

Vulnerability and adaptation to climate change and variability in semi-arid rural southeastern Arizona, USA

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Abstract

Agricultural and livestock producers experiencing climate change and variability are simultaneously subject to other sources of environmental vulnerability, as well as political, social, and economic uncertainty. Producers' adaptive decision making takes into account short-term seasonal factors, while seeking to preserve livelihood stability over the long term. This study identifies multiple sources of vulnerability for farmers and ranchers in southeastern Arizona, and the adaptive strategies they have adopted including the use of information such as seasonal climate forecasts (SCFs). Interviews with producers and extension agents in Pima and Cochise Counties reveal that the principal climatic risks are drought, floods and frosts, and that groundwater use remains a crucial strategy despite increasing pumping costs. Low risk tolerance and uncertainty of seasonal production and marketing conditions diminish the utility of SCFs as a decision-making tool. Instead, farmers and ranchers continue to rely on past experience and short-range forecasts, hedging each year instead of taking significant risks. By examining the role of climate information in complex production decisions, the study shows that access to information is not the principal limitation to improving decision making. Comparison to other regions reaffirms common vulnerabilities among producers and highlights research and communication needs that have global relevance.

Keywords: Climate; Agriculture; Vulnerability; Risk; Adaptation; Information.

1. Introduction

Climate variability poses one of the major challenges facing agricultural and livestock producers around the world. Climate variability can be experienced as variation in weather events, which occur on a timescale of hours to days, and in climate events, which occur on a timescale of weeks to years (NCDC, 2009b). Both can be devastating to production. Farmers and ranchers must hedge risks to minimize possible losses, and as a result often do not have the opportunity to fully capitalize on good years. Not only do rural producers contend with environmental risks such as climate variability and water scarcity, the multiple risks they face may be: 1) financial (e.g., inadequate credit, investment, or hedging capability); 2) economic (fluctuations in input costs and commodity prices); 3) institutional (groundwater

regulations); 4) social (aging of the rural population and implications for labor and farming knowledge); and 5) political (conversion of farm- or rangeland for urban growth). Farmers and ranchers therefore face an ever-changing combination of factors that fundamentally challenge their enterprise and way of life. The paper will explore these vulnerabilities and agricultural producers' adaptive response strategies in semi-arid southeastern Arizona in the United States; further development of the case study is presented below. Because each region is unique, a case study of a specific region may have little relevance in other contexts. However, generic implications for climate and water-related decision making within complex livelihood strategies are drawn out. Furthermore, the article considers that access to information is not the critical barrier to improved adoption of climate information, in contrast to some less developed countries where information access is a barrier. Access to information alone does not guarantee that it will be applied.

To better understand the specific weather- and climate-related vulnerabilities of rural producers, the paper builds upon the definition of vulnerability by Blaikie *et al.* (1994: 9): 'the characteristics of a person or group in terms of the capacity to anticipate, cope with, resist, and recover from

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the impact of a natural hazard.’ Both production and livelihoods are considered (Finan *et al.*, 2002) because risks are experienced differently over time. Individuals, communities, and governments may take a variety of actions in order to reduce vulnerability (Adger *et al.*, 2003). Vásquez-León *et al.* (2002) distinguish between two types of strategies for vulnerability reduction, buffering and coping. Buffering refers to long-term adaptation strategies such as technological innovation and social restructuring that can reduce or eliminate certain sources of vulnerability. Coping strategies, on the other hand, are activities that reduce negative impacts in the short term, but do not reduce overall vulnerability. However, some buffering and coping strategies may prove maladaptive over time, increasing rather than decreasing vulnerability to climate variability (Burton *et al.*, 1998). In the short term (seasonal to annual), the risks are primarily to production (lower crop yields and livestock output), whereas in the long term (years to generations), climate variability exerts a fundamental threat to farmers’ and ranchers’ way of life.

The concept of livelihood used in this study is modeled on the livelihood strategies framework in anthropological development studies as described by White (2009), in which the term ‘livelihood strategies’ implies that individuals or households seek to accumulate resources, rather than merely survive or cope. She also stresses the importance of identity and ties to place, and argues that ‘[i]dentity is both an asset, to be exploited by the individual or household, and shaper of livelihood expectations and trajectories’ (White, 2009: 557). Therefore, identity and place significantly affect which livelihood strategies are available, preferred, and actually employed. As indicated above, threats to livelihoods endanger economic stability as well as identity and the ability to remain rooted in place. As the paper will show, these effects are interlinked. Our model for the vulnerability assessment therefore builds on Blaikie *et al.* (1994) through application of the ‘hazards of place’ conceptual framework (Cutter, 1996). We emphasize that vulnerability should be considered within complex and dynamic political, economic, social, and environmental contexts (see also Burton *et al.*, 1993; Wisner *et al.*, 2004; Cutter *et al.*, 2008).

This paper is organized as follows. It begins with an overview of farming and ranching in southeastern Arizona, specifically Pima and Cochise Counties. The methods for primary data collection, informed by the conceptual advances presented for this region by Finan *et al.* (2002), Eakin and Conley (2002), Vásquez-León *et al.* (2002), and Vásquez-León *et al.* (2003) are then described. The next section addresses weather- and climate-related risks based on interviews with farmers and ranchers regarding sources of vulnerability as well as adaptive strategies used to counter vulnerability and their limitations. Of particular interest is the role of information in decision-making processes and its implications for mitigating risk and reducing vulnerability. The paper concludes with a

prognosis of future climate-related risks for rural livelihoods in the region and draws out lessons of potential value to other regions.

2. Context: Farming and ranching in southeastern Arizona

Agricultural and livestock production has figured prominently in the history of southeastern Arizona. The ancient Hohokam developed expansive irrigation networks, which were adopted by subsequent settlers (August & Gammage, 2007; Meyer, 1984). Settlements were organized around valley-bottom farms and extensive cattle ranching during the Spanish Colonial (17th and 18th Centuries) and Mexican periods (19th Century). The influx of Anglo-American settlers began in the late 1800s as rumours of vast and productive grasslands attracted farmers and cattle ranchers (Vásquez-León *et al.*, 2002; Finan *et al.*, 2002; West & Vásquez-León, 2008). Although production has been in decline over the last few decades (Vásquez-León *et al.*, 2002; Finan *et al.*, 2002), agriculture and livestock remain vital to the economy of Arizona. The Census of Agriculture conducted by the United States Department of Agriculture (USDA) defines a farm as ‘any place from which [USD]\$1,000 or more of agricultural products were produced and sold, or normally would have been sold during the census year’ (NASS, 2009: viii). According to this definition, which includes ranches as well, 36% of the total area of the state of Arizona is considered farmland (NASS, 2009; US Census, 2000). The US\$ 9.2 billion dollar agrarian sector contributes enormously to the state’s economy and employment (Mortensen, 2004; AZDA, 2008).

Farming and ranching in southeastern Arizona experience a variety of weather- and climate-related hazards, but vulnerability is primarily felt in relation to water because it is vital for agricultural and livestock production and because the devastating extremes of flood and drought are commonly experienced. Crops may be grown year-round because of the warm temperatures and available sunshine, but lack of sufficient precipitation leaves the agricultural sector reliant on large amounts of rapidly-depleting water for irrigation. In 2000, irrigated agriculture accounted for 80% of groundwater use and 81% of surface water use statewide, a rate more than double the national average irrigated water use rate (Hutson *et al.*, 2004). Yuma County in southwestern Arizona is the seat of agricultural production in the state, but has been excluded from this study because access to Colorado River water reduces the vulnerability to climate variability of producers there.

Very little perennial surface water is available in southeastern Arizona (see map, Fig. 1), which makes farmers and ranchers primarily dependent upon groundwater for irrigation of water-intensive crops such as cotton, wheat,



Figure 1. Map of Arizona showing Pima and Cochise counties.
 Source: Adapted from USDC (1990).

pecans, and alfalfa for cattle feed. Groundwater depletion and declining aquifer levels are discussed in the section on vulnerability below. Cattle ranching remains a major farm activity in Arizona, with 40% of farms in Pima and 46% in Cochise County maintaining cattle, primarily for beef (NASS, 2009). Most of the cultivation in Pima County is devoted to its famous Pima cotton as well as durum wheat (AZDA, 2009), although other cereals and vegetables are grown as well. Farmers in Cochise County increasingly shift from field crops such as cotton, wheat, corn, sorghum, and alfalfa towards fruit and nut orchards, chilli, and other vegetables (AZDA, 2009). In 2007, 48% of cropland in Cochise County was irrigated, while 72% in Pima County was irrigated (NASS, 2009).

In addition to heavy reliance on a scarce resource, agricultural and livestock producers in the study area operate under high temperatures, high evaporation rates, and spatially and temporally variable precipitation events (Garfin *et al.*, 2007; Sheppard *et al.*, 2002). Figure 2 shows average monthly temperature and precipitation for southeastern Arizona (1931–2000), but averages and extremes vary within the area due to factors such as

elevation (NCDC, 2009a). Climate researchers attempt to improve seasonal predictions by identifying connections between cyclical fluctuations such as the El Niño Southern Oscillation (ENSO) and regional precipitation patterns (e.g. Sheppard *et al.*, 2002). ENSO appears to be the ‘strongest and most important influence on interannual climate and weather variations in Arizona, particularly in winter’, which is when the majority of aquifer recharge occurs (Garfin *et al.*, 2007: 67).

Annual variability can also be affected by long-term climate change (Dolan *et al.*, 2001). Researchers have recently discovered evidence that annual flow distribution has been changing as a result of earlier snowmelt runoff, as well as later and fewer summer rains (Anderson *et al.*, 2007). Climate models predict higher temperatures, higher evaporation rates, and increased precipitation variability for this region, meaning more frequent extremes such as droughts and floods (Christensen *et al.*, 2007). Droughts limit vegetative growth on rangeland and further strain groundwater supplies that farmers must rely upon in the absence of reliable rainfall, and floods cause damage and contribute only marginally to groundwater recharge despite

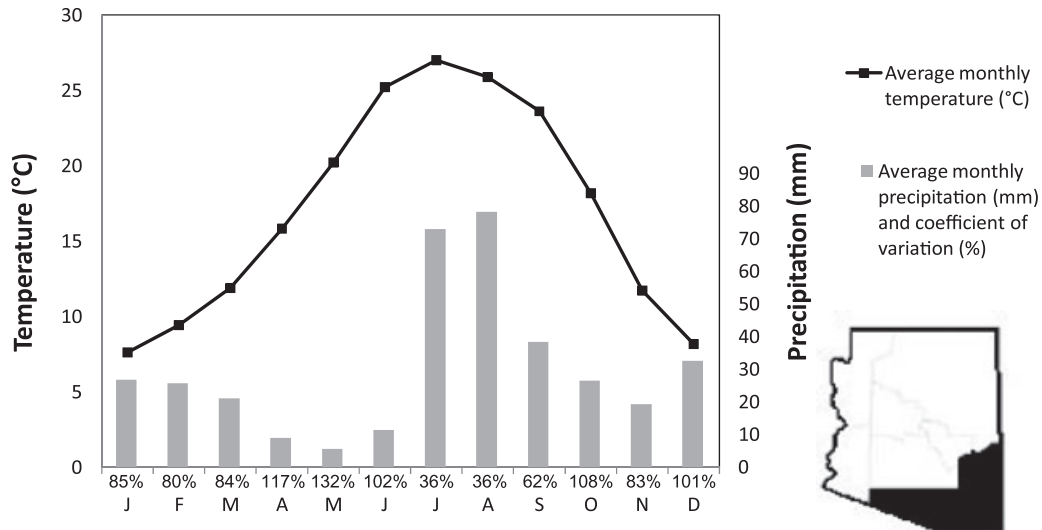


Figure 2. Average monthly temperature and precipitation for southeastern Arizona, 1931–2000 (Climate Division 7).

Source: Data and inset from NCDC (2009a).

that which occurs along mountain fronts during ephemeral runoff from heavy rainfall events (Goodrich *et al.*, 2004).

3. Methods

Primary data were collected in order to investigate climate change and variability-related vulnerabilities experienced by farmers and ranchers in southeastern Arizona, as well as the importance of weather and water information in adapting to variability and change. In late 2008 and early 2009, farmers, ranchers, and USDA Natural Resources Conservation Service (NRCS) agents in Pima and Cochise Counties were interviewed about what types of weather or climate phenomena cause losses for their operation, the ways in which they can or cannot mitigate or adapt to these phenomena, and the types of information they seek or exchange with others that is incorporated into their management strategies. NRCS agents were asked these questions with reference to the geographical areas they represent. Special emphasis was placed on water sources and usage, given that water and producers' access to it represents a critical vulnerability factor. Additionally, three public business meetings held by a water users' association and two natural resource conservation districts were attended. Topics of the meetings were focused on organizational issues, but time was set aside for a brief discussion of the questions listed above and contacts for later interviews were established. Other initial contacts were made through local NRCS offices, and subsequent contacts were made through 'snowballing' with respondents' recommendations. As a result, it is possible that sampling bias has resulted in a set of respondents that are more connected and informed than in general. This limitation has important implications for the findings of this

study, as will be revealed later. However, many of these participants indicated that it is difficult to remain unconnected and uninformed in small rural communities.

Seventeen in-depth interviews were conducted in total. Of the 13 interviewees in Cochise County, six were ranchers, one was a farmer, two ran both a farming and a ranching operation, and three were NRCS agents, two of whom also run a farming operation. Another individual interviewed maintains a wildlife refuge. In Pima County, three interviewees were farmers, one was an NRCS agent, and one was a Cooperative Extension agent.¹ Each Pima County farmer interviewed harvests over 1,000 acres each year, a farm size which places them in the top ten% of Pima County producers (NASS, 2009). Ranches were more variable in size, ranging from 30 to over 400 head. Most of the ranchers interviewed sustain herd sizes between 100 and 300 head, which is large enough to be commercially viable but small enough that climate variability is a serious threat to long-term livelihood sustainability (Eakin & Conley, 2002). Most of the fieldwork was conducted during four visits to rural communities in Cochise and Pima County. Four interviews were carried out over the telephone. Field notes were taken for each meeting and interview, which ranged in duration from half an hour to over four hours.

A narrative analysis entails the interpretation of respondents' answers in an effort to convey meaning and

¹ Although none of the farmers interviewed were of the Tohono O'odham Native American Nation, it should be noted that their reservation covers a significant portion of Pima County and that their agricultural practices may differ from dominant practices off-reservation, such as communal rangeland management (Arnold & Fernandez-Gimenez, 2007). Additionally, all non-extension interviewees were farm or ranch owners, but previous research has shown that farm labor is another livelihood strategy that is largely affected by weather and climate (Vásquez-León *et al.*, 2002; Vásquez-León, 2009a).

values to others through ‘cultural stories’ (Silverman, 2003: 345). Narrative analysis is particularly useful with small samples that are not statistically representative of the population. Rather than attempt to extrapolate to a broader population, we use narrative analysis to reveal the stories that would be missed in a more structured analysis. The results can be used to design further inquiries within the same or other contexts. The farmers and ranchers in this study describe their experiences with respect to vulnerability, adaptation, and the use of information to make decisions. Their accounts illuminate some of the attitudes, concerns, and hopes of rural agricultural and livestock producers in the study area. The following section contains results of the narrative analysis.

4. Results and discussion

The multiple sources of vulnerability and adaptive strategies identified during interviews with farmers and ranchers are presented and discussed below. These results build upon previous studies in the region (Eakin & Conley, 2002; Finan *et al.*, 2002; Vásquez-León *et al.*, 2002; Vásquez-León *et al.*, 2003) and provide a context for information use and sharing as adaptive strategies with applications beyond the specific case study region.

4.1. ‘Double exposure’: vulnerability to economic forces and climate variability

The principal concern for all of the farmers and ranchers interviewed is commodity prices, echoing previous findings for southeastern Arizona (Eakin & Conley, 2002; Finan *et al.*, 2002; Vásquez-León *et al.*, 2002) and elsewhere (Breuer *et al.*, 2007). As one rancher put it, economic concerns such as commodity prices ‘get to the bottom line quick.’ Consequently, most decision making revolves around current and projected commodity prices, which are tied to political, social, economic, and environmental events on the local, regional, or global scales. Subsidies and trade policies such as the North American Free Trade Agreement (NAFTA) influence which crops are produced within this region as in others, which has environmental implications not the least of which include irrigation demand. For example, free trade agreements such as NAFTA have been linked to aquifer overdraft and increased vulnerability among small-scale producers in nearby Sonora, Mexico (Wilder & Whiteford, 2006; Vásquez-León, 2009b). As another example, one rancher noted that even though Arizona’s beef industry is not directly related to rainforest destruction, negative media attention following a series of protests suppresses the entire industry. Thus global economic forces, in addition to climate change and variability, can raise vulnerability through what Leichenko and O’Brien (2008) refer to as ‘double exposure’. Most of the climate-related sources of vulnerability have an

economic component to them, particularly through people’s ability to adapt to or cope with climate variability and change.

While Leichenko and O’Brien (2008) describe double exposure primarily in terms of global economic and climatic phenomena, this concept can be expanded to include other social, political, and environmental effects at any scale from global to local. In southeastern Arizona, for example, there is increasing pressure away from agriculture and ranching and towards suburban development, noted in earlier studies and listed among the major concerns of those interviewed for this study (Eakin & Conley, 2002; Finan *et al.*, 2002; Vásquez-León *et al.*, 2003). Finan *et al.* (2002) attribute the shift to socio-economic conditions rather than to climate, but interviewees certainly feel the additional constraints of sustained drought. Intensive agricultural water use, increasing demand from a rapidly growing population, and climate variability thus combine to strain groundwater supplies, leading to aquifer overdraft, changes in surface and subflows, and relative scarcity (Zekster *et al.*, 2005). One ranching couple described fears that they would lose their water supply entirely if the housing subdivisions creeping ever closer to their ranch continue to pump water at their current rates. This couple noted that ranchers ‘have to be committed to the lifestyle,’ and that they have gone without water themselves to ensure that the cattle had enough. They and other ranchers expressed fears that they will be ‘forced out’ of the area and the business as ranching becomes less profitable and housing subdivisions replace their own and their neighbours’ grazing pastures. Those whose families have been ranching in the area for generations especially lament the shifting landscape and the potential loss of their livelihoods. As White (2009) indicated, they stand to lose their social support in addition to their economic support, and their identities as ranchers in addition to their land.

Drought is by far the most important climate-related concern among each of the ranchers interviewed, all of whom depend upon rainfed pastures to raise livestock. Winter rains are seen as a bonus because they can boost spring grass growth, but ranchers have learned not to depend on them. Summer rains are much more critical for grass production and herd maintenance, and can be a determining factor for how many calves a rancher sells in the autumn. The other extreme is problematic as well, however. One rancher indicated that continuous rains can waterlog grasses and lower their protein content. He and three other ranchers mentioned that heavy rains can wash out or make roads impassable, making travel to markets difficult.

Drought is less of a concern for farmers, who rely almost entirely upon groundwater. In fact, farmers in this and previous studies prefer dryness so that they can control water inputs (Vásquez-León *et al.*, 2002; Vásquez-León *et al.*, 2003). Rain also contributes to soil erosion and interrupts planting and harvesting schedules. A mixed-crop

farmer mentioned that beans cannot be planted when the soil is too wet, 'or you do and wish you didn't.' Another farmer said that at least one out of 8 to 10 alfalfa cuttings is lost each year to early or late rainfall. Floods were also frequently cited as problems for the Marana farmers whose properties lie near the Santa Cruz River or the numerous dry stream beds in the area through which storm water flows. On the other hand, lack of rainfall creates high costs for farmers. While the water itself is heavily subsidized and therefore cheap given the relative scarcity, the energy required to pump water can be extremely expensive. Many of the farmers and ranchers interviewed for this study indicated energy for pumping water as their largest and least avoidable cost. Energy considerations for pumping groundwater (Scott *et al.*, 2007) are especially important because the demand for water and energy both increase with temperature (Garfin *et al.*, 2007).

Other important short-term weather phenomena for farmers include frosts, winds, and hail. Even though longer crop seasons potentially produce higher yields, planting and harvesting schedules must take into account the possibility of late spring or early fall freezes. Winds can also create problems for farmers, particularly in the spring. Seeds blow away, wheat lodges (blows over and lies down), and in rare but extreme events, a center-pivot sprinkler can be tipped over and damaged. Hail is a primary concern among all three Pima County farmers, and while usually only a part of the crop is lost there are occasions of total crop loss to hail. According to one farmer, hail coverage carries the highest premium in crop insurance for southeastern Arizona. Frosts, winds, and hail are less of a problem for ranchers, who simply avoid working cattle on days with extreme weather events. Lightning was cited by a few ranchers as a threat to electrical systems, equipment such as tractors, and cattle, not to mention the threat of fire from a dry strike.

4.2. *Adaptation and limitations*

Most of the farmers and ranchers interviewed have been in the business for generations and have developed adaptive strategies to reduce vulnerability to weather and climate threats. High costs and low profits have forced many agricultural producers to diversify income sources, in southeastern Arizona as well as much of the world. In 2007, only 49% of farm operators in Cochise and 41% in Pima County listed farming as their primary occupation (NASS, 2009). Even those whose primary occupation is farming often take supplemental income from off-farm activities, including several interviewees. The supplemental income helps support farmers and ranchers when weather and climate reduce yearly production. Subsidies and other types of government payments can also reduce vulnerability, although access to these programmes is uneven. In 2007, an average of US\$ 25,157 was paid to 147 Cochise County farms, while an average of US\$ 91,987 was paid to 41 Pima County farms (NASS, 2009). Additionally, marginalized

social groups such as Hispanic farmers in southeastern Arizona experience greater difficulty in obtaining assistance (Vásquez-León *et al.*, 2002; Vásquez-León, 2009a).

Other adaptive strategies are found within farm production decisions. For example, all of the ranchers indicated that they use rotational grazing strategies to reduce stress on pasture vegetation. In the event of a drought, some will release cattle onto other pastures or will lease additional land off-ranch. Maintaining a combination of deeded and leased land also allows ranchers more management flexibility during extreme events (Vásquez-León *et al.*, 2003). A mixed fortune of drought is that many private or state grasslands dry out and become a wildfire danger, and temporary grazing permits may become available in an effort to reduce fire risk. Others may exchange favours for range access, such as one rancher who maintains the fences of a partially developed subdivision in exchange for access to the grass in empty lots. The use of social networks to reduce vulnerability has been documented in this area, particularly among Hispanic farmers who have less access to more formal types of assistance (Vásquez-León, 2009a).

When alternative grazing options are not available many ranchers are forced to purchase supplemental feed. Supplemental feed is not the most desirable option, however, as feed prices often rise along with demand during a drought. One rancher noted that while most ranching costs such as vaccinations, labour, and taxes remain the same from year to year, supplemental feed prices are a variable 'wild card.' Costs for supplemental feed surpassed all other costs for Cochise County producers in 2007, accounting for 21% of all farm production expenses — including operations that do not produce livestock (NASS, 2009). One farmer with a small feedlot operation faces a small range of ideal conditions, since a slight drought encourages ranchers to send their cattle there for supplemental feeding, but extreme drought reduces total cattle numbers in the area and by extension the demand for his services.

Closely related to strains on feed supply are the market prices for beef. Two ranchers noted the tendency for many ranchers to hold on to calves during a drought until they panic and sell at the same time, driving down the prices. Several ranchers said that they prefer to keep their herd numbers lower than the ranch's maximum capacity and ensure a year's supply of feed is on hand so that they can choose when they sell, since beef is always a buyer's market. Three of these ranchers indicated that with this type of preparation, they may incur a large financial loss but can avoid disaster even in the unlikely event that no rain falls in any given year at all.

The droughts of longer duration are more of a concern, however. Uncertainty in the future of cattle ranching in southeastern Arizona due to market, social, and climatic factors has left ranchers in the area searching for more viable alternatives. One rancher is concerned about the

volatility of beef prices and the long-term climate predictions of longer and more severe drought. He is currently experimenting with small animals such as sheep and goats in case the cattle industry becomes no longer viable as a livelihood strategy. The conversion to small ruminant production would be difficult because the animals require different management, and the 30,000 acre ranch would have to be redesigned with the appropriate fencing. Another rancher reluctantly sold much of her land and cattle in order to reduce current and potential debts, believing that the frequency of extended and severe droughts associated with climate change will increase in the future and prevent her from recovering costs in later years.

While both farmers and ranchers face high energy costs to pump water, ranchers require much less water for their operations and can therefore replace generators with solar- or wind-driven pumps. Initial start-up costs for these improvements provide a substantial barrier to adoption, however, and only 4% of farms in Pima County and 5% in Cochise County generated energy or electricity on the farm in 2007 (NASS, 2009). Several of the ranchers obtained federal funding through NRCS to install solar panels on their wells. Some have also received funding to lay pipelines throughout their property to distribute water among their pastures, allowing the cattle to travel smaller distances to access water, reducing the need to drill more wells. This measure also reduces their reliance upon earthen stock tanks, which are livestock watering ponds that may run dry or fill with sediment. Without these cost-sharing programmes, many ranchers in the area would not have the capital needed to invest in these improvements.

Although farmers can at best supplement the generators with solar panels or windmills due to the quantity of water required for farming, pumping costs do figure into irrigation decisions. One farmer in Cochise County indicated that he and other farmers in the area aim to have crops reach their peak water demand during the summer rains in order to lower irrigation costs. He irrigates his feed grass during the dry spring months and hopes to shut off the pumps for up to two and a half months during the summer rains. He also produces a native grass species that is well-suited for the soil and climate of the area, which requires less water than some of the introduced species. Another farmer has recently switched to a drought-resistant variety of sorghum, which has performed quite well during the growing season and even provides soil nutrients after harvesting for subsequent crops.

Flood mitigation is also being addressed by both farmers and ranchers. Some ranchers in Cochise County have installed berms and rock falls in order to slow storm water, reduce erosion, and increase groundwater recharge. Landowners do not always have control over such processes on their property, however. A rancher whose property lies adjacent to the international border with Mexico has suffered erosion damages, including the loss of two wells, as a result of the construction of the border fence and access

roads. Area ranchers were consulted prior to construction but their comments were ignored, and no compensation is available for the losses. Access roads have also increased drug trafficking through ranches, which was previously low because the area was nearly impassable by vehicle.

Farmers in Marana, Pima County, have had mixed success in flood mitigation. After the record floods of 1983, new flood control infrastructure was constructed and fields were rearranged with attention to watercourse proximity. However, at least one farmer believes that mitigation measures on the Santa Cruz River are insufficient, and that the next major flood will have serious consequences for those who live and produce in the area.

Hail and winds are more pressing issues for farmers, however, because they devastate crops more frequently. Each of the Pima County farmers obtains hail insurance each year, particularly on cotton and wheat crops. As mentioned before, they pay higher premiums for hail insurance than any other type but find it absolutely necessary since hail is difficult to mitigate. Winds appear slightly easier to deal with. Farmers noted that they could wait until winds lessen to plant seeds, or plant them deeper in organic material to shelter them. Also, they avoid moistening the soil in advance of high winds so that wheat or other tall crops will not blow over.

Adaptation to climate risk does not ensure success, however. The largest producer of greenhouse tomatoes in the United States with 318 acres of facilities is located in the study region. Despite recognition for the quality of their produce and innovative techniques, the agribusiness's profits have fallen consistently over 2005–2008 notwithstanding increasing revenues, leading to bankruptcy filing in 2009. Tomato plant diseases and whiteflies resulted in thousands of tons of produce lost, a problem compounded by consumers' concerns over the 2008 US salmonella bacteria outbreak traced to tomatoes from other producers. The company also experienced labour problems and mounting debt levels driven by rising costs, including the cost of energy to control environmental variables (Wichner & Scarpinato, 2009).

Further complexity arises when adaptive strategies may inadvertently increase vulnerability. Invasive grass species including buffelgrass, Lehman lovegrass, weeping lovegrass, and kleingrass were introduced to the area in the early to mid 20th Century for their drought tolerance and high productivity relative to native grass species (Williams & Baruch, 2000; Vásquez-León *et al.*, 2003). One ranching couple sows Lehmann lovegrass, which 'greens up' earlier in the season and can help sustain cattle herds during the dry spring months before the summer rains arrive. However, sowing non-native species can be detrimental. Although buffelgrass productivity exceeds that of native grasses during mild drought, an extreme drought decimates buffelgrass. In climatologically-similar Sonora, Mexico, ranchers who converted their pastures to buffelgrass as a widely-encouraged method of vulnerability reduction were

devastated by a severe drought while those who maintained native species continued to produce nutritional feed (Vásquez-León *et al.*, 2003).

The spread of invasive species is often unintentional throughout this region where soil moisture, temperature, and fire regime conditions have been altered by climate change processes (Schussman *et al.*, 2006). Farmers have particular trouble with tumbleweeds, which deposit seeds as they roll across cropland and require careful removal by hand. One farmer in Pima County noted that most of his tumbleweed problems originate in vacant plots of land adjacent to his property. Much of this formerly cultivated land was purchased and fallowed by developers, but a decreased demand for housing has delayed construction and a lack of property maintenance has led to a surge in tumbleweed growth. Furthermore, many ranchers spend a great deal of effort and resources to battle the invasive species on their property because they receive federal or state financial support and further secure their land tenure if they sustain native plant and animal species (see also Vásquez-León *et al.*, 2003).

The Central Arizona Project (CAP) was proposed and built as a solution to water scarcity for Arizona's mainly agricultural economy by delivering Colorado River water to central and southern Arizona. However, in the prior appropriation ('first in time, first in right') system of water rights the CAP allotment has 'junior' status on the Colorado River and therefore is the least likely to receive water during a drought (August & Gammage, 2007). In order to receive CAP water, customers must have access to the canal directly or indirectly, such as through the tailwater that leaves a neighbour's irrigation system and flows into irrigation district-managed canals. Thus, very few producers in Pima and no producers in Cochise County have access to CAP water. Additionally, farmers have more incentive to continue to pump the cheaper groundwater than to switch to the slightly more sustainable but significantly more expensive CAP water (Colby *et al.*, 2007). The use of irrigation thus serves as an adaptation to the semiarid climate, but the potential for overdraft suggests that this strategy may be maladaptive over time.

To further combat groundwater overdraft and fulfill requirements for construction of the CAP, the Arizona State Legislature passed the Groundwater Management Act (GMA) in 1980. The GMA requires that developers demonstrate an assured (100-year) supply of water in the area of proposed development, regulates the monitoring of wells and the construction of new wells, and prohibits expansion of water use related to agriculture within five Active Management Areas (AMAs) (Pearce, 2007; ARS 45, Section 401). Thus, lack of regulation in areas outside of AMAs or conservation areas may lead to aquifer depletion, but farmers and ranchers within these areas face additional constraints to certain adaptive strategies such as drilling new wells. As land goes out of agricultural production, such as for housing construction, the water rights grandfathered

in under the GMA can no longer be used for irrigation and instead become available for domestic and other uses (Pearce, 2007). Thus, water is transferred over time from rural to urban use, marking a dramatic shift in priority over the course of state history from water for agriculture to water for urban development (August & Gammage, 2007).

Some have argued that rural–urban water transfers increase the sustainability of the water supply because small decreases in agricultural water withdrawals create large increases in water available for other uses (Frisvold *et al.*, 2007). However, increasing population density while decreasing food production lowers local food supply sustainability, which indicates that the conversion of agricultural land for urban development will not solve Arizona's sustainable development problems. Additionally, August and Gammage (2007: 14) marvel at the stability of rural-to-urban transfers and suggest that farmers 'have often not been at odds with the conversion of their water to urban purposes because their land is simultaneously being converted to the highest value crop: a housing subdivision.' Simple economic efficiency arguments obscure externalities (Molle & Berkoff, 2009), such as the social, cultural, and environmental costs of the replacement of a traditionally important industry with sprawling subdivisions (Colby *et al.*, 2007). Farmers and ranchers who have dedicated a lifetime of effort and financial resources to their operations are not likely to view the loss of their livelihood positively because a housing subdivision momentarily earns a contractor greater profits, and all of the study participants expressed unfavourable views of this trend.

Thus, farmers and ranchers experience vulnerability and ability to adapt or cope in various and complex ways. Since much effort has been dedicated to the idea that better information will improve decision-making under uncertainty, particularly within agricultural and livestock production, the following section will discuss what types of information are incorporated into decision-making strategies, and how this information is sought or exchanged.

4.3. *Information use and sharing*

In some regions around the world, lack of access to information about climate or markets is another source of vulnerability (Archer, 2003). This is not likely a widespread constraint for rural communities in Arizona, who are the targets of information from the University of Arizona Cooperative Extension (UA Extension, 2009), the Climate Assessment for the Southwest (CLIMAS) (Lemos & Morehouse, 2005), the North American Monsoon Experiment (NAME) (Ray *et al.*, 2007), and NRCS offices (USDA, 2009). The focus of each of these agencies and research initiatives is on stakeholder interaction and the development of decision-support tools while simultaneously making scientific advances in climate, crop, or conservation science (Lemos & Morehouse, 2005; Ray

et al., 2007; UA Extension, 2009; USDA, 2009). They stress the bidirectional flow of information between scientists and decision makers over multiple iterations in order to ensure that end users receive information that is useful for decision making.

CLIMAS, NRCS, and Cooperative Extension communicate with agricultural and livestock producers by conducting workshops, visiting individuals at home, receiving phone calls and office visits, distributing newsletters by mail or e-mail, and providing information on the Internet. According to NRCS and Cooperative Extension agents as well as some of farmers and ranchers themselves, most of the people living in these communities have access to the Internet, but even those who do not have Internet access have other methods of obtaining information. One community of ranchers in Cochise County established a radio network several years ago through which they communicate upcoming events or emergencies such as floods. This community also maintains an e-mail listserv through which they share information about technology demonstrations, workshops, and other relevant news, including recent climate conditions and forecasts. Others exchange information during chance encounters in public spaces or while visiting friends and neighbours. Access to information therefore does not appear to be an important source of vulnerability in this region, since the vast majority of individuals in rural southeastern Arizona appear to be in some way engaged with others in their communities and exchange information through a variety of media.

Much effort in climatological research has been dedicated to the improvement of seasonal climate forecasts (SCFs) and their dissemination to agricultural and livestock producers with the intent of enhancing decision-making strategies, increasing production output, and reducing vulnerability to climate variability (Hill & Mjelde, 2002; Meza *et al.*, 2008). However, despite the potential for increased profits, improvements in seasonal forecasting, and multiple opportunities to exchange information with researchers, many farmers and ranchers around the world do not use SCFs in their decision-making strategies (Hansen, 2002; Hill & Mjelde, 2002; Hansen *et al.*, 2006). The benefits of using SCFs are often determined by the combination of climate and crop yield modeling (Hill & Mjelde, 2002), but they often assume rational economic decision making (Smit *et al.*, 1996). Thus they tend to ignore important influences such as tradition, identity, and other non-economic factors. Many suggest that improving communication of uncertainty will help decision makers understand forecasts better and encourage more extensive usage (Marx *et al.*, 2007), but agricultural producers have a low risk tolerance because their livelihoods are at stake. If they take the risk on one inaccurate forecast, they may not have the opportunity to make up the loss by taking advantage of a correct forecast later. In other words, these producers do understand forecast uncertainty and will not risk their livelihoods on a potentially inaccurate forecast,

especially when climate is only one of many considerations (Ziervogel *et al.*, 2006; Breuer *et al.*, 2007).

Nearly all of the interviewees indicated that they at least read SCFs out of curiosity, even if they do not use them. Similar to findings in previous studies (Vásquez-León *et al.*, 2002), interviewees frequently mentioned that they also check SCFs for the regions that produce competitive crops in addition to those for their own region. These SCFs tend to come from secondary sources such as CLIMAS, NRCS, and various farming or ranching magazines, which compile forecasts from primary sources such as the National Oceanic and Atmospheric Administration, the North American Drought Monitor, and the International Research Institute for Climate and Society (IRI). The Southwest Climate Outlook (SWCO) is an example of a publication that is produced monthly by CLIMAS and contains recent conditions as well as monthly and seasonal forecasts for temperature, precipitation, drought, and ENSO in Arizona and New Mexico. The Border Climate Summary (BCS)/Resumen del Clima de la Frontera (RCF) is a similar publication started by CLIMAS in 2008 that covers southern Arizona and northern Mexico. The BCS/RCF is published quarterly in both English and Spanish, and can directly assist Spanish-speaking producers previously identified as a particularly vulnerable group in this region (Vásquez-León *et al.*, 2002; Vásquez-León *et al.*, 2003; Vásquez-León, 2009a). Over 2,000 individuals in the southern United States and Mexico – including many farmers and ranchers – receive the SWCO or BCS/RCF directly by mail or e-mail, and they are also available on the CLIMAS website. Others receive the forecasts through NRCS or Cooperative Extension agents, neighbours, or other sources.

Every interviewee cited lack of forecast accuracy as a limiting factor in their use of SCFs, repeating similar results around the world (Johech *et al.*, 2001; Ash *et al.*, 2007). Two ranchers in Cochise County mentioned that forecasting summer precipitation in southeast Arizona is particularly difficult, and as a result the accuracy is lower there than elsewhere. In fact, most precipitation forecasts give equal probability to dry, wet, and normal seasons, meaning that forecasts are technically not inaccurate because they are rarely made (HyDIS, 2009). A few interviewees indicated that better forecasts would not help them make better decisions. For example, every one of the farmers said that they plant what seems to work best in this climate and that any changes in crop selection reflect changes in commodity prices more than forecasts. Most of the interviewees do not use SCFs as a decision-making tool, but those that do tend to be larger ranches with over 300 heifers or farms with over 1,000 acres. These interviews support the findings of Eakin and Conley (2002) that the larger operations seem to have greater adaptive capacity than smaller operations and therefore may be more willing and able to take risks such as the use of SCFs. The implications of these findings are that those most vulnerable are also those less capable of incorporating climate data, while those least vulnerable

may continue to gain a competitive edge through the use of SCFs. Similar results have been found around the world, including Peru (Pfaff *et al.*, 1999), Brazil (Lemos *et al.*, 2002), and Burkina Faso (Ingram *et al.*, 2002), and across several countries in Africa (Maddison, 2007), although in one South African case the impoverished farmers with access to climate forecasts were using them while wealthier farmers depended entirely on market conditions (Ziervogel *et al.*, 2006). The implication that forecasts may inadvertently cause harm to some reiterates the need to understand societal groups and their decision-making constraints (Broad *et al.*, 2002; Eakin & Conley, 2002; Archer, 2003; Roncoli *et al.*, 2009).

Still, even the interviewees that actively use SCFs do not exclusively rely upon them. Three ranchers mentioned that they will ignore a forecast for a wet summer, but will begin to consider contingency plans if drought is forecast. While risk minimization appears to be the main reason for paying more attention to a dry forecast, they will not necessarily cut their herd size based on one. Previous studies in the region found that farmers with diversified crops may use a forecast to determine the relative percentage of each crop that they will grow in a season (Vásquez-León *et al.*, 2002). One farmer in this study mentioned that he might grow more wheat than cotton if the forecast calls for a hotter or wetter July and August, but only ‘if the price is right’ – again, relying more heavily on commodity price forecasts than on climate conditions.

Weather events that happen on short- or medium-range time scales are more difficult to prepare for and are often more devastating than long-term events (Vásquez-León *et al.*, 2002). Farmers and ranchers in this study are more likely to use short- or medium-range forecasts to make decisions for their operations. For example, most of the ranchers indicated that they check the local news or the Internet for a weekly forecast in order to schedule cattle roundups or other work around extremes such as heat, winds, and storms, including one who jokingly self-identifies as a ‘fair-weather cowboy’. Farmers use short-term weather forecasts to determine whether it is too hot or too windy to disperse pesticides, or to make sure that they are planting or harvesting in optimal soil or weather conditions. Some will try to ‘outguess the rain’ for harvesting alfalfa or cotton, for example, or plant earlier in the season if it seems warm enough. There are some limits to these behaviours, however. The farmers interviewed typically use a certain planting window of time each year and will not usually alter planting dates based on an SCF. They also will not shut off irrigation for a rain forecast because rain is rarely distributed uniformly across a wide area, but rather is usually concentrated in smaller areas. Nearly all changes to irrigation schedules happen after the rain. According to one NRCS agent, about half of the farmers in southern Cochise County use irrigation operations software that allows them to remotely control their irrigation systems, and others are considering adopting this technology. While the software allows them to shut off

pumps more quickly since they are not required to physically travel among their fields, they still tend to wait until after it rains to do so.

These results have important implications for producers around the world. Participants in this study have extremely high access to information, assistance programmes, and financial support through their direct and indirect connections to NRCS and Extension. Despite their relative advantages compared to other producers in this area (e.g., Vásquez-León, 2009a) and around the world, these interviewees find themselves limited in their ability to reduce vulnerability through the incorporation of SCFs and other types of information into decision-making strategies. If the even the most ‘connected’ producers face such obstacles, then special consideration must be made for those with fewer options and points of access to critical information sources.

Similar to findings from previous studies (Vásquez-León *et al.*, 2002), all of the farmers and ranchers interviewed in this study pay attention to daily weather forecasts on the local news or the Internet, and the weather is described by many as the primary topic of conversation among rural communities. Interviewees suggested, however, that weather discussions tend to focus on recent conditions such as rainfall observed on individual farms and ranches, rather than forecasts or upcoming weather-dependent decisions. One rancher in Cochise County claims that ‘any time two cattlemen get together the first subject that comes up is weather,’ but that they only discuss upcoming decisions based on the weather if they are doing something exceptional such as moving cattle off-ranch. Farmers and ranchers also discuss commodity prices or new technology and techniques with each other, including those that may reduce vulnerability to climatic or non-climatic stresses. While some of the interviewees are considered ‘early adopters’, meaning that they are willing to test the feasibility of new technologies or techniques (Rogers, 1995), most indicated that they will wait to see how well it works for others before they will adopt those strategies themselves. Some are even more resistant to new technology and techniques. One farming-and-ranching couple said that they prefer to ‘tweak what works rather than try something new’, and would need a substantial financial incentive to change their operation.

5. Conclusions

Agricultural producers in southeastern Arizona face a wide variety of risks to their livelihoods, primarily from market volatility and climate variability. Although operating under economic and climatic uncertainty can be difficult, the farmers and ranchers in this study are determined to stay in the business as long as possible. These individuals view their livelihoods as more than an economic strategy. They have ties to the land, their communities, and their identities as farmers and ranchers. As a result, they carefully manage

their operations with long-term survival as their primary goal and prefer to err on the side of caution rather than take major risks.

The farmers and ranchers interviewed in this study listed drought, heavy rains, winds, hail, lightning, and frosts as sources of weather- and climate-related vulnerability. While many have implemented some adaptive strategies such as altering work schedules to avoid complications from extreme events or procuring supplemental feed, they are often limited in their ability to mitigate or adapt to the risks associated with these phenomena. Producers tend to rely upon experience and are not inclined to change major behaviours from year to year for several reasons. Changing livestock type or crop selection may require high monetary, labour, and time costs in the form of new equipment or fencing, land preparation, and learning new management strategies. Farmers and ranchers are also reluctant to change strategies that have worked well enough in the past, particularly those that minimize risks regardless of that particular year's climate or market conditions. While cost appears to be the primary limiting factor in the adoption of new strategies, uncertainty in the viability of new strategies as well as both climate and commodity price forecasts discourages propensity to change behaviours. Moreover, the possibility that adaptive strategies may prove maladaptive over time leaves agricultural producers with difficult decisions every year.

The concept of double exposure expanded to include sources of vulnerability other than economic and climatic change on any scale illuminates the complex and dynamic ways that agricultural producers experience and mitigate risks to their livelihoods. Reducing sources of social and economic vulnerability can help farmers and ranchers towards climate adaptation, such as through extant USDA cost-sharing or subsidy programmes. Care must be taken, however, to ensure equity in access to such programmes.

Access to information does not appear to be a primary limiting factor in the adoption of adaptive strategies. Information about different types of management strategies as well as conditions and forecasts for both climate and commodity prices are frequently shared through social interactions. Agricultural producers maintain social network connections among themselves and with intermediary agents such as those from NRCS or Cooperative Extension. Based on the interview results, it is likely that very few individuals in southeastern Arizona are not exposed to these types of information.

However, complex vulnerabilities experienced by agricultural producers in this region limit how this information can be used to reduce risks. This limitation does not preclude the necessity for such information, nor does it mean that information cannot be improved or made more useful. As climate, population, the quality and type of information, and information needs change over time, interactions between rural communities, intermediary agencies, and climatologists will become increasingly

important. For example, since ranchers depend so heavily on summer rains, yet summer precipitation forecasts rarely differ from climatological probability, the communication of forecast skill improvement may help ranchers utilize forecasts as soon as possible. Researchers with NAME are well-positioned to address this issue, as they have already made significant efforts and achievements in the communication of summer precipitation forecasts. Additionally, connecting related phenomena such as effects of climate on commodity prices or disease and pest outbreaks would help agricultural producers use each type of information to their advantage.

Although many of the specific sources of vulnerability experienced by farmers and ranchers in the study area are unique to southeastern Arizona, the results of the case study do provide important findings relevant to other parts of the world. Social and economic risks interact with climate- and water-related factors to exert vulnerabilities on rural producers, including both short-term production risks and long-term livelihood vulnerabilities. To mitigate or adapt to climate change, complex decision making must address particular impacts such as higher temperatures or more variable precipitation within a larger context. Improved information on climatic factors and price trends for inputs and outputs must be integrated into producers' overall decision-making strategies and explicitly account for risk-taking ability. Farmers and ranchers in southeastern Arizona have greater access to information, assistance programmes, and other methods of vulnerability reduction than producers in many other regions of the world, and yet their ability to incorporate information to enhance their adaptive capacity in the face of climate variability remains somewhat limited. Access to information, such as experienced by producers in settings with less developed forecasting resources and dissemination systems, is part of the challenge; however, ultimately it is a question of producers' own understanding of their risks and willingness to adopt strategies they feel will reduce their own vulnerability.

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