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How limiting factors drive agricultural adaptation to climate change

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A B S T R A C T

Consensus is growing that agriculture is vulnerable to climate change and adaptation responses are necessary to minimize impacts. Nonetheless, the diversity of potential impacts, agro-ecological contexts and regional capacity for change make understanding adaptation behaviors challenging and ensure that climate change adaptation will not be the same across all contexts. Considering this heterogeneity, this paper aims to develop a theoretical approach to connect agro-ecosystem diversity with farmer decision-making in the context of agricultural adaptation to climate change. We combine the ecological principle of Liebig's Law of the Minimum with the Psychological Distance Theory to suggest how adaptation behaviors vary across regional contexts. We argue with our limiting factors hypothesis that limiting factors within a farm system (water or temperature impacts) influence the adoption of adaptation practices differently across regions and farm systems. Limiting factors varied across farm systems and regions, based on historical climate changes, agro-ecological contexts, infrastructure and adaptation capacity. Using farmer survey data from New Zealand we show that limiting factors mediate the effect of past climate experiences on the adoption of adaptation strategies differently in two regions with water acting as a limiting factor in Hawke's Bay and water and temperature as a limiting factor in Marlborough. This suggests that farmers perceive and respond to climate change in part due to their personal experiences with climate change and the limiting factors within their system. Such results are relevant for the development of regional adaptation strategies, effective policies and targeted climate change communication.

1. Introduction

There is emerging consensus that agriculture is vulnerable to climate change and that adaptation strategies are urgently needed to assist in minimizing climate impacts (Rosenzweig et al., 2013). Increasing the adaptive capacity of agriculture requires a better understanding of the drivers and barriers for adoption of climate-smart practices (Howden et al., 2007). While a significant body of research exists to assess the adoption of innovations (Rogers, 2003) and conservation practices in agriculture (Prokopy et al., 2008), growing research seeks to understand what drives the adoption of climate change adaptation and mitigation practices among farmers (Barnes and Toma, 2012; Arbuckle et al., 2013a,b; Wood et al., 2014).

A major challenge is that climate change adaptation is not a one-size fits all phenomenon; adaptation strategies and farmer responses will vary across regions (Berry et al., 2006) based on agro-ecological contexts, socio-economic factors (Adger et al., 2009), climatic impacts, and existing infrastructure and capacity. Despite this heterogeneity, there remain gaps in our psychological understanding about how farmer experiences and concerns for varying ecological impacts differentially influences farmer decision-making on adaptation strategies across different farm systems and regions. This paper aims to address this gap by theoretically linking the agro-ecological context of climate change with farmer decision making across farm systems and regions. We focus on the drivers and barriers for adopting adaptation strategies to assist communities and policymakers in devising targeted adaptation strategies (Howden et al., 2007).

We link the agro-ecological system and farmer decision-making by combining a classic ecological principle, "Liebig's Law of the Minimum" with the Theory of "Psychological Distance" (Liberman and Trope, 2008) to suggest that adaptive behaviors within an agricultural system are influenced by the most limiting factor.

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Based on these existing theories, we develop and apply a "Limiting Factors Hypothesis" that assesses how farmers' past climate experiences influence their concern for future climatic limiting factors (water and temperature) and in turn, their likelihood to adopt adaptation behaviors. This hypothesis became evident from our previous work with California farmers, which demonstrated that adaptation decisions were most responsive to experiences and concerns about water availability (Haden et al., 2012), which historically is the most limiting factor in California's Mediterranean climate (Tanaka et al., 2006; Schlenker et al., 2007).

Here we more systematically develop the limiting factors hypothesis and apply it in two regions of New Zealand that have different agro-ecological and climate contexts, and therefore different limiting factors that translate into farmer adaptation decisions. We focus on two New Zealand farming regions (Marlborough and Hawke's Bay) and farm system types (sheep/beef and viticulture), which have had varying climatic changes and infrastructure responses. We predict that in Marlborough, a region known for its wine production, temperature will be a key limiting factor for climate change given previous temperature-related climatic changes, wine's temperature sensitivity, and its already established irrigation infrastructure. Conversely, in Hawke's Bay we hypothesize that water will be the climatic limiting factor given a history of drought, and the prevalence of sheep/beef systems that lack irrigation and water infrastructure. We compare these two farm system types across both regions using quantitative data from a comparative survey to develop statistical models (multiple mediation models, a form of path analysis) to test for the direct and indirect effects of limiting factors, global climate concerns, and climate change experiences on adaptation behaviors (Fig. 1).

2. Connecting ecological and psychological theories

Liebig's Law of the Minimum, originally applied in agriculture but now broadly used in ecological research, states that an organism's growth is limited by its most scarce resource (von Liebig, 1855). We argue that an agricultural system's adaptation to climate change is fundamentally hindered by, and vulnerable to, the most limiting factor within the system. In this study there is a clear link between limiting factors and productivity in a climate change context because both water and temperature impacts can fundamentally impact the growth potential of a crop or animal. However, limiting factors will vary across regions and agro-ecological systems.

In fact, climatic factors are just one type of limiting factors that farmers contend with and farmers certainly make decisions based on other agronomic and socio-economic limiting factors. For example, a farmer's debt load may have a profound effect on their ability to implement irrigation, which may help them respond to water as a limiting factor. We hope that future work can assess the interaction of these potential factors and examine the limiting factors hypothesis in other agronomic and socio-economic contexts as well. The limiting factors hypothesis is consistent with the idea that farmers must adapt to multiple constraints in order to maximize their productivity and desired outcomes (Lubell et al., 2013). As such, it can be considered a subset of the broader work in adaptive management of agricultural systems, for it enables understanding about the link between climatic variables and farmer decision-making.

We connect Liebig's Law of the Minimum with the Psychological Distance Theory to suggest that limiting factors will have a strong influence on climate change attitudes and behaviors because they are psychologically "closer" to the community that must contend with them. Psychological distance and the related Construal Level Theory (Liberman and Trope, 2008) suggests that events perceived to be "closer" to an individual (temporally, geographically, socially, and in certainty) are more salient and have a stronger proximate influence on individual decisions (Spence et al., 2012). Many have argued that reducing the psychological distance of climate change and making it more personal and relevant can increase the potential for behavior change (Kates and Wilbanks, 2003; Nicholson-Cole, 2004; Lorenzoni and Pidgeon, 2006; Leiserowitz, 2007; Scannell and Gifford, 2013). As such, personal experience with climate events can influence climate change attitudes and behaviors (Brody et al., 2008; Spence et al., 2011; Haden et al., 2012). Emerging research also suggests that recent climatic and weather events can strongly influence individuals' climate change perceptions and beliefs (Hamilton and Stampone, 2013; Rudman et al., 2013; Zaval et al., 2014).

Here we argue that a farmer's future climate concerns are oriented towards the most limiting climatic factor within their system as informed by previous weather and climate events. Because farmers must repeatedly contend with limiting factors in a particular agro-ecological context, their attitudes have a higher cognitive "availability" (Kahneman, 2011). These limiting factors in turn mediate the relationship between past climate experiences and potential adoption of adaptation practices.

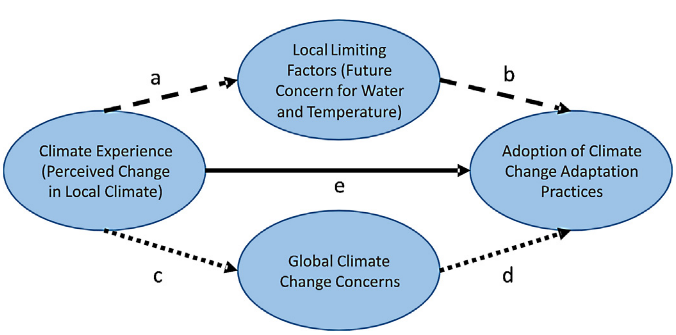

Fig. 1. A sample multiple mediation model. The " Limiting Factors Pathway" (dashed (a, b)) is hypothesized to be significant and tests for the indirect effect of local limiting factors (future climate concerns for either water or temperature impacts shown in Fig. 2) mediating climate experience on adoption of adaptation practices. The dotted "global pathway" below (c, d) tests for the indirect effect of global concerns mediating climate experience on adoption of adaptation practices. The solid line (e) tests for a direct effect of climate experiences on the adoption of adaptation practices.

3. Place context and hypotheses

3.1. Water as a limiting factor: Hawke's Bay New Zealand

Hawke's Bay sits on the central east side of New Zealand and is the 5th and 3rd largest region for sheep and beef production respectively in New Zealand. It also produces horticultural crops and is the 2nd largest wine grape growing region, though it produces four times fewer grapes than Marlborough (Statistics New Zealand, 2012). Hawke's Bay has been historically plagued by water shortages in part because it is bordered by mountain ranges, which shelter it from prevailing westerly winds, resulting in a fairly low mean annual rainfall (less than 1000 mm). It has one of the lowest number of rain days in the North Island of New Zealand (Fowler et al., 2013). Despite this climate, Hawke's Bay doubled the amount of hectares given permits to take surface water between 1999 and 2010 (Hawke's Bay Regional Council, 2014). The region has also proposed the development of the Ruataniwha water storage scheme, a project with 91 million m^3 storage capacity to address chronic water shortages in the area.

These regional water shortages have been exacerbated in recent years as Hawke's Bay contended with four years (2006–2009) of consecutive droughts (Hawke's Bay Regional Council, 2014). Rainfall records were significantly below average particularly for the September to April time-frame, and many areas of Hawke's Bay experienced extreme drought conditions receiving less than half their normal rainfall. As a result, there were decreased flows for the region's rivers as well. Long-term data analysis of 11 regional sites showed that the majority (9/11) of these sites experienced below average mean monthly flow between 2004 and 2009 from the long-term average (Hawke's Bay Regional Council, 2009a,b). In addition, climate projections for Hawke's Bay suggest that such events are likely to continue in the future, and the region is expected to see a decrease in annual average rainfall and frost frequency (National Institute for Water and Atmosphere, 2008). Hawke's Bay pastoral farming is particularly sensitive to precipitation changes given its reliance on rain-fed pasture, and future climate scenarios suggest an overall average decrease in pasture productivity as a result of decreased rainfall (Fowler et al., 2013).

Given this context, we suggest that drought and water scarcity are a significant concern for Hawke's Bay sheep and beef farmers, and we expect that water will be the limiting factor in Hawke's Bay. Climatically, we suggest that: (1) the historical relationship that farmers have with drought has made water a fundamentally "closer" phenomenon; and (2) climate projections for the future indicate that water will continue to be a major issue as average annual rainfall will decrease and droughts will worsen. However, in addition to these climatic factors, land use and agronomic factors within the region also suggest that water will be a limiting factor. The dominant land use in the region is sheep and beef, which is largely rain-fed and vulnerable to climate variability, particularly droughts (Fowler et al., 2013). As a result, sheep and beef farmers have limited adaptive capacity to deal with water shortages. We do not expect to find that water is a limiting factor for viticulture in the region, which has large irrigation infrastructure in place to handle water shortages.

3.2. Temperature as a limiting factor: Marlborough, New Zealand

Marlborough, located at the top of the South Island, grows sixty-five percent of all wine grapes in New Zealand. Between 2007 and 2012, wine grape acreage in Marlborough increased by 32%. Related to this expansion is the growth in irrigation between 1999 and 2010 from 6,300 to 55,000 ha – an increase of more than 700% (New Zealand Ministry for the Environment, 2010). Despite the expansion of irrigation, some areas of Marlborough are seasonally water limited due to high evapotranspiration rates and reliable water can remain a challenge (Marlborough District Council, 2012). More than

Table 1
Model variable means and measures of reliability.

Variable	Question/statement	Scale	Eigenvalue	Factor loadings	Cronbach alpha	Mean	Standard error
Perceived change in local climate (independent)	*Local _____ (see below) has (increased, stayed the same, decreased) over the course of your farming career*						
	Summer temperature	Three point scale (1 = increased, 2 = stayed the same, 3 = decreased				1.755	0.032
	Winter temperature					2.244	0.032
	Annual rainfall					2.338	0.028
	Water availability					2.028	0.023
	Frequency and/or duration or drought					1.885	0.032
	Frequency and/or duration of flooding					2.301	0.029
	Frequency and/or severity of wind					1.92	0.027
	Frequency of slips					2.188	0.027
Local water concerns (mediator)	*How concerned are you about the following climate related risks and the future impact they may have on your farming operations during your career?*		2.90		0.82		
	More severe droughts	Four point scale (1 = not concerned, 4 = very concerned)		0.78		2.636	0.050
	Change in timing, intensity or frequency of rainfall events			0.79		2.591	0.046
	Less reliable surface water supply			0.72		2.663	0.054
	Increased frequency or intensity of flooding			0.78		2.418	0.051
	Increased frequency or intensity of slips or erosion			0.73		2.224	0.054
Local temperature concerns (mediator)	*How concerned are you about the following climate related risks and the future impact they may have on your farming operations during your career?*		2.22		0.73		
	Fewer winter chill hours	Four point scale (1 = not concerned, 4 = very concerned)		0.74		1.972	0.046
	Increase in frequency or intensity of frost			0.66		2.199	0.052
	Warmer temperatures			0.82		2.082	0.043
	More frequent heat waves			0.76		2.303	0.048
Global climate change concerns (mediator)	*Indicate your level of agreement with the following statements*		2.91		0.82		
	The global climate is changing	Five point scale (1 = strongly disagree, 5 = strongly agree)		0.76		3.424	0.056
	Average global temperatures are increasing			0.76		3.106	0.052
	Human activities such as fossil fuel combustion are an important cause of climate change			0.78		3.218	0.057
	Climate change poses risks to agriculture globally			0.80		3.777	0.052
	Climate change presents more risks than benefits to agriculture globally			0.71		3.409	
Climate change adaptation practices (dependent)	*If the future climate in Hawke's Bay/Marlborough resulted in more extreme weather or changes in water and temperature, which of the following management strategies would you use beyond what you currently do?*		3.12		0.78		
	Participate in a community irrigation scheme	Six point scale (1 = very unlikely, 5 = very likely, 6 = already use)		0.74		2.779	0.084
	Concentrate river water on a smaller percentage of acreage			0.74		2.248	0.070
	Pump more groundwater			0.65		2.396	0.066
	Drill more wells or seek alternative water sources			0.71		2.466	0.067
	Build water storage facilities			0.72		3.351	0.076
	Adopt a water monitoring technology			0.77		3.894	0.087

86% of wine grapes grown in Marlborough in 2012 were sauvignon blanc (Wine Marlborough New Zealand, 2012). As a result of a unique "terroir" (wine attributes that result from the environment in which a grape is grown), (Van Leeuwen and Seguin, 2006) New Zealand sauvignon blanc has become widely known around the world for the highly distinct characteristics of the Marlborough region (Parr et al., 2007). Sauvignon blanc requires lower average temperatures than many other varieties (Jones, 2003), and growers in the region are driven to maintain its current flavor profile given its international fame (Sturman and Quénol, 2013).

Climatically, Marlborough is unique compared to other regions of New Zealand including Hawke's Bay. While overall New Zealand has seen a general decrease in frost days over the past century (Salinger and Griffiths, 2001), Marlborough has experienced increased frosts and an increased temperature range not seen in other parts of New Zealand in the past several decades (Sturman and Quénol, 2013). These events can be damaging to the wine industry dominant in Marlborough since frosts can influence wine grape yield and quality, particularly if the frosts come at a late date with bud burst or fruiting. Furthermore, the increased temperature range that has been observed in Marlborough in recent years threatens to influence the quality of sauvignon blanc wine that has a lower temperature threshold compared to other varieties like the red varieties dominant in Hawke's Bay. In the future, Marlborough is expected to see an increase in droughts, wetter summers and autumns, and up to 2 °C warming by 2090 (Mullan et al., 2008).

As a result of the described climatic conditions and agronomic characteristics of the region's wine industry, we predict that temperature will be the limiting factor in Marlborough for several reasons: (1) air temperature is the major cause for inter-annual variations in wine quality (Sturman and Quénol, 2013), and Marlborough viticulture is heavily focused on the temperature sensitive variety sauvignon blanc; (2) the increased prevalence of frosts and temperature range in the past has made temperature issues psychologically "closer" to growers within the region; and (3) though droughts may increase in the future, irrigation infrastructure is significant within the region, providing growers with a more resilient water supply portfolio.

4. Materials and methods

A total of 20 qualitative interviews were conducted across the regions in 2012 with farmers and stakeholders. Interviews were used to assist with the development and adaptation of a survey, which was previously implemented among growers in Yolo County, California in 2011 (Haden et al., 2012; Jackson et al., 2012; Niles et al., 2013). The survey was adjusted for local context including relevant practices and language; however, much of the survey was the same and future work will compare farmer responses across the regions.

The quantitative survey was implemented via telephone with assistance from Research First, a professional survey company based in Christchurch, New Zealand utilizing their database of farmers from census and other sources. The survey was piloted among ten farmers outside of the two target regions. A stratified sample was used for the survey allowing for responses within the region to be consistent with the land use type of those areas. Data were collected between August and October 2012. A total of 490 farmers responded to the survey ($n = 177$ in Marlborough, $n = 313$ in Hawke's Bay), with a total response rate of 40%.

We conducted a factor analysis which yielded a single factor solution with factor loadings significantly higher than 0.40, a generally accepted cut-off point (Costello and Osborne, 2005). We used the factor analysis to construct four scales: local water concerns, local temperature concerns, global climate change concerns and climate change adaptation practices. Local water and temperature concern scales each measure the concern for future climate-related impacts for each limiting factor. The global climate change concern scale measures a farmers' belief in climate change and its potential risks. Our dependent variable, the likely adoption of climate change adaptation practices, was a scale aggregated across six different potential adaptation strategies. Each scale achieved an internal reliability (Cronbach's alpha) higher than 0.70 (Nunnally, 1978).

We considered farmers' perceptions of the changes of eight past climate experiences – summer temperature, winter temperature, annual rainfall, water availability, drought, flooding, wind, and slips (landslides). However, the different climate experiences did not yield into factor solutions or scales with acceptable loadings or Cronbach's alpha. As a result, all eight climate experiences were treated as individual variables. Table 1 gives further detail on variable statistics and reliability measures across the models.

To test for how climate experiences affect climate change concerns (local and global) and thus the adoption of adaptation practices we built a series of multiple mediation models for each of the dominant farm types within a region (Marlborough viticulture = 65%, $n = 155$; Hawke's Bay sheep/beef = 81%, $n = 239$). The mediation models were designed to test for how the eight different climate change experiences influenced a farmer's limiting factors and global climate change concerns, and how these affected the adoption of adaptation practices. We also tested for a direct effect of climate change experiences on the adoption of adaptation practices. We tested the viticulture and sheep/beef models in both regions to control for farm system type. In running these series of models we aimed to test for the interaction effects of farm type, region and limiting factor.

We utilized bias-corrected bootstrapped ($n = 1000$) confidence intervals (95% confidence) to test for indirect mediation effects within our models (Preacher and Hayes, 2008). Mediation occurs if the reported confidence intervals do not contain zero (Fritz and MacKinnon, 2007) and we built off of work by Zhao et al. (2010) suggesting that a direct effect is not necessary to indicate indirect mediation effects. We used bias corrected bootstrapped results because they have been shown to perform the best with regards to power and Type I error results (Briggs, 2006) particularly for multiple mediation models and smaller sample sizes (Preacher and Hayes, 2008).

Since we had eight separate independent variables (each climate experience) and two separate local concerns/limiting factors mediators (temperature and water concerns) we ran 16 models for each farm system (viticulture, sheep/beef) in both regions for a total of 64 models. Supplementary Table 1 provides the coefficients, and bias-corrected bootstrapped confidence intervals for each model. We aggregated total indirect effects across all models for a farm system and region to determine the cumulative effect of a limiting factor on farmer adoption of adaptation behaviors. Across all 64 models we found no significant mediation effects of past climate experiences on global climate change concerns and then on the adoption of adaptation practices, so these results are not reported. Instead, all significant mediation effects were through a local perception to influence adaptation behaviors, which we report below.

5. Results

5.1. Perceptions of past climate changes

Across both regions, farmers indicated that they have observed a number of changes in the climate and extreme events over time (Fig. 2). In particular, there are notable differences between Marlborough and Hawke's Bay with regards to water related events

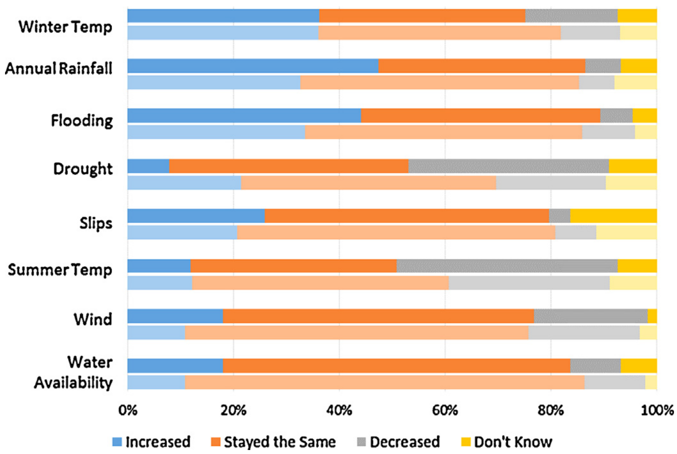

Fig. 2. Perceived changes in climate over time. Darker color bars on top represent Marlborough farmer responses while lighter color bars on the bottom represent Hawke's Bay farmer responses.

and availability. In Marlborough, 47% of farmers believe that annual rainfall has increased over time while only 33% believe so in Hawke's Bay. As well, 44% of farmers in Marlborough suggest that flooding and water availability have increased (44% and 18% respectively), but in Hawke's Bay only 34% believe flooding has increased and only 11% believe water availability has increased. This trend is also observed in perceptions of drought – more than 21% of Hawke's Bay farmers believe drought has increased, while only 8% of Marlborough farmers have observed an increase in drought.

Trends in temperature and other extreme events are less diverse. Thirty-six percent and 12% of farmers in both regions believe winter temperatures and summer temperatures have increased respectively. However, a plurality also believes that summer temperatures have decreased (30% in Hawke's Bay and 42% in Marlborough). Wind frequency and intensity was perceived to have increased by 11% of Hawke's Bay farmers and 18% of Marlborough farmers. Finally, 21% of Hawke's Bay farmers and 26% of Marlborough farmers believed that the frequency and/or intensity of slips (landslides) had increased.

5.2. Future concerns and limiting factors

Fig. 3 shows the average level of stated future concern (1 = not concerned, 4 = very concerned) for water and temperature limiting factors across all farmers in the two regions. Overall the average level of future concern across the five water issues was higher than for temperature concerns in both regions (average water concerns in Marlborough = 2.56, Hawke's Bay = 2.48; average temperature concerns in Marlborough = 2.22, Hawke's Bay = 2.09). However, comparing water and temperature concerns across the two regions was not statistically significant ($p < 0.05$) indicating that overall there are not clear differences in these climate change concerns across the two regions. Despite this, our model results provide evidence that these same concerns have different impacts in the way they interact with farmers' past climate experiences to drive the adoption of adaptation practices.

5.3. Model

Fig. 4 shows the cumulative total indirect effects (significant and non-significant, $p < 0.05$) derived from multiple mediation models to test the effect of past climate experiences, global climate change concerns, and local limiting factors on the adoption of agricultural adaptation practices. Across all of the models we did not find any significant indirect effects from the "global pathway" of past climate experience, global climate change concerns and the adoption of agricultural adaptation practices. However, we do find evidence for our hypothesis that water is the limiting factor driving adaptation behaviors in Hawke's Bay. Water as a mediating limiting factor has the greatest indirect effect on the adoption of adaptation practices among sheep/beef farmers while temperature has no influence.

In Marlborough, we do not find evidence for our hypothesis that temperature is the only limiting factor for viticulture. Instead, we find that the combined effect of temperature across viticulture and sheep/beef systems has an overall more significant effect compared to water (total significant indirect effects from temperature = 0.501 compared to 0.262 for water); however, temperature was not the only limiting factor in the viticulture industry as we hypothesized. Wine grape growers water concerns also indirectly influenced the adoption of adaptation behaviors, though to a lesser extent. Conversely, sheep/beef farmers in

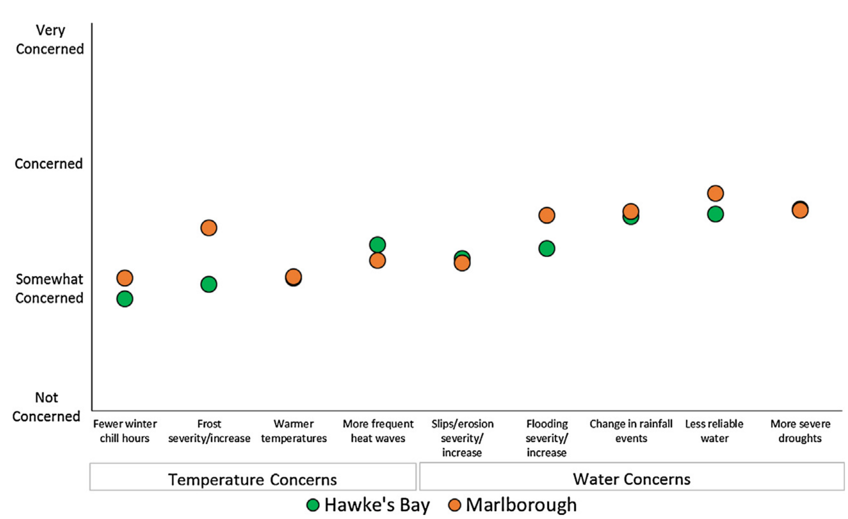

Fig. 3. Mean Levels of concern for future temperature and water climate risks ("Limiting Factors"). The events listed for each type of concern make up the aggregate mediating variables for temperature and water limiting factors in the multiple mediation models. There were no statistically significant differences across the two regions and limiting factors collectively on average; however, the difference shown between Marlborough and Hawke's Bay for increased frost and flooding is statistically significant individually ($p < 0.05$).

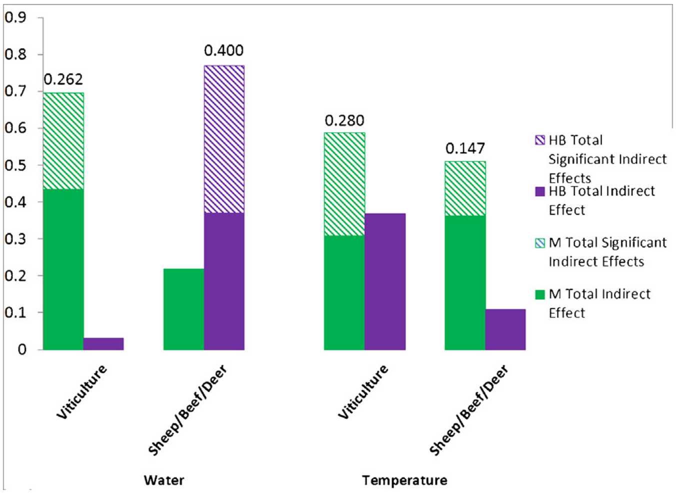

Fig. 4. Total indirect effects of water and temperature limiting factors across farm types and regions. Marlborough results are indicated in green on the left side of the pairings while Hawke's Bay results are indicated in purple on the right side of the pairings. Data labels show the total statistically significant ($p < 0.05$) indirect effects across the eight models ran for each farm system, region and limiting factor (if no label, there were no statistically significant effects). These results are only for the limiting factors pathway, as the relationships between past climate experiences, global climate change concerns and the adoption of adaptation practices was insignificant across all models. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Marlborough are only influenced by temperature as a limiting factor in affecting their adoption of adaptation practices, which was unexpected given that water was the limiting factor for sheep/beef farmers in Hawke's Bay.

6. Discussion

Our work demonstrates a correlation between past climate change experiences, limiting factors (future climate concerns) and the adoption of agricultural adaptation practices. Importantly, we find no significant indirect effects of a "global" pathway where past climate experiences affect global climate change concerns and then the adoption of adaptation practices. Instead, consistent with our previous work in California, the adoption is climate adaptation practices is influenced mostly by a "local" pathway where past experiences influence local concerns about future climate change (Haden et al., 2012). In our previous work, we also did not find evidence that global climate change concerns influenced the adoption of adaptation practices; instead global climate change concerns influenced the adoption of mitigation behaviors. These results suggest that across agricultural contexts, countries and policies, there is consistent correlation between past climate experiences, local level concerns or limiting factors for the future, and the adoption of agricultural adaptation practices.

These results also demonstrate the applicability of a limiting factors hypothesis and the Psychological Distance Theory. We find that limiting factors appear to be both regionally specific and farm system specific, often differing across both. As we predicted, our results suggest that water is a limiting factor in Hawke's Bay where historical and future climate events coupled with the agro-ecological context of water infrastructure have made water a limiting factor for the sheep/beef farms in the region. The recent North Island drought in 2013 (which occurred after our data collection) provides some additional context as to why we observe water as a limiting factor for sheep/beef systems but not viticulture. The worst drought to hit the North Island of New Zealand since World War II, the 2013 drought caused an estimated NZ$2 billion in losses with devastating impacts on the area's sheep/beef farmers who had to de-stock their animals and purchase additional feed. These impacts also affected rural livelihoods spurring campaigns to encourage farmers to talk about possible mental health issues in an effort to thwart rural suicides (Hawke's Bay Regional Council, 2013).

On the contrary, wine grape growers in Hawke's Bay celebrated the best vintage in a century. Drought conditions coupled with the warm temperatures and clear skies helped concentrate flavors in grapes and increase quality (Rogers, 2013). The irrigation infrastructure for viticulture in the Hawke's Bay area made drought conditions easier to manage and adapt to compared with sheep/beef farmers who lacked the same capacity on a whole. In our interviews, we had one sheep and beef industry professional mention, "*If you ask most sheep and beef farmers, it will be a small minority even in the dry areas that have any irrigation at all.*" As a result, the agro-ecological context and farm system as well as the available infrastructure for those systems influenced how two different industries responded to the drought.

The cross-regional differences that we observed among the same farm types is likely because of historical changes, regional varieties, and mixed farm systems. Temperature was significant for Marlborough viticulturalists but not for Hawke's Bay potentially because the varieties in Hawke's Bay have a higher adaptive capacity for warming temperatures in the future. While sauvignon blanc dominates in Marlborough, red varieties like cabernet sauvignon are prolific in Hawke's Bay. These red varieties have higher average growing season temperatures (Jones, 2003) and research from major red wine growing regions indicates that warming temperatures historically have increased wine quality and grape yields (Nemani et al., 2001). On the contrary, as indicated earlier, Marlborough has seen an increased temperature range and frosts in recent decades, which could have a significant effect on sauvignon blanc that has a lower temperature threshold than many red varieties. During our interviews one viticulturalist from Marlborough summed up his concerns succinctly stating, "*Our biggest challenges probably don't revolve around rainfall presence or lack of, they revolve around temperature and fruit set and yield.*"

The results that water was also a limiting factor for Marlborough viticulture was unexpected; however, can likely be explained by the existing irrigation context and the varieties grown in the region. White wine varieties can fare worse than red varietals in water stressed situations as aroma development is restricted (Peyrot des Gachons et al., 2005). Since the majority of wine grown in Marlborough is the white variety sauvignon blanc, water stress would likely influence these crops more than they would the dominant red varieties found in Hawke's Bay where water as a limiting factor had no mediating effect. Furthermore, Marlborough has high evapotranspiration rates, and while irrigation has massively expanded, the region is very limited in its future capacity to expand water rights. In essence, the mere presence of irrigation does not necessarily guarantee that the Regional Council will not restrict water allocations for the future. Finally, we suggest that the temperature signal present among sheep/beef farmers in Marlborough and not in Hawke's Bay is likely in part because of mixed farming systems. The expansion of wine grapes into sheep/beef land in Marlborough means that many of these farmers also now grow wine grapes, which may be influencing how they perceive temperature concerns.

Our results indicate that farm system types alone may not determine climate change perspectives and behaviors; these systems are also imbedded in regions with varying climate experiences and impacts and infrastructure. The interaction of the two presents perhaps the greatest potential for assessing climate adaptation behaviors based on limiting factors. These results demonstrate how farmers' personal experiences with climate change are translated through limiting factors and future concerns to affect their behavior with both farm system and regional differences. We are also conscious that adaptive capacity is not exclusively based on climate experiences and biophysical components of climate change – skill sets of individual farmers as well as their own perceived capacity to deal with change are also widely acknowledged in the broader literature as being key factors for adaptation (Marshall, 2010; Marshall et al., 2014).

Application of this work to other regions and systems suggests several important considerations. First, farmers' appear to be reacting and behaving in part because of limiting factors in their system. This limiting factors hypothesis is inherently connected to the concept of Liebig's Law of the Minimum: a farming system will be hindered by its most limited resource. In adapting to changing conditions, it makes sense both psychologically and ecologically that these are the effects farmers find to be most salient. These factors are psychologically "close" to them, having contended with them in the past, making them concerning issues for the future. Given this historical nature, it is likely that a farm's limiting factor will be the single greatest adaptation issue for farmers.

Within this context however, it is also important to recognize the role that infrastructure can play. The extensive irrigation capacity within viticulture, especially in Hawke's Bay where drought has been more prevalent, has appeared to provide wine grape growers with additional security and capacity to manage water within the drought context. To the extent that irrigation or water storage is feasible within farming systems in Hawke's Bay it may provide this additional capacity to assist farmers with future water shortages. However, the expansion of such infrastructure projects may also present challenges if water allocations are limited by institutions, or if such infrastructure enables land use change with additional environmental or social impacts. Water management infrastructure is thus insulating farmers from the environmental limiting factors inherent in the agro-ecological context.

If limiting factors are the most salient for farmers, it likely has significant implications for assessing how short-term responses can influence long-term adaptations and the subsequent policies that may be needed to accompany such actions (Howden et al., 2007). Frameworks like the Adaptation Cycle (Wheaton and Maciver, 1999) and Adaptation Action Cycle (Park et al., 2012) aim to assess what individuals adapt to, and these results corroborate other work (Spence et al., 2012) suggesting that psychologically close phenomena may actually change behavior. Our work can assist a region to understand what the limiting factors of a system may be and communicate potential risks to develop robust adaptation strategies, a need clearly articulated by Rosenzweig et al. (2013). This may also provide deeper perspectives for assessing a farmer's potential for short-term reactive incremental adaptation versus longer-term transformative adaptation as discussed by Park et al. (2012). Limiting factors are likely the most immediate issue for a system and could result in short-term responses, which may actually hinder longer-term transformative adaptive strategies if it remains the sole focus of a farmer. We believe that future work could more clearly distinguish climate change experiences by different temporal time-frames to determine whether nearer-term experiences have greater influences on behaviors than longer-term trends or experiences.

Second, it is crucial to recognize that, at least in our work, limiting factors will not be defined by either a region itself or the farm system type as a whole; rather, there is an interaction of the two. Even in a small country like New Zealand, local differences in climate change are possible and require regional focus and planning (Sturman and Quénol, 2013). Broad agricultural adaptation strategies for a given farm system or country therefore may be fruitless if they do not consider heterogeneity among farm types within a given region or consider how ecological contexts affect all farm system types more broadly. While climate change mitigation strategies may be aggregated and determined at a larger scale given its global nature, our work suggests that regional and local-based adaptation strategies will likely be the most effective.

Finally, we believe it is time to join together ecological and social/psychological theories and apply them to real-world data to advance work in climate change adaptation. Though many have highlighted the need to make climate change work more multidisciplinary (Howden et al., 2007; Swim et al., 2011), empirical examples of joining disciplines and theories to actually link ecological contexts with decision-making to predict behaviors are scarce. By doing so here, we couple climatic data, ecological and psychological concepts to assess how farmers may change their behavior based on both Mother Nature and human nature. Additional work could also be done to more completely link our psychological data with regional environmental data through agent-based modeling, which we hope to do in the future.

7. Conclusion

This paper has aimed to address a gap in theory linking ecological contexts with farmer decision-making within climate change adaptation by using empirical data to assess the factors that drive the adoption of adaptation strategies. Agricultural adaptation to climate change is crucial not just for farmers, rural communities, and economic sustainability but for a growing population and global food security (Schmidhuber and Tubiello, 2007). Though significant attention has been given to agricultural adaptation in the developing world (Bryan et al., 2009; Mertz et al., 2009), fewer papers have looked at developed country adaptation across varying farm system types. Through our limiting factors hypothesis, we demonstrate both theoretically and empirically the correlation between climatic experiences, climatic limiting factors and the adoption of adapting behaviors. Coupling ecological and psychological theories demonstrates that the limiting factors within a given region, farm system, or both are the most relevant, as they are both psychologically and ecologically "close" to a farmer. As such, they are indirectly mediating how farmers translate their past climate experiences into future behaviors.

Of course we recognize that this work is thus far limited to only two regions in New Zealand and our work in California and additional analysis across many other agro-ecological systems is needed to determine whether the limiting factors hypothesis can be broadly applied. More explicit modeling through agent-based simulations can assist researchers in coupling environmental and climatic data with farmer perceptions and behaviors. We also intend to explicitly test whether global concerns mediate the relationship between past climate experiences and the adoption of mitigation behaviors as our previous work has demonstrated. Researchers, regional planners, and policymakers can build on this work by utilizing a more interdisciplinary approach for climate change adaptation decision-making and working with farmers and rural communities to assess the most limiting factors and related adaptation practices for a given region and farm system.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agee.2014.11.010.

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