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CASE REPORT

Co-innovation to increase community resilience: influencing irrigation efficiency in the Waimakariri Irrigation Scheme

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Abstract The implications of a co-innovation project including elements of biophysical and social science are examined, particularly as they relate to conceptualisation(s) of community resilience. The framework of community resilience is used to explain how a farming region in New Zealand has increased their social, human, and environmental capital, despite a recent decline in economic capital as a result of a reduction in the global value of milk powder. The social learning, alteration of the project, and changes in decision making as a result of the project are reported in an example of positive outcomes from effectively facilitated transdisciplinary work.

Keywords Co-innovation · Community resilience · Tragedy of the commons · Case study research · Irrigation efficiency · New Zealand

Introduction

It is important to use science-based predictions to strengthen the resilience of socio-ecological systems, to reduce systemic vulnerabilities (Walker and Salt 2006; Smith and Stirling 2010). In this paper, a conceptualisation of integrated community resilience is used to frame the implications of an innovation project that evolved to simultaneously increase endogenous community social, economic, environmental, and human capital, and hence overall resilience (Davidson et al. 2016). We build on Wilson's (2012) human geographical framing of community resilience, and concepts from agricultural innovation systems' literature (Knickel et al. 2009; Klerkx and Nettle 2013; Lambrecht et al. 2014), to argue that our case study is an example where co-innovation has contributed to outcomes that have been fed back into farming practice to avert what could be described as a 'tragedy of the commons' (Hardin 1968; Feeny et al. 1990). The focus of this case report is to answer the primary research question, *how can co-innovation foster innovation to increase the resilience of agricultural communities?*

This paper is structured by first merging community resilience and agricultural innovation system literature, with a focus on potential transitions to more resilient and innovative individuals and communities, in the conceptual framework. These ideas build on recent work to incorporate innovation and resilience research (Smith and Stirling 2010; Pelletier et al. 2016), as well as broader conceptualisations of resilience (Gunderson and Holling 2001; Berkes and Ross 2013; Bailey and Buck 2016). The transdisciplinary case study method utilised is then explained, before the results are presented. A discussion follows that links the innovation project results to the theory introduced in the conceptual framework before the conclusion summarises the work and asks further research questions.

Conceptual framework

The aim of this section is to introduce the theoretical framework that will be applied to the Waimakariri

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Irrigation Scheme (WIS) case study community. Hardin's (1968) conceptualisation of a 'tragedy of the commons' is used to assist in framing the situation within the WIS prior to the initiation of a co-innovation project that was enacted to reduce individual farmer demand for the freshwater resource. Co-innovation is then introduced as a form of collaborative engagement under which resilience dimension thresholds can be crossed, leading to the introduction of community resilience literature.

A tragedy of the commons?

The WIS case could be viewed as a 'tragedy of the commons', because it involved a shared resource (the fresh water to irrigate) amongst a group of co-operative members linked via the scheme (Basurto 2005). Under the model of water use described in existing documents and by stakeholders (Primary Innovation 2015; Srinivasan et al. 2015, forthcoming), WIS water was being used by a number of farmers 'just-in-case' future supplies became restricted, resulting in water use that subtracted from other farmers ability to utilise water (Ostrom 1990; Ostrom et al. 1994). The use of an alternative 'just-in-time' approach (deficit irrigation) has been encouraged, where irrigation is scheduled on the basis of soil and/or crop demands rather than supply. However, this is not as widely practiced owing to the concern that farmers may not get water when it is needed. Use of the resource, whenever there was supply, led to regular restrictions of fresh water for irrigation and unnecessary waste (Srinivasan et al. forthcoming). In this context, prior to the initiation of the innovation project, farmers within the WIS risked producing a 'tragedy of the commons' (Hardin 1968).

Co-innovation

An innovation project was enacted in an effort to increase water use efficiency in the WIS utilising a co-innovation approach. Innovation is not just an idea but the process of harnessing ideas and turning them into reality (Lundvall 2007). Co-innovation involves alternative ways of organising social, economic, and regulatory systems to provide an enabling environment that increases the fit of technologies within a sector, thus enhancing their uptake and impact (Klerkx et al. 2012b; Klerkx and Nettle 2013; Mylan et al. 2015). An agricultural innovation systems (AIS) lens has been used to describe co-innovation (Klerkx et al. 2012c; Bitzer and Bijman 2015), where conventional methods of science delivery have tended to involve technological transfer including minimal network cooperation (i.e., research to extension to farm). More recently, the complexity of network cooperation has been used to increase the potential and buy-in of agricultural innovation (i.e., an issue determining stakeholders who collaboratively initiate a reflexive programme to address the concern and simultaneously build the capacity and social capital of those involved). Importantly, while co-innovation has been found to increase potential for cooperation, it does not discount more linear approaches to technological innovation, rather it provides an alternative process for more complex problems or issues (Malerba 2005). In effect, co-innovation can be most successful where a number of problems converge and potential solutions can create winners and losers among stakeholders in the problem (Klerkx et al. 2012a). Co-innovation involves the negotiation of concerns among stakeholders leading to collaboratively-agreed transition pathways toward future resource organisation (Hounkonnou et al. 2012; Klerkx and Nettle 2013). Leeuwis (2000) also describes innovation as a process of negotiation between stakeholders.

Implications for community resilience

The WIS system boundaries are defined in the conceptual framework (Fig. 1) based on two key papers involving irrigation cases (Schlüter and Pahl-Wostl 2007; Walker et al. 2009). The conceptual framework indicates the systemic variables divided into five resilience dimensions (social, economic, environmental, physical, and human) and the cascading potential of thresholds, or feedback loops, is indicated by dotted-grey arrows to inform the discussion that follows (Gunderson and Holling 2001).

With recognition that farmers in the WIS were using a just-in-case approach to freshwater management, river flows would drop and supplies were restricted. The co-innovation project was enacted in 2012 to steer away from the just-in-case approach to just-in-time and justified approaches, to improve water use efficiency (Srinivasan et al. forthcoming). Just-in-case accounts only for water supply, just-in-time accounts only for water demand, and justified irrigation accounts for both demand and supply simultaneously. This led to changes in practice, the building of a community interested in the innovation, decreased economic costs from pumping, productivity increases from more water to share and use when it was required, and environmental benefits in regard to more consistent freshwater flowing through the WIS. As Fig. 1 highlights the 'lock-in' effect of structural, endogenous economic and socio-psychological path dependencies within a community help explain why farmers utilised just-in-case irrigation (Wilson 2014; Wilson et al. 2016). The co-innovation project enacted is hypothesised to have initiated a form of transitional rupture by providing an evidence-based mechanism to improve water use efficiency to have both environmental and economic benefits. Wilson (2012, pp. 56–57) explains that although most notably transitional ruptures

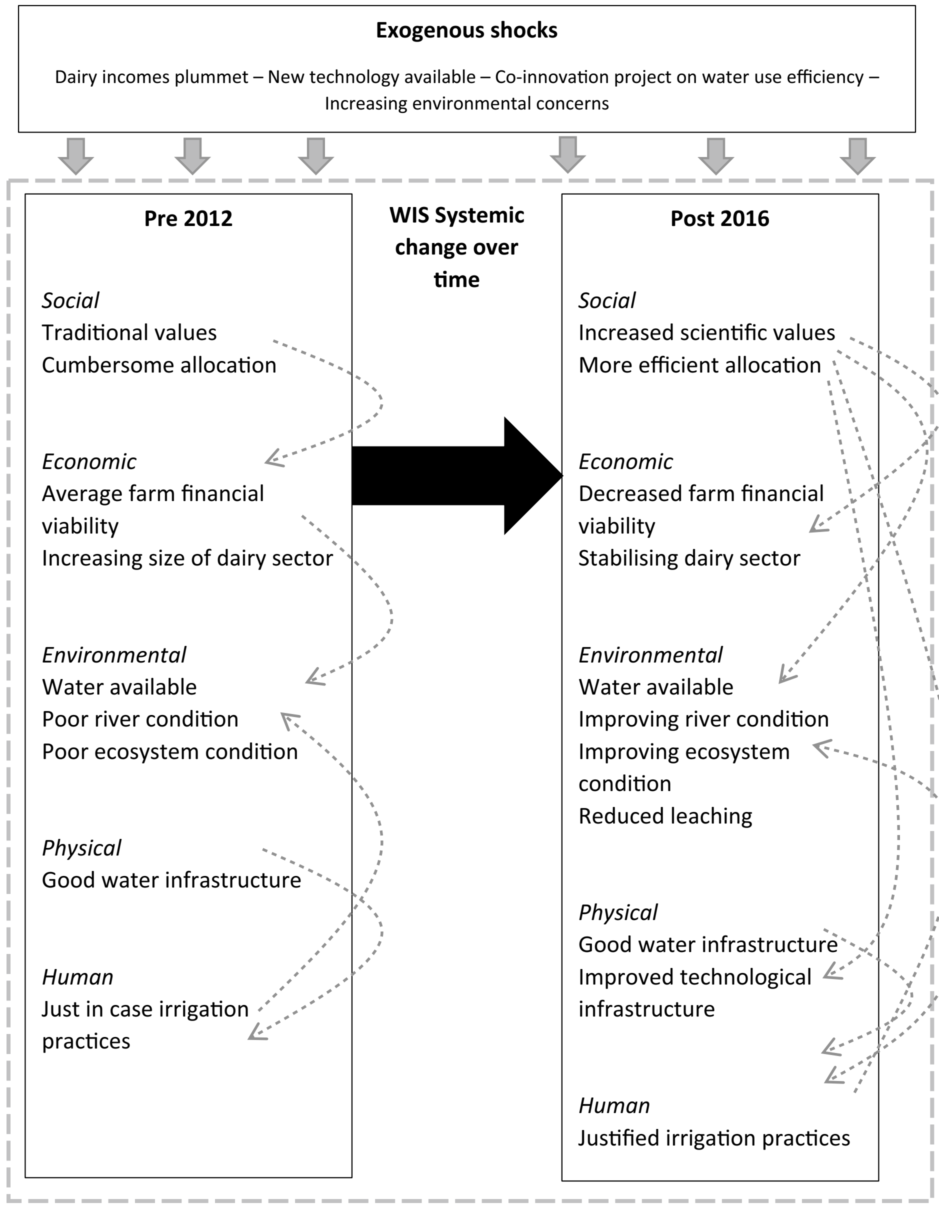

Fig. 1 Hypothesised WIS case community resilience pathway (within *grey dotted box*) including feedback loops (*grey dotted arrows*) indicating possibly cascading threshold crossing

are the result of exogenous events, such as an earthquake, volcanic eruption, political upheaval, or revolution (see shocks in Fig. 1), they can also be the result of a number of smaller events leading to 'cascading threshold crossing' of resilience dimensions (Kinzig et al. 2006). In this paper, we assess the interaction of resilience dimensions involving the crossing of 'thresholds', due to both external and knock-on effects in other dimensions (see dotted-grey lines in Fig. 1) (Kinzig et al. 2006; O'Connell et al. 2016). Events such as economic recession or a dramatic alteration in commodity prices (such as the price of milk powder in the case of dairy farming in New Zealand) may be the catalyst for the cascading of thresholds. The social memory of a community then determines how the community reacts to such external shocks—as it provides the basis for what decisions are imaginable, possible, and practical—in turn providing the corridor within which decisions are made (Wilson 2013b, 2014).

In accordance with much of the thinking around sustainability and sustainable development post the Brundtland report (World Commission for Environment and Development 1987), socio-ecological system resilience has grown to recognise the holistic ability of humans and their environments to adapt to slow onset changes and shocks economically, socially, and environmentally (Walker and Salt 2006; Oxfam International 2009; Singh-Peterson and Lawrence 2014). A move toward understanding both the implications of rapid changes and ongoing structural adjustment, at various scales (and/or levels), has resulted in resilience thinking utilising transdisciplinary projects in an attempt to deal with challenges of increasing complexity (Lebel et al. 2006; Beilin et al. 2013; Lamine 2015). Community resilience, as a component of social resilience, involves the 'ability of groups of communities to cope with external stresses and disturbances as a result of social, political, and environmental change' (Adger 2000, p. 347; Wilson 2012, p. 17).

As far as expressions of community resilience are concerned, Wilson (2012) argues that at the individual/household level, actions are most direct, and through communities, regions, nations, and global levels, actions become more indirect. The primary reason for the focus on the local community is that applicability of decision making in regard to bounded (in whatever capacity) structures that loosen as decisions rise upward toward the global. In accordance with previous work in community resilience, we recognise that defining the 'community' in question is problematic, although here, we have taken the spatially bound WIS and various systemic properties highlighted in Fig. 1, as the point of our study (Schlüter and Pahl-Wostl 2007; Wilson 2010). The importance of community resilience dimensions at the local level justifies the case report format of this study, and others like it, as it allows for discussion of decision making affecting practice/s on the ground—in our case with regard to when and how much to irrigate (Walker et al. 2006; Schlüter and Pahl-Wostl 2007; Yin 2014; Park et al. 2015; Galdeano-Gómez et al. 2016).

Wilson (2012) argues that a community's resilience can be measured utilising information to provide indicators of the levels of social, environmental, and economic capital at any given time. Another name given to these capitals is 'pools' of community resources that can be drawn upon when required and they can be further broken down into human and physical capital, amongst other dimensions (for example, as evident in Fig. 1) (Resilience Alliance 2007). While the resilience dimensions can vary depending on the community involved and the perceptions of researchers and others, the general concept that resilience is measurable by examining these capitals is one that resonates with the particular case examined in this report. Similarly, understanding the trade-offs between forms of capital is also critical to this work and has been recognised recently as integral to understanding the concept of community resilience (Nair and Howlett 2016; Tidball et al. 2016). For example, environmental capital in the form of freshwater (which can be measured in quantity and quality) can be utilised to irrigate and thus turned into economic capital (which can be measured in value of production). Some of that economic capital may then be converted at local shops or donated to local community causes to increase social capital (which can be measured with indicators, such as population numbers, social cohesion, and wellbeing).

It will also be argued that resilience dimension thresholds have been crossed in the WIS community, as a result of the recent rapid decline in the milk price (which over 50% of farmers in the scheme depend on), and due to the co-innovation project that was enacted in 2012. These conceptualisations of community resilience will be used to frame the WIS case examined here, in terms of past events through to the present day, to explain how changes in the forms of capital have influenced community resilience and how social memory has determined the decision-making corridor that has been followed.

Method

Drawing together specific case study insights across disciplines is central to this paper. In particular, the hydrology of the region and repercussions for irrigation policy and practice are considered in respect to the social, economic, environmental, physical, and human capitals that combine to contribute to the resilience of individual farms, as well as the local farming community as a whole (Wilson 2012). This combination of biophysical and social sciences results in a transdisciplinary report on a transition from the situation before innovation project intervention and subsequent changes. Evidence suggests that the ongoing practice of five pilot farms and perceptions of other farming community members within the WIS has changed as a result of the interventions made as part of the innovation project (Srinivasan et al. forthcoming).

In this paper, the innovation project and the implications for the WIS community are used as a case study, with an in-depth analysis of past documents relating to the WIS and more recent news articles, YouTube clips, feedback sheets, meeting minutes, monitoring and evaluation information, conference papers, posters, and journal articles analysed in an effort to determine the trajectory of WIS community resilience over time (Yin 2014). This work builds on documented findings and qualitative research in light of a new theoretical angle, namely, how has community resilience in the WIS been shaped by the irrigation efficiency co-innovation project (Higgins et al. 2015).

Document analysis was undertaken to draw out community resilience dimensions over time (Bryman et al. 2008; Silva 2011; Pant 2012; Brandt et al. 2013). Follow-up qualitative research was undertaken with key project stakeholders to clarify the events and the impact on the community (Beers and Bots 2009; Lamprinopoulou et al. 2014). Key questions asked revolved around the challenges and benefits of adopting a collaborative and innovative approach to water use efficiency in the WIS.

The results are organised in two sections in relation to a timeline of important WIS community events. First, findings in the years prior to the implementation of the innovation project, when just-in-case irrigation practices were followed, are presented. The implications of the project, and external influences, from initiation in 2012 to the present day, are then discussed. The future of the WIS and involvement of co-innovation are further examined in the discussion that follows the results. Use of resilience dimensions to form the measurable components of resilience, complementing conceptualisations of sustainable development, has been commonplace to form the methodological basis of community resilience studies (Wilson 2013b; Singh-Peterson and Lawrence 2014; Ban et al. 2015). Measurements of social, economic, environmental, physical, and human capitals, at any one point in time, have been estimated and averaged to compute resilience indices utilising a similar methodology to Wilson (2012, p. 49). In this work, a timeline is presented that, although specific event details are debatable, aims to visually guide the reader to understand the effects of events on different capitals, and hence WIS community resilience. This timeline provides information over an extended period of time, differing from previous community resilience work that has focused on a sudden onset event or hazard (Imperiale and Vanclay 2016), recognising the ongoing implications of endogenous decision making, as well as exogenous occurrences, for communities (Wilson 2013b). The resulting resilience assessment is condensed to show how this particular use of co-innovation (along with other concurrent events) can cause thresholds to be breached, leading to reorganisation of the WIS community, alteration in farming practices, and an upward trend in community resilience (O'Connell et al. 2016). Ultimately, the case presented draws together innovation and resilience theory to highlight a local example of the potential of such work to alter the direction of a community, similar to other case reports published in this journal (Fielke and Bardsley 2015b; Galdeano-Gómez et al. 2016).

Results

The analysis of the WIS case begins with recognition that over a century ago an irrigation scheme was enacted to increase the socio-economic capital of the region, well before more recent developments (Allison 1999). In line with the transitional nature of resilience over time, significant variations and alterations to the WIS, as well as external factors, are analysed to provide the context for a discussion of current community resilience indicators. The WIS region is shown in Fig. 2, located on the Canterbury Plains on the South Island of New Zealand, north-west of the largest city on the island, Christchurch. By reducing the irrigation applied, the scheme abstracts less water from the river. This also means that there is more water in the main stream for environmental services initially and for use further downstream if required (indirect economic benefit).

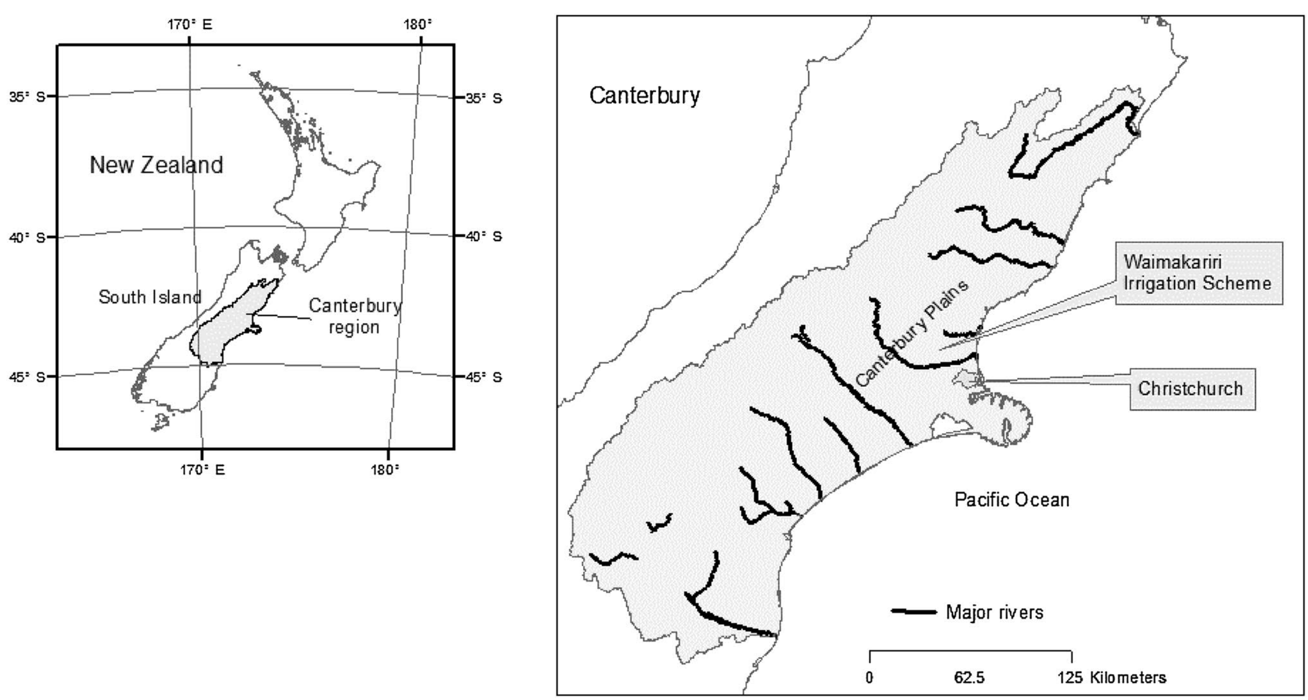

Fig. 2 Location of Waimakariri irrigation scheme

Each farm pumps the water they require from their race and incurs the cost of pumping, therefore, reduced irrigation also has direct economic benefits for each farm. In addition, a careful application of irrigation has been shown to result in environmental benefits such as reduced drainage of water and leaching of nutrients from the productive soil zone (Srinivasan et al. forthcoming).

WIS community resilience pathway pre-2012

In a historical report on the WIS, Allison (1999) explains that the inception of the Waimakariri-Ashley Water Supply Board in 1892 heralded the beginning of a vision to provide irrigation to the regions agricultural lands through water diversion. Despite the creation of such a board, the use of the fresh water resource primarily involved individual water races and locks to siphon water from the nearby water courses until 1983 (Allison 1999). In 1983, a plan was proposed to irrigate 12,000 ha between the Waimakariri and Eyre rivers; however, the local government of the time was not willing to fund such an endeavour and the idea never came to fruition (Allison 1999). Following a drought in 1988–1989, farmers were unable to use surface water from the streams as, for the first time, it was required for the urban water supply downstream in Christchurch (the nearest urban centre) (Allison 1999). The resulting economic loss led to meetings to discuss the water supply, resulting in a feasibility study on a newly developed irrigation scheme. The proposed scheme was to have both economic (productivity) and environmental benefits in terms of providing wetlands and increased flow (Allison 1999). Cooperation between the local government, farmers, and champions of the scheme led to the initiation of an NZ$7 million dollar project (value at the time) creating the present day WIS, which became operational in 1999 (Allison 1999). In mid-2000, the WIS community decided to build storage ponds to increase the irrigation reliability from 74 to 91%, directly targeted at increasing economic capital through more consistent and reliable water supply and hence agricultural production. However, this was (and still is) resisted by a community group who are worried about potential breeches of ponds and inundation of their properties, resulting in a setback to social cohesiveness (capital). Around the same time, the local regional council imposed conditions that Waimakariri Irrigation Limited (WIL—the company that manages water within the WIS) start measuring water use of major users with water meters.

Figure 3 charts a hypothetical path of community resilience based on the equal weightings of social, economic, environmental, physical, and human capital since 1990 to indicate the implications of such a scheme on resilience dimensions. Although each of the dimensions and their equal weightings might be debateable—in particular realms that are hard to retrospectively measure—the purpose of

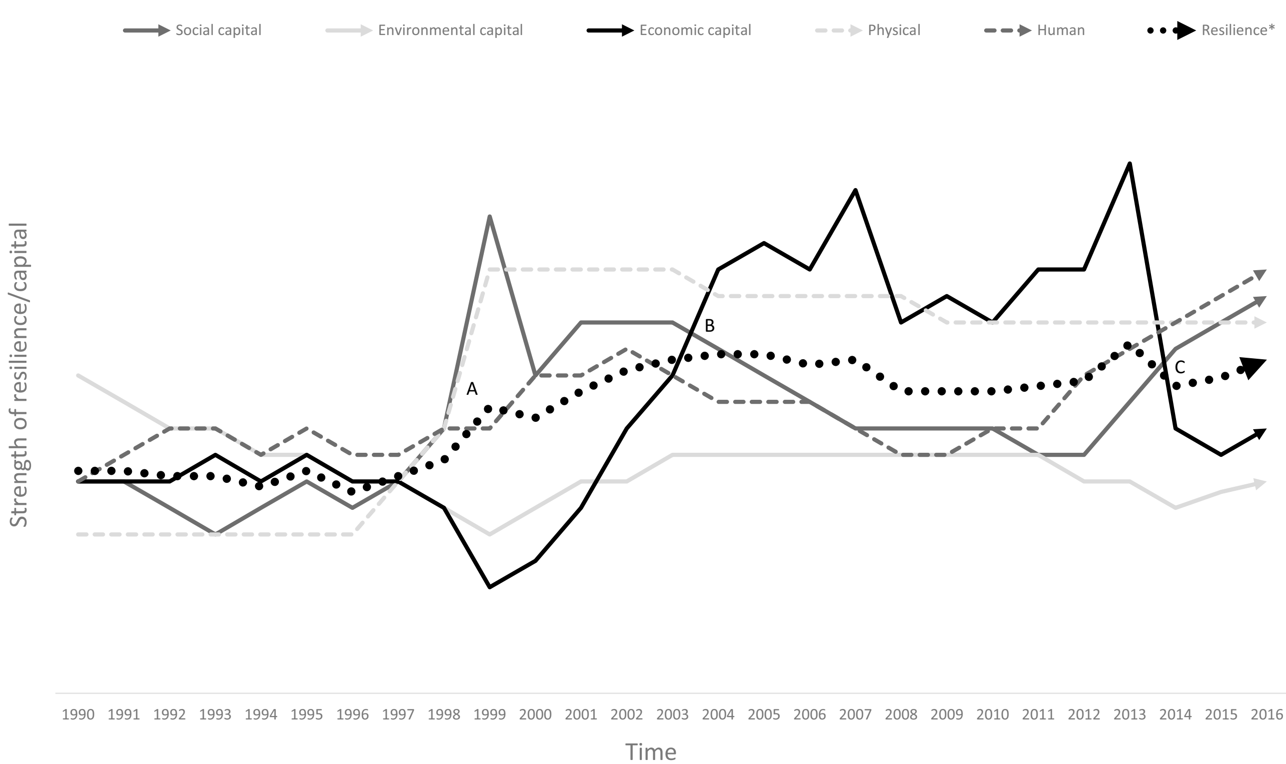

Fig. 3 Hypothetical WIS community resilience by capital where resilience* is the average of five capitals (1990–2016)

the graph in this work is to highlight the key points in time for decision making since 1990 in a methodological manner similar to that utilised by Wilson et al. in relation to a European Research Program (2012). While recognising the limitations of such a method, Fig. 3 is an effort to describe how decisions that have been made have affected community resilience and the associated capitals with reference to a specific applied example. It follows recent work to map community resilience in the aftermath of the 2011 earthquake in nearby Christchurch by Wilson (2013b).

Inconsistent seasons determine the trajectory of economic capital until the opening of the WIS at point A when significant economic capital has been mobilised to implement the scheme. The scheme disruption to the ecosystem also has negative implications for environmental capital, and while there are more people in the region working on the scheme, a reduction in worker numbers after the scheme and debate over aspects of development see a drop in social capital at point A. Gradually, the economic benefits of the project are realised post point A.

As described by one of the members of the WIS community in a recent video clip, the scheme has allowed agriculturally-based industries to be developed in the region, with dairying becoming an increasingly significant component of local farm systems to the present day, along with traditional horticultural cropping and livestock finishing (Primary Innovation 2015). A continuation of the resilience trend from 1995 to 1997 may have resulted in the community shifting below the threshold that allowed them to survive. The boost in economic and environmental capital following the WIS project through to point B in Fig. 3 puts the community in a much better position for the future in regard to their resilience. In fact, one farmer explained that without the development of the WIS throughout the 1990s, it is unlikely that they would have been productive enough to remain in the region—meaning that their household resilience would have dropped below a threshold, forcing them to migrate elsewhere (Primary Innovation 2015). This provides an example of economic capital being increased, by the initiation of the present day WIS, with the decisions made in the past leading to outcomes that have allowed community members to stay in the region. Community members have continued to pursue agricultural endeavours, building and passing on the social memory and adaptable psychological characteristics that it is argued have been of further benefit in the following sections (Wilson 2013b; Robinson and Carson 2015).

The trajectory of environmental capital increases after the WIS project works are completed in 1999 and the ecosystem recovers somewhat. However, consistent and increasing demands on the water resource and the implications of environmental issues created by the rise of the dairy industry result in a plateau of environmental capital, which begins to decline as dairying intensifies, particularly beyond 2010 (Memon et al. 2011; Weber et al. 2011; Duncan 2014). Interestingly, the social and economic capitals, while going through an increase post-WIS development, have quite different trajectories based on occurrences exogenous to the WIS community itself. Social capital declines steadily from 1999 until 2012, as employment drops after the scheme finishes and external neoliberal policies in New Zealand drive competition and individualism (McDermott et al. 2008; Rosin 2008, 2013; Roche and Argent 2015). This decline in social capital reflects the implications of such a policy focus, assuming that the sense of community within the region has followed the path of other regions in similar situations in Australia (Argent 2011; Smailes et al. 2012, 2014; Argent et al. 2014a). Economic capital is also influenced significantly by factors external to the WIS community itself, with deregulation of agriculture and agricultural support leading to more pronounced fluctuations in commodity markets. While initially embedding into global markets provided significant benefits for the WIS community as a result of the physical capital developed through irrigation infrastructure, more recently, this embedding has pushed farmers into agricultural intensification, particularly dairying, where recent price fluctuations have led to significant uncertainty (point C in Fig. 3). Therefore, while the community-based decision to increase the long-term productivity of the region through economic investment in physical infrastructure seemed to initially and rapidly increase community resilience, the simultaneous external globalisation of New Zealand agricultural production has created rather unstable conditions, particularly in the commodity production (economic capital) realm and due to a reduction in social services (social capital) (Weber et al. 2011).

Highly variable commodity prices, increased demand for water despite no increase in supply (constant at 10,500 litres per second since 1999), and the practice of irrigating when water was available led to the situation whereby farmers risked creating a 'tragedy of the commons' as discussed earlier (Hardin 1968; Memon and Selsky 2004). The rate of irrigation was not justified and based more on established routines (human capital), as opposed to whether the soil was dry enough to warrant irrigation—particularly considering the potential of upcoming rainfall, the wasting of freshwater (environmental capital), and the opportunity cost of pumping water that was not required (economic capital) (Srinivasan 2015; Srinivasan et al. forthcoming). This led to the initiation of a co-innovation project to help inform farmers of soil moisture levels and the likelihood of upcoming rainfall that would alter their irrigation schedule and eventually their approach to irrigation in practice.

Co-innovation and economic turmoil 2012-present day

The initial concept of a project to increase water use efficiency in the WIS was joint with another large research project attempting to increase co-learning and co-innovation in New Zealand agriculture to address complex challenges by including multiple stakeholders in project design and development. The WIS became one case in the larger 'Primary Innovation' project (Botha et al. 2014; AgResearch Limited 2016). With community resilience pools comprising relatively high economic and physical capital and low social, human, and environmental capital values at the beginning of the project (see Fig. 3 at 2012), this section analyses the implications of this project (and external factors) on WIS community capitals.

A wide array of information is already available concerning the WIS innovation project case, but some of the most important findings in relation to irrigation practice alteration and community resilience building will be re-examined (Primary Innovation 2015; Srinivasan 2015; Srinivasan et al. 2015, forthcoming; AgResearch Limited 2016). Importantly, when linking the findings to implications for community resilience, some significant points stand out. The social memory of the WIS community, in relation to their ability to be open to new ideas in the form of such an innovation project, is important to consider (Wilson 2013b). For example, had the community not undergone such a large project with the development of the WIS in 1999, would they have been prepared to utilise their time and energy on a project involving non-traditional transdisciplinary science, new technologies, and farming practice?

While the project began with just five pilot farms and farmers being informed of the measurements taken on their properties, over the course of the following years, an increasing number of farmers in the region have become involved, requesting and being sent the information from the pilot study sites (along with rainfall forecasts), and attending the annual meetings. There are currently 25 farmers receiving daily soil moisture measurement and rainfall updates, and an increasing number of researchers, businesses, and farming stakeholders have attended the annual meetings over the past 4 years (Srinivasan et al. forthcoming). At each of these meetings, the farmers provide feedback on the information they each receive. Since the project began, the Project Leader has used this information to alter the scientific and information distribution methods employed (Srinivasan 2015). The biophysical measurements on the pilot farms when the project was initiated were soil moisture levels at a 20 cm depth to let farmers know when their soil was dry, paired with rainfall forecasts, so that they could see the rainfall forecast over the next 2–6 days, to make a choice about whether to irrigate or not. After feedback from the farmers, the Project Leader introduced another soil moisture probe to a depth of 80 cm at each of the pilot farms. The information from this instrument allowed farmers to understand when to stop irrigating as their soil was sufficiently irrigated in the productive region of the soil horizon and any further irrigation was not going to increase productivity but result in water and nutrient drainage leading to environmental damage. While this information was useful for the scientist leading the project, it was not always practical for farmers to understand—in another reference to the tragedy of the commons, why stop watering when the 80 cm probe registers moisture if a neighbour is still watering their field and may have been for longer? To make tangible the benefits of stopping irrigation when the productive soil was sufficiently moist, the Project Leader conducted some calculations to formulate the cost of continuing to irrigate. Even though the cost of the freshwater itself is negligible, there were economic costs in regard to the electricity required to pump the water as well as lost nutrients applied to the field as they drained past the soil horizons in which they could be accessed. This example of co-learning and co-innovation provided an economic justification for farmers to alter their practice to both increase economic capital (save money and increase productivity by not pumping when they do not need to) and environmental capital (by increasing river flows and not further leaching nutrient into the soil).

In the last few years, the local regional council has imposed environmental conditions on WIS users. WIL, supplying the WIS, are now being held responsible for improper and unwise use of irrigation by the share-holders (anything that could result in excessive nutrient losses to receiving waters). Improper use to date has led to a reduction in environmental capital, as such new policy restrictions involve economic consequences for farmers and WIL. Similarly, the process of distributing daily soil moisture and expected rainfall information updates, as well as holding annual meetings with the community, has increased social and human capital by reinforcing relationships that can then be drawn upon in times of need and increasing participants knowledge of hydrology (Kilpatrick 2007; Heenan 2010). The project is now in the phase of including other researchers and corporate stakeholders to explore how the networks that have developed could be utilised in the future, an example of potential scaling up and/or out to other regions/irrigation schemes/communities (Pachico and Fujisaka 2004; Hermans et al. 2013). Linking back to the conceptual framework, this is an example of an innovation project that has turned multiple stakeholders ideas into what could become a commercial tool or application, which may lead to further increases in physical (technological) and economic capital (New Zealand Government 2016).

The innovation project has had positive implications for each capital involved in forming community resilience, and thus has increased the resilience of the WIS community. This is despite the fact that overall, due to external factors, the economic capital within the region fell significantly during the project lifespan. Figure 3 at point C shows a decline in economic capital within the community due to an increasing reliance on the dairy industry (which now comprises almost 50% of the WIS area) and the impact of a decrease in the milk powder price due to oversupply in global markets, from over \$8 per kilogram milk solids (MS) in 2013/2014 to less than \$5 per kilogram MS over the last 4 years (Fonterra Co-operative Group 2016). This reliance on global markets, and one in particular, has seen many farms in regional New Zealand suffer significant economic hardship (Meadows 2016). In terms of the effect on the innovation project, however, the Project Leader reports that it may have helped the uptake of the techniques of co-learning and co-innovation to gain traction in the WIS community, because members realised action was required, perhaps in a manner similar to the initiation of the WIS project through the 1990s. This may be an example where existing social memory of what was possible contributed to project outcomes that had positive impacts on community resilience (Wilson 2013b).

The innovation project examined is this case report highlights that positive alterations in community resilience, as a result of changes in social, economic, environmental, physical, and human capital, are possible when community champions (such as the key figures in the project) emerge to shape decision-making possibilities (Nettle et al. 2013; Wilson 2013a, 2014). If the resilience dimensions are weighted evenly, despite the significant decline in economic capital as a result of a low commodity price, social and human capital increases have led to a relatively stable trend in community resilience over the last few years (c in Fig. 3). The implications are at least in part due to the innovation project informing this case report. Arguably, the social and human capital built and maintained is the cause of community resilience stabilising despite exogenous economic shocks. In the following section, the theoretical links between resilience and this example of co-innovation are made more explicit to answer the research question, before what this report might mean for the future of the WIS community is discussed.

Discussion: innovation projects and their potential to influence community resilience

The initiation of the innovation project and subsequent economic uncertainty created by fluctuating commodity prices could be seen as threshold cascading relating to WIS community resilience (Kinzig et al. 2006; Wilson 2014), similar to innovation theory conceptualisations of ruptures to scale up and across regimes, driving new practice and behaviour at the local level (Hermans et al. 2013). Both AIS and community resilience theoretical frameworks lend themselves to projects, such as the one reported in this case, due to the focus on change over time (Bremmer et al. 2014; Minh et al. 2014; Wilson 2014; Robinson and Carson 2015). In a hypothetical community in New Zealand, without a reliable source of freshwater or the initiation of such a co-innovation project the threshold crossed by a significant decline in economic capital could (and likely has) pushed many households past the point of economic viability resulting in them having to migrate off-farm (Ihaka 2012). The implications of out-migration, perhaps of multiple farming family's during a discrete period, would then result in further cascading of thresholds throughout the community, resulting in economic and service decline and in the worst cases the loss of local community resilience altogether (Westley et al. 2013). Perhaps only large corporate farms would remain and the nearest regional centre becomes their supply hub. These narratives are commonplace in the history of agricultural communities globally as a result of an increasing dependency on global markets and a lack of control over exogenous factors influencing resilience (Argent et al. 2014b; Smailes et al. 2014; Fielke and Bardsley 2015a). In an attempt to avoid (or reduce) the decline of such hypothetical communities, it is important to address the primary research question: *how can co-innovation foster innovation to increase the resilience of agricultural communities?*

The importance of this case report comes from the linking of co-innovation projects, such as the one discussed, and the actual (in this case) and potential benefits of such projects to simultaneously increase the capitals involved with resilience in a non-prescriptive, bottom–up manner. By including multiple stakeholders in the research project, for example, farmers, industry, and other researchers, results have had real-time application to influence agricultural decision making (Klerkx and Nettle 2013; Boon et al. 2014; Polk 2015). The bottom–up example of co-innovation in the WIS community resulted in increased social and human capital and network formation around the topic of water use efficiency and nutrient management (Srinivasan et al. forthcoming).

The findings reported suggest that although complex decision making occurs at various scales, there is significant potential in utilising a co-innovation approach in project development. Importantly, biophysical scientists need to be willing to incorporate the flexible and adaptive thinking involved into their more objective everyday practice, in an example of trial and error through social learning (Hinrichs et al. 2004; Ahamer 2012; Beers et al. 2014).

The inclusion of local stakeholders means that the 'community' in whatever form that may take, through facilitation and reflection, can enact decision-making pathways that determine how they themselves want their community to look in the future (Bohnet and Beilin 2015; Fielke and Bardsley 2015b; Santhanam-Martin et al. 2015). As Wilson (2012) suggests, a whole range of decisions can then be made that allow for different mixes of the capitals, diversifying the risk of rapid fluctuations, for example, with local/direct marketing (Fielke and Bardsley 2013), increased social links to networks that can be drawn upon (Fisher 2013), or environmental capital that can be transformed into economic capital and vice versa (Raymond et al. 2009). Being involved in the co-innovation project reported here, and facilitating a process to feedback involvement into action, allowed stakeholders to see the world in different ways that led to an increase in resilience dimensions, without an explicit focus on the resilience framework. The social network formed then fed back information to the innovation project team, who altered their technologies and methods accordingly. In this instance the co-innovation approach, led by the project team, allowed for alteration in on-farm practice to address both economic and environmental drivers (Srinivasan et al. 2015). The potential for future work in this community, utilising the social capital developed, is another benefit of the approach taken as essentially the foundation for relationships has been built between researchers, farmers, industry and policy stakeholders (Park et al. 2015).

In regard to specific future implications for the WIS community, perhaps, the human and social capital formed by the problem solving undertaken and the future-orientated vision of the WIS scheme overhaul in 1999 provided the social memory required to be confident in accepting the process of co-innovation to positively influence community resilience (Kinzig et al. 2006; Wilson 2013b). Work is already underway in an effort to scale the innovation project up and out to other relevant regions in an example of an innovation evolving to (hopefully) be applied through commercialisation of the technologies and methods (Millar and Connell 2010). Similarly, the social learning of those involved has now equipped them with skills in co-innovation, which will have some effect on the future resilience of the WIS community (Beers et al. 2014). This case has provided one example of a co-innovation project having practical implications for sustainability and community resilience.

Conclusion

The most important points to take from this case report are the links between theoretical framings of community resilience and the implications of well-executed co-innovation projects as a means to increase communities' resilience. In this particular case, the co-innovation project had positive local outcomes in terms of: increased productivity on farm via reduced pumping costs and input loss (economic capital); the creation of a network interested in irrigation efficiency (social capital); the feedback of community members thoughts and ideas to the researcher/s and vice versa leading to new skills (human capital); and, ultimately more efficient use of the freshwater resource (environmental capital).

Obviously, there have been limitations in generalising these findings due to the case specific nature of the report. For example, a more thorough examination of the concepts of co-innovation and agricultural innovation systems and the implications for rural and agricultural community resilience would have significant benefits for transdisciplinary projects in this space. Potentially these conceptualisations could contribute to understanding the possible futures for rural communities considering increasing uncertainty and complexity (Woods 2012; Zscheischler and Rogga 2015). Similarly, while resilience thinking has become widespread in the transdisciplinary space further exploration of methodological considerations as well as theoretical questions, such as whether increased resilience in one system results in reduction in another, would help strengthen both the conceptual basis and methods on which work like this is based (Gunderson and Holling 2001; Wilson 2012; Dwiartama and Rosin 2014; Robinson and Carson 2015).

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