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Travelling in antique lands: using past famines to develop an adaptability/resilience framework to identify food systems vulnerable to climate change

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Abstract This paper builds on existing theory and proposes a framework to identify vulnerability to climate change in food systems by examining historic cases where common environmental problems caused famine. Cases presented are (1) Ireland's Potato Famine, (2) El Niño induced famines during the Colonial period, and (3) Ethiopia between 1965 and 1997. Three factors stand out as common in each. Prior to each famine: (1) there were very few ways that people could obtain a living in the worst affected regions; (2) livelihoods in famine stricken communities came to depend on highly specialized agro-ecosystems that were sensitive to environmental change; (3) institutions failed to provide adequate safety nets to protect livelihoods from failure. This analysis suggests that vulnerability to climate change in food systems can be assessed by looking at agro-ecosystems, livelihoods and institutions. Local conditions, however, mean that ways of measuring these three factors will vary from place to place. As a result, direct comparisons are difficult. By conceptualizing these three variables as the axes of a three dimensional "vulnerability" space, it is possible to compare regions and look at trends over time by studying the paths through this "space" as traced by changes at the agro-ecosystem, livelihood, and institutional scale.

"I met a traveller from an antique land
Who said: Two vast and trunkless legs of stone
Stand in the desert.
..... on the pedestal these words appear:
"My name is Ozymandius, king of kings:
Look on my works, ye Mighty, and despair!"
Nothing beside remains. Round the decay
Of that colossal wreck, boundless and bare
The lone and level sands stretch far away."
Excerpt from *Ozymandius* by Percy Bysshe Shelley.

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1 Introduction

As the world wakes up to the possible realities of climate change, it is worth remembering that the climate has always changed. Often, we take these changes in stride. Sometimes, however, the change is too large, or our ability to adapt is constrained, and we find ourselves facing a big problem. Occasionally, the change is so big, the problem so enormous, that entire societies vanish. This is the spectre Shelly invokes when he describes Ozymandius' lost world in the poem quoted above. After all, history is littered with examples of cultures who failed to adapt when the environment changed. Although we have virtually no first hand evidence about what happened to the Maya who inhabited the ruined cities of Tikal and Palenque, archaeological evidence suggests that drought may have precipitated their collapse (Haug et al. 2003). In other cases, we have more direct evidence about the role the environment played and know through the saga of *Eirik the Red* (which itself is part of the *The Vinland Sagas)* that the Vikings colonized Greenland during a warm period around 1,000 years ago (Anon 1970). These farms were later abandoned as the climate cooled and icebergs re-invaded the North Atlantic (Diamond 2005).

Therefore, as we stand on the edge of an uncertain future, where increased climatic variability seems inevitable, it is helpful to cast our eye back to see what lessons history can offer. At the heart of this enquiry is the desire to see if common features stand out as predisposing communities to suffer in the face of changes in the environment. To accomplish this task, this paper uses historic cases where relatively small environmental changes led to big impacts on communities' food supply as an analogy through which to develop the tools to anticipate areas where food systems may be vulnerable to climate change in the future (Glantz 1991).

2 Theoretical overview

The academic literature has dealt with the vulnerability of food systems to climate change in a number of different ways. For example, some have used the outputs of global circulation models to link grain yields with climate scenarios (Adams et al. 1995; Adams et al. 1990; Reilly and Graham 2000). These studies often produce maps that show where food production may be vulnerable to future climate conditions. Although analytically very strong, this approach has been criticised for ignoring the extent to which farmers adapt to changing circumstances, thus, the results from these studies may over-estimate vulnerability to climate change (Kandlikar and Risbey 2000). To address this, others have built models that assume farmers will change practices and only plant those crops most suited to new climate conditions (Mendelsohn et al. 1994). These models tend to downplay factors like land tenure and international competition that may constrain farmers' behaviour (Fraser 2004; Fraser 2006). Recently, researchers from the European Union have linked socio-economic scenarios developed by the Intergovernmental Panel on Climate Change (2001) with the outputs of global circulation models. Results of these studies have identified areas where key ecosystems services (such as biodiversity and food production) may be vulnerable to both changes in climate as well as large-scale socio-economic forces (Schröter et al. 2005; Abildtrup et al. 2006). Although impressive in their scope and approach to interdisciplinary, these studies do not look at the conditions under which the communities that depend on these ecosystem services may be able to adapt.

Coming at vulnerability from a very different angle is the work of cultural and political historians who have tried to tackle the manifold reasons why societies may suddenly

collapse (Tainter 1988; Goldstone 1991). Although this work often does not have an explicit environmental focus, it provides a foundation for those involved in climate change research who argue the need for locally relevant indicators to capture whether or not a community is vulnerable to environmental changes. For example, chapter 18 of the 2001 Intergovernmental Panel on Climate Change's report on impacts and adaptation proposes that the structure of critical institutions, the allocation of decision-making authority, decision criteria, the ability of decision-makers to manage information, the processes by which decision-makers determine which information is credible, and the credibility of the decision-makers themselves are all necessary to understand the processes whereby a region may become vulnerable to climate change (Intergovernmental Panel on Climate Change 2001). These sorts of discussion lead O'Brien and Leichenko (2000) to conclude that many people are especially vulnerable because they face a "double exposure" to risks caused by both economic globalisation as well as climate change. Consequently, many focus on the role institutions may play in promoting new climate adaptation technology (Tompkins and Adger 2005), the scales (individual, community, regional, national) at which institutions can play a role in promoting adaptation to climate change (Adger et al. 2005) and write about the need to for institutions to ensure that climate adaptation strategies are fair and equitable (Paavola and Adger 2006; Tol and Dowlatabadi 2001).

Another important body of social science literature emerges out of development economics. Most notably, Sen (1981) suggests that people access food using different "entitlement bundles" (for example a subsistence farmer would rely on a "direct entitlement" whereby food is produced directly by the household). According to Sen, problems arise when one food entitlement strategy is disrupted and the individual is unable to switch, for example to an "indirect entitlement" (i.e. working for a wage) or to a "transfer entitlement" (where someone transfers an entitlement in the form of charity, food aid, etc.). This suggests that "food entitlement bundles," are more robust if they are based on both a diversity of "livelihood options" (Scoones 1998) as well as access to financial, social, natural and human capital (Bebbington 1999). Sen's focus on constraints that prevent people from changing entitlement strategies has both directly and indirectly led to an extensive literature on how people adapt to droughts (e.g. Buchanan-Smith and Davies 1995; Davies 1996) and floods (e.g. del Ninno et al. 2003) by examining 'coping strategies.' Generally, this is done using in-depth social survey methods, such as household livelihoods analysis. This approach provides an excellent and well tested framework for assessing the assets that people may be able to use when confronting a problem such as climate change. However, the livelihoods approach tends to only provide snapshots and does not really lend itself to analyzing changes over time. Also, although livelihood assessments generally include an evaluation of "natural capital" and reveal whether people have access to natural assets that can be used as a coping strategy, it does not provide much insight into whether specific agro-ecosystems are likely to be sensitive to environmental problems.

Situated somewhere between the quantitative work based on climate modelling and qualitative studies rooted in social science and development studies, is the work of Turner et al. (2003) and Kasperson et al. (1995) who use devices like nested flowcharts that show how social and environmental forces interact to create situations vulnerable to sudden changes. This approach highlights the way in which individuals are situated within coupled socio-ecological contexts and forces researchers to look beyond the specific perturbations and stressors faced by a system (Gregory et al. 2005). This argument is also made by Watts and Bohle (1993) who propose food security is a function of three elements: the exposure to a risk or hazard such as climate change, the capacity to adapt to this hazard, and the potential of the

problem to have severe consequences. While very interesting, and providing an invaluable foundation through which to analyze vulnerability, these works are not intended as predictive tools. Rather, Turner et al. are at pains to point out that their framework, "... is not explanatory but provides the broad classes of components and linkages that comprise a coupled system's vulnerability to hazards" (Turner et al. 2003, p. 8076).

Although not generally used to analyze the vulnerability of food systems, the "Panarchy Theory" (Fraser et al. 2003), which comes from landscape ecology and tries to explain why some ecosystems are resilient to environmental shocks (Peterson 2002), provides important insights. In this case, resilience is defined as the amount of a disturbance an ecosystem can absorb and still remain within the same state (Holling 1973). Through field work in settings where ecosystems cycle through periods of stability and collapse (such as wild fires in the boreal forest), Gunderson and Holling (2002) suggest that vulnerability to environmental shocks can be explained using three key characteristics. First, after a disturbance (such as a wind storm or wild fire), ecosystems are quickly colonized by plants that are generally short lived and have relatively little biomass. Over time, these plants give way before longer lived species such as trees and the progress of ecological succession generally increases the amount of biomass present in an ecosystem. This increases vulnerability as ecosystems rich in biomass have abundant fodder for pests or fuel for a fire. Second, as this process continues, ecological niches are filled in and individuals in the ecosystem become more and more tightly connected in both space and time as well as in terms of nutrient and energy flows (such as food webs). The degree to which individuals are connected contributes to vulnerability to environmental change as disturbances can quickly spread in tightly connected ecosystems. Third, over time, more successful species out-compete those less fit, and although the diversity of many landscapes initially increases after a disturbance, it then starts to decline. This is important in terms of vulnerability because if there are few species present, disturbances are more likely to affect large proportions of individuals in a landscape (Peterson et al. 1998). More important than just the number or abundance of species is the diversity of functional groups within an ecosystem and Elmqvist et al. (2003) hold that "response diversity" – defined as "the diversity of responses to environmental change among species that contribute to the same ecosystem function" (p. 488) – is key. These three characteristics are presented in a three dimensional cube where one axis represents the amount of biomass present in an ecosystem (where a low amount is considered resilient and a high amount is an indicator of vulnerability), one axis is for diversity (high diversity is resilient and low diversity is vulnerable) and the third is connectivity (low connectivity is resilient, high connectivity is vulnerable). By plotting changing levels of connectivity, diversity and biomass for different ecosystems over time, this model shows that in many ecosystems, there is an evolution from diverse, unconnected landscapes that have little biomass and are resilient to environmental changes, to specialized landscapes, that are tightly connected, have abundant biomass and are "...accidents waiting to happen" (Holling 2001, p. 396).

The Panarchy framework is an important contribution to our understanding of why some food systems are vulnerable to environmental change for three reasons. First, it lends itself to observing changes over time and the trajectory an ecosystems takes in this three dimensional figure determines whether or not it is vulnerable to environmental problems. Second, it helps identify tradeoffs between characteristics of vulnerability such as in old growth temperate rainforest forests where vulnerability due to high biomass is balanced by old trees falling over, thus decreasing connectivity. Third, it provides insights into the ecological characteristics of landcapes vulnerable to environmental change. However, it is inappropriate to apply this framework too literally to socio-ecological systems (Fraser 2003). For example, although

tightly connected ecosystems are often the most vulnerable, social science research suggests it is unconnected or isolated human communities that are far more vulnerable to problems caused by droughts or floods because they do not have access to the sort of social networks that help people overcome such hurdles (Pretty and Ward 2001).

Given this rough assessment of the various strengths and weaknesses of different theoretical approaches, the purpose of this paper is to use the Panarchy framework as the basis of a synthesis that tries to explain how food systems become vulnerable to climate change. This will be done by exploring the lead up to three historic case studies where relatively common environment problems triggered widespread famine. By adopting a similar strategy as the ecologists who developed the Panarchy framework, this is an attempt to ground theory in empirical evidence by examining the lead up to major collapses in order to identify common factors.

3 Case studies

The Great Irish Potato Famine, which was caused by an outbreak of an agricultural pest in the mid nineteenth century, El Niño-induced famines in South and South East Asia at the turn of the twentieth century, and the Ethiopian famines during the 1970s and 1980s provide a basis for this analysis. In each of these cases, the environmental problem that caused the collapse was not isolated or unique. In South/South East Asia during the decades leading to the El Niño famines, and in Ethiopia leading up to the 1970s, droughts were a recurrent problem. Similarly, Ireland's potato crop had failed due to fungal pathogens before. None of these earlier events, however, caused anything like the widespread suffering experienced during these famines and should lead us to wonder what was different about the years when the environmental problem cascaded into catastrophe. Was it that the environmental problem that caused the famines were particularly severe, or had something about these societies changed, making each one more vulnerable to environmental disruption? For the two nineteenth century cases, there is only limited data available. As such, this analysis is forced to rely on historic accounts and testimonials to evaluate the social, economic and agricultural trajectories that led to the famines. In Ethiopia's case, however, there is much more data available. As such, it is possible to be more quantitative for the third case study.

3.1 The great Irish potato famine

When Napoleon fell at Waterloo in 1815, the socio-economic context changed for the rural poor throughout Europe. First, Europe's military powers de-commissioned their armies and navies. This caused an influx of rural labour as men who had been employed for decades of fighting on the continent, flooded back onto the land in search of livelihoods (Holmes 2002). This was one factor that contributed to rural crowding in Ireland.

More importantly, the war had ensured decades of high international grain prices as the governments of England, France, Spain, Belgium and Prussia struggled to keep troops fed. The end of the war spelled an end to these high prices. Faced with a decline in the price of wheat, and a sharp increase in the demand for livestock products caused by affluent industrialists and the emerging middle class, landlords found it uneconomical to maintain large areas of land under continuous cultivation and began switching to livestock production. This caused large-scale evictions as the best land was turned into sheep pastures (Foster 1988). This development was not unique to Ireland; Scotland underwent a similar upheaval as chiefs conducted mass evictions in the infamous Highland Clearances.

This same period saw massive growth in England's industrial sector. Oddly, Ireland, Britain's closest neighbour, actually de-industrialized during this time. The 1821 UK census shows that 41.2% of Ireland's population was involved in the industrial or commercial sector, and 40.1% involved primarily in agriculture. By 1841, only 30% of Ireland was considered industrial or commercial, while 53% found their livelihood in agriculture (Mokyr 1987). The primary reason for this decline is that the "industry" in Ireland consisted almost entirely of cottage industries such as linen production that would have taken place on the farm. These firms were simply unable to compete with the large textile mills from Northern England. For example, in 1825, the town of Bandon had an excess of 2,000 private, self-employed weavers. By 1840, fewer than 100 remained (Foster 1988).

Over this time, Ireland also experienced significant population growth, with the total population exploding from 2.2 million in 1600 to somewhat over eight million on the eve of the Famine (Daly 1986). By European standards of the time, this was unusually high: in the 1840s Ireland's annual growth rate was 1.3 people per 1,000 people while France had only 0.4. Thus Ireland, with 700 people per square mile of arable land, boasted the highest rural population density in Europe (O'Grada 1989).

Faced with these social, economic and demographic pressures, there were only three choices for the poor of Ireland: become wholly dependent on agricultural production, become a landless labourer, or emigrate. Many of those who stayed in Ireland eked out a meagre existence on inadequate land. This meant that marginal and geographically isolated land was brought into cultivation where only the hardiest of crops could survive and where there were few opportunities to participate in trade or commerce. For those who clung to Ireland, the potato, a remarkably hardy crop that can grow on even the most marginal of soil, seemed a Godsend. Compared to other crops, the potato is an extremely efficient source of nutrition, and O'Grada (1989, p. 62) comments that, "...an acre of land could feed 2.08 people on wheat or 4.18 people on potatoes." Very quickly, therefore, the potato became the only viable crop for millions of the poorest, most marginal and most remote communities.

Earlier in Irish history, however, potatoes had not been seen as fit for regular human consumption but were used as source of animal feed, and only eaten by people if cereal crops failed and there was no money to buy food (Bourke 1993). By 1845, however, much of the country, especially the west, had switched over entirely to potato subsistence. Not only that, the strains of potato changed over time, and, starting in the 1730s, the most commonly grown varieties degenerated as quality and nutrition were replaced by productivity and tolerance to poor soils. For example, the Lumper, was by far the most common variety grown in Ireland just before the Famine. The Drummond Report (a report that was written for the Irish railway in 1838) describes the Lumper as:

> A species of potato...[that]...has been brought into general cultivation, on account of its great productiveness, and the facility with which it can be raised from an inferior soil and with a comparatively small portion of manure. The root, at its first introduction, was scarcely considered food enough for swine; it neither possesses the farinaceous qualities of the better varieties of the plant, nor is it as palatable as any other, being wet and tasteless, and in point of substantial nutriment, little better as an article of human food, than a Swedish turnip. (Drummond report, 1838, in Bourke 1993, p. 34)

Even worse, the Lumper could not be stored for a full year. As a result, many people went hungry every summer, between the time when the last year's crop was no longer fit to

eat, and the new crop was ready. This situation accentuated the differences between social classes. A well established farming family would have been unaffected by the seasonal hunger, and would also have been in a position to sell their surplus to the peasants whose potatoes did not sustain them.

Then, in 1845, disaster struck. An unusually rainy season provided ideal conditions for a disease, caused by the fungal pathogen *Phytophthora infestans*, to attack the potatoes on which these millions depended (Woodham-Smith 1962). Field after field was struck, with plants and tubers either rotting before harvest or in storage. Very shortly, as much as one third of the 1845 crop vanished (Whelan 1995). Seventy five percent of the next year's crop failed. Although 1847 was known as "Black 47" there was a reprieve of the blight, but since people had eaten all their seed potatoes to survive the previous winter, harvests were minimal. The disease re-appeared in 1848, and 1849. By the time the potatoes began to grow again, famine had cut a path of destruction and human misery that changed Ireland forever. Approximately two million people lost their lives, families or homes during these years. The population continued to fall until the early twentieth century when just 25% of the original inhabitants lived in the country (Allen Figgis Publishers 1968).

The official response was sporadic. The British Government did embark on a significant famine relief programme, through its "poor law" but this was oversubscribed and inadequate in the face of the tragedy (Hollis and Sweetman 2004). The government also employed poor people on work for food programmes and sold low quality grain onto the market to bring costs down. While these programmes helped many, the worst hit areas were also quite remote. As such, the people most in need were beyond the reach of these initiatives (O'Grada 1989).

Thus, beginning about 100 years before the Famine, poorer communities sacrificed quality of food for productivity, to the point that some regions – the west coast in particular – depended on one poor cultivar that was unable even to provide food throughout the year. When this supply of food was eliminated by the blight, there was no realistic alternative and no money to buy other food.

3.2 The late Victorian famines in Asia

During the second half of Queen Victoria's reign, somewhere between 12 and 30 million Indians, 20–30 million Chinese and 2 million Brazilians died of famine. Famine also struck Java, the Philippines, New Caledonia, Korea, southern Africa, and Mahgreb. On three separate occasions (1876–1879, 1889–1891 and 1896–1902), El Niño induced droughts caused one of the most significant human disasters ever. Disease quickly spread through the ranks of the impoverished: malaria, bubonic plague, dysentery, smallpox and cholera were commonplace. Despite the severity of these climate events, droughts and floods, even serious ones, are common throughout the monsoon region. There are also well-documented cases of massive famines in China. However, according to Davis (2001) although the environmental problems experienced by these regions during the late nineteenth century were not unique, the scale of the suffering was unprecedented. This suggests that socio-economic forces may have created vulnerable conditions.

A good illustration is the Philippines' island of Negros. According to Billig (1992), in the 1850s, local textile manufactures fuelled a rich regional trade in cloth. This, mixed with subsistence farming and some hunting/gathering from native forests, provided a food-secure and vibrant region. However, in 1855, the British vice-consul encouraged locals to purchase lower-priced cloth made in the UK. He also provided opportunities for farmers to invest in lucrative sugar exports. Over the next 20 years, newly minted sugar barons gained

control over most arable land and, by the 1870s, the local textile industry had collapsed in the face of international competition. People were now dependent on exporting sugar, and little land was left for either subsistence agriculture or hunting and gathering. The drought of 1876–1878 hit a population with little to fall back on, and when a worldwide recession hurt sugar prices, people had few assets left to cope with the drought. According to parish records 10% of the total population died, with some towns losing as much as 50% of their population (Billig 1992).

Borneo and Java were similarly affected (Davis 2001). The Dutch authorities in the colony provided a short-term solution by hiring poor labourers to dig a canal linking the Kahayan River and Banjarmasin. This allowed an increase in forestry exports, bringing remote regions into connection with the global economy and had both positive and negative impacts. Some people benefited from these trading links. However, many of the most impoverished regions quickly found themselves under exploitative contracts called *culturrstelsel* or "cultivation systems" with the Dutch government that obliged them to produce export crops for European markets. At one point, the moneys from this system provided 1/3 of all state revenues in the Netherlands. Furthermore, according to Davis (2001), local officials who attempted to purchase and stockpile rice were criticised by the Council of Dutch East Indies for abandoning free market principles. In Java, the drought, the loss of local industry, and reduction of grain storage led to unimaginable human suffering with famine mortality being counted in the tens and hundreds of thousands (Davis 2001).

These cases highlight an interesting dilemma. On one hand, globalized food trade should provide security against environmental problems as it allows local shortfalls in food to be compensated for through imports (Fraser et al. 2005). For example, Lord Elgin, best known for moving the marble Parthenon sculptures from Athens' Acropolis to England, worked to ensure that railways and telegraph networks could move grain across India in order to compensate for regional shortages. Similarly, ex-US president Ulysses Grant, while touring Asia during the famine of 1877, argued that rail and telegraph networks could reduce the impact of drought. "...In America, there could be no famine such as had recently been seen in China...If the crops failed in one State, supplies could be brought from others at little extra expense in money and time" (J. T. Headley, The Travels of General Grant, Philadelphia 1881, quoted in Davis 2001, p. 5). However, the opposite seems to have happened, and when the droughts struck, instead of allowing food to be imported, rail and telegraph networks meant that locals were competing with much wealthier consumers from elsewhere. For example, a letter written by a local official from the time argues that grain prices in Godavari, India, were high despite plentiful harvests since they "...depend almost entirely on the condition in other parts of India..." (Quoted in Ludden 1994, p. 207). Seen in this light, the telegraph lines and rail networks that President Grant extolled as a way of famine-proofing regions, may actually have exacerbated local food shortages, "It was apparent to the Government that facilities for moving grain by the rail were rapidly rising prices everywhere..." (Letter from Madras Government to Government of India, 30th November, 1876, quoted in Bhatia 1963). This point is supported by Post (1974) who shows how immediately following the Napoleonic wars, economic integration meant that European-wide grain prices became synchronized and that poor weather in one region started affecting prices across the continent, and reinforces Polany's (1944) view that it is wrong to see famine in the colonial world simply as a result of exploitation as this hides the greater issues of how cultural degeneration increases vulnerability.

Therefore, what marks the famines during Queen Victoria's reign as different from ones in previous generations is that these droughts occurred at a period of massive economic

transformation. In the process of colonizing remote area, the European empires hurt traditional communities and damaged traditional ways of coping with environmental irregularities. So, even though the famines were triggered by highly irregular weather patterns, social and economic forces seem to have played a role in creating situations especially vulnerable to weather related shocks.

3.3 Ethiopia in the twentieth century

There are two reasons that Ethiopia in the twentieth century is especially interesting for the purposes of this paper. First, there is considerable data available that allow more of a quantitative analysis of why was this region was vulnerable to perturbations in climate. The second reasons is that thanks to El Niño events and (possibly) the long-range effects of industrial pollution (Nowak 2002), there have been declines in rainfall since the 1960s (Tilahun 2006) and the Centre for Research on the Epidemiology of Disasters (CRED) identified a number of individual drought events in Ethiopia between 1960 and 1997, most of which happened in the northern provinces (see also: Unruh 2004, United Nations University 2005). Of particular note are those that occurred in 1973, 1974 and 1984 when the impact of drought cost hundreds of thousands of lives (Table 1). This raises the question; were these droughts just particularly bad (in terms of a reduced rainfall) or were there other social, economic and political factors at play that made communities especially vulnerable? After all, this sort of environmental problem is common and studies show that droughts happen approximately every 3–8 years in northern Ethiopia and every 8–10 years across the whole country (Haile 1988).

Interestingly, monthly rainfall levels for the drought years were not particularly different from long term median rainfall, as calculated from data collected at weather stations in northern Ethiopia where the famines were concentrated (Fig. 1). As a result, Meze-Hausken (2004) suggests that community perceptions of drought and precipitation data often do not match and Gommes et al. (2004) caution that although a reduction in precipitation may

Table 1 Ethiopian droughts, their location within the country, and the number of people killed during each drought since 1965

Year	Location	No killed
1965	Nationwide	2,000
1969	Hamasion division	0
1973	Tigre, Wollo, North Shoa	100,000
1974	Wollo, Tigray, Kangra provinces	200,000
1975	Kangra	0
1977	Wollo, Tigre provinces	0
1978	Wollo, Tigre provinces	0
1983	Wollo, Gondar, Goe, Eritrea, Tigrai	0
1984	Wollo, Tigray, Eritrea, Shoa, Gonder, Harerge, Sidamo	300,000
1987	Eritrea, Tigray, Wello, Shewa, Gama, Gofa, Sidamo, Gondar, Bale	0
1987	Ogaden	367
1989	Northern Ethiopia, Eritrea, Tigray, Wollo, Gondar, Harerge	0
1990	Eritrea, Tagray, Harerge	0
1991	Togray, Wello, Gondar, Ogaden, Harerghe,	0
1992	Eastern and Southern	0
1997	Somali state, Borena, Bale (Oromiya state), South Ome zone	0

Source: (Centre for Research on the Epidemiology of Disasters 2006)

qualify as a "meteorological" drought, such variation may not result in an "agricultural" drought (noted by a loss in production) or a hydrological drought (identified by changes in stream flows).

The opposite is equally true, and these data seem to suggest that conditions in Ethiopia were such that changes in rainfall were so subtle that they were not even captured by monthly precipitation data from the north of the country. This conclusion is confirmed by Tilahun (2006) who uses a "rainfall anomaly index" to show that very subtle changes in rainfall kicked off the crisis in these years. Comenetz and Caviedes (2002) point out the 1972–1973 El Niño event that ostensibly caused the famine was not particularly sever in comparison with subsequent events.

An extremely simple way of quantifying sensitivity to drought is by looking at the relationship between the intensity of a drought (which can be calculated in a number of ways including using van Rooy's (1965) rainfall anomaly index or just looking at the degree to which monthly precipitation deviated from long term patterns) and the impact of the drought (also calculated in a number of ways including by using long term grain production, food availability and seed production trends to determine yearly expected production levels and dividing this by the actual production levels for years in which drought occurred). Interestingly, there is no statistically significant relation between rainfall anomaly and the extent to which grain production, food availability, or seed production deviated from expected levels for the years that CRED identified as having a drought. However, when the residuals of these relations are plotted over time, it seems that the link between food availability, and grain/seed production and growing season precipitation was strongest during the 1970s and 1980s. Figure 2 illustrates this analysis, showing that Ethiopia was particularly sensitive to drought during this period. This figure was generated by plotting the residual over time from of the relationship between the severity of these droughts (determined by using Van Rooy's rainfall anomaly index) and the impact of the drought (determined by calculating grain production losses for the years of the drought) ($p<0.01$). Since grain production data is based on national level statistics that represent averages across a large landmass, and grain production tells us nothing about the ability of people to command food, this is a very crude way of quantifying sensitivity to drought. However, these results are consistent with other studies and provide additional evidence

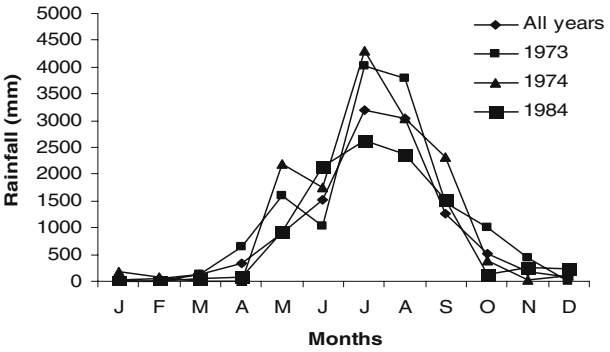

Fig. 1 Median monthly rainfall (mm) collected by weather stations in Northern Ethiopia (for a 2.5 by 3.75° region centred at 12.5° north, 37.5° east) for all years and for years in which droughts in this region caused hundreds of thousands of famine victims. Drought years were identified by the Centre for Research on the Epidemiology of Disasters (2006). Rainfall data was supplied by Dr. Mike Hulme at the Climatic Research Unit, University of East Anglia (Hulme 2006)

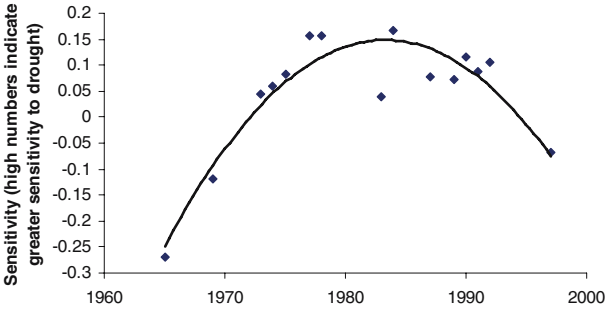

Fig. 2 Sensitivity of grain production in Ethiopia to drought severity for years in which a drought was declared between 1960–1997 fitted with a quadratic curve. *Y*-axis is calculated by plotting residuals of relation between the "rainfall anomaly index" for the growing season precipitation and the deviation from expected levels of grain production for years in which droughts were declared. High numbers indicate that grain production was lower than expected given the level of rainfall during the growing season. $P<0.01$, $R^2=0.86$, $n=15$. Each data point is for a year that CRED identified a drought to have occurred in Ethiopia (Centre for Research on the Epidemiology of Disasters 2006). Crop production data was obtained from the Food and Agriculture Organization (Food and Agriculture Organization 2006). Rainfall data was supplied by Dr. Mike Hulme at the Climatic Research Unit, University of East Anglia (Hulme 2006)

that social, political and economic factors were at work in the 1970s and 1980s, making the region especially vulnerably to changes in rainfall patterns.

There are a number of ways to account for why Ethiopia became sensitive to environmental changes in the 1970s and 1980s. The first is environmental. The cumulative effective of successive droughts meant that Ethiopian agro-ecosystems, specifically in the north of the country, lost soil moisture, organic matter, and other ecological buffers (Suhrke 1993). The causes of sensitivity to drought in Ethiopia, however, go beyond a simple environmental explanation and many argue that social unrest and economic/political upheaval played a significant role too. For example, the 1970s and 1980s were dominated by protracted and bloody civil war. Initially a monarchy, the Ethiopian government did little to combat the 1972–1973 famine. According to Hancock (1985), the king was poorly advised as to the severity of the problem and delayed distributing food in the Northern Highlands. This inactivity was the justification used by a pro-Soviet junta called the "derge" who deposed the king in 1974. Ironically, the derge also proved ineffectual at providing solutions to famine. In the 1970s, food aid was only distributed to those who had supported their political platform, and the derge also used strict military measures to prevent people from fleeing famine plagued fields. In 1980's, the derge initially denied that any problem existed and then conducted what Comenetz and Caviedes (2002) describe as a "hasty" and "disorganized" distribution of cereals. To deflect attention from the problem, the government again used repressive measures to prevent people from leaving their holdings in search of food.

The analysis by Comentz and Caviedes also shows the extent to which the government policies in the late 1970s exacerbated the problems caused by drought in the 1980s. They note that the worst affected in the 1980s famine were from newly built communities in the northern provinces of Wello and Tigray where people had been transported by the government in the 1970s in an effort to set up Soviet style agricultural communes. Separated from traditional kinship networks, these people had few resources to draw upon during the drought, and these newly settled areas immediately contributed to the flow of refugees fleeing the famine.

As the famine progressed, families from famines stricken areas were simply moved by the military to even remoter areas in an effort to hide the problem. Comentz and Caviedes note that native populations in target regions became displaced by the newcomers, and this led to ethnic violence and a further erosion of communities' access to social, natural and human capital. It was not long before famine encroached upon these new areas as well, and this caused a further exodus as people began fleeing to the Sudan as drought-famine refugees. As such, traditional coping strategies, which would have been based on natural and social capital, were disrupted both by the government's long-term agricultural policy of "villagisation" as well as their short-term famine policies of forced removals.

Changes in crop patterns provide a clue as to how people may have adapted to the socio-economic problems that existed in the last 1970s. Much earlier in Ethiopia's history, agriculture was marked with a large amount of crop diversity that typically included some drought-tolerant species (such as maize which can continue growing in quite dry conditions due the presence of an extra carbon molecule in the chloroplasts, see Parry 1990) as well as higher yielding but less drought-tolerant crops:

> The fertility of the lands ...is extraordinary. Maize, rice, millet, ground-nuts and peas are largely cultivated...sheep cattle and goats are in sufficient numbers to be bought for export... (J.F. Elton, Travels and Researches among the Lakes and Mountains of Eastern and Central Africa, 1879, quoted in Rau 1991, p. 23)

Maintaining these sorts of diverse agro-food systems involved a trade-off, however. On one hand, diverse agro-ecosystems are often viewed as one way of reducing the risks of losing everything in the event of an environmental or economic crisis (Altieri 1999, Gliessman 1998). However, diversity may prevent farmers from maximizing productivity and capturing economies of scale. So, although most farmers are extremely risk-adverse, there are significant incentives to specialize in order to obtain highest possible returns (Sinebo 2005).

By the early 1960s, Ethiopia's agriculture had become quite specialized, with sorghum, barley and wheat each representing almost 20% of the total harvested land (Food and Agriculture Organization 2006). By the 1970s and 1980s, however, Ethiopian farmers had diversified their crops. The area of the top five most common crops (sorghum, barley, wheat, maize, and coffee) declined significantly from 69% of the harvested land base in 1960 to just over 60% in 1983. Between 1985 and 1990 this then rose to 66% ($p<0.05$). The "herfindahl diversity index" (calculated by summing the squares of the proportion of the annual harvest for each crop thereby returning a high number for more specialized crop systems) shows a similar inverted "U" shaped relation ($p<0.01$) indicating that agricultural output become more diverse until the early 1980s but has become more specialized since then (Fig. 3). These results are consistent with theoretical (Figge 2004; Fraser et al. 2005) and empirical work from elsewhere (Fraser 2006) that shows farmers may consider the range of crops they produce in a similar way as a financier who diversifies an investment portfolio. In both agriculture and investment, the goal is generally to maximize returns for minimum risk, and under relatively stable political, social and environmental conditions, specialization is a sound strategy. However, in cases of widespread uncertainty, such as Ethiopia experienced during the 1970s and 1980s, diversifying operations – thereby sacrificing overall productivity – is warranted to minimize risk. Interestingly, national inflation rates, which are a good indicator for economic stability (Fischer 1996) match this trend, rising significantly during the 1970s, peaking in the mid-1980s at almost 30% per year, and then declining in the late 1980s and 1990s ($p<0.05$) (World Bank 2006).

In some ways diversifying agricultural crops represents a preliminary line of defence against a drought, and reduces the risk that rainfall anomalies will destroy annual livelihoods. When the drought actually struck and caused significant productivity losses in affected regions, the people worst affected were those who had few economic opportunities outside of agriculture. Doocy et al. (2005) observe that in response to the crisis, people first tended to mobilize extra household labour whenever possible, reduced household expenditures, sold assets, consumed stocks/reserves/savings, and borrowed food and money from family and friends. When all this failed, as many as six hundred thousand people migrated out of Ethiopia to the Sudan. Under these circumstances, no amount of coercive measures taken by the military could hold back the tide. Based on extensive interviews, Meze-Hausken (2000) notes that those families who had access to the largest number of coping strategies were also the last to migrate. This observation confirms Corbett's (1988) three stage hierarchy of coping to a famine: stage one is to use insurance mechanisms such as changing planting practices, selling of small stock, and reducing current consumption levels; stage two involves disposing of productive assets by selling agricultural tools or livestock; stage three involves measures born of desperation, such as "distress migration."

Overall, the picture that emerges is quite consistent. Precipitated by political unrest, rising inflation rates, recurring drought and draconian policies, the poorest and most marginal communities in Ethiopia lost access to various forms of social and natural capital. This, and the lack of effective famine relief (Wolde-Georgis et al. 2001), made them far more vulnerable to droughts than they had been in previous decades. To adapt, evidence suggests that farmers adopted a strategy of crop diversification, sacrificing economies of scale and production efficiencies to reduce risk. However, given the nature of the Ethiopian agro-ecosystem, even slight changes in the timing of the early rains can have huge impacts on agricultural productivity. As such, when the rains were late in the 1980s, even this small perturbation was enough to overwhelm the people's defences. The problem then cascaded through Northern Ethiopia, ruining the only form of livelihoods open to people and sent waves of refugees fleeing into the region where the additional demands placed on the land caused the problem to keep growing.

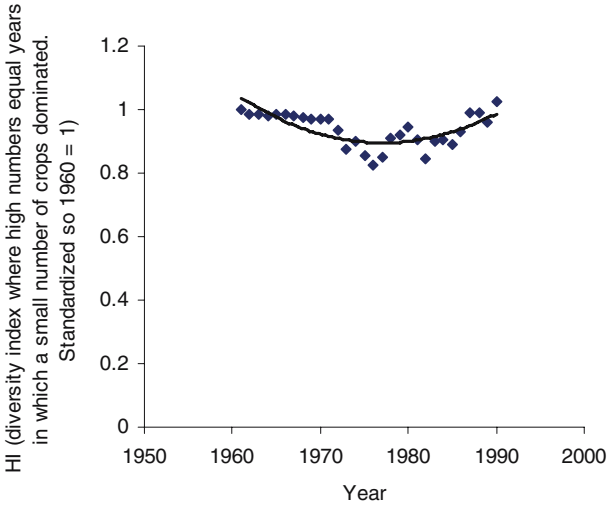

Fig. 3 Herfindahl Diversity Index (HDI) for all crops grown in Ethiopia between 1960 and 1990 and quadratic curve fitted by SPSS V13. A higher number indicates that crop production was more specialized. Standardized so 1960=1; R^2=0.5705; n=30; p<0.05. Source: (Food and Agriculture Organization 2006)

4 Discussion: what lessons may be learned from the case studies?

Three points stand out as affecting vulnerability to environmental change in all three cases. First, changes at the agro-ecological level affected the degree to which agricultural productivity was sensitive to changes in the environment. Irish peasants adapted to the Industrial Revolution and population growth by specializing on a crop that was productive in even marginal soil. This increased the productivity of their farms in the short-term but ultimately meant entire regions depended on very brittle landscapes for sustenance. Relatively complex traditional agro-ecosystems in the places like the Philippines were replaced with ecologically simple sugar plantations before the colonial famines in the late nineteenth century. In Ethiopia, the situation may be a bit more complex. On one hand, there is evidence that the cumulative effect of years of drought eroded natural buffers against anomalous rainfall. On the other hand, farmers may have diversified crops in order to shore up agro-ecosystem resilience and reduce the risks they were exposed to. In any case, the resilience of the food producing agro-ecological landscapes stands out as an important factor in determining whether a region is sensitive to environmental change.

The second key characteristic that stands out as important in these three case studies is the degree to which the worst affected people affected were unable to change livelihood strategies and find alternatives when agricultural systems failed. In all three cases, there were little in the way of off-farm sources of income. The Irish were so constrained by population density and the loss of the local textile industry that they were completely dependent on a crop that could not even be stored for an entire year. In the colonial famines, local industries lost out to European commercial interests. The best land was turned into plantations, and former farmers were hired back as labourers. The problem was that unlike the farmer from the pre-colonial period who would have had the opportunity to plant a diversity of crops or seek alternative employment, the plantation labourer was hired to produce a single crop. When the drought destroyed that crop they had nothing to turn to. In Ethiopia, the worst affected were those with the fewest off-farm sources of income and those who had access to the greatest number of coping mechanisms were the last to abandon homes in search of food.

The third important point is the key role that institutions can play at both reducing vulnerability to climate change but also in exacerbating problems. In all three of the cases studied, the rich and powerful agents in society did little that was effective to prevent the famine. In Ireland's case, the government's main famine relief policy was the "poor law." It was immediately over-subscribed and it was some time before policy makers in London realized the severity of the problem on their door step (Hollis and Sweetman 2004). In Ethiopia's case, the government's main agricultural policy in the years between the famines of the 1970s and 1980s led to wide spread rural upheaval as people were moved from traditional villages and onto Soviet-style communes. Severed from traditional sources of social and natural capital, these villages had little resilience in the face of even small perturbations in rainfall. In the case of the colonial famines, despite the fact that British Government tried to "famine proof" regions by building rail and telegraph networks into poor regions, these measures actually helped the famines spread and allowed food to be exported away from starving people to be sold to more affluent consumers elsewhere.

Using the resilience of the agro-ecosystems on which people depend for food, the availability of different livelihood strategies that would allow people to switch source of food, and the ability of institutions to respond to crises in the food system, it is possible to construct a framework similar to the one used by landscape ecologists to understand how ecosystems become vulnerable over time to ecological problems (Fig. 4). If the lead up to

these three famines were plotted onto Fig. 4, all three examples would be see to move towards the top, back and right-hand corner (indicated by the number 8) of the figure. Figure 4 also helps explore how changes that may reduce vulnerability on one axis may increase vulnerability in other ways. For example, research done in Ethiopia following the 1984 famine shows that many slightly better-off households have diversified incomes away from agriculture since the crisis (Blocka and Webb 2001). While this may reduce vulnerability to drought by providing off-farm sources of income, research done by Holden et al. (2004) suggests that as employment opportunities away from agriculture increase, soil conservation practices decline. The authors conclude that non-agricultural economic activity increases the opportunity costs associated with maintaining resilient agro-ecosystems. Taken together, these two studies suggest that although economic development will reduce vulnerability to climate change for some people by providing economic opportunities that are not tied to farming, it may result in increased vulnerability to climate change at the agro-ecological level. On Fig. 4, this would be reflected by a shift towards the fourth corner of the figure indicating a trade off of agro-ecological resilience and livelihood options.

It is possible to imagine any number of other trajectories through the space bounded by the eight corners of the figure and the direction a region is heading will suggest different types of vulnerability to climate change. To develop this, it may be appropriate to imagine real-world examples of the types of regions that would typify the eight corners of this figure. For example, this paper has argued the cases reviewed here had conditions typical of number "8" in the framework. Any number of modern-day cases might fit this description such as pastoralists who are dependent on fragile range land and raise cattle in the Kalahari (Dougill et al. 1999; Fraser et al. 2006). The opposite situation, where agro-ecosystems are robust, there are plenty of economic opportunities, and institutions provide good safety

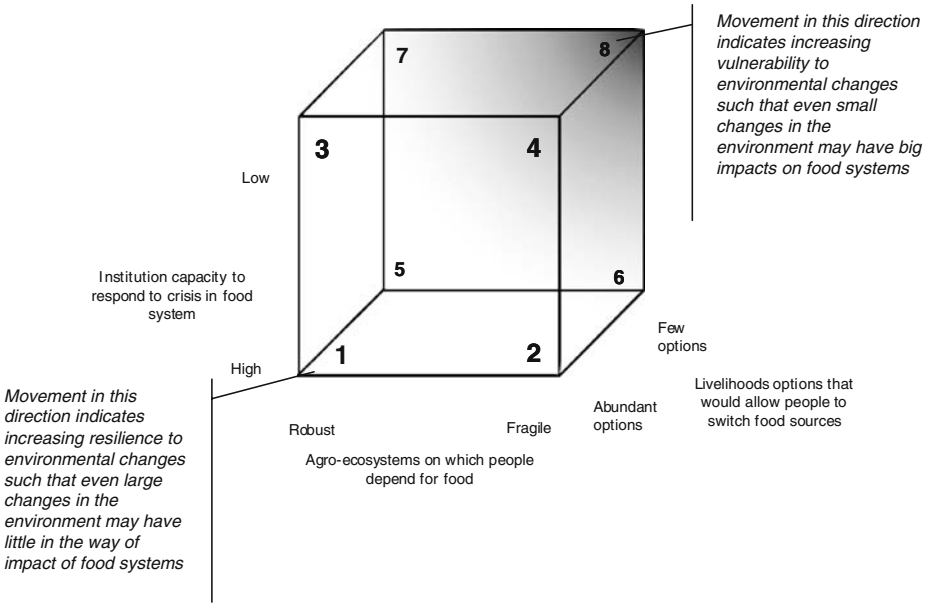

Fig. 4 Vulnerability to climate change framework based on three key scales (agro-ecological, livelihoods and institutional). Movement over time towards the top, back, right-hand corner indicates increased vulnerability to climate change

Table 2 Illustration of possible changes in vulnerability to climate change as identified by the framework proposed in Fig. 4 with possible effects of climate change and examples for each type of region

Direction towards:	Characteristics	Possible example	Potential response to climate change
Corner 1 of Fig. 4	Robust agro-ecosystems Abundant livelihood options High institutional capacity	Diverse agro-ecological regions in developed world. Possibly areas like the Emilia-Romagna region of Italy (Montreson and Mazzocchi 1999)	Agro-ecosystems will have a high threshold for environmental change. In the event of environmental change causing problems, communities will likely have economic opportunities to help them cope. Institutional safety nets will likely be provided.
Corner 2	Fragile agro-ecosystems Abundant livelihood options High institutional capacity	California's horticultural industry has enormous demands for water and dwindling water supplies but abundant institutional capacity and ample non-agricultural economic opportunities (McClurg 2000)	Agro-ecosystems will be sensitive to perturbations in the environment, but a combination of economic opportunities and institutional policies will protect livelihoods from effects of environmental change.
Corner 3	Robust agro-ecosystems Abundant livelihood options Low institutional capacity	Ecologically diverse urban agriculture in cities like Bangkok provides a source of subsistence along side economic opportunities provided by the city (Fraser 2002)	Robust agro-ecosystems and economic opportunities protect livelihoods from climate change. A lack of strong institutions, however, means that problems may emerge in the face of persistent or severe environmental problems.
Corner 4	Fragile agro-ecological Abundant livelihood options Low institutional capacity	Ecologically fragile agriculture such as shrimp farming around cities in Asia that is vulnerable to changes in the environment though people may have easy acesss to other sources of economic activity (Ali 2006).	Fragile agro-ecosystems and weak institutional support make livelihoods vulnerable to environmental problems though access to non-farm economic opportunities provide people with alternative strategies.
Corner 5	Robust agro-ecosystems Few livelihood options High institutional capacity	Ecologically robust farmers in rural parts of the developed world perhaps including low input or organic grain producers in the Canadian prairies (Bradshaw 2004).	Ecologically robust agro-ecosystems ensure a high tolerance to environmental changes. In the event of a problem, however, people may have few economic opportunities, and may quickly rely on institutional help in the form of government aid.
Corner 6	Fragile agro-ecosystems Few livelihood options High institutional capacity	Mainstream grain farmers in North American who use ground water to produce small number of crops and rely on government insurance programmes (Opie 2000)	Regions that depend on ecologically fragile agro-ecosystems with few other economic opportunities will be vulnerable to changes in the environment and quickly need to rely on institutional help to survive.
Corner 7	Robust agro-ecosystems Few livelihood options Low institutional capacity	Projects in West Africa, where new water harvesting methods have been used to improve agricultural management in poor regions. (Oweis and Hachum 2006)	Robust agro-ecosystems may increase the tolerance to environmental problems, though if environmental problems affect productivity, there will be few other strategies to protect help people obtain a living.
Corner 8	Fragile agro-ecosystem Few livelihood options Low institutional capacity	Pastoralists in the Kalahari depend on the ecosystem producing fodder as sole source of livelihood. Decades of mis-management, including the drilling of new bore holes to access water, has led to bush encroachment on productive land and a loss in the carrying capacity of the region (Fraser et al. 2006)	Livelihoods vulnerable to even small changes in the environment and no real alternatives.

nets, might be an area like Emilia-Romagna in Northern Italy that has a reputation for having high levels of economic development, produces a large range of diverse agricultural products and is supported by generous European Union and Italian agricultural policies (Brusco 1982; Montreson and Mazzocchi 1999). Grain production in the Great Plains of the USA may be typical of sixth corner, where there are few economic opportunities not tied to agriculture, and decades of ground water exploitation have made this region vulnerable to drought (Opie 2000). The wealth of the US government and the political power of the farmers will in all likelihood, however, ensure that farmers will not starve in the case of a drought. Table 2 provides examples of how different agricultural regions in the world today might fit onto this framework and speculates on the possible impact of climate change on each type of region. As a result, this if used, this framework might provide a way of recognizing the signs of vulnerability to climate change by highlighting changes over time as different regions evolve to become more or less like the regions identified in Table 2.

5 Conclusions

The purpose of this paper is to use past case studies as the basis for understanding how social and economic factors may make regions vulnerable to environmental changes. Drawing on a number of different bodies literature, and illustrative examples from European, African, and Asian history, the framework presented here suggests that vulnerability to climate change can be identified using three key factors. The first is whether or not the agro-ecosystems on which people depend for food is itself robust. The second key variable is whether there are a range of livelihood options open to people that will allow them to switch from one source of food to another. The final variable is whether the institutions active in a region are able to provide help in the event of problems within the food system. These variables can be used to define a three-dimensional space where changes over time can be plotted as progress towards one of the eight corners of this space. Each corner of this space will have more or less likely responses to sudden changes in the environment that may render the local environment unproductive. Although this framework may be a useful analytic and descriptive tool to help expose the principle components of vulnerability to climate change, it may also be of use in directing policy. If communities are seen to be losing economic opportunities and relying on specialized agro-ecosystems, then policies can be established to alter this progress. Alternatively, policies could be directed at helping communities develop more robust agro-ecosystems. In conclusion, it should be noted that this framework is presented in a heuristic form. The next step in the research is to use a wider range of contemporary case studies to validate these axes to determine their relative importance in different socio-ecological situations and assess the costs and benefits of policies directed at improving vulnerability in these three areas.

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