gaining statistically robust estimates of average sustainability and resilience indicators. Repeated measures gradually increase the power of any tests of the ARGOS null hypotheses because between-year variations are gradually accounted for and there is an accumulating sampling effort that increases the reliability of average estimates of indicators. For example, accumulation of bird sightings after three successive biennial surveys allows better characterization of 'distance detection functions' that underpin estimation of the number of birds per hectare (Macleod *et al.,* 2012b). Because it is necessary to estimate a separate detection function for each species by measuring at least 60 sightings (each with a measured distance from our surveyors to the bird), it is not until three surveys that the abundance of several rarer species can be monitored. In addition, qualitative analysis gains from long-term study, through more refined understanding of situation and praxis by familiarity over time.

Clustering of Farms Within Each Sector

Accumulation of long-term data on a fixed number of farms can only minimise uncertainty around averages or trends in sustainability indicators at those places - it cannot provide greater confidence about what is happening to all farms in a given sector that follow a given farming system. As expected, we found that variation between individual whole farms within each panel remained large no matter how many years of results were analysed. Part of this variation between farms relates to location, both at regional and local scales. Therefore ARGOS confronted a trade-off between (a) achieving the most powerful test of the null hypothesis by bunching the farms together as much as possible to expunge background regional variation, and (b) spreading the sampling effort over as wide an area as possible to make sure ARGOS results are representative and therefore relevant to farming in that sector for as much of New Zealand as possible[10]. This latter concern relates to the 'zone of inference' that is possible from the ARGOS study[11]. ARGOS sought the best of both worlds by monitoring orchards and farms that were arranged in 'clusters' of closely-spaced farms and where there was a representative of each panel (organic, IM, conventional) within each cluster, but with clusters spread widely throughout our zone of inference. 'Unexplained variation' in sustainability indicator measures can be further reduced by close 'matching' of the study

[10] For example, it would clearly be misleading if we attempted to generalise our results to all kiwifruti orchards if we only sampled orchards around Te Puke.

[11] A clear zone of inference for the ARGOS panel results is provided in the General Discussion, in which we consider the broader strengths and weaknesses of our study.

farms within each cluster for factors that are likely to affect the sustainability indicator measurements (Moller, 2004a).

Before-After-Control-Impact Study Design

The before-after-control-impact (BACI) study design is a potent method for overcoming large spatial variation (e.g. between-farm differences) to discern the impacts of experimental or management perturbations (Morrison *et al.,* 2001; Smith *et al*., 2002). The BACI design is a widely used technique for examining how closely parallel systems change relative to each other. BACI enables identification of the cause, magnitude and outcomes of subtle changes in systemic activities, especially if it operates over many years. Essentially, the same techniques that are used to examine changes over time at ecological sites like adjacent river catchments can also be used to study detailed changes in paired farming systems. Thus, in the ARGOS context, conversion to an alternate farm management system can be seen as a 'management experiment'. Such investigations require longitudinal measures of sustainability indicators 'before' farm conversion occurred (the starting conditions on each whole farm), and to track changes 'after' conversion relative to that farm's starting condition(s). The degree of change of the experimental farms (e.g. those converting to organic) is then compared with the relative change in a 'control' or 'reference' group that did not undergo farm conversion. This approach gains statistical power because the experimental effect is now measured as a time-treatment interaction effect from repeated measures of indicators on the same farms, rather than from comparing the indicators only for the 'after' period across panels made up of individually highly variable farms (Moller, 2004b; Moller and Fairweather, 2004).

The power of the BACI model is well illustrated by one set of ARGOS results concerning milk production before and after the conversion of 12 dairy farms to organic production (Figure 5). Production fell steadily on dairy farms that switched to organic methods compared to their non-converting counterparts. However, the average milk production of the farms that chose to convert to organic was already lower in the year before conversion (Figure 5). As such, it is possible that farmers who are more likely to go organic have less emphasis on productivity in the first place. Whatever the reason for the initial differences, the starting conditions on the converting set did not confound the detection of an 'experimental effect' of changing farm management because the crucial test in the BACI analysis is the time x treatment interaction effect.

A BACI design was implemented for twelve pairs of dairy farms that were converting to organic (Table 2) as part of a Fonterra initiative to support 180-200 dairy farm conversions to organic by 2014 (http://www.dairyexporter.co.nz/article/26967.html). However there was a significant lull in the number of sheep/beef farmers or orchardists about to convert to organic production at the time we were establishing the ARGOS panels. Therefore the BACI design was abandoned for these sectors and instead we chose farms to fit into panels of already organic farms and matched conventional farms. In kiwifruit and sheep/beef sectors there was an additional panel of farms using IM, resulting in clusters of three management types in those sectors (Table 2). This design was augmented with case study analysis of eight Māori land-holdings and seven High Country sheep farms. In total, 107 farming enterprises are being studied in the ARGOS programme.

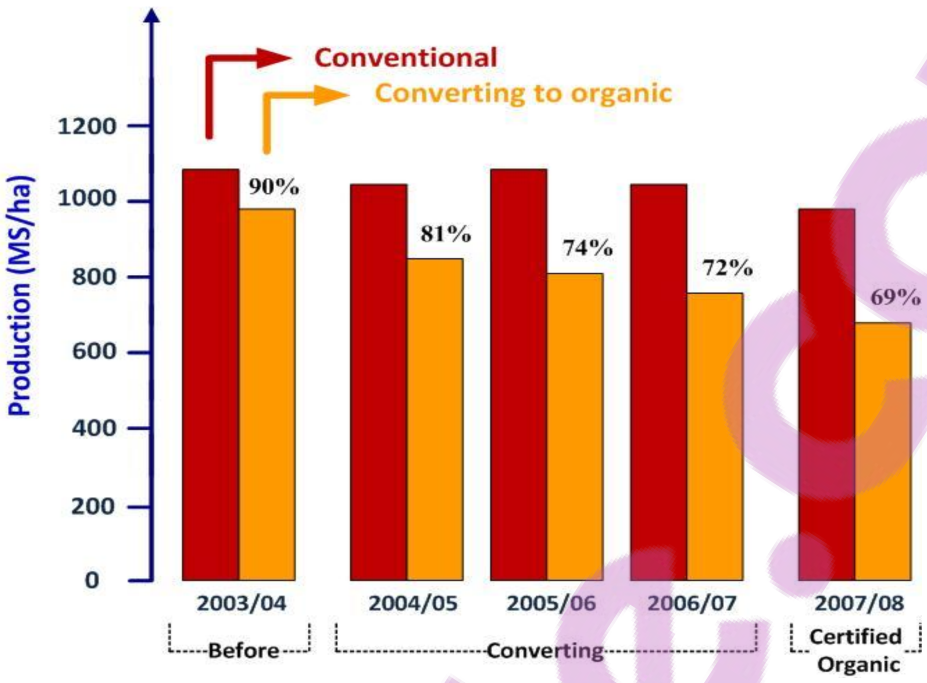

Figure 5: Average production of milk solids by ARGOS dairy farms as they underwent conversion to organic methods. *The underlying design is a before-after-control-impact, in which changes in the response variable (here production of milk solids) over time are compared between treatment groups (those converting to organic and those remaining conventional). The percentages show the production of converting farms as a percentage of the observed production in the control (reference) group in a given year. The null hypothesis (organic and conventional farms are equally productive) was tested by examining the time-treatment interaction. In this case the interaction was highly statistically significant, exerting a strong influence on farm performance ($p < 0.001$).*

Measuring a Wide Variety of Co-variates to Better Test Farming System Differences

Fairweather and Campbell (2001) emphasised the importance of establishing a broad range of variables to be monitored. For the ARGOS programme, the broad focus on the farming system and the inclusion of multiple disciplines demanded this focus. These variables ranged from technical production data, soil systems, energy, environmental performance, economic performance, food analysis and social change. Due to the general lack of familiarity with the basis of sustainable agriculture as a practice in New Zealand, there was a need to monitor widely in order to uncover the most relevant, important and significant variables going forward. The wide variety of measures partially reflects the need for transdisciplinarity and systems understanding over multiple spatial and temporal scales. However, including a variety of indicators is a further way of increasing the power of tests of the ARGOS null hypothesis. From a qualitative analysis perspective, the diverse indicators also contribute to a better understanding of the context within which the project operated. As such, we sought to identify and quantify many 'explanatory variables' that help predict sustainability indicators, farmer behaviours, or farmer's investment decisions. In terms of testing the ARGOS null hypothesis, these additional explanatory variables may even be considered 'nuisance variables'; unless they are measurable (and, indeed, are measured) and their effects are 'filtered out' of the statistical models, they add unexplained variation between study farms so that the ultimate test of the panel null hypothesis is much blunter (Moller, 2004a). On the other hand, from an applied ecologist's perspective, quantification of the strength and direction of the influences of these explanatory variables (often referred to as 'co-variates') on sustainability indicators is valuable information in its own right (i.e., they help the advisor to understand the system processes and predict where or when reliable extrapolation and inference from ARGOS farms is possible, and where or when it may mislead). Similarly, our social scientists examined a number of variables identified in the literature as relevant to differentiation in the social practice of farming and sustainability. The ARGOS results were interrogated to determine whether they supported these indicated linkages (Campbell et al, 2011). In this case, the analyses were not based on statistical procedures but on a standard qualitative analysis of transcribed interviews (see Hunt *et al.,* 2005, p. 19-21, for a more detailed description).

It might be expected that transitioning into organic farming (or choosing to remain conventional) would begin to influence the average measures of several putative explanatory variables themselves (e.g. soil nutrient levels). If so, they would become effects of farm conversion themselves, and could thus be considered 'response variables' to farm conversion. Nevertheless, individual variation between farms within panels is also always present, and incorporating multiple explanatory variables for each whole farm when predicting a sustainability indicator (e.g. farm profit or biodiversity indices) can greatly reduce the amount of unexplained variation left after statistical model building. The lower the residual unexplained variation, the more potent will be the test for mean differences in sustainability indicators between panels (Moller, 2004a). Thus, the art of statistical model building is to achieve an appropriate trade-off between adding many weak explanatory variables and the inclusion of fewer stronger variables to achieve the most parsimonious but powerful test of the null hypothesis[12].

Standardisation of Methods, Quantification and Triangulation

We sought to apply several of the norms of rigorous scholarship to provide reliable and testable information to realise the ARGOS goals and objectives, including:

- Objectivity; primarily as an aid to accurate observation. Although objectivity is valued in both the natural and social sciences, social science tends to more openly recognise the subjectivity of interpretation while the natural sciences tend to focus on statistical rigour.
- Traceability of methods, results and logic of inference; aids to reduce error rates in debate and critical peer review

[12] Every addition of a new potential explanatory variable reduces the 'degrees of freedom' in statistical testing, so the addition of many weak explanatory variables (many of which may indicate explanation just by chance) is not just counter-productive, it is also misleading.

- Repeatable methods; to allow others to check our inferences in other places. This also enables replacement researchers to be confident that they are repeating measures of indicators in exactly the same way as conducted by their predecessors in ARGOS (i.e., if the new measures are different, we know this reflects a change on the farms or within farming families rather than simply a difference in the way we have estimated an indicator).
- Quantification where possible; reducing an indicator to a fixed number[13] can help the repeatability and generalisability of inference, but can also force unreal abstraction and introduce error when the indicator cannot be reliably quantified. From the outset we guarded against privileging either quantitative or qualitative approaches. However we also sought legitimate quantification as a tool of bridging inferences across sectors and disciplines. Finding a common currency to allow pooling of inference across sectors also enabled much greater joining of disciplines and the beginnings of transdisciplinary dialogue
- Triangulation of strands of evidence; reliability of inference is gained when similar interpretations result from a greater variety of methodological approaches to the same problem. Accordingly, we deliberately built in a level of redundancy of evidence by having the different disciplinary teams attack the same component of the system in their own way. There was particularly conspicuous and useful variation within the social team to exploit the strengths and weaknesses of quantified and highly structured forms of inquiry (such as questionnaires and associated Likert scales for grading farmer responses) compared to the qualitative interview techniques that used very lightly structured interview trajectories.

To address the need to provide broad national benefits for all New Zealand agriculture, we undertook a meta-analysis of emerging themes across all the sectors chosen by ARGOS for detailed study. There are also several sound scholarly reasons for attempting to divine commonalities across very different forms of agriculture. If the same general outcomes were observed in quite different systems, we could be more certain that the research identified more universal 'truths'. Therefore, where possible, we measured a set of indicators that could make sense and be directly compared across the kiwifruit, sheep/beef and dairy farms as well as between panels within each of these sectors. Common approaches were most readily identified in the economic and social dimensions of sustainability (finance and the human condition, with components of identity, agency, basis of choice etc., are the same across all farms and farming families). In strong contrast, environmental variation made the choice of common indicators problematic. For example, most of the sheep/beef and dairy farms contained streams, while this was the case for very few kiwifruit orchards. The balanced cluster design (one of each farming system per cluster) therefore became rapidly fragmented for stream health inquiries, leaving no statistical power to compare the relative impacts of organic and IM kiwifruit growing on streams to the relative impacts of organic, IM or conventional pastoral farming. There was therefore a need to design some environmental indicators that were relatively specific to a particular sector, while still seeking to maximise the commonality of the indices measured across sectors. We therefore focused on a standardised set of soil quality indicators in all ARGOS farms, partly because soil systems

[13] Or sometimes a probability that say an individual farmer belongs to a particular set or has a particular attribute or orientation

provide the engine room for any farm/orchard, but also because soil quality is critical to sustainability in all sectors. Similarly, because certain bird species occur in all farms and sectors, we expended considerable effort in designing and testing a standardised method of measuring the abundance and diversity of birds in all sectors, even though the physical characteristics of each type of farm affected the detectability of the birds present (Blackwell *et al.,* 2005).

Trading off Depth and Breadth: Hierarchical and Nested Designs for More Reliable Inference

Limited funds and team capacity necessitated trade-offs between studying a few agricultural systems processes in considerable depth compared to examining more processes relatively superficially; and between studying fewer farms in considerable depth compared to more farms relatively superficially. Strident debate between the disciplinary teams on this trade-off reflected our different scholarly traditions, but also a general reductionist presumption in all disciplines that detailed study of the parts of a system can be re-joined back together to reconstruct a whole system. The result was a marbled, inter-layered and somewhat uneven treatment of the depth of inquiry for different components of the system.

Overall, we sought to maximise reliability and the zone of inference by closely cross-linking deeper investigations with broader but shallower methods. For example, qualitative interviews with participating farmers were conducted first to identify key issues that were then taken to a much wider panel of farmers using a national survey of randomly selected farmers who were invited to respond to closed questions, often utilising Likert scales (e.g., Fairweather *et al.,* 2007b, 2007c; Fairweather *et al.,* 2009a, 2009b). The same questionnaires were also administered to the ARGOS farmers, enabling assessment of the responses of our detailed informants to the same questions[14]. This nesting of the ARGOS panel within a national survey using the same questionnaire also allowed us to assess the representativeness of the ARGOS panel compared to their counterparts in the same sectors and farming systems, and to make broad comparisons with other agricultural sectors not included in the intensive ARGOS programme (Fairweather *et al,.* 2007a). Similarly, the expense of bird studies precluded year-round and detailed surveys of habitat use on all kiwifruit and sheep beef farms. As such, we conducted brief surveys (1-3 days) during the breeding season on all orchards and farms every 2-3 years, and narrowed year-round surveys to just four clusters over 1-2 years.

The social and environment objective teams used a step-down model to narrow the investigation to ongoing research of fewer variables and processes. Soil monitoring followed well-established standard procedures that could be applied to all aspects of all ARGOS farms, but other environmental variables demanded a wide variety of techniques and could only be applied to some farms. For example, since streams do not occur on all farms, balanced designs

[14] The semi-directed nature of the initial interviews meant that farmers themselves revealed their beliefs and orientations through their relative emphasis in what they chose to talk about. This strengthens inference from their discourse by avoiding any opportunity for interviewees to inadvertently elicit answers that the researchers themselves want or have at least channelled onto areas of minimal importance to the informants. On the other hand, inference of the generality of the unstructured qualitative testimony may be weakened if too few farmers have been interviewed and where only a few of them chose to talk about a given topic.

to compare stream health in different panels were difficult to achieve (impossible for kiwifruit). Broad descriptive terrestrial ecological surveys and habitat mapping were deemed essential to first determine what landforms, habitats and species we had to work with. In some instances the ecological techniques themselves had to be trialled and gradually perfected before a final set of focal species, processes and optimal methods for available resources were chosen for repeated measures. In contrast the economics team identified a series of standard economic indicators from year one, and have maintained all of these measures as the bulk of their contribution to the ARGOS mission. We expect that similar differences in pace and the scope of study of different disciplines would be likely to present challenges to any transdisciplinary systems team study, and urge tolerance and realism about what can be achieved by a certain time. Inevitably one disciplinary team will be waiting for another before a wise and collaborative choice of the next research priority can be settled.

ARGOS TEAM MANAGEMENT

ARGOS operates on the assumption of collective responsibility. Consequently, many responsibilities fall across the three institutions and these were managed mainly through the Academic Research Committee (ARC) and the Programme Management Committee (PMC).

Programme Management Committee (PMC)

The PMC was responsible for the overall management of the ARGOS Programme. The PMC comprises four people including, the chair of the Academic Research Committee, the Programme Leader, a Programme Design and Development Specialist and the Programme Manager. The PMC, before the Programme Leader and Manager were appointed, initiated the original FRST bid, developed the research design and established rapport with key end users. It appointed the objective leaders, the Programme Manager and other key staff. Initially the PMC met on a monthly basis to discuss financial and operational management of the programme and make decisions on funding, budgets, human resource management and issues that affect the overall management and running of ARGOS.

Specific PMC responsibilities included:

- The well-being of participating farmers[15] (delegated through the Programme Leader)
- Maintaining and developing the funding base
- Maintaining and developing relations with funding bodies
- Regulating, controlling and enabling access to data
- Ensuring data storage, security and safety
- Maintaining relationships between the three institutions involved.

[15] Defined as including farmers or kiwifruit growers.

Academic Research Committee (ARC)

The Academic Research Committee (ARC) was responsible for the academic quality of the research being undertaken in the ARGOS Programme. The ARC comprised all Objective Leaders, the Programme Leader and the Programme Manager, and included all members of the PMC. The ARC also met on a monthly basis to discuss the ongoing academic requirements, research progress and research direction of the programme.

Specific ARC responsibilities include:

- Reporting of progress for specific research objectives
- Maintenance of ethical standards
- Co-ordination of research and personnel
- Initiating new research ideas or funding opportunities
- Achievement of transdisciplinary aims
- Constructive critique of academic research ideas
- Writing and publishing results of ARGOS research.

The PMC and ARC merged in 2007 to improve overall communications and transparency in decision-making. Key roles in the management of the programme included:

Programme Leader - The Programme Leader is responsible for meeting the contract objectives of the ARGOS Research Programme. The Programme Leader is also responsible to users of the research and for the presentation of results to the general public. Other responsibilities include:

- Ensuring the continuation of good relations with participating farmers and managing all contact with participating farmers, although this may be delegated.
- All correspondence with participating farmers which must be over her/his signature.
- The employment and supervision of all personnel working with participating farmers.
- Accounting for funds awarded to ARGOS.
- All communications with the media.

Programme Manager - The programme manager was deputised for the programme leader and assisted in the responsibilities outlined above. The programme manager role was absorbed into the Programme Leader role in 2010 following an internal review.

Field Officers - Field Officers are the main point of contact between ARGOS and the participating farmers. They are responsible for on-farm data gathering and the coordination of visits to farms by researchers.

Objective Leaders - Objective Leaders are the designated research leaders of each research objective. They are responsible for the delivery of outputs and outcomes at the objective level and they are responsible for the scientific merit of the objective.

DISCIPLINARY APPROACHES TO SUSTAINABILITY

The original bid for the ARGOS project was derived from two discussion documents that sketched out the broader intent of a longitudinal study design (Fairweather and Campbell, 2001; Manhire *et al.,* 2003). Those documents (and the ARGOS bid document itself) signalled the intent to deploy a suite of measures of on-farm change that ranged across disciplinary areas. The following section covers some details of the methods and key topics deployed by each of the five research objectives.

Farm Management

The lead objective in ARGOS (Objective 1) was titled 'Farm Management'. This objective provided administrative and research services, and spearheaded establishment and nurturing of relationships with key stakeholders. Objective 1 employed the ARGOS Field Officers and administratively organised the whole research programme. This acted as the key site of political liaison with farmers and industry groups. At the same time, Objective 1 also used its Field Officers to administer an annual 'Management Survey'. This survey both enabled a sequential collection of relevant on-farm production (and other) data, but also became the vehicle by which other objectives could ask questions to farmers about aspects of farm management. Hence, in Survey 2 a section was included on farm energy. In the next survey the Environment Objective asked questions about Weeds and Weed Management. In another survey, the Economic Objective asked questions about off-farm economic connections and social capital. Due to the non-expert nature of the delivery of this set of surveys, this instrument became the vehicle to ask relatively straightforward 'Yes/No' questions of ARGOS farmers.

The Annual Management surveys were deployed around the following themes:

- Annual management survey no. 1:

  Kiwifruit —

  1. Orchard details: size, type, ownership
  2. Management practices and concerns
  3. Grower characteristics: age, contribution to management

  Sheep/Beef —

  1. Physical characteristics
  2. Management practice
  3. Personal information: age, ownership, labour, contractors
  4. Calendar of events
  5. Stock sales
  6. Financial summary: revenue, costs, assets, etc.
- Annual management survey no. 2 (with energy survey):

  Kiwifruit —

  1. Orchard management: timing, actor, location, duration, cost, inputs
  2. Energy survey: orchard structures, fuel consumption, contractor use, capital equipment, implements, irrigation

3. Accessibility of records

Sheep/Beef

1. Economic: succession, land acquisition/disposal, work, land use
2. Management practice: stock on hand, marketing, cultivation, fertilizer use, record keeping
3. Energy survey: fuel consumption, contractor use, capital equipment, implements, irrigation
4. Financial summary (as above)

- Annual management survey no. 3 (with Weed management sub-survey (S/B)):

Kiwifruit —

1. Changes in ownership and orchard structure cf. survey no. 2
2. Soil management practices
3. Canopy management
4. TASTE ZESPRI response
5. Other data request – soils, fertilizer, financials, etc.

Sheep/Beef

1. Farm descriptor changes (cf. survey no. 2) including stock handling and marketing
2. Farm management: reproduction, shearing, disease prevalence and control, fertiliser use
3. Weed survey: management plan, relative importance, control of, information on, effect off, attitudes and approach toward, etc.

- Annual Management Survey No. 4 (with Economic extras).
  1. Birds, Shelterbelts.
  2. Labour – paid and unpaid
  3. Learning
  4. Feedback from consumers
  5. Linkages to local community
  6. Innovation
  7. Technology Adoption
  8. Social Capital

He Whenua Whakatipu: Case Studies in Sustainable Agriculture of Māori

The second objective within ARGOS was termed *He Whenua Whakatipu*, which translates loosely as 'making the land grow.' The *He Whenua Whakatipu* objective was established to identify the key ingredients for the sustainable development of Māori owned land (Reid, 2005). It is estimated that over 40% of Māori land is not utilised to fulfil the development aspirations of its owners. Some of this land consists of small dispersed blocks that may be landlocked, marginal, or even abandoned by owners, and therefore unsuitable for development. However, a significant area of unutilised Māori land does have good development potential, yet is not being developed or utilized. For example in Te Waipounamu, the South Island of New Zealand, there are 13,341 hectares of high production grass land in Māori ownership of which less than 2000 hectares is developed or utilized by its owners (Reid, 2008).

Consequently this objective of ARGOS focussed its efforts on supporting and working with Māori landowners that have strong development aspirations for either unutilised land, or underutilised land, but are constrained in their ability to unlock its potential. The research was committed to following a kaupapa Māori approach, which demands that the research produce positive tangible outcomes that solve actual problems within Māori communities. In addition to this ethical obligation, there was also a moral commitment to ensure the full participation of landowners involved in the research. The research therefore embraced participatory praxis and action learning, remaining fully embedded within five case study communities of landowners over a period of five years. The *He Whenua Whakatipu* team worked with these case studies of Aspiring Owners to identify their developments goals, take action toward achieving their goals, identify constraints experienced whilst taking this action, and find solutions to overcome constraints.

All case studies were based in Te Waipounamu, the South Island of New Zealand, and located with the tribal takiwā (area) of Te Rūnanga o Ngāi Tahu – the elected tribal council of the Ngāi Tahu Māori people. The *He Whenua Whakatipu* team were not passive observers during the research but assisted case study groups to plan their future direction for land development, provided hands-on work assistance around the farm, and offered technical advice where appropriate. Furthermore Te Rūnanga o Ngāi Tahu provided funds that could be used to contract in specialist help to deal with particular problems, in situations where case-study groups considered it necessary. An oversight Komiti (committee) was also established by Te Rūnanga o Ngāi Tahu to guide the research, which consisted of four Ngāi Tahu rangatira (leaders) and one Ngāi Tahu researcher.

Through this research across five Ngāi Tahu communities some clear research results were delivered identifying the following:

1. The development goals of Aspiring Owners;
2. The constraints on development goals; and
3. The mechanisms for overcoming constraints on development.

Environment Objective

Two main perspectives provide the rationale for ARGOS's environmental research: the need to understand disturbance ecology operating on New Zealand farms, and a need to retain or even build biodiversity present on the farms (Moller *et al.,* 2005). Understanding ecological disturbance on farms is useful because the farmers' interventions (e.g. choice of species to plant and weed out, application of ecological subsidies and agrichemicals, physical disturbance like tilling and close management of grazing by stock) are all designed to drive the ecological systems in an optimal direction to maximise the amount or efficiency of food and fibre production. Viewed in this way, the farmer is a large-scale 'gardener' and agent of disturbance, and the ecological responses could either counteract such disturbance or accelerate its impacts. The 'intermediate disturbance hypothesis' in ecology states that maximum biodiversity occurs at middle levels of disturbance: too many shocks to a system means that few species can prosper from the constant knock-backs; too little disturbance leads to competitive dominant species monopolising available spaces and energy or nutrient opportunities. We also took as axiomatic that systems with relatively high and enduring biodiversity are more likely to be sustained and resilient and more likely to be appreciated by New Zealand farmers and public, and potentially by consumers of their farm produce.

The Environment Objective team recognised the need for an initial descriptive phase of rapid ecological surveys to discover which plants, animals and habitats that farmers had ‘to work with’ (Moller *et al.,* 2005). The environment research team also took responsibility for building simple GIS maps of main habitats and management units (paddocks, blocks) on each farm during this preliminary stage.

Long-tailed bats, some lizards and native fish were considered to be the main threatened species that conceivably might have occurred on ARGOS farms[16], so we searched for them in particular. Since none were found, subsequent environmental research has concentrated on (a) comparing species richness on different farming panels, and (b) monitoring the abundance of a range of ‘focal species’ as species of particular interest (Table 4), and where necessary, (c) testing the reliability and precision of a variety of techniques for long-term monitoring of those focal species.

In attempting to select the most useful focal species from the huge number of potential candidates it was necessary to decide whether to focus on “agricultural biodiversity” or more generally on all biodiversity on the farms. Agricultural biodiversity consists of the diversity of animals and plants that directly support food and fibre production, but also those microbes, plants, and animals that provide ecosystem services such as nitrogen fixation, decomposition, facilitation of nutrient uptake by plants, pollination, pest control and ecosystem engineering (Matson *et al.,* 1997; Perley *et al.,* 2001; Roschewitz *et al.,* 2005). Caring for agricultural biodiversity is a primary priority in an overall “conservation for future use” philosophy, and of course this resonates strongly with farmers, agricultural industry actors and potentially overseas consumers. On the other hand, most of New Zealand’s general public’s attention has focused on a “preservation for intrinsic value” philosophy, a strategy of non-use and creation of ecological reserves to minimise ecological disturbance. The latter focuses mainly on New Zealand’s native species, whereas food and fibre production depends mainly in introduced plants and animals. Agricultural biodiversity may enhance a system’s capacity to absorb and recover from perturbation, or resilience (Fischer *et al.,* 2006), which in turn potentially reduces reliance on external inputs to maintain production (Milestad and Darnhofer 2003; Darnhofer *et al.,* 2010). However, there are clear signs that New Zealanders are turning increasing attention to caring for ecosystems and biodiversity in their production landscapes, so farmers face increasing pressure to support all life forms on their land, even those species that have no apparent direct impact on food and fibre production. Today’s seemingly redundant species may be tomorrow’s agricultural biodiversity, may affect the abundance of agricultural biodiversity through a myriad of “indirect ecological interactions” within the food web (Yodzis, 1988), and may contribute to important ecological flows among reserves, the surrounding matrix of production land, margins of production landscapes and large reserves in national parks.

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[16] Several unknown and potentially threatened native insects may well be present, especially in forest remnants in lowland fertile sites (Perley *et al.,* 2001). However searching for and identifying them was beyond the resources and scope of our research team.

Table 4: Focal species and habitats for environmental research in ARGOS, 2004 - 2010.

Focal species		
Type of Focal Species	**Species chosen**	**Comments**
Beneficial species	Spiders, some birds, earthworms	Spiders prey on potential insect pests and indirectly help phytosanitary management for exporting. Some birds prey on insect pests (e.g. grass grubs).
Indicator species	Earthworms, Soil nematodes, soil microbes, cicadas, birds, stream macro-invertebrates and spiders	Soil biota are key to making nutrients more available for uptake by plants. Earthworms are particularly common indicators of soil health. Cicadas were monitored in kiwifruit orchards partly because they are a pest, but partly also as an indicator of soil biotic conditions (early stages of the lifecycle of cicadas spend many years in the soil). Birds are important indicators of sustainability in European agri-ecosystems. Native stream macro-invertebrates are common indicators of stream health. Spiders are predators of insects and so sensitive to insect biodiversity, and also a common food of birds.
Ecosystem Engineers	Earthworms	Ecosystem engineers affect habitat structure and so promote the abundance of several other species dependant on those habitats. Earthworms help generate and bioturbate soil, are crucial in maintaining and building soil structure and thereby affect aeration, soil moisture retention, soil biota abundance and diversity and plant production.
Keystone/Critical species	Earthworms	Earthworms are an important food of many birds, and as soil ecosystem engineers affect the abundance of many other beneficial species.
Character species	Birds	Character species are seen as emblematic of given habitats and ecosystems e.g. skylarks are characteristic of open farmland habitats
Flagship species	Birds	Flagship species have popular appeal, are usually highly visible, and are used to promote and demonstrate environmental care. Native bird species are prime examples in New Zealand.

Market flagship species	Birds	The ARGOS research team is developing a new concept referred to as "Market Flagship Species" that can be used to support consumer choice of NZ export produce because food and fibre production is environmentally friendly.
Pests	Leaf rollers, scale insects, cicadas, grass grub, rodents, weeds	Pests provide biodiversity but also directly threaten sustainable food and fibre production. Cicadas are a notable pest in kiwifruit because they damage leaders retained for next year's fruit production. Woody weed patches have been mapped for longitudinal monitoring of large scale changes in sheep/beef and dairy panels. Herbaceous weeds have been surveyed in sheep/beef pastures and farmers interviewed on weed threats and their management.

Focal habitats and elements within farm ecosystems

Element	**Main measures**	**Comments**
Soil quality and biology	A mixture of rapid inventory Visual Soil Assessments (VSA), Bulk Density, Cation concentrations, Cation Exchange Capacity, Microbial activity and earthworm abundance.	ARGOS environment invested more in soil quality measures than any other environmental indicators. Standard soil quality laboratory analyses and VSAs have been repeated every 2-3 years at marked soil monitoring sites.
Woody vegetation patches	GIS mapping and rapid inventory of woody vegetation patches.	A general conclusion from ARGOS and other studies is that increasing the extent and quality of woody vegetation is the key to retention and restoration of biodiversity on farms. Woody vegetation provides structural diversity, increased variety of microhabitats and an important area of 'ecological refuge" from disturbance by farming activities. However they are also potentially important sites for weed infestation.
Shelterbelts and species growing underneath	Surveys of the main tree species forming shelterbelts and their stature; plant and insect biodiversity measures within and under these shelter belts.	Shelterbelts are important refuge sites for biodiversity where many plants are sheltered and protected from grazing and chemical applications. They form "corridors" and ecological connectivity between populations of plants, insects and birds living on farms.

Riparian planting	Surveys of the extent of riparian planting, species composition and stature; and whether or not they are fenced from grazing.	Riparian planting is rapidly accelerating and therefore provides a significant opportunity for enhanced biodiversity care. Riparian planting promotes stream bank stability and traps nutrients, so is important for maintaining and enhancing stream health.
Streams	Rapid inventory (SHMAK) were supplemented with some water chemistry and macro-invertebrate abundance and diversity measures (in all but kiwifruit farms), taken at the point where water ran into each ARGOS farm and where it left.	Few kiwifruit orchards had streams running through them so stream health measures there could not be used to test the ARGOS null hypothesis. The riparian management (vegetation, fencing, stream crossings for vehicles) were monitored in stretches along a 'focal stream' on each farm (i.e. the longest reach of a stream passing through each farm).

ARGOS invested in developing monitoring protocols for several species, especially birds, which are not usually considered directly important through affecting food and fibre production (Table 4). We simultaneously sought to maximise the direct value of caring for this general biodiversity by developing the concept of "market flagship species" to encourage consumers to buy New Zealand farm produce if we could first verify that our farmers sustained good numbers of these species with high public appeal (Table 4, MacLeod *et al.,* 2008; Coleman *et al.,* 2009; Meadows 2010, in press). Finally, the ARGOS research team has attempted to stimulate the emerging national debate about the value of biodiversity in New Zealand's production landscapes. In particular, we sought to test unquantified and generalised assertions of links between agricultural intensification and the loss of terrestrial biodiversity (Blackwell *et al.,* 2008; Meadows *et al.,* 2008; Moller *et al.,* 2008a, c) by addressing the need for better statistics on farming and transdisciplinary approaches to support biodiversity (Fairweather 2008; Rosin *et al.,* 2008c). If farmers are to make cost-effective decisions to promote biodiversity while still securing production and economic and social goals, there is clearly a need for a much more nuanced discussion and definition of intensification compared to extensification, scale, calculation of ecological damage thresholds or risk curves and formulation of realistic but ecologically robust targets for the restoration of biodiversity on farms.

As well as concentrating on important focal species, ARGOS's environment team also prioritised investments in soil systems and waterways (Moller *et al.,* 2005; Table 4). Since soil constitutes the main "engine room" of farm production, we considered it as a potentially large focus of farmers' investments and chemical applications and energy budgets. Differences in soil management are the most common points of difference between organic and other types of farmers, so a focus on soil health was considered to go to the heart of the main ARGOS null hypothesis. In view of clear evidence of impacts of farming on stream health (Moller *et al.,* 2008c), and rising public concern about pollution of waterways, we also invested in repeated measures of stream health (Table 4).

In its first 8 years, ARGOS's environment team invested around 50% of its funds in surveying, monitoring and understanding biophysical processes and stocks on ARGOS farms, especially soil and stream habitats; around 30% on developing methods and measuring the abundance of agricultural biodiversity, and around 20% on general (non-agricultural biodiversity). The *He Whenua Whakatipu* Team investigated about 20% of its funds into monitoring the environmental effects of changes implemented on case study farms. A further 30% was spent on monitoring the social and economic changes, whilst a further 20% was spent on providing technical and specialist input into farm development. Finally 30% of resources was spent on time spent communicating results and working across Ngāi Tahu communities to maintain support for the project.

Over the course of the first phase of the ARGOS programme, the environment research has progressed from (i) a predominating emphasis on mapping, surveying and testing methods for monitoring abundance and diversity of species and habitats on farms in years 1-3; to (ii) testing the ARGOS null hypothesis with a wide variety of potential focal species; to (iii) measuring interannual variance in a reduced set of measures and methods chosen for longitudinal study (years 3-8). The latter will be used to simulate the power of different levels of investment of sampling in order to make detection of long-term trends in biodiversity so that longitudinal trend analysis can be most cost-effective. Population ecology research will then be escalated with key potential market flagship species and earthworms (an ecosystem engineer, keystone species and primary beneficial species and indicator species for agricultural production), if on-going funding is secured.

The original ARGOS contract included consideration of the importance (or otherwise) of the control of introduced mammalian predators (rodents, stoats, ferrets, hedgehogs and feral house cats) for enhancing avian biodiversity on production landscapes. A simulation to check the power of an experimental test of the value of predator control identified that over $400,000 would be needed per year for four years to secure an interpretable result (Weller 2011). Since this would have used up the entire available budget for environmental research, the experimental test for the need for predator control on top of habitat restoration for promoting biodiversity on farms has been postponed indefinitely until adequate resourcing can be secured.

The biodiversity and habitat research described above contributes to a foundation understanding of ecological communities (not strictly ecosystems in the way defined by ecologists) present on New Zealand farms. The farm management and environment teams therefore also constructed energy budgets for farm production as their only formal ecological ecosystem metric. Energy investments and returns are clearly key indicators of the efficiency and intensity of agricultural production. However, energy fluxes are also a convenient "common currency" for comparing diverse farms across sectors (dairy, kiwifruit, sheep/beef, high country), just as financial indicators provide a common economic currency for comparisons.

Economic Objective

The Economic Objective took its starting point in the working paper 'Research Rationale for the Economic Objective, ARGOS's (Saunders and Emanuelsson 2004). Further developments and research were presented in the reports 'Applicability of Performance Indicators to Farms and Orchards' (Saunders *et al.,* 2007b) an interim 'Economic Objective Synthesis Report' (Saunders *et al.,* 2007a) and a final synthesis report (Saunders *et al.,* 2009a).

The initial working paper focused on outlining the essence of environmental resource economics, sustainability and sustainable development and suggested some possible research themes. In the second study, the purpose was to establish the extent to which the information collected to assess the financial performance of conventional businesses applied to farm businesses. The third and latest document, a synthesis report on the Economic Objective, further developed the applicability of the performance indicators and provided financial analysis of the relevant farms.

Methods for economic research

The economic data for ARGOS was collected in several ways: the applicability of the 13 indicators to farms was assessed using a questionnaire and two additional indicators obtained from the ARGOS database along with annual financial data from farm accounts. The different sources of data facilitated comparisons of indicators, and the overall Economic Objective was directly pursued in this way.

Performance indicator questionnaire: a detailed questionnaire was used to survey the farmers and orchards of interest 'face-to-face'. Prior to release, the questionnaire was reviewed by experienced agribusiness researchers to ensure applicability to the agricultural sector. The final questionnaire contained 22 questions relating to 13 performance indicators. Specifically, the questions concerned business management plans, information on customers, innovations, employment and finally social and environmental factors.

Annual financial data: farm accounts were provided by the farmers/orchards as the main source of financial data. Since the accounts are primarily produced for taxation purposes, challenges arose in providing a clear and current picture of the business. These challenges were mainly due to historical cost reporting, varying ownership structures, missing values relating to non-cash resources and farm activities irrelevant to the purpose of the ARGOS project. To counteract the effects of the mentioned deviations, government valuations were applied, internal transfers and atypical years excluded, prevailing average wages were used and additional data from accountants and farmers were obtained.

Key Topics for Economic Research

The Economic Objective sought to monitor and review the international trends in policy and market access likely to affect New Zealand. A further key objective was to model the impacts of changes and potential changes in world markets on New Zealand's trade using the Lincoln Trade and Environment Model (LTEM).

The LTEM is a multi-country, multi-commodity trade model focused on the agricultural sector; links to other industries, factor markets and the macroeconomy are exogenously specified. This partial equilibrium framework allows a high degree of commodity disaggregation and uses readily available OECD and FAO data on production, consumption and trade. In addition, the model is transparent, allowing the impacts of simulated policy shocks to be traced through the agricultural sector.

Eighteen countries and 22 agricultural commodities are included in the model. Major grain producers, including Australia, Brazil, and the United States, are included as specific countries in the LTEM. Major sources of intermediate demand for corn are also included: intensive beef, intensive dairy, poultry meat and eggs. The model simulates the commodity-based world market-clearing price on the domestic quantities and prices in each country, accounting for the impacts of agricultural and trade policies. Excess domestic supply or demand in each country spills over onto the world market to determine world prices. The world market-clearing price is determined at the level that equilibrates the total excess demand and supply of each commodity in the world market using a non-linear optimisation algorithm. The model is unique in linking trade through to environmental consequences such as greenhouse gas emissions and groundwater quality.

The LTEM is used to simulate the impacts of alternative policy scenarios into the near future (eg. Saunders *et al.,* 2009b). Scenarios include changes in agricultural, environment and trade policies.

Assessing the management literature on the optimal approaches to management for achieving societal and business outcomes is also part of the Economic Objective, along with an on-going review of the literature on sustainable development (eg. Penrose 1997).

The performance indicator questionnaire facilitated analyses of 15 performance indicators belonging to one of the following seven categories:

1. Structure of firm
2. Business strategy
3. Customer focus
4. Quality
5. Employee relations
6. Innovation
7. Social/environmental indicators

The data obtained from the performance indicator questionnaire was compared with the financial data gathered from farm accounts.

The annual financial data originated from three panels of farms defined in each of the kiwifruit and sheep/beef sectors, based on the growers'/farmers' involvement with market audit and certification schemes. The involvement was expected to possibly affect farm/orchard costs and one objective of the financial analysis was to estimate the extent to which financial sustainability was influenced.

Social Objective

The Social Objective designed its research around two documents: a 'Rationale for Research Methods' paper, which designated a suite of methods for social research in ARGOS (Campbell *et al.,* 2004a), and a 'Compendium of Key Research Issues' paper (Campbell *et al.,* 2004b), which reviewed and addressed key social research questions.

Methods for social research:

The methods employed in the collection of social data for the ARGOS research objectives varied from those of a more qualitative, semi-structured interview to that of a formalised survey. This variety of methods was utilised to best collect different types of data and facilitate the triangulation of findings within the Social Objective.

First qualitative interview (Qual 1): a semi-structured interview designed to gather baseline data across social dimensions of interest to the social, economic and environmental objectives of the ARGOS project. This included open-ended queries of participant identity, vision (for self and farm), wellbeing and indicators thereof (for self, family, community, economic and environmental condition) and expectations of participation in the project. Participants were also asked to create a map (referred to in this report as *sketch maps)* of their farm/orchard that included aspects important to their management practice. For both Qual 1 and Qual 2, the interviews were transcribed and coded by themes using NVivo qualitative analysis software.

Second qualitative interview (Qual 2): also a semi-structured interview designed as a means to investigate participants' response to constraints (and enablers) on their management practice. This included open-ended questions that encouraged participants to describe constraints (grouped by their relationships to the environment, society, industry or inputs to management) and elaborate the effect of these on management strategies. The participants were also asked to identify the sources of information on which they relied and to indicate their response to innovation and change more generally.

Causal mapping: a more structured exercise in which participants mapped the relevant relationships between factors important to the management of the farm/orchard. Factors were listed and placed on a sheet. The relationships were then indicated by arrows (both uni- and bi-directional) and weighted (on a scale of 1-10) as an index of their relative importance. The resulting maps were combined for each panel and assessed on the basis of number of factors and arrows included, the relative importance of factors (*centrality*, reflecting the number and weight of connections involving that factor) and the structure of the resulting maps[17].

National farmer survey: a survey including queries on various demographic characteristics and management intentions as well as attitudinal positions (using Likert scale responses) on a range of topics including assessments of the environment, farm practices and attitudes to nature.

Key Topics for Social Research

The Social Objective sought to address similar themes across all the survey instruments rather than targeting particular surveys or instruments at specific, isolated themes. The two main surveys were directed at a particular cluster of topics.

The first Qualitative Survey (Qual 1) addressed three key themes:

1. Self-identification and positioning: seeking information on farmer identity and how they saw themselves. This measure helped to construct a sense of how farmers understood 'good farming' and also how they saw themselves in terms of their own farm practice and management.
2. Visions: for self and for farm
3. Indicators: environmental, economic, and social wellbeing: This was examined with a key set of questions about how farmers examined and engaged with feedbacks in their farm management practice, and what types of economic, environmental or social information influenced their activities.

[17] For a detailed discussion of these methods and results, see Fairweather *et al.* 2007c, 2008; Fairweather 2010; Fairweather and Hunt, in press)

The second Qualitative Interview (Qual 2) theme was ‘constraints on capacity to act’ and topics included farmers’ perceptions of:

1. Biophysical constraints: climate, soils, etc.
2. Government (local to national) policy constraints: general, environmental
   - including wetlands and waterways
3. Constraints associated with their industry sector —
   - industry standards: dry matter requirements in fruit (kiwifruit); contracts to processors (sheep/beef); productivity (dairy)
   - audit systems: EurepGAP (kiwifruit); Quality Assurance (sheep/beef)
4. Input constraints: labour, purchased inputs, capital
5. Knowledge as a constraint and processes of knowledge acquisition

Causal mapping and sketch mapping exercises provided an alternative way for farm household participants to report insights into aspects of farm management and farming systems than what was available from the qualitative interviews. The causal mapping exercise enabled insights to be drawn about:

1. How farmers understood their management approach
2. What was important in their farming system
3. Issues of productivity versus other outcomes from farming
4. The extent to which farmers were ‘systems thinkers’ in management
5. The importance of farm/orchard environmental health
6. The importance of family and farm succession in their planning
7. The kinds of constraints that operated in their farming system

Having assembled this data from the 100+ ARGOS farm/orchard households, the Social Objective then deployed a national survey (n = 2,000) to evaluate the extent to which the data from the ARGOS households was representative of their wider sectors (the ARGOS households were included as a sub-sample on the national survey).

The national survey addressed:

1. Farming or orcharding background, upbringing and education
2. Farm or orchard management system and practices
3. Condition of farm or orchard environment, including wetlands/waterways
4. Relationship to land and nature
5. Responses to key topics around sustainability, organics and environmental management practices.
6. Questions designed to gauge the extent to which farmers utilised strategies that might improve farm resilience.
7. Māori connections and attachment to place.
8. Farm and personal data

The intention of the project is to repeat the National Surveys, and Qualitative Surveys over a regular interval during the life of the project. Each of these instruments will be redeployed with a selection of questions/topics repeated in each iteration to enable some measure of change over time among the ARGOS farm households. The rest of these measures will also assess ‘one-off’ issues that have not yet been covered in significant depth.

TRANSDISCIPLINARY RESEARCH THEMES

The ARGOS programme was designed in consideration of the growing call for researchers to take a more 'transdisciplinary' approach to sustainability research to help redesign agricultural systems to deliver more secure and resilient food production. Offering the potential for collegial and insightful interchange among informed perspectives, the concept of transdisciplinarity serves as a utopia – a position beyond the established (and perhaps the possible) situation. This utopia helps to facilitate critique and movement toward more positive relations between researchers, other process professionals (farm advisors, policy makers and regulators, marketers), and the growers and their families.

Once the ARGOS researchers established and perfected research within each of our own disciplines, the team gradually formed transdisciplinary goals to reintegrate the research objectives:

- Resilience thinking
- Market quality assurance systems
- Agricultural intensification
- Indigeneity - Kaupapa Māori pathways to sustainability
- Constraints on action
- Work
- Focal species and processes
- Transdisciplinary research process enablers and constraints
- Practical outcomes

Eventually constraints on action become less important, with a shift to identifying multiple drivers of change. Our economists did not develop the 'work' theme due to limitations in data availability/gathering and so instead they shifted to leading research of 'capitals for sustainability and resilience'. The 'focal species and processes' was in the end mainly completed by the ecologists themselves (Table 4), although they added economic and practical farming dimensions to existing flagship species concepts when they developed a more nuanced "*Market Flagship Species"* concept for use in international food systems (eg. Coleman *et al.,* 2010; Meadows 2010, in press). Also surveys were co-designed by social and ecological researchers to examine the constraints and willingness of farmers to promote biodiversity and habitat refuges (eg. Fairweather *et al.,* 2009 a & b).

Resilience thinking

Despite calls for interdisciplinary and transdisciplinary approaches to address the sustainability challenge in a holistic way, there remains a dearth of conceptual models integrating ecological, social and economic sustainability over various temporal and spatial scales. Definitions of sustainability remain hotly contested, partly because researchers and actors often restrict the domains to be considered or operate in different time and spatial scales (Perley *et al.,* 2001; Aerni 2009) and measuring it is problematical (Knickel & Renting 2000; Howarth 2007). From the very beginning ARGOS has explored one approach that integrates these dimensions: resilience thinking. This approach is based on an understanding of the world as a system that is complex, adaptive and uncertain i.e., where subsystems co-evolve, and where change is the only constant and responses to management intervention are uncertain (Holling, 2001; Manson,2001; Mayumi and Giampietro 2001; Holland, 2002; Lansing, 2003; Carpenter *et al.,* 2005; Allen *et al.,* 2005; Beratan 2007; Berkes 2007; Loring 2007; Rammel *et al.,* 2007; Scoones *et al.,* 2007). Studies on resilience have shown that the persistence of a social-ecological system is born out of both the resistance to change and the transformation of the system (Colding *et al.,* 2003; Olsson and Folke, 2004; Walker *et al*., 2004). The key for adaptability is to retain flexibility and avoid rigidity traps (Scheffer and Westley, 2007; Walker *et al.,* 2009). Framing farming systems as complex adaptive systems may thus open a new perspective on understanding sustainability of farms and farming systems. Such an approach is compatible with calls for transdisciplinary approaches to farming and sustainability issues (Cousins et al., 2007; Saifi and Drake, 2008; Aeberhard and Rist, 2009; Wiek and Walter, 2009). Resilience thinking recognises individual humans, families, communities and nations and international links all as part of linked human and natural systems with particular sites of action for transformative change (Walker *et al.,* 2002; Westley *et al.,* 2002; Liu *et al.,* 2007), so it naturally invites social research as a key tool for promoting sustainability – an abundance of research emphasising the importance of farmers (their orientations and capacities for change or persistence) for agricultural production exists for New Zealand[18] and overseas[19], yet social dimensions of sustainability are often ignored in the more traditional "command and control" (Holling and Meffe, 1996) approaches to planning and engineering food and fibre production.

Resilience thinking focuses on long-term adaptive changes or transformations of systems to make them more resilient to shocks. Resilience theorists typically categorise transformations as having an initial rapid 'exploitation' phase, followed by a 'conservation' phase as resources run out and intensification of management is deployed to maintain production. This system, at its current limits, can then be triggered to collapse by a shock or long-term driver that squeezes production and business as usual. A 'release' and then finally a rapid 'reorganization' phase ensues to establish a new adaptive cycle, which can drive the system to a more sustainable orientation (the "back-loop to sustainability") or to an even more degraded and temporary resource exploitation cycle that is less likely to be sustained. For example, the concept of adaptive cycles can be applied to the creation of integrated management QA programmes for kiwifruit, which form the main focus of ARGOS1 in the kiwifruit industry (Figure 6). Resilience thinkers also link different adaptive cycles operating at vastly different spatial and temporal scales into a 'panarchy' (Figure 7). Slow background cycles may hold local systems in current phases, or change in these background cycles may stress and tip local systems (for instance the individual farm enterprise). Focus on the different layers and players in a global food chain from paddock in New Zealand to a consumer's plate in Europe is a fine example of a complex panarchy when viewed through the social-ecological resilience lens.

Although resilience thinking provides a useful and flexible framework with which to approach a complex system like global human food production systems, this very flexibility and all-encompassing facility cramps its ability to make specific predictions for farming

[18] Fairweather and Keating (1994), Fairweather and Campbell (2003), Hunt (2010)

[19] Burton and Wilson (2006), Slee *et al.* (2006), Ingrand *et al.* (2007)

recommendations. Application and research of resilience has been constrained by a lack of practical measures of resilience (Carpenter *et al.,* 2001; Cumming *et al.,* 2005). We remain sceptical of the utility of this approach at a specific tactical guidance level, but there appears to be no doubt that it is a useful framework with which to identify broad 'rules of thumb' to move New Zealand agriculture to a more sustainable orientation, just as it is being increasingly used overseas for supporting agricultural production (Darnhofer, 2009; Darnhofer *et al.,* in press). Its emphasis on systems level transformations (Dedieu *et al.,* 2008).

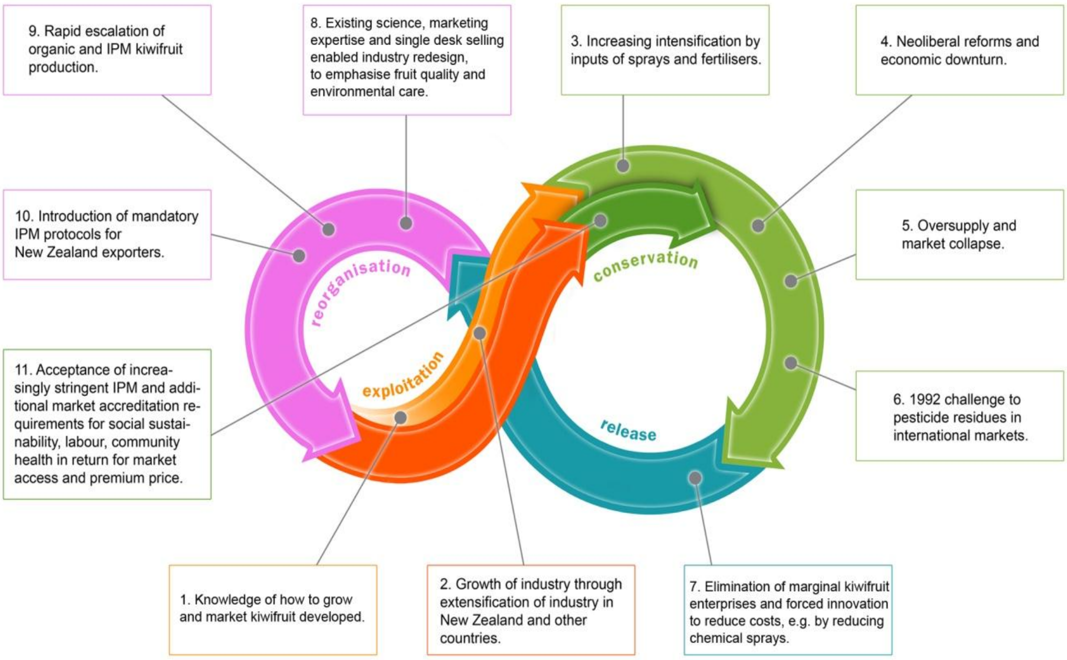

Figure 6: An adaptive cycle in the New Zealand kiwifruit industry that lead to the predominance of IM and organic growing QA systems. *Resilience thinkers conceptualise systems as fluxing through successive stages of an 'adaptive cycle' Gunderson and Holling 2002). From an initial 'exploitation' phase the system transitions to a 'conservation' phase when competition for resources (e.g., land or market share) and increasing specialisation of the production methods begins to stress the system. Shock or unbearable stress triggers collapse and rapid 'release' of organisational structures and norms that creates opportunity for 'reorganization'. The transition from release to re-organisation is sometimes referred to as "the back loop to sustainability" if the new, re-organised, state promotes more sustainable resource use. Here we depict a full adaptive cycle (including the start of a second cycle) of the New Zealand kiwifruit industry, covering the period 1970–2000. Source: Darnhofer et al. (2010) who modified the adaptive cycle presented by Berkes et al. (2003).*

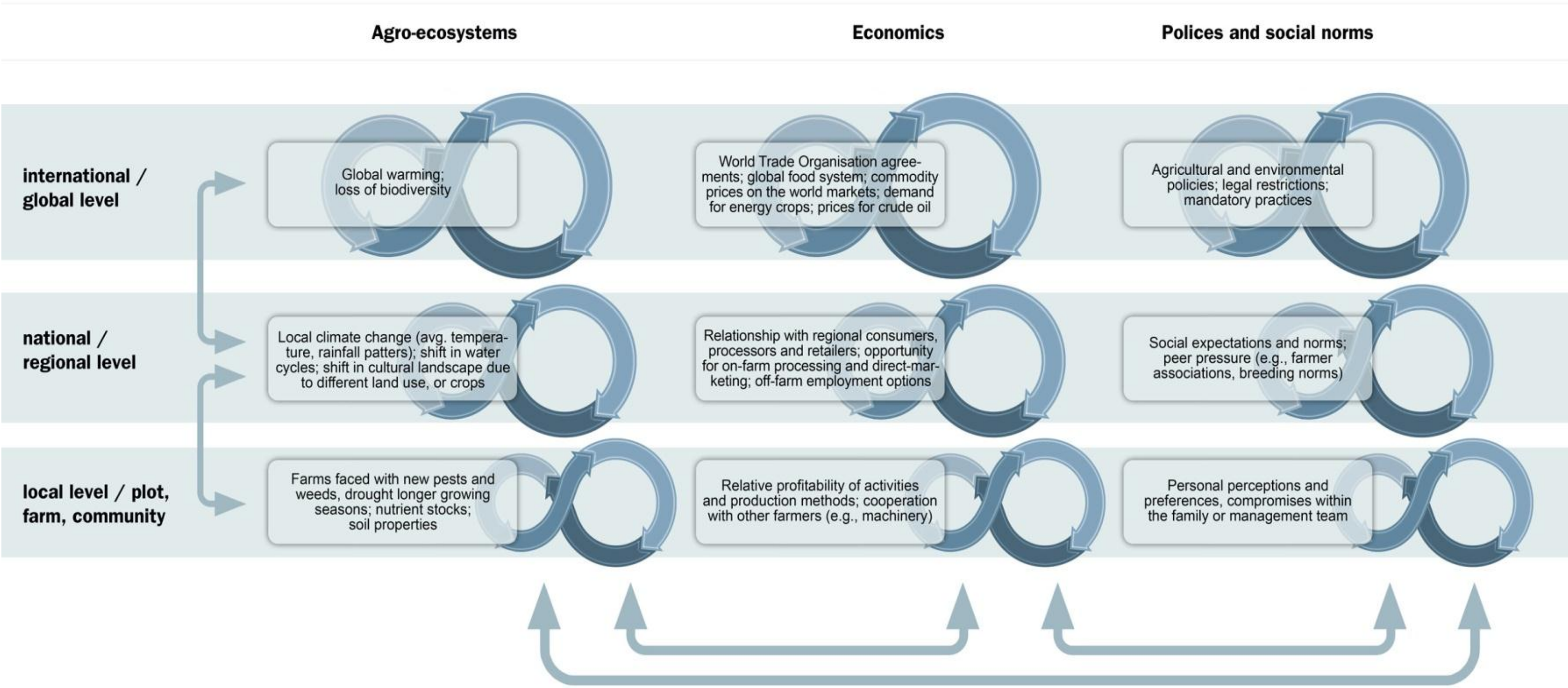

Figure 7. Interactions between hierarchies of nested adaptive systems within the ecological, economic and social domains. *The adaptive systems are semi-autonomous but they influence each other, both within and between domains. Source: Darnhofer et al. 2010.*

Market Quality Assurance Pathways to Sustainability

As a result of an economic context that has placed increasing demands on New Zealand agricultural exporters to conform to best practice standards developed by retail interests in target markets (Campbell, *et al.,* 2006; Campbell and Le Heron 2007), market quality assurance was a formative element of the ARGOS research design. In other words, such market driven regulation of practice had largely become an element of the farming reality—albeit to a greater extent in some sectors (e.g., kiwifruit) than others. These practices (in various guises from organic and fair trade certification to supplier contracts) were also drawing increasing academic attention (Busch and Bain, 2004), often with negative assessments of the social and environmental impacts of their implementation. Given both its apparent pervasiveness and its conformance to New Zealand's neoliberal policy arena, the practice of audited quality assurance raised questions of the implications of for society and the environment. Thus, this focus drew on the project's discipline based observations to develop a transdisciplinary explanation of the role of market quality assurance in the evolving food system. The findings provided both an assessment of the relative legitimacy of existing quality assurance practices as well as greater understanding of the context of sustainable agriculture in New Zealand (Campbell *et al.,* 2006; Rosin *et al.,* 2008a,b).

As a transdisciplinary focus, quality assurance auditing gained immediate traction as a social research question examining the impact of an imposed regulatory structure on the behaviour and identity of producers. This interest proved relevant to several social theoretical perspectives. The emerging power relationships between participants in the respective commodity chains provided insights to the for the consolidated interests of large retail firms in Europe to impose sourcing efficiencies under the guise of 'best practice' and to shift consumer demands for product quality to the producer (Campbell *et al.,* 2006; Campbell and Rosin 2008). Using a Bordeausian approach, quality assurance practices were also assessed on the basis of their capacity to alter the established culture (or *habitus*) of farming in the sectors (Hunt 2010). Finally, the implications for the broader identity of producers were addressed from a convention theory perspective (Rosin, 2008; Rosin, *et al.,* 2008). These analyses illuminated the issue of the legitimacy of quality assurance audits as a means to drive social change. On their own, however, they failed to address the issue of the environmental impacts and economic implications associated with their implementation.

The legitimacy of quality assurance schemes for consumers lies in their promise to deliver greater environmental and social benefit at the point of production. The audit in this case has the capacity to verify that such promises are achieved. As a process, however, the audit can only measure conformance with set practices that have been associated with positive outcomes. Thus, in addressing the ARGOS null hypothesis, the ecological research provides a *de facto* assessment of the actual impacts of the audited practices. In this sense the focus on quality assurance as a pathway to sustainability engages a question that crosses disciplinary boundaries.

In a similar manner, the broader issues surrounding the practice of quality assurance auditing in New Zealand agriculture involved the expertise represented by farm management and economic researchers in the project. The legitimacy of auditing for the producers lies in the practicalities of both the enforced practices within their management systems as well as the economic return achieved through participation in a quality assurance programme. The existing understandings of these aspects of the programmes were evident in the usual data collected by respective elements of the ARGOS research team. Data from annual farm management surveys helped to establish the extent to which the quality assurance resulted in altered management practice on farms and whether such changes were considered viable aspects of farming. In a manner similar to the ecological data, financial account data for each of the participating farms and orchards was used to test the null hypothesis and draw conclusions regarding the impact of audit compliance on financial viability. There was a natural link between resilience thinking and Quality Assurance themes eg. was one market accreditation more resilient than another, in the way claimed for organic agriculture overseas (Milestad and Darnhofer, 2003; Darnhofer, 2005, 2009)?

As a whole, the focus on quality assurance contributed to the emerging transdisciplinary dialogue within the ARGOS project. While limitations in the scale of inference impeded strong conclusions regarding the relative potential of quality assurance to operate as a pathway to sustainability, the shared examination of the current context of export agriculture in New Zealand elicited theoretical questions relevant to the diverse disciplinary interests in the research team. The gathering of data and the analysis appropriate to examining these questions provided a broad perspective on the implications of market driven quality assurance demands for the sustainability of New Zealand agriculture.

Agricultural Intensification

Despite increasing public discourse about the putative threat of agricultural intensification on New Zealand's natural capitals and environmental wellbeing, we have found little published evidence for such effects, nor formal risk assessments of the continuity of supply of nutrients or energy subsidies upon which the sustainability of New Zealand's intensive agriculture must rely (Meadows *et al.,* 2008; Moller *et al.,* 2008c). Nevertheless, absence of evidence does not constitute evidence of absence of intensification effects, and common sense suggests that such threats are plausible and indeed likely. Nor did ARGOS interviewees emphasise intensification as a threat to social and personal wellbeing or economic sustainability to the degree it is hypothesised to threaten environmental sustainability – indeed, intensification and consequent growth in production was normally considered to promote economic sustainability. However our review of available land use and agricultural indicators underscored its ongoing and seemingly unstoppable nature (MacLeod and Moller, 2006), leading us to conclude that ARGOS can assist most by trying to 'go with' rather than advising on ways to 'stop' intensification. We therefore identified agricultural intensification as a critical cross-cutting transdisciplinary theme.

The first step in untangling the confusion and identifying strategies to direct intensification in ways that might mitigate putative impacts was to clarify definitions of exactly what constitutes intensification. We suspected that the term 'intensification' is often used as a convenient label, a type of Gestalt term referring to perpetually escalating production. The Food and Agriculture Organisation (FAO) defines agricultural intensification as:

> "*…an increase in agricultural production per unit of inputs (which may be labour, land, time, fertilizer, seed, feed or cash). For practical purposes, intensification occurs when there*

is an increase in the total volume of agricultural production that results from a higher productivity of inputs, or agricultural production is maintained while certain inputs are decreased (such as by more effective delivery of smaller amounts of fertilizer, better targeting of plant or animal protection, and mixed or relay cropping on smaller fields)" (FAO 2004, p.5).

However, this definition confounds issues of agricultural and economic efficiency (the main interest of FAO) and the more fundamental ecological issue of faster input and/or off-take of production per unit land area. For example, if a farmer greatly increased fertiliser inputs but only reaped a moderate increase in productivity, technically this would amount to a decrease in intensification according to the FAO definition. The ARGOS team prefers to refer to intensification as any increase in farm inputs or farm production off-takes per unit area of land, irrespective of trends in relative efficiency of off-take per unit input. Therefore we are considering a broader land use intensification rather than economic intensification. We prefer our definition for our purposes because rates of nutrient and biomass transfer and associated rates of ecological disturbance potentially play the largest role in determining ecological outcomes, such as changes in biodiversity.

It is clear that some commentators (e.g. Lee *et al.,* 2008) confuse intensification with extensification and conflate spatial scales when they assert that intensification must necessarily drive biodiversity extinct because it removes woody vegetation and other 'ecological refuges' (*sensu* Blackwell *et al.,* 2008) via agricultural disturbance within the farm boundary (Moller *et al.,* 2008a). Removal of shelterbelts within a farm boundary may be seen as a sign of net intensification if the collective parcel of all the land within the property, but if one defines the land unit independently of the total farm area, then spreading pasture production to areas of the farm that were formerly covered in trees is actually a form of agricultural <u>extensification</u> on a local scale. There is currently little evidence that ongoing intensification of land use within existing pasture or cropped areas is a threat to agrobiodiversity living in those areas (Moller *et al.,* 2008c). Indeed, amongst many possible complex systems feedbacks one can identify that agricultural intensification of the pasture area might protect overall biodiversity on the farm. For example, it might increase profits and obviate the need or temptation to remove woody vegetation to increase overall production of the farm, leaving the woody vegetation as the crucial refuges for biodiversity (Blackwell *et al.,* 2008). This is an example of the 'land sparing' hypothesis used by Rowarth (2008) to justify agricultural intensification as saving biodiversity, although our example operates on a local within-farm scale, whereas Rowarth (2008) is referring to national and global scale feedbacks.

In addition to clarifying definitions of intensification and their dependence on spatial scales, we have identified three meta-hypotheses, and some additional key questions to link intensification to the other constructs of the ARGOS programme in a transdisciplinary manner (Table 5). Preliminary analyses have rejected both H_0 and H_1 i.e., organic farms are less intensive, but no less efficient in delivering a return on energy input (Norton *et al.,* 2010), kiwifruit is more intensive than dairy farming, and both kiwifruit and dairy production are much more intensive than sheep/beef farming. Preliminary analyses also uphold H_4 i.e., we are finding more and stronger differences in sustainability indicators between organic/IM/conventional panels in kiwifruit than in dairy, and even fewer and smaller differences in sheep/beef sectors compared to the other more intensive sectors. Finally, with regard to the descriptive question #7 in Table 5, organic farms tend to constitute outliers in

Table 5: Key hypotheses and questions for exploring links between farming intensity and sustainability outcomes

1. Within-sector comparisons (ARGOS1's main null hypothesis):
   ***H_0* : There are no differences between organic, IM and conventional panels within each sector in (a) current intensity of farming and/or (b) the rate of intensification**

2. Between-sector comparisons:
   H_1 : There are no differences between dairy, kiwifruit, sheep/beef, High Country and He Whenua Whakatipu farms in (a) current intensity of farming and/or (b) the rate of intensification

3. The putative link between intensification and sustainability indicators
   H_2 : Intensity of farming is a major driver of environmental, social and economic sustainability outcomes

4. ARGOS's preliminary investigations have rejected H_0 and H_1 for many sustainability indicators, including those proposed for intensity measures (Norton *et al.* in press). Therefore, if H_2 is true, the following hypotheses, predictions and questions will be of interest to help achieve the ARGOS mission:

5. **H_3: Different sustainability indicators of organic, IM and Conventional systems within a sector are caused by differences in intensity** Or, phrased differently; *Differences in intensity provide a sufficient explanation for observed differences in sustainability indicators between panels within each sector*

6. **H_4: Farming system (organic, IM, conventional) affects outcomes more in sectors where farming is more intensive** (i.e. an interaction exists between panels and intensification of the sector, such that bigger differences will appear between panels in which agriculture is more intensive)

7. How do the panels position themselves in terms of intensification relative to each other? Are IM farms intermediate between organic and conventional farms? Or are differences in intensity between organic and conventional, and between organic and IM larger than differences between conventional and IM? These questions are of interest as part of an overall inquiry about what it means to be an IM farmer - are IM farmers in some sense intermediate in sustainability indicators between conventional and organic farmers?

8. Are more intensive farms more profitable?

9. What are the land characteristics (natural capital) associated with relatively more intensive farming?

10. Are the most intensive farming operations more vulnerable to failure in the current economic crisis (i.e. are they more or less resilient to shocks?)

terms of intensity measures; that is, the difference between organic and IM, and between organic and conventional farms is much greater than that between IM and conventional farms. This is another example of a common pattern that conversion to organic growing is associated with stronger differences in sustainability indicators compared to conversion to IM (Figure 7).

A capitals approach to sustainability assessment

Economics, like other disciplines, has developed theoretical and applicable methods to assess and determine whether resource allocation decisions meet the conditions of sustainability. This methodology is commonly referred to as a capitals-based approach to sustainability. While this approach has limitations, it is able to incorporate social, environmental, cultural and economic aspects, and has been applied internationally.

The concept was first described by Solow, the originator of modern growth theory in economics. While Solow defines economic sustainability as 'non-declining per-capita human well-being (utility) over time', Hartwick interprets sustainability as non-declining consumption over time (Hartwick, 1977). A combination of these concepts is commonly referred to as the Hartwick–Solow condition for sustainability. This condition requires 'a non-declining capital stock over time' (Solow, 1986; and Repetto, 1986), where capital stock is understood in its broadest terms to include human capital, social capital, cultural capital, human-made capital and natural capital.

Human capital includes knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being. It is created through lifelong experience as well as formal education. Social capital has been defined as the 'network of shared norms, values and understanding that facilitate co-operation within and between groups' (OECD, 2001). Cultural capital is the set of values, history, traditions and behaviours that link a specific group of people together. This can be particularly important where a minority culture exists alongside a dominant majority culture, e.g., Welsh in the United Kingdom; Québécois in Canada and Māori in New Zealand. Human-made capital refers to public and private capital such as buildings, factories, office blocks, industrial plants and machinery, computers, infrastructure, airports, seaports, highways, roads, railways, schools, hospitals, courts, telecommunication networks, and electricity networks. Many of these forms of human-made capital are either under the direct or indirect influence of local government.

Natural or environmental capital in economics is generally classified into three types: extractive resources such as soils, minerals, forests, fish and water; amenity values (direct and indirect) such as landscapes, native bush, recreational fishing; and assimilative capacity (the ability of the environment to 'process' waste pollution). Natural capital is different from the other types of capital discussed in the previous paragraph because of the irreversibility of some forms of natural capital when used. Accordingly, this leads to the implementation of 'well-being' rules about the use of natural capital, which may include restrictions on the use of renewable resources such that the harvest rate is not more than the renewal rate, or ensuring that waste flows remain within the assimilative capacity of the local environment (Pearce, 1988). This is particularly important for stock natural resources that do not renew themselves (e.g. coal, oil). One rule for stock resources is that planners and/or policy makers must ensure that reductions in the stock are compensated for by increased investment in renewable resources or other forms of capital (Hartwick, 1977). Importantly, this assumes there is substitutability between stock resources and other capital (Solow, 1974), an assumption that is not universally accepted (for example see Daly, 1996, pp. 76-80).

Another factor in assessing natural capital (and indeed other forms of capital) is the multi-functionality of this capital and hence whether all the associated benefits are properly assessed. This is related to the stability and/or resilience of the natural system, resilience being the ability of an ecosystem to maintain itself when shocked by natural or human disturbance. Sustainability therefore requires that human interactions with the environment should consider the impact on ecosystems as a whole rather than just on resources themselves with care to avoid threatening the stability of the ecosystem (Common and Perrings, 1992).

All the forms of capital mentioned above, including natural capital, can be enhanced by technological development. A constant or increasing standard of living is assumed to be possible from a reduced set of natural resources through technical advances and/or greater efficiency, which is why governments pay such attention to fostering innovation in their industry and higher education policies.

Within economic thinking, it is considered important to view capital as possessing two aspects in reference to time – stocks and flow. This concept was described by Fisher (1896, p. 514) as follows: *'Stock relates to a point of time, flow to a stretch of time...The total capital in a community at any particular instant consists of all commodities of whatever sort and condition in existence in that community at that instant [i.e. capital stocks], and is antithetical to the streams of production, consumption and exchange of these very same commodities [i.e. capital flows].'*

Agriculture has since been a central concern in sustainability debates for two key reasons – first, its extensive use of natural resources which means a potential for widespread and extensive environmental effects, and second, the fact that its end product is food, making it a foundation of human society (Bell and Morse, 2008). These factors mean that agricultural sustainability is of critical importance, creating a need for viable tools to measure it.

Thus, a key challenge for sustainable agriculture and the concept of sustainability in general lies in placing greater emphasis on consideration of each type of capital when measuring progress towards sustainability. As such, establishing a clearer understanding of each type of capital within an agricultural system is critical. The establishment of such an understanding and the use of capital-based indicators in measuring sustainability not only has the potential to provide an important measurement device that can prescribe ways for moving forward in making the concept of sustainability a viable goal, but it also has the potential to uplift sustainable agriculture as an appealing approach.

From an overarching perspective, the research programmes undertaken by ARGOS provide a preliminary examination of the use of the various categories of capital indicators in evaluating the sustainability of farming systems.

Māori approaches to sustainable farming

As outlined previously the *He Whenua Whakatipu* research objective worked with case study groups of Māori landowners to identify their developments goals, take action toward achieving their goals, identify constraints experienced whilst taking this action, and find solutions to overcome constraints. A number of transdisciplinary themes emerged through the research. First, it emerged that all case study groups shared a common set of values that motivated, or underpinned their goals and actions. It is not initially surprising that a shared set of values should exists across an ethnic group, however the result does become surprising when critically compared with transdisciplinary and transcultural theories concerning human needs.

Human needs theory argues that human beings have a distinct set of needs that require satisfaction to support life. For example humans need food and shelter to meet their subsistence needs. In 2002, Alkire undertook a literature review and critical comparison of different human-needs models developed within multiple fields including development studies, psychology and systems theory. In her work she noted uncanny similarities existing between all models despite each originating from different fields and disciplines. Alkire refers to these approaches to human development as 'human-ends', given that the needs that human beings must satisfy are 'ends unto themselves.'

The first similarity Alkire identifies between models is that the motivations behind human action can be reduced to sets of definable human-ends. The second commonality between approaches is that the human-ends are non-hierarchical, which means that all dimensions are equally important – one cannot be used to replace another. For example one of the most famous human-end theorists, Max-Neef (1992, p. 199) identifies and classifies nine interrelated human needs, all of which must be satisfied. The needs are: subsistence, protection, affection, understanding, participation, creation, leisure, identity and freedom (Max-Neef, 1992: p. 200). Max-Neef suggests that human-ends must be understood as a system, in that all human-ends are interrelated and interactive. For example, the need for subsistence may also provide for the need for protection, as in the case of shelter (Max-Neef, 1992: p. 199).

When examining the values underpinning the actions and development plans of case study groups in the *He Whenua Whakatipu* objective, it was surprising how similar these values were to key themes expressed across the multiple human-ends theories identified by Alkire. First, Alkire (2002) outlines that all human-ends models outline the human need to participate effectively in choices that govern their life. From the perspective of case study groups this human need is encompassed by the value of tino rangatiratanga, or self-determination. Second, human ends models also outline the human need to give and receive affection, and form affiliations with others. Likewise, the case study groups outlined the values; *whanaungatanga* (togetherness), *manaakitanga* (unqualified giving), and arohatanga (care, love and respect). Further human-ends approaches outline the human need for a meaningful (perhaps spiritual) aspect to life, control over the resources required for subsistence, and a solid identity, which are respectively valued by Māori as; *wairuatanga* (spirituality); *manawhenua* (legitimacy to control resources); and *whakapapa* (knowing who you are through genealogical links to human and non-human beings). The values, or human-ends used to guide the actions of case study groups are outlined the in Table 6 below:

This research finding suggests that Māori landowners participating in the research were aware of their human needs and were able to label these needs. Why this is so relevant is that human-needs theorists such as Max-Neef argue that when communities, or societies, fail to identify and fulfil all their human needs they will become pathological, or unwell. For example, in indigenous contexts, not being able to fulfil the need for self-determination (having ownership of the political choices that govern one's life) can cause social pathologies such as pervasive distrust, fear, apathy and xenophobia. Similarly, not satisfying the human need for strong and coherent identity within indigenous societies, can lead to loss of self-mastery, autonomous personal dignity, trust and self-efficacy. On a global level national insecurities can influence the formation of pathologies like arms races.

Max-Neef (1993) also argues that unsustainable development is a pathology. For example, within Western countries the accumulation of material goods is much more than what is required to satisfy the subsistence and protection needs of those societies. This excessive consumption might constitute pathological behaviour that provides compensatory escapes in response to certain needs not being met. This consumer demand gives rise to ever-increasing economic production which, in turn, degrades the environment. Consequently fulfilling human ends is crucial for fundamentally dealing with environmental crises and transitioning toward sustainable development.

Table 6. Māori values and goals associated with sustainable agriculture.

Māori values and human ends	
Value/Human-end	**Definition**
Manawhenua	Control over resources
Whanaungatanga	Togetherness
Arohatanga	Care, Love, Respect
Manaakitanga	Hospitality, Kindness
Wairuatanga	The spiritual dimension
Kaitiakitanga	Guardianship
Tino Rangatiratanga	Self-determination
Taonga Tuku Iho	Holding and passing down protected treasures – may include knowledge, objects or natural resources
Whakapapa	Geneaology, lineage, descent

When translated into plans for action, we see that the values of case study groups assisted these landowners in developing plans that took social, economic, cultural and environmental factors into account to form a holistic development approach. In particular, case study groups all shared common plans that envisaged the development of their land into contemporary papakainga, or a contemporary village supported through sustainable land utilization. Land development involved pursuing a strategy of restoration, commercial development, and community development. Restoration was considered important for improving the health of soils, remnant forests and streams. Commercial development was valued for its contribution of cash income to the land owners, and for the employment opportunities it could provide. A number of highly innovative and entrepreneurial ideas for business development were explored. Furthermore, a number of options were also imagined for value-added processing and sale of produce, principally to increase income to the farm gate, but also to create local economic development through employment. Also of high importance was the desire for cultural revitalisation and community development through building non-market production and exchange, principally via increasing the capacity for *mahinga kai* (wild food) harvesting and fibre production. The common goals of case study groups are provided in Table 7 below, which outlines the holistic development approach adopted.

Overall the approach to development offered by case studies in the *He Whenua Whakatipu* provided an avenue for opening debate on the values underpinning the actions across all research participants in the ARGOS programme – including the researchers themselves. Although such a debate has not yet taken place, it would no doubt provide an opportunity to compare the case studies in *He Whenua Whakatipu* with the research participants within the broader programme. This would have involved a direct comparison of the values/human ends underpinning actions of different farming communities/families, and whether particular human ends were being satisfied within different cultural settings. Furthermore, debate would have been opened as to why certain human-ends were being met in some contexts while not in others, and the potential pathological behaviour resulting from failure to meet particular needs resulting in social or environmental externalities.

Transdisciplinary themes also emerged within the *He Whenua Whakatipu* project as the team explored the constraints on development experienced by case study groups (Table 8). It is clear that each of the constraints identified can be attributed to the absence of particular 'capitals' within communities. This reinforces the transdisciplinary nature of the capitals approach to sustainability. Under the social capital banner we find that rivalry and jealousy (box a2) between communal landowners constrains development. This demonstrates a lack of social capital or trusted networks that can be relied upon to collectively plan and cooperate. Further under the human capital banner we find that the absence of technical skills and knowledge required for development planning and implementation (box b4), and the lack of confidence and self-efficacy to gain technical skills (box h2), constrains development. Finally without ready access financial capital the ability to either access human capital (e1 and c1), or invest in plant and machinery (human made capital) (box e1) then sustainable development is constrained. Consequently it can be concluded that indigenous communities that have limited access to different capitals are constrained in reaching their goals and have their development options limited.

Table 7: Strategies of participating Māori whānau for adopting agriculture and other land use enterprises for sustainable livelihoods.

Development strategies of Case-study groups to bring about desirable change

1. Establishing a mandate for ongoing management rights over communal tenure land

2. Enhancing the *mauri of ngaa taonga katoa*

Development options to transform land fall into three categories and six sub-categories

2A. Maintaining and increasing the health of the whenua	**2B. Maintaining or building non-market production and exchange**	**2C. Maintaining and increasing cash income from the market economy**
Managing land resources to provide resources for landholders in perpetuity through the following mechanisms:	Procuring and offering the following food and other resources for subsistence living and gifting (manaaki):	Providing cash to purchase goods and services
2A(a) *Ecological restoration* Replanting and allowing marginal land areas to revert to natural state	2B(a) *Mahinga Kai (examples below)* Garden produce (e.g. table greens) Fish (e.g. trout, tuna) Game (e.g. pigs, deer, ducks) Gathering (e.g. food and medicine)	2C(a) *Improving existing enterprises in the following sectors:* Sheep, Beef, Dairy, Forestry, Horticulture
2A(b) *Conserving soil, forest, stream and pasture health* Engaging in appropriate farm management practices	*2B(b) Opening land to settlement and making available traditional materials to maintain customs* Firewood Timber Fibre Land sections for house sites	2C(b) *Developing new enterprises with the following characteristic:* Producing high-value novel products Targeting niche markets Low risk Low capital requirements **VALUE ADDING**

3. Through achieving the above goals provide resources as a foundation for *whanau* to return and maintain existence on land (Nohoanga Kaaingi - dwelling place centred around food production)

*Employment opportunities to procure cash income to maintain contemporary Maaori existence
*Resources necessary for partial subsistence existence and to engage in traditional cultural practices (e.g. gardening, hunting, gathering, carving and weaving)
*Knowledge of land management practices to maintain resource base

Values Underpinning Development Strategies

Arohatanga
Manawhenua
Manaakitanga
Whanaungatanga
Taonga Tuku Iho
Tino Rangatiratanga
Kaitiakitanga
Wairuatanga

However, the Table below also demonstrates a set of solutions for overcoming constraints. Once again each of the solutions for overcoming constraints involves the provision of a type of capital. In particular the Table below identifies three key solutions to the constraints experienced by case study groups, which are highlighted in blue. The first is the presence of good leadership that can further the collective interest (box a3). This leadership quality is a type of human capital. Second is the presence of a well-resourced institutions that can co-invest with landowners providing key capitals such as human-made and financial capital (box f3). Third, is the provision of professional on-site and culturally matched training to build the technical skills and competency of landowners (box h3). Once again this involves the provision of human capital.

The absence or presence of different capitals within the *He Whenua Whakatipu* case studies offered a significant opportunity for cross-cultural comparisons with farm families within the broader ARGOS programme. Such comparisons have the potential to stimulate debate on where the Ngāi Tahu case studies possessed particular capital surpluses or deficits in comparison to non-Māori. Furthermore it would have allowed analysis of where cross-cultural synergies could be built through complementary strengths, and where inequalities of access to capital exist.

Finally, analysing the constraints to development of case study groups opened up a third transcultural and transdisciplinary theme. This theme concerns the role of leadership in sustainable land development, and in particular the role of wisdom traditions in cultivating appropriate leadership qualities in community members. It is outlined in box a3 in the Table above that driving development on communally owned land requires leadership that acts in the collective interest rather than self-interest. The research found that leadership that failed to act in a way that benefited the whole was unable to gain the support of owners. Furthermore, leadership required excellent communication, visioning and inductions skills to not only listen to the voice of different interests, but to also take these different voices and establish development priorities that captured the various interests within a single vision. Leadership was also then required to drive such initiatives and communicate progress back to the various interests in a manner that enabled support to be maintained. Overall leadership required a large degree of humility, to not only remain open to the ideas of various interests but to also set-aside personal interests and perspectives to establish a broader outlook that transcended their own view of world.

Interestingly these key elements of successful leadership identified within these contemporary Māori communities, also matches the key attributes of leadership described historically within Māori wisdom traditions. Below a set of quotes from Herangi (1883 – 1952), a leader in Kingitanga tradition, demonstrates the need for leadership to serve the people and be open to new ideas and perspective through a sharing process.

> *'This is the position of one who leads in recognising that the natural sharing process of all things Māori is sourced in the wairua (spirit) of the people whom he serves. The sharing process involves no thought for personal gain or reward, only the need to maintain acknowledgement in oneself that a leader is one who keeps the door open at all times.' (Mitaki and Ra 2004)*

Table 8: Constraints to achieving social, economic and environmental changes sought by the Ngāi Tahu whānau which participated in ARGOS's He Whenua Whakatipu project.

	Constraint	**Cause**	**Solution**
a.	a1. Challenges to establishing a mandate for decision-making	a2. Rivalry and jealousy emerging when benefits to communal landowners are thought to accrue within some landowners and not with others. Misunderstandings and misconceptions regarding the distribution of benefits.	a3. Leadership that acts to further collective interest rather than personal interest. However, there are limits to leaders acting in the collective interest being able to perform this function if lines of communication and accountability with land shareholders are poor or inadequate.
b.	b1. Insufficient farm scale	b2. Fragmentation of land blocks brought about through communal tenure	b3. Look to develop high-value niche and novel products that are more profitable per unit of land
	b4. Shortage of technical skills in piloting and growing niche, high value crops	b5. Inexperience and requirement for formal training	b6i. Contract appropriate technical skills in planning and developing enterprise – go to c4 b7ii. Participants enroll in course offering necessary technical training – go to hi
c.	c1. Shortage of development capital or financial assets	c2. Shortage of technical skills in: • Business Planning • Technical Planning	c3i. Contract technical expertise to assist with business and technical planning – go to c4 3cii. Participants enroll in course offering necessary training (e.g. night classes in small business planning and development) – go to g1
	c4. No resources to contract technical expertise	c5. Lack of development capital	c6. Write funding application to Te Puni Kōkiri (TPK), or other relevant government agency for resources to contract technical expertise
	c7. Lack of experience in, and knowledge of, how to write a funding application	c8. Inexperience and lack of formal education	c9. Develop relationship and rapport with TPK development officer who has bureaucratic language writing and networking skills to either advise on, or write application, and support application through process
	c10. Decision-making on applications takes time and with no guarantee of success. Contracts for technical help are typically short term in nature not permitting long-term capacity building	c11. Fear of hefty investment in projects that might fail, which would be politically unpalatable	c12. Meet this need for technical capacity building not through the Ministry of Māori Development, but through education institutions. However, there is reluctance to engage in institutional training, see g1.
d.	d1. 'Bridging income' while establishing enterprise	d2. Need to provide whānau income	d3. Significant investment of development capital into enterprise to provide bridging income needed– go to d4

Table 8 continued: Constraints to achieving social, economic and environmental changes sought by the Ngāi Tahu whānau which participated in ARGOS's He Whenua Whakatipu project.

	Constraint	**Cause**	**Solution**
e.	e1. Need for adequate plant and machinery	e2. Lack of capital	e3. Significant investment of development capital into enterprise required
f.	f1. Obtaining significant investment of development through investment	f2. Communal tenure land cannot be used as collateral for taking loans	f3. Need for joint partnership with either iwi or Crown institutions that understand needs, and invest and support the development.
g.	g1. Lack of business administration skills	g2. Inexperience, time constraints and shortage of administration skills	g3i. Contract individual to develop business administration skills – Go to c4 g3ii. Participants enroll in course offering necessary training – go to h1
h.	h1. Reluctance to engage in institutional training	h2. Distance to facility, illiteracy, desire for 'hands on' training on-site, fear of failure, lack of time	h3. Need for professional and culturally matched on-site extension and formal training from education provider based upon open and trusting relationships.
i.	i1. Fear of taking on debt	i2. Anticipated personal and financial consequences of business failure	i3. The need for a business partner and investor who can understand needs and partner development – see f3
j.	j1. Process for gaining reservation status	j2. Lack of experience and knowledge of legislation and bureaucratic process	j3. Contract specialist skill in legislation and bureaucratic process, or use skills of TPK development officer to work through process – go to c4 and c9
k.	k1. Shortage of technical knowledge in land development	k2. Lack of experience and specialist knowledge of land management practice	k3. Contract specialist skills in land management, and/or engage in institutional training to gain necessary skills – go to c4 and h1
l.	L1. Whānau members leading and driving development initiatives leave	L2. Whānau members decide to change their life course, or 'fall-out' with other whānau members	L3. A particular initiative needs to be supported collectively, so that, if one member leaves, there are others to take on the initiative. This is primarily an issue of identifying the right initiatives that get broad support.

'The prime objective of leadership is, the people first, the leader last. By this is meant that one who leads has a deep knowledge and understanding of the role of rangatira (leadership) and its source rangatiratanga…' (Mitaki and Ra,2004)

'Our teachings that have followed us through time have placed much emphasis upon sharing from within the self without thought for reward of any kind.' (Mitaki and Ra, 2004)

Further, in the following quote Herangi outlines the need for leadership to be guided by life principles, or values, that bind communities together, with the goal of establishing direction and a unified body that can pursue collective aspirations.

'Within the family of Māori, the efforts of those who lead has always been directed toward building the integration of life principles that bind us together. The objective of that is to maintain a unified body that is disciplined and organised.' (Mitaki and Ra, 2004)

The wisdom tradition communicated by Herangi and embodied within a contemporary setting by some case study groups raises an important question regarding the role leadership in establish pathways toward sustainability. In particular the Māori model of leadership outlined above emphasizes the role of humility, and in particular the ability of individuals and groups to accommodate and adopt new perspectives that might transcend the views of an individual. Exploring the role of humility and leadership in allowing families, communities and society to unlearn and learn new ways of behaving seems to be particularly relevant to building resilience and the capacity of social groups to adapt to change and new demands to establish ecological balance. Of particular relevance is the adaptive cycle outlined in Figure 6. Such cycles require that individuals and social groups are able to reorganize in response to environmental changes. Reorganizing with appropriate responses is ultimately dependent upon creative decision-making processes that are capable of incorporating new and relevant information. Such processes, from a Māori wisdom perspective, are ultimately dependent upon good political leadership that can establish the conditions for appropriate decision-making.

This raises a transdisciplinary and transcultural theme given that the ability of decision-makers to incorporate information from multiple science disciplines, cultures, and perspectives is fundamental to making good decisions concerning pathways to sustainability. This link between political leadership, information, resilience, and pathways to sustainability needs greater exploration within the ARGOS programme as it provides a means of testing the ability of governance to respond to crisis, whether within particular industries, communities or New Zealand society itself.

GENERAL DISCUSSION

As an outside observer, Le Heron (2005) considered the formation of ARGOS to constitute a unique attempt to re-model research relationships and governance to meet the needs of complex sustainability issues in the context of a highly export-oriented economy. We would add to this an emphasis on the transdisciplinary nature of our research, and the choice of the whole farm enterprise as the primary unit of replication, as additional unique features of the ARGOS project. Overall, the ARGOS programme represents the successful design of a locally grounded study that can contribute both applied and theoretical contributions at local, national and international levels.

The transdisciplinary nature of the design allowed the emergence of the concept of resilience to influence our interpretive framework. In particular we came to understand that there was not one model of 'best practice' in either the kiwifruit or the sheep/beef sectors. Farmers/orchardists could be grouped according to their different practices and cultures, and these made for a more resilient supply system to national and international markets. Some farmers/orchardists followed more conservative and traditional ways of doing things, being a stable source of industry supply. Others were more entrepreneurial and risk-taking, and were a source of learning and innovation. Others were taking time to develop or expand a property. Some were very protective of their land resource. It is notable that such similarities and differences could be independent of audit systems. This development led to the different emphasis of ARGOS 2 on resilience to shocks and pathways to sustainability.

The following section provides a discussion of the strengths and weaknesses of the design of the first phase of the ARGOS programme, and the valuable lessons learnt in undertaking such an ambitious longitudinal transdisciplinary study. We then consider some of the challenges and opportunities for the next 20 years of the research programme, including the proposal of future studies and new research directions.

Strengths and Weaknesses of ARGOS Design

Representativeness and ARGOS's zone of inference

The ARGOS design imposed several limitations to the representativeness and zone of inference, but also provided a number of important benefits. We found that ARGOS panel farms exhibited similar average sustainability indicators and characteristics to nearby farms (Fairweather *et al.,* 2007a). ARGOS results are therefore likely to be reliably representative of wider farms of their type. In addition, ARGOS achieved a wide zone of inference by sampling clusters spread throughout the main areas of production for each agricultural sector (although the absence of sampling of kiwifruit in Hawke Bay, and of sheep/beef farms in North Island hill country are the conspicuous gaps, so we urge caution in presuming that our results apply in those regions). Similarly, ARGOS has structured its investigations across a broad continuum of farming intensities so that commentary about some generic aspects of New Zealand agriculture is possible. We have successfully established a cost effective and broad sampling framework that can now be deepened by further long-term research. One of the interesting differences between disciplines collaborating in ARGOS was that the ecologists were insistent on prior definition a zone of inference to guard against extending conclusions and predictions beyond the limits of the data and sampling available. In contrast the social researchers were resistant to any such prior definitions and some even asserted that they did not have susch a concept.

A potentially important constraint to ARGOS's zone of inference is that we have only selected farming enterprises that are successful enough to persist for a sufficient period to allow examination; in a sense, this means that all of the selected study farms are relatively sustainable (Moller, 2005). Imagine a bucket with holes drilled in the top half. We continually pour in water (more farms attempt to convert to organic) but most drains out (i.e., farms fail as organic enterprises). The ones most likely to fail may be on unsuitable land (for organic growing) or may involve unfavourable financial circumstances, limited knowledge or skills, or lack something else that is important for sustainability (e.g. stubborn staying power or independence). In addition, challenges to sustainability and resilience are likely to be very different for a recently established farming enterprise, or one recently converted to organic, compared to a long established enterprise and farm. Since the ARGOS longitudinal design only sampled the successful long-stayers, we might wrongly conclude that outcomes for everyone are like those in the successful group. This is a problem in any longitudinal study, but unless exit interviews are performed on those failing, or failure rates of converting cf. non-converting farms are formally compared, caution is required to avoid interpreting a lack of observed difference among survivors as evidence that farm conversion does not cause real differences. Future research should analyse the organic register to determine whether turnover rates are different for organic growers. If not, we can be confident that this potential confounding effect is not driving the lack of panel differences.

Is ARGOS's statistical power adequate and inferences reliable?

Repeated rejection of the ARGOS null hypothesis indicates that replication is sufficient in many instances to detect the differences (effect sizes) occurring between farming systems. This finding suggests that the fundamental design contains appropriately balanced depth and breadth by investing in enough replication for many of the sustainability indicators of importance. Nevertheless, we urge extreme caution in interpreting the lack of a significant difference as evidence of a lack of actual difference between farming systems, unless a calculation of statistical power has first demonstrated that we would indeed have been able to detect any meaningful difference between the panels. For example, very few statistically significant differences have been detected between panels for financial indicators (Greer and Kaye-Blake, 2009). This finding could (a) result from inconsistency between accountants in the way they aggregate and report financial stocks and flows, or (b) indicate that financial performance is so variable between farms that we cannot detect average panel differences that nevertheless do exist, or (c) arise from a mixture of these reasons; or most fundamentally, (d) indicate that conversion to organics does not trigger average shifts in financial outcomes. As price premiums for conversion to organics are partly engineered by industry players to incentivise supply of organic produce rather than purely being market driven by consumer willingness to pay, we actually expected relatively little difference in economic outcomes (especially profit) between panels. This assumption would suggest that (d) is the more likely reason for lack of significant differences in economic performance, but some contribution of a-c cannot be excluded *a priori*.

Assessment of the power of a study to detect differences, or to assess the reliability of inferences and conclusions from the research, is often an intuitive and skilled judgement of the experienced researcher rather than a formal calculation of power using metrics. The concept of analytical power is somewhat foreign within the qualitative approach – as is, to some extent, the concept of inference. For example, a published qualitative analysis holds value (is powerful and allows for inference) to the extent that its findings are founded in an acceptable and appropriate methodology and it provides a logical and coherent set of findings. Inference holds subject to similar explanations holding in other analyses. Commonalities across several similar analyses would suggest more reliable inference—but this reflects the explanatory power of the arguments over diverse contexts. The power of the analysis of a given project's social research is therefore difficult to establish in isolation, and instead the social researchers exert considerable effort to place findings within the literature. Where consistent with that literature, the inference of the observation can be extended; where contradictory, social researchers can begin to offer explanation of the influence of context that might explain why the 'unexpected' result has been found. Quantitative scholars follow the same *post hoc* comparisons to create a meta-analysis for evaluating whether an observation is as expected from earlier research, and if unexpected, context and rejection of methods or models follows. However the quantitative scholars also commonly examine statistical power of sampling in the first instance to test whether the initial observation is likely to have arisen by chance because of low sampling intensity or high spatial or temporal variation in the metric under examination.

Even where metrics and variance estimates are available, we have found that the standardised and formulaic methods to calculate statistical power are too simplistic for a nested and clustered design like the ARGOS programme. We are therefore developing a generalised simulation package that can be customised for the ARGOS design to calculate statistical power for comparing indicators between panels and trends in those indicators. A preliminary calculation of power from the package has already been applied to bird abundance and diversity metrics (Macleod *et al.,* 2012b) and soil quality measures (Monks and Macleod, 2012). Future ARGOS research will run simulations for all the key longitudinal monitoring investments to ensure that power is adequate and research and monitoring investments are optimised (Manhire *et al.,* 2012) i.e. just frequent and intensive enough to detect differences and trends while not wasting resources on expensive monitoring).

Different disciplinary approaches to clustering of study plots

Prolonged discussion about clustering during the experimental design process revealed intriguing differences in the traditions of scholarship between the disciplinary teams. Ecologists in ARGOS routinely matched study plots and immediately sought to 'control' for variation in soil type (a base driver ecological productivity just as much as it drives farm production of foodstuffs or fibre), temperature (a key driver of animal and plant growth rates) and rainfall (a frequently critically limiting variable in herbaceous ecological communities). In practice, this need for ecological matching was reduced to finding farms with requisite farming system regimes that were as close together as possible (Figures 2-4), then checking that they had similar soil, altitude and aspect profiles. The ARGOS ecologists further sought to match 'landforms' where intensive sampling was concentrated within each farm. The farm management team matched for predominant farm produce type (mixed cropping cf.

predominantly livestock; similar sheep/beef ratios) and had a bottom line that farms within the panels needed to be of a viable size and have a serious commercial orientation. The economics and social teams did not seek to impose any matching criteria whatever, so we can expect any effects of economic and social conditions to generally be uncontrolled in the ARGOS design and analysis of results. This makes any differences observed in the economic and social domains to be more broadly applicable to wider population of farmers and farm enterprises, but it may have dented the power to discern social and economic differences between farming systems.

Issues arising from structuring the design around a null hypothesis

The research team stridently debated the value of framing such a null hypothesis as a heuristic tool for ordering initial research planning. It suited initial comparisons of the current sustainability indicators on different types of farm, and the way these might or might not be transitioning as different types of farming systems were established or maintained by participating farming families. Nevertheless, the very act of stating a null hypothesis precipitated some of our first intriguing, albeit somewhat disconcerting, realisations of the different approaches by which each discipline seeks to break down complex problems (like 'sustainability').

One benefit of orientating divergent research strands around a single null hypothesis was that it forced us to confront the relative importance of variation between farms (and farming families) within each panel compared to the way their counterparts performed on average. However, the environmental research team in particular was concerned that focus on a simple null hypothesis would divert attention from investigation of the mechanism (why differences occurred) which they saw as the key to sound advice on transitioning farming practice to more sustainable orientations. Ecologists expected that the most interesting and useful information would probably be found in the variation within panels rather than comparisons between them. Part of these differences in emphasis stem from ecologists pre-occupation with environmental variation in different places and times, and partly from their frequent disappointment in statistical power to detect pattern (like mean differences between panels) when faced with such natural variation and the high cost of environmental sampling. The environmental team expected ARGOS to accept the null hypothesis much of the time simply because of low statistical power and the way any 'signal' (e.g. different outcomes from converting to organic farming) was likely to become lost in the 'noise' of local environmental variation predominating on individual farms or between years. Even if the null hypothesis was rejected, the really challenging and crucial next steps would be to find out why the difference occurred and what its consequences will be for sustainability. The environment team supported the group need to order multi-disciplinary investigations around a common null hypothesis as a first step, but set a goal that focus on the null hypothesis would concern 80% of research investment in years 1 and 2, reducing to 70% in years 3 and 4, and 60% in years 5 and 6. Although research investments trended in that direction, the transition took a lot longer because it is extraordinarily expensive to initiate and develop robust ecological measures.

Future opportunities and challenges for ARGOS

The ARGOS research team has now established a common vocabulary and understanding between different disciplines and team members, a transdisciplinary research culture and a critical momentum. The exploratory phase of the study is complete, and primary methods have been tested and perfected. A relatively stable set of panels of study farms has been established, although conversion of sheep/beef farms to other types of farming and the sale of other properties means that the sheep/beef panels will need to be "topped up" for the next phase of ARGOS's longitudinal study. Farmer and industry level support is strong and has remained steadfast. A prioritised and reduced set of sustainability indicators has been identified for long-term monitoring, and power simulations are underway to optimise the frequency and intensity of monitoring to make the long-term study as cost-effective as possible. We expect that a robust trend analysis will not be possible for most environmental indicators until another 6 years of monitoring have been completed. Many of the economic indicators vary greatly between years, so trend detection will be even more problematic for them. As social scientists are interested in change and in particular, for this project, governance, we are also interested in what influences change and how social change is reflected in farming practices. Moreover, ARGOS is very much tied to exploring the links between markets and farm products and practices. As before, this analysis will be of a more qualitative, interpretive nature.

Research process challenges arising from a 30-year longitudinal design

The expectation to maintain the ARGOS programme for 30 years led to several practical and tactical decisions regarding how the research was conducted and managed. The first phase of research led to an appreciation of a number of salient qualities for research of this type to be successful, listed in Table 9. In the ARGOS case, we seriously underestimated the time and investment required to forge a team and common consensus of how to tackle a transdisciplinary and complex systems level inquiry like agricultural sustainability. This suggests that future expectations of rate of progress need to be moderated to be more realistic and the new members of the ARGOS team will need to be selected as much for their team and transdisciplinary working skills as for their disciplinary expertise and relevance.

Table 9: Design and team management challenges to establish and maintain a long-term transdisciplinary research project. *These recommendations are based on ARGOS's own experiences and reviews of long-term studies in ecology (Strayer et al. 1986, Likens 2001, Moller et al. 2009)*

Leadership, direction and ongoing access to study sites

- Dedicated guidance by one or a few passionate leaders that have time to concentrate on the group's agenda
- Manage transfer of leadership when leaders retire
- The team needs to accept guidance – good followers are as important as strong leaders
- Keep the project design simple
- All participants collaborate to firmly prioritise the research activities
- Clearly define objectives to help long term coherence (c.f., descriptive studies which might wander and be never-ending
- Manage ongoing access and protection of sites (implement a farmer retention strategy); Exhaustion of participating farmers and therefore attrition in panel membership was identified as the key risk
- Co-authorship of academic papers needs to be managed to incentivise group and individual contributions and establish career opportunities for long-tern researchers

Consistent methodology

- Standardise methods as soon as possible
- Minimise changes in methods even when new options seem better
- Calibrate new and old methods against each other if changes must occur
- Save reference samples
- Collect general historical information (e.g., aerial photos are very useful for retrospective ecological analyses)
- Cross-check measures between laboratories if technically demanding assays are performed

Maintaining data quality and institutional memory

- Maintaining data quality and consistency of measurement has proved difficult and demands careful management
- Record in painstaking detail the research protocol and minor adjustments to it as you go – it is unlikely that the people who designed and collected the data will also be those that analyse it in the longer run so a clearly traceable research path must be described
- Eliminate redundancy in data collection as soon as possible
- It is exhausting to have a large number of temporary workers and students, so their contribution needs to be curtailed and completely annotated and reported before they leave and are swallowed by other priorities
- Staff retention and support is key
- A senior-level technical field or group manager is needed to maintain institutional memory of ground-level logistics, study areas, participants and oversee data quality and storage

Table 9 continued:

Data management is crucial

- Database establishment and management from the outset; more than 20% of the budget should be allocated to this issue
- A user-friendly database is needed to encourage participation and contributions from all disciplines
- Collective data must be made available to all team members to encourage group collaborations
- Availability of group databases to outsiders can bring synergy and power, but needs to be managed for risks (e.g. misuse because of lack of consultation with those that collected the information and understand its weaknesses, erosion of group funding opportunities by others capitalising on our investments)
- IPR / Privacy of farmers must be maintained and demonstrated to retain the trust of the primary research participants

Selection of the type of people that can maintain group commitment. The personal qualities and values required include:

- Trusting and trustworthy
- Abundant common sense
- Creative
- Willingness to share with team
- Collective ability to make up deficiencies
- Willingness and capacity to give the team time
- Flexible (serendipity reigns)
- Patience – transdisciplinarity takes a lot longer than most researchers at first assume
- Ability to listen
- Ability to assert expertise and alternative views
- Enjoy working with others
- Curiosity / interest
- Open to new ideas
- Courage to take risks and experiment in a transdisciplinary way while retaining scepticism and the fundamental requirements of their own discipline
- Liking for one another (otherwise they are unlikely to link with each other)

The main ARGOS sampling framework is quasi-experimental in that land, enterprises and farming families that adopted IM or organic farming systems were not assigned randomly and then followed as their enterprise and attitudes transition to the new market accreditation[20]. Most of our research has simply compared sustainability indicators associated with already converted farms. In many cases we rejected the null hypothesis (Maegli *et al.,* 2007; Campbell et al., 2009; Carey *et al.,* 2009, 2010; Magbuani *et al.,* 2010; Todd *et al.,* 2011; Campbell *et al.,* 2012; Fukuda *et al.,* 2011; Macleod *et al.,* 2012a; Fairweather *et al.,* 2006, 2007b, 2007c, 2008a, 2008b, 2009a, 2009b; Hunt *et al.,* 2005, 2006; Rosin *et al.,* 2007a, 2007b, 2007c, 2009). However such differences provide evidence of the effects of conversion only if conditions on the farm and the subjectivities and attitudes of the famers were the same on average before conversion to their market accreditation schemes (Moller, 2004; Blackwell *et al.,* 2011). For example, we found that farmers choosing to convert to organics already had lower production before starting the conversion process (Figure 5), and others may have chosen to buy land that already had diverse and profuse woody vegetation cover to support biodiversity, or fenced off riparian zones. Conversion to organics may be triggered by poor overall financial performance of the sector because organic farming requires less immediate expenditure on inputs – the financial crisis in the kiwifruit industry was a key driver in conversion to organics in the 1980s (Darnhofer *et al.,* 2010). Similarly, ARGOS's IM panel in the sheep/beef sector was actively recruited by a meat processing company (i.e., they selected top performing farmers, especially those that could supply high quality meat at crucial periods of the year to supply overseas markets). Accordingly, some of the differences we have observed between panels may reflect the 'capture' of particular land, enterprises and families rather than reflecting a consequence of converting *per se*. This is only a problem if we assume that conversion is solely the product of individual decision making. Social theory is largely predicated on highlighting the impact of social context on the choices available or accessible. We expect that a mixture of these effects combine to generate the (limited number of) observed differences between panels in ARGOS – for example, even though milk production prior to conversion to organics was lower than on conventional farms, a clear pattern of increasing differences in production emerges as conversion effects become embedded in the farming system (Figure 5). As such, recent differences in milk production are partly a result of prior land conditions or orientations of the farmers who decided to convert to organic, but are much more strongly caused by the actual conversion process. Since a BACI design was only achievable in the dairy panel, we cannot be certain that the other preconditions affected the results in the sheep/beef and kiwifruit sectors.

One potential solution to this problem is to include 'time since conversion' in statistical modelling as a test that conversion to organics or IM actually causes the shifts in sustainability indicators (Moller, 2005). However, if the shift in an indicator is too slow, virtually instantaneous, or temporary, this approach will not test causation (Figure 8). In addition, it proved impossible to include an equal spread of farms that had converted recently, some years ago, and a long time ago. Accordingly, time since conversion is a weak tool to test

[20] A formal experiment requires that samples are allocated at random to different treatment groups; that an experimental manipulation is imposed (and usually measured) which is the only thing varied (other potential disrupting variables are thereby 'controlled'); and that the consequences of just the experimental manipulation is studied.

causation in the ARGOS study. Long-term monitoring of the degree of difference between panels is the remaining way of detecting slow shifts in farming outcomes, so we look forward to having longer runs of data to test whether the observed differences in indicators are stretching or trending in the same directions.

The ARGOS project is in its infancy and will need to be sustained for another 20 years before its full potential is realised. Ongoing monitoring builds statistical power for all the questions we have already investigated in a preliminary way, including detection of long-term trends in sustainability indicators. However improved understanding of resilience to shocks and systems-level responses will also emerge from researching inter-annual perturbations in sustainability indicators.

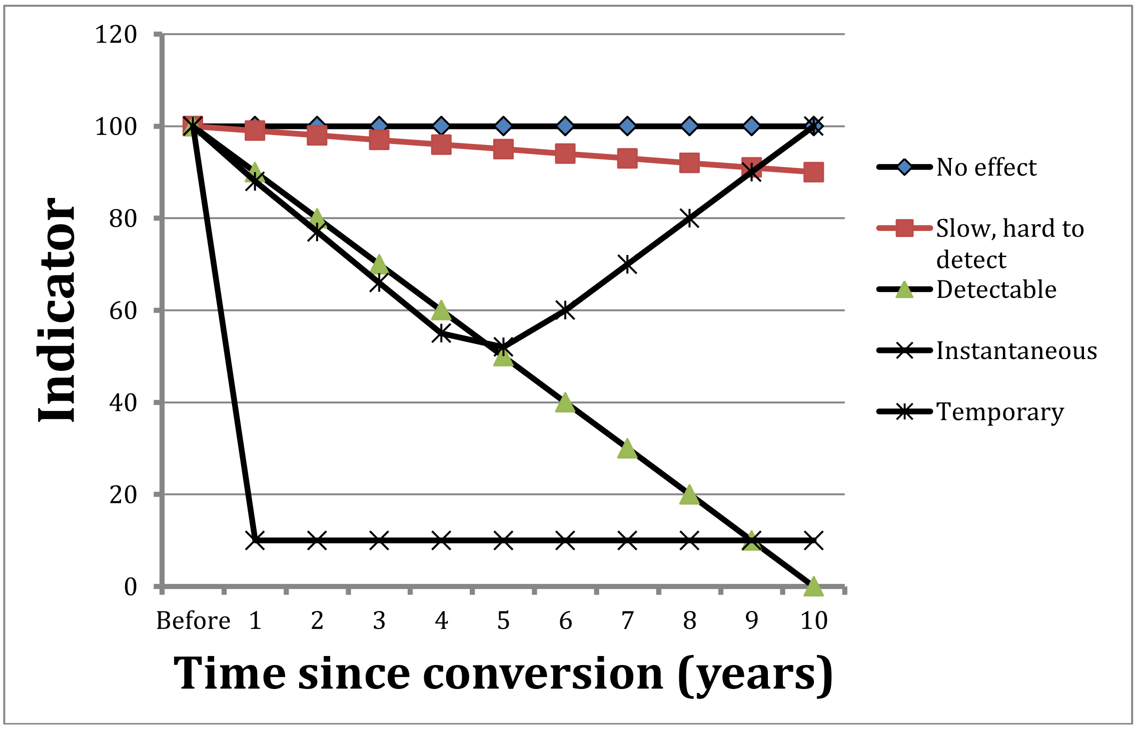

Figure 8: Hypothetical trajectories in sustainability indicators following conversion to IM or organic. *Changes are depicted as declining indicators, but could equally be increasing following conversion. If no 'before conversion' measures are available, association of indicators with time since conversion will only test causation for moderately fast and prolonged changes. Near instantaneous changes will not be detected even if conversion to a new farming system causes a shift in sustainability indicators.*

There is little practical value in simply demonstrating that some difference exists between panels if we cannot show that the difference actually results from (i.e., is caused by) the different methods of farming. Certification might indeed act as a rallying point for adherents to a philosophy and some customers, and this might be enough for a relatively short period – but in the longer run if we cannot demonstrate 'real' change in sustainability/resilience outcomes, confidence in the market brand will be eroded. We expect that many farmers signing up to market accreditation programmes may initially do so purely for short-term gains (especially premium prices and access to high quality markets) rather than because they particularly embrace and act on the philosophies embodied in the rules of the accreditation systems. However, it may be that compliance with the rules eventually changes the understanding and beliefs of the farmers themselves (pathway C in Figure 10) so that farmers eventually stretch beyond the minimum requirements of the market accreditation itself. Once environmental care and social concerns are fully embedded alongside economic performance in the farmer's belief system, innovation and accelerated transition to more resilient and sustainable farming will be locked in to secure long term gains in land care and community care in New Zealand.

Experiments to test causation and improve models

Modelling will enable ARGOS to transcend a purely monitoring framework in other ways by running "virtual experiments" to test the efficacy of different farming sustainability strategies. It might also identify optimum trade-offs between environmental, economic and social goals of multi-functional agriculture. However model predictions will only be reliable if the underlying system is well understood and a reliable causal link has been proven (or can be inferred) between elements of the model. Changing farm practise can be expensive, either because new infrastructure or equipment and time inputs are involved, or if the advised changes actually decrease farm profitability without capturing added benefits for the farmer. Experiments are perhaps the best way of proving causality when researching the biophysical components of the farming system and their interactions and feedbacks with each other. However experiments are also expensive and in practice many of them are often insufficiently replicated or maintained for too short a duration to provide reliable inference (Raffaelli and Moller, 2000). Future research in ARGOS should therefore perform only a few experiments to embed within the wider quasi-experimental design of the overall whole farm sampling framework. The most important experiments would be those identified as key predictors of sustainability outcomes, production and profitability from the first stage of ARGOS, or those subsequently identified by an elasticity analysis of preliminary models as the most critical to improve the accuracy of predictions. We propose that well replicated trials at individual Management Units (blocks or bays in kiwifruit; paddocks in dairy and sheep/beef farms) on a subset of well-matched farms be conducted first, until preliminary results confirm that putative causal links exist, and, if so, that they are quantitatively important enough to explore further. If the experimental lead is promising, these small scale experiments can then be replaced by what Walters and Holling (1990) call 'active adaptive management' trials at the meso-scale (larger parts of more orchards and farms) and even whole farms in a way that then more safely guides farmers to transitions for increased productivity or sustainability.

Experimental tests of the link between fertiliser inputs and production are a prime example of the value of such future well-focussed experiments within the wider ARGOS framework. The first phase of ARGOS has formed a general hypothesis that many farms overfertilise their land in order to guarantee high productivity. Fertiliser costs a lot, is a large component of a farm's energy budget, adds risk of pollution of waterways and is seen as a key component of the ecological subsidies that is part of farming intensification. However, if fertiliser application is reduced too much, production and profitability may be reduced. Small-scale well-replicated experiments of different fertiliser application regimes and associated measures of changes in quantity and quality of production are therefore potentially very valuable as guides for potential changes in farming. The transdisciplinary nature of ARGOS and its whole farm approach is ideally placed to predict the outcome were farmers to change their management to match the experimentally demonstrated optimum outcome. Social dimensions of our research can explore barriers and enablers of the farmers to a proposed change and interpret the uptake of the experimental lead (or lack of uptake) in a wider context of farming attitudes and praxis. Several other high priority experiments can be identified and prioritised for future ARGOS research.

A shift to more predictive modelling

Long-term monitoring of sustainability indicators is an important traditional method of assessing sustainability – it is equivalent to monitoring whether economic, social, human and natural capital is eroding, being maintained or increasing. Maintaining capital stocks will future-proof farming by keeping the land, farmers, and associated agricultural networks fit for current use. Also, transformative resilience theory predicts that high capital stocks are key enablers for farmers to transition to new ways of farming when external shocks and drivers demand it. High capital gives confidence and a safety margin to allow experimentation and contemplation of change. It generally provides "ballast" for the system in times of turbulence while its actors learn to farm more effectively in new conditions. Overall, high economic, social and natural capital provides a wider range of choices for transition and improved means to pick the best choice for each specific piece of land and family. Although it remains extremely valuable, monitoring the long-term trajectory of capitals, and their indicators (proxies) is not a sufficient approach on its own to guide sustainability and resilience. Knowing why the observed trajectory occurs is the key to advising how to maintain or alter the trend according to the needs of society. More fundamentally, monitoring is always about looking backwards rather than forwards – the equivalent of trying to drive a car safely on a long journey by only looking into the rear-vision mirror. Past trends will only guide future trends if nothing important changes in New Zealand agriculture. In reality, a set of drivers and shocks threaten New Zealand agriculture as we know it (Figures 1 and 9), so even if farmers change little themselves, conditions around them will potentially make formerly sustainable practices unsustainable (or conceivably, by chance, solve current problems by enabling more sustainable outcomes). The ARGOS programme is dedicated to future-proofing New Zealand agriculture by informing preparation and predicting problems and opportunities in advance so that farmers, industry professionals and national policy makers can transition to remain resilient and prosperous. In contrast to monitoring, predictive modelling is a forward-looking approach, generating predictions based on simulations informed by measured data sets. These predictions can then be used to guide future decision-making by running "virtual experiments" that can test sustainability outcomes from different choices.

Figure 9: Drivers and shocks triggering turbulence in New Zealand agriculture.

Evidence from the *He Whenua Whakatipu* objective suggests that the wisdom of leadership will be a predictor of levels of resilience to external shocks. In particular it is argued that the ability of leaders to incorporate information from multiple science disciplines and communities into their decisions, and maintain support from their communities of interest in the implementation of decisions, is crucial to establishing appropriate responses to environmental, social and ecological perturbations. Ultimately this involves examining the openness of leaders and their communities to learn and unlearn. Those unable to adapt to change should ultimately be unsustainable. Arguably wise leadership should sit under the capital stock theory given that quality leadership is essentially a form of human capital. However, the decision to build and generate capital stock to improve resilience is ultimately dependent upon wise leadership, which makes this category transcend other capital-stock categories in a unique way.

The ARGOS programme therefore proposes to shift into a more predictive modelling approach in the next phase of its funding. A range of potential model types are being evaluated in 2011/12 for model construction in the following four years. An optimal subset of models will be constructed using ARGOS's current understanding of how to depict the systems. Where possible, ARGOS's measures of key features of 100 farms and results published in the literature (and possibly data from MAF monitoring farms) will parameterise these models. Elasticity analyses from preliminary models will prioritise gaps in knowledge for subsequent research to construct increasingly accurate models of New Zealand whole farms and critical components within them.

The salient advantage of using a working model is that we will be able to simulate upcoming shocks and drivers of change and "experimentally" explore outcomes from potential responses of farmers, industry actors and national policy makers in a virtual arena. The transdisciplinary nature of the ARGOS team will enable it to construct a complete set of realistic scenarios for shocks and drivers, and perhaps understand how a complex adaptive system like New Zealand agriculture will respond. Nevertheless, incorporating social, economic, environmental, and farm management feedbacks into a model will be extremely challenging. It is realistic to expect initial models to be crude and predicted outcomes uncertain, so there is a need for scepticism and testing of models before their predictions are considered reliable or even useful.

The ARGOS monitoring framework provides three central questions that provide opportunities for checking model predictions: (i) Does the model predict the trajectory in sustainability indicators and production observed in ARGOS's longitudinal study?; (ii) Does the model predict the differences seen on average between organic, IM and conventional farms?; and (iii) Does the model predict the variation in sustainability observed between individual farms within each panel? It will be important to construct the model from data other than that tested as response variables – otherwise the correlation of model predictions and observed data is only an "internal validity check" for consistency (akin to testing whether the model's sums have been done correctly) rather than a full "external validity check" to test whether the system has been configured accurately within the model. Model predictions should only be considered reliable if the model passes these validity checks and ARGOS's longitudinal monitoring study is able to continually update and check successive generations of models to converge on a more reliable prediction of the system's ability to absorb shocks and drivers or transition to new states.

A need for increased investment in dairy research

ARGOS funding has been most constrained for studying dairying, despite this being conspicuously the most important agricultural sector in New Zealand (based on economic value), extending over an increasingly large area of New Zealand (Table 1). We propose to increase funding of the dairy research in ARGOS3, provided that sufficient funds are secured to not compromise existing investments in the kiwifruit and sheep/beef sectors. A full BACI design has been achieved in dairy already, and differences between farming systems are predicted to be most strong there (Table 5). In addition, a strong 'conventional' panel persists in dairy (it has completely vanished in the kiwifruit industry; Table 3). These strengths make dairy results more interpretable than those in other sectors. Moreover, dairy is also the agricultural sector that is most under public scrutiny in New Zealand for its environmental impacts.

Potential addition of a dairy conversion study

A rapid increase in the number of 'dairy conversions' (former sheep/beef farms converted to dairy), in most cases supported by irrigation, has attracted increasing public concern in New Zealand. Our meta-analysis of differences between farming systems across three sectors offers only very course predictions about the environmental, social and economic outcomes of converting farming from one sector to another, especially when a new input like irrigation accompanies the shift. By far the most powerful inference will emerge if a BACI design is deployed as farms convert from sheep/beef to dairy farming. ARGOS cannot stretch to study this important development without an increase in funding, but adding a conversion study would neatly complement existing ARGOS work and would be cost effective because the research team infrastructure has already been established and methods developed. The optimum design would be monitoring a cohort of 12 clusters, each with three farms: one long-established dairy farm; one farm converting to dairy; and a third remaining as a sheep/beef farm. It could be that irrigation and dairy conversion effects can be partitioned by choosing half the clusters in areas where irrigation made the conversion possible, and half where no (or limited) irrigation is involved (e.g. Southland). Some localised ecological effects could also be investigated by comparing irrigated and non-irrigated parts of the same farms.

Transdisciplinarity: a challenging but eventually rewarding research process

A distinguishing feature of the ARGOS programme within New Zealand agricultural research is its honest (if at times somewhat turbulent and frustrated) attempt to break down disciplinary boundaries to meet the complex and multi-dimensional problem of determining what enables and constrains sustainability and resilience. We therefore decided to monitor and report our own experiences and reactions to transdisciplinary research practice itself and so far have reported twice on some of the key criteria for success (Moller *et al.,* 2008b; Hunt *et al.,* 2010).

ARGOS's original FRST research grant application arranged objectives around agricultural sectors (e.g. dairy, sheep/beef, Māori, kiwifruit and pip fruit) rather than academic disciplines. This structure would have naturally forced integration between academic disciplines because the design of research and immediate application of results would have to be packaged for end users in the way they primarily see their responsibility – to build the sustainability and resilience of their own industry. However award of only partial funding forced major re-arrangement of objectives to reflect the contraction of the scope of the overall programme. In addition, FRST contracting managers urged restructuring of the programme around classic academic disciplinary boundaries (social science, economics, ecology) as described above. In retrospect, we now see this as unfortunate because it reinforced disciplinary partitions. In particular this was unfortunate in relation to Objective Two (the Māori objective), which became to some extent the 'odd one out.' This was because *He Whenua Whakatipu* was not in itself a discipline but a case-study oriented investigation on Māori land development. In reality, this objective should have been developed horizontally across the disciplines given that it was investigating social, economic and environmental phenomena simultaneously. However, this structure was precluded by kaupapa Māori ethics and the desire of Ngāi Tahu to drive the research. This demanded that the research be focussed on solving problems relevant to those involved in the research (the case studies), and committed to community involvement in the research process itself. This required a strong participatory development and action-learning approach was not compatible with the methodology adopted across the rest of the programme.

The ARGOS programme somewhat underestimated the difficulty of establishing genuinely transdisciplinary synergies and the time required for researchers in each discipline to learn each other's' terminology, gain trust in each other, abandon certain disciplinary traditions and take risks (Moller *et al.,* 2008b; Hunt *et al.,* 2010). Ecology, through its research of systems, multiple spatial and temporal scales, flows and feedback loops might be considered to be ideally suited to transdisciplinary co-discovery of knowledge. However the ecologists in

ARGOS underestimated the practical challenges of applying their science to guide the sustainability of food production. Transdisciplinarity required researchers to find courage to “camp out” in territories traversed by others’ disciplines, to take risks when participating in interpersonal and team collaborative processes, and to jump out of comforting traditional channels of ecological research process (which use reductionism and frame tightly focused questions, explicitly define zones of inference and assumptions, demand repeatability of evidence and prediction, and seek evidence of causation from observed patterns).

The difficulties ARGOS faced in achieving effective transdisciplinarity can be broadly separated into three categories. One set of issues revolves around understandings of research design and methodological approaches, including: underlying epistemologies; the willingness (and perceived appropriateness) to act as ‘involved assistors’ rather than ‘independent assessors’; the negotiation and prioritisation of the fundamental research questions; deployment of research methods; the meaning and usefulness of data for analysis; claims of significance and the ability to generalise; representativeness, replication and zones of inference from findings. Within this methodological process, a particular dynamic emerged around understanding what each discipline considered to constitute ‘useful’ and ‘reliable’ information. The social research team struggled initially to incorporate concepts of interest to ecologists into qualitative research frames, and vice versa. We were slow to learn the strength of inference arising from complementary quantitative and qualitative methodologies applied with the same farmers and on the same ground. Of all the epistemological clashes, the quantitative-qualitative divide was the most fundamental barrier to forming effective partnerships.

A second set of issues is more directly related to the social and intellectual engagement among project members and with stakeholders and farmer participants. To some extent this reflects the ability of different disciplines to use shared languages, and the emphasis on status based on promotion and publication along disciplinary lines within the academic environment. While postmodern scholarship plays upon the instability of meaning within the terminology of individual disciplines, this is even more challenging across disciplinary fields. The first three years of the ARGOS project contained many team discussions seeking to accurately establish what researchers from different disciplines meant by terms like: systems, feedbacks, functionality, redundancy, normative, significance, sustainability, resilience, intensification, post-modernism, structuralism, materialism, subjectivities, habitus etc. A somewhat surprising corollary for some team members emerged from the realisation of the extent to which disciplinary separation is peculiar to ‘pure’ as against ‘applied’ academic discussion. Engagement with farmers and with industry groups demonstrated that food production is intrinsically a transdisciplinary activity. Farmers do not operate their farms along the lines of academic disciplines and have, by contrast, become practiced at reintegrating isolated streams of knowledge (like soil fertility measures) back into the wider complexities of their farming system. Likewise, we found that some industry groups had become impatient with traditional agricultural science for producing ‘innovations’ that failed to connect with the complex realities on the farm.

Beyond the level of effective communication, several situations suggest that the specifically academic/scholarly context of the project created additional barriers to effective collaboration. Often progress toward transdisciplinarity (in contrast to cross-disciplinarity or multidisciplinarity) was constrained by the willingness of researchers to take risks that challenged established patterns of explanation and research in their respective disciplines. Instead of pushing the boundaries of understanding and perspective, challenges to proclamations framed by disciplinary perspectives were sometimes met by intractable defensive stances. Individualism encouraged by academic training and professional advancement limited the desirability of collective engagement (although physical scientists appeared to be more used to working in teams and producing co-authored publications compared to social scientists). Finally, the development of strong champions of transdisciplinary approaches and outcomes in ARGOS was hampered by a shared unwillingness to assume leadership given the particular configuration of researchers in the team and the hesitancy to assert claims to prominence.

We found that achieving personal transitions to enable transdisciplinary engagement was just as important as resolving the intellectual challenges of synthesising quantitative to qualitative information, accepting different traditions of problem definition and hypothesis or model generation as valid, and dealing with enormous systems and parameter uncertainty. Our experience suggests that members of transdisciplinary research teams need to possess and nurture a balance of humility and confidence if they are to persist long enough to reap the excitement and reward from melting and recasting disciplinary structures and boundaries (Table 9). Although we now realise that achieving deep transdisciplinary will be much slower and more difficult than expected, we remain convinced that it is essential for finding innovative global, national and local solutions for a problem as complex as ensuring sustainable food production.

The ARGOS experience with transdisciplinary approaches to the analysis of sustainability points to several general recommendations for the analysis of sustainability. First, the utopia of transdisciplinarity provides a valuable perspective from which to motivate greater collaboration within the research group. It is fundamentally important to establish a non-threatening environment in which the perspectives of all participants are acknowledged and valued. As trust develops within the group, researchers must be willing to accept the risk of exploring alternative methods and representations of data in the spirit of greater understanding and collaboration. The research team needs to be stable and have adequate time to dedicate to the project. There is a need to actively plan for transdisciplinarity and manage the process in a reasonably structured way, while remaining flexible about where the process will end up. Pay more attention to good process and team relationships than planning concrete milestones and timelines. Expect surprise, uncertainty, fear, and excitement – but this should not be expected to happen without active management and adequate resourcing. All this planning, resourcing and emotional effort is clearly necessary, because participants are likely to retreat to their own discipline's comfort zones, especially when group collaboration is attempting to solve a complex 'wicked' problem like unsustainable primary production (Ludwig, 1999).

Pathways to sustainability other than market accreditation

A more nuanced and complete integration of between-panel and within-panel comparisons gradually emerged within ARGOS's collective research, as shown in Figure 10. This approach allowed more space to examine alternative pathways to sustainability beyond the putative importance of accreditation to market audit schemes (a theme that is being explored further in ARGOS2). We were particularly interested in the potential role of transformations of the sustainability orientations of individual farmers that might lead them to act (or not act) in a particular way, irrespective of the requirements of QA accreditation. This later transformation was articulated by the environment team as the formation and enrichment of a 'land ethic' amongst farmers, by which environmental care within production landscapes might catch up to eventually match the embedded and strong national investment in preservation-oriented conservation within non-production areas like National Parks (Norton 1998; Norton and Miller 2000; Perley *et al.,* 2001; Macleod *et al.,* 2008). ARGOS's *He Whenua Whakatipu* objective team enunciated a similar yet culturally distinct pathway to individual and especially whānau-level (family-level) transitions (pathway 'B' in Figure 10). Although our research team has discussed the potential complementary importance of regulation and subsidies as pathways to sustainability, it was decided at the outset of ARGOS to not overtly study these factors. This decision was made partly because regulation and government subsidisation of activities on private property is nationally almost 'unthinkable' in New Zealand's neoliberal socio-political paradigm, partly because New Zealand is not wealthy enough to contemplate subsidisation to any great degree, but also because our collective expectation was that lasting and real compliance with sustainability provisions would necessarily only emerge from voluntary mechanisms (i.e., accreditation to market audits of families acting because of their own sustainability philosophy).

Although for simplicity we divided pathways to sustainability into two alternatives ('A' and 'B') in Figure 10, a systems understanding emphasises the ways in which they interact (Arrow 'C' in Figure 10). Therefore, one of the most important transdisciplinary questions for ARGOS researchers was whether subscription to a market accreditation scheme, perhaps at first motivated largely by financial returns and market security, may eventually change the sustainability orientation of the farmers themselves, leading them to develop their own land ethic (Moller, 2005). Equally, rising community and individual awareness may make farmers more likely to sign up to the accreditation scheme in the first place. A mixed model recognises constant positive feedback loops in which a growing land ethic escalates market accreditation and improves compliance with its provisions, while active participation in the accreditation scheme (together with its attendant facilitation and support mechanisms) itself escalates the sustainability commitment of the farmers. The same systems-level and commonly unseen influences of regulation pathways may also be at work in this situation. For example, industry facilitators that actively promote market accreditation mechanisms might be partially motivated by a wish to avoid regulatory 'interference', just as individual farming families may comply with 'their own' market accreditation scheme, even if it involves some relatively unpalatable requirements, because it makes government less likely to impose regulation to ensure land care.

CONCLUSION: THE FUTURE VALUE OF ARGOS

Overall, the first phase of the ARGOS programme successfully designed a locally grounded, long-term, transdisciplinary study that can contribute both applied and theoretical contributions at local, national and international levels. Despite a number of difficult challenges, we have laid a solid foundation for the next 20 years of the research programme. An evaluation of the strengths and weaknesses of the design of the first phase of ARGOS highlighted issues surrounding the zone of inference of the study, the statistical adequacy of our methodology, and the extent to which our design allows an understanding of causation. The next phases of the programme will be designed in careful consideration of these emergent challenges.

Several specific issues emerged in the course of designing and implementing the first phase of our longitudinal research. In particular, the transdisciplinary nature of our programme, with its focus on breaking down disciplinary boundaries to meet the complex and multi-dimensional problem of determining the factors that enable and constrain sustainability and action, was associated with several important difficulties and valuable lessons. It became apparent that we underestimated the difficulty of establishing genuinely transdisciplinary synergies and the time required for researchers in each discipline to learn each other's terminology, gain trust in each other, abandon certain disciplinary traditions and take risks. However, we remain convinced that transdisciplinarity is essential for finding innovative global, national and local solutions for a problem as complex as ensuring sustainable food production.

The unique features of ARGOS's design include strong replication of whole farms and a balanced sampling frame to provide baseline measures for detecting future trends in key sustainability indicators. The value of the baselines will become evident and valuable both nationally and internationally.

Nationally, the need for transitions to more sustainable and environmentally friendly farming is an escalating priority. Public opposition to ongoing intensification is increasing and so far has focussed mainly on dairy farming impacts on stream and lake health, and water allocations for irrigation of dairy conversions. It is inevitable that concerns will spread to the impacts of nutrient and sediment loads on estuaries and near-shore marine ecosystems around river mouths. There is also increasing concern for terrestrial biodiversity and environmental care in production landscapes, as part of a general rise in a New Zealand conservation ethic that is extending its historical pre-occupation with preservation for intrinsic value (by creating reserves in which extractive use is prohibited) to conservation through sustainable use. Similarly, the current emphasis on dairy farming impacts is likely to spread to concerns about sheep/beef farming. New Zealand society and farming stands at a crossroads - will farmers take more proactive steps to invest in environmental care and voluntarily reduce intensification, or will regulation force this upon them? All the legislative mechanisms are in place for regulation, so public opinion and the erosion of the prevailing neoliberal paradigm are the main potential triggers for enforced action. A related debate surrounds the question of who should bear the cost of the environmental good generated from private land: if New

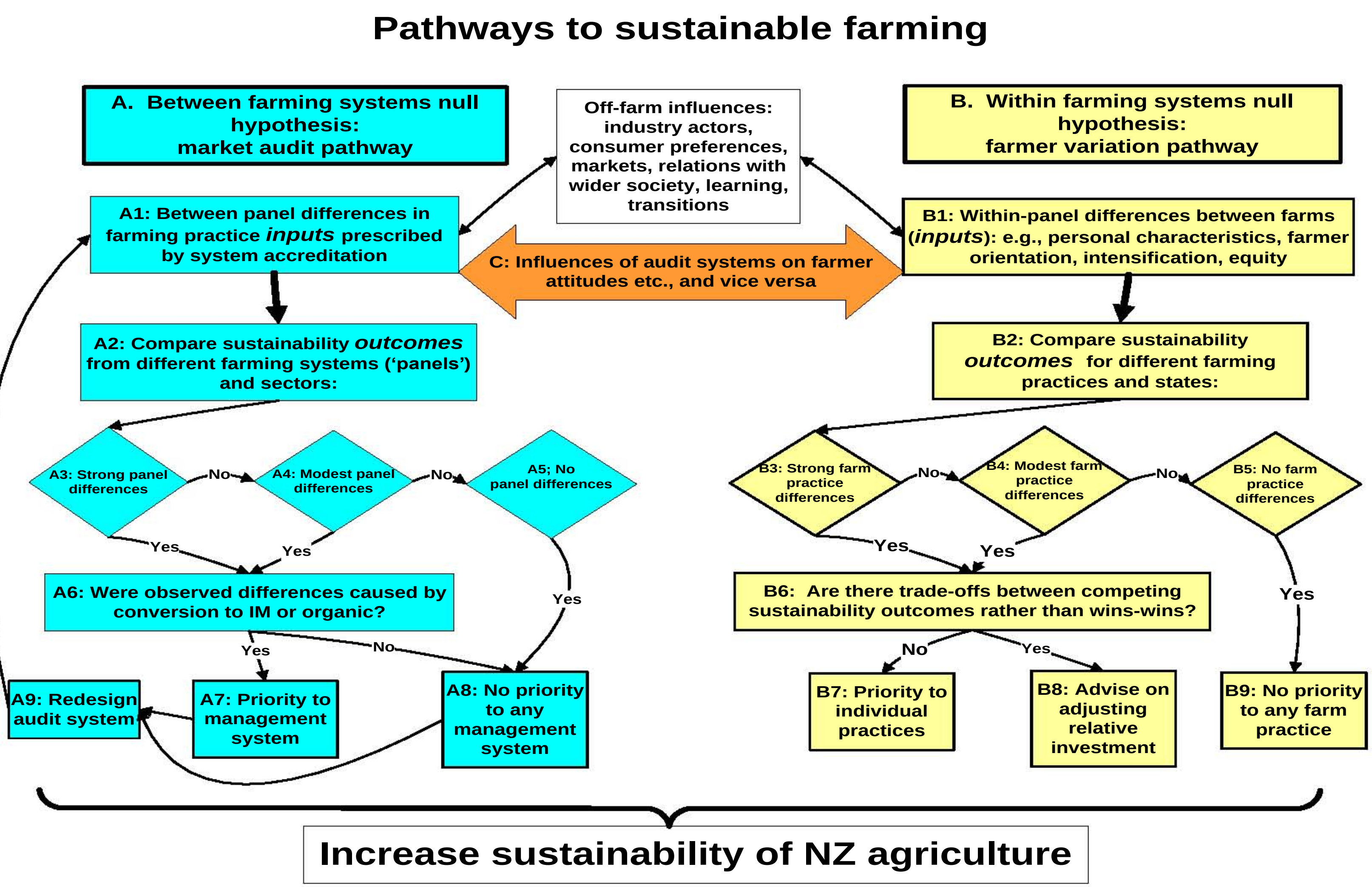

Figure 10. Potential pathways to discovery of sustainable and resilient agriculture in New Zealand.

Zealand's general public demands environmental care on private land, should farmers alone be expected to pay for it?

The role of the market accreditation schemes in delivering transitions to more sustainable agriculture are particularly important in New Zealand, because of the comparative absence of regulation and associated subsidisation of farming to secure environmental care. Nevertheless we believe that ARGOS has much broader significance to agricultural researchers, facilitators and policy makers throughout the world. Although there has been a gathering momentum of research into certified organic agriculture, research of the new market accreditation systems is in its infancy. We expect mounting political interest in Europe and North America regarding the verification of the efficacy of QA systems in delivering sustainability in its full variety of dimensions. This is partly because overseas producers will wish to be assured that New Zealand producers are delivering on their sustainability claims, but also because market driven sustainability measures are likely to partially substitute for expensive nationally funded agricultural subsidies, and because regulation is politically unpopular compared to voluntary subscription to market accreditation requirements. Collaborative research with similar transdisciplinary teams in Scandinavia and UK (potentially Asia and North America later) is proposed to form part of ARGOS3, starting 2012/13.

Building on the successes and learning from the difficulties encountered in the first phase of the ARGOS programme, the upcoming phases are set to continue to provide valuable insights into the increasingly urgent challenge to move towards sustainability in agriculture. We are confident that future investment in this type of long-term, transdisciplinary research can add considerable value to the wellbeing of people and land in New Zealand and internationally.

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APPENDIX 2: GANT CHART OF ARGOS'S MAIN SAMPLING RHYTHMS

Research Objective	Activity	Description
Objective 1: Farm Management	Farm recruitment	Identification of suitable farms and farmers using Industry contacts
	Annual management survey	Field managers interview farmers annually to discuss and document farm management, production and financial outcomes
	Annual stakeholder reporting	Key findings to date compiled into a report for ARGOS stakeholders
	Annual stakeholder workshops	Key findings to date presented to stakeholders by ARGOS
Objective 3: Economics	Annual analysis of financial accounts	Financial data collected during management interviews analysed
	Development of Lincoln Trade & Environment Model	ARGOS data used to develop trade model
	Market access reporting	Global market access issues and trends monitored and reported to stakeholders
Objective 4: Environment	Baseline habitat & biodiversity survey	Each farm surveyed to identify habitats & animal biodiversity (incl. bats, birds)
	Lizard survey	Kiwifruit orchards surveyed for the presence of lizards
	Cicada & spider survey	Cicada shells & spider webs surveyed in kiwifruit orchards
	Soil survey	Soil structure, chemistry and biology rigorously measured on farms
	Bird survey	Bird populations surveyed on farms
	Fantail study	Fantail abundance, seasonal patterns & feeding behaviour measured in kiwifruit
	Stream survey	The health of streams assessed using NIWA's Stream Health Monitoring & Assessment Kit
	Orchard sward survey	The composition of sward under kiwifruit vines surveyed
	Farm mapping	GIS maps created for all Sheep/Beef properties
	Intensity survey	Sheep/beef farmers surveyed to identify the intensity of their operations
	Weed study	Weeds identified on sheep/beef farms and management surveyed
Objective 5: Social	Qualitative interview 1	Participants interviewed about visions, goals and constraints to achieving those. Farmers also used to sketch pictures of their farms and the components of them
	Qualitative interview 2	Farmers interviewed specifically about constraints
	Causal Mapping	Farrmers asked to illustrate their farming systems using a cognitive mapping approach
	Qualitative interview 3	Farmers asked to retrospectively reflect on how they came to be where they are now and how their orchard came to be how it is now
	National Farm Surveys	ARGOS and non-ARGOS farmers surveyed via postal questionnaires about relevant and current farming issues

	2004												2005											
Activity	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Objective 1: Farm Management																								
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Annual stakeholder reporting									All												All			
Annual stakeholder workshops									SB	KF											SB	KF		
Objective 3: Economics																								
Annual analysis of financial accounts						All												All						
Development of Lincoln Trade & Environment Model																								
Market access reporting																								
Objective 4: Environment																								
Baseline habitat & biodiversity survey							KF																	
Lizard survey												KF												
Cicada & spider survey															KF									
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Fantail study																								
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Annual stakeholder workshops									SB	KF											SB	KF									SB		SB	KF		
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Bird survey												KF, SB																								
Fantail study																														KF						
Stream survey												SB, D																								
Orchard sward survey	KF																																			
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National Farm Surveys																														All						

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