ENVIRONMENTAL RESEARCH
LETTERS

LETTER • OPEN ACCESS

Rural institutions, social networks, and self-organized adaptation to climate change

To cite this article: Harry W Fischer *et al* 2021 *Environ. Res. Lett.* **16** 104002

View the article online for updates and enhancements.

IOP Publishing Environ. Res. Lett. 16 (2021) 104002 https://doi.org/10.1088/1748-9326/ac22bf

ENVIRONMENTAL RESEARCH
LETTERS

CrossMark

OPEN ACCESS

RECEIVED
4 May 2021

REVISED
11 August 2021

ACCEPTED FOR PUBLICATION
1 September 2021

PUBLISHED
15 September 2021

LETTER

Rural institutions, social networks, and self-organized adaptation to climate change

Harry W Fischer[1,*], Ashwini Chhatre[2], Sripad Devalkar[2] and Milind Sohoni[2]

[1] Department of Urban and Rural Development, Swedish University of Agricultural Sciences, P.O. Box 7012, SE-750 07 Uppsala, Sweden
[2] Indian School of Business, Gachibowli, Hyderabad, Telangana 500 111, India
[*] Author to whom any correspondence should be addressed.

E-mail: harry.fischer@slu.se

Keywords: climate adaptation, rural livelihoods, social networks, rural institutions, development

Supplementary material for this article is available online

Abstract

Support for rural livelihoods to adapt to climate change is a top policy priority around the world. We advance the concept of 'self-organized adaptation' to analyze how long-term pathways of transformation come about as the organic outcome of farmers' incremental and continuous responses to climate and other challenges. Through an analysis of four decades' responses to changing climate conditions in an agricultural system of the Indian Himalayas, we show how several key policy interventions—institutional support for the dissemination of agricultural knowledge, investments in infrastructure, and strengthening of market linkages—have produced favorable conditions for successful, long-term self-organized adaptation to climate change. This has led to the transformation of an agricultural system specialized in apple production to one with a great diversity of fruit, vegetable, and food grain crops. We find that farmers growing these crops cluster into five distinct agricultural portfolios that reflect the constraints and opportunities that different farmers face, and which are patterned by interaction with rural institutions and household social networks. We highlight the role of distributed decision-making in shaping broader trajectories of systemic transformation, and we argue for the need to move beyond pre-defined climate interventions toward the identification of policy mechanisms that can support more effective self-organization over the long-term.

1. Introduction

Climate change poses significant threats to the well-being of the rural poor, particularly in developing countries [1–3]. Planning for the challenges of climate change is now viewed as an essential aspect of international and national development planning [4–6]. There is growing consensus of the need to move beyond predefined interventions targeting specific threats to promote broader transformation of production systems so that they are more secure and sustainable to begin with [7–9]. Ongoing debates have focused on what kinds of measures need to be coordinated at higher scales and those which may be more effectively designed and coordinated at subnational and local levels [10–12]. Despite extensive research on individual and collective responses to various climate challenges [13–16], knowledge of how policy interventions shape long-term processes of climate adaptation in rural livelihood systems is still limited overall, while there remain comparatively few empirical examples from which to draw lessons for policy [17]. In this paper, we advance the concept of self-organized adaptation as a means to explore how public support systems—comprised of multiple institutions and programs for public support—influence trajectories of livelihood transformation in response to climate risk and change.

Our focus on self-organized adaptation responds to several fundamental challenges to development planning in the context of climate change. First, the unpredictability of future conditions underscores the need for governance arrangements that are responsive to changing needs. Current climate models do not allow us to project precisely how climate changes will affect specific localities, much less the convergence of events through which their effects will cascade through complex livelihood systems [18–21]. Second, different localities, groups, and households often have very different susceptibilities to exposure and divergent capacities to respond to shocks [22–25]. It thus follows that no single program or policy is likely to be sufficient by itself: there is a need for interventions that can bring together multiple forms of support to address varying local needs [26–28]. Third, while individual, 'first-order' responses may play an important role in mitigating loss to specific challenges, broader transformation in the nature of production systems are often necessary to sustain and secure rural livelihoods over the long-term [7, 29]. Recent scholarship has attended carefully to the path-dependent trajectories through which adaptations unfold, highlighting the limits of command-and-control approaches for facilitating transformative change [30–34].

When considered together, these three dimensions—the uncertainty of future conditions, highly differentiated needs, and the path-dependent nature of transformations—present fundamental challenges to development as often practiced. In short: identifying necessary interventions, their possible sequences, and the appropriate combinations may not be possible in advance. Our use of self-organized adaptation thus seeks to shift the focus away from specific, readily identifiable interventions to the broader set of supportive conditions that can enable ongoing, incremental responses to diverse and changing needs as they arise. Self-organization is more than just the sum of individual, autonomous household-level responses; it is a system-level attribute that emerges as an effect of ongoing experimentation and innovation that alters the horizon of opportunities for actors within the system as a whole [35, 36].

Although much adaptation planning to date has focused on macro-level policy structures and program design, the idea that adaptation is context-specific, localized, and emergent underlies a great deal of social science scholarship on climate adaptation [9, 25, 37, 38]. The language of self-organization is itself often invoked in the literature on both resilience and polycentricity to signal the limitations of top-down planning as well as the importance of planning initiated by actors most able to identify and carry out responses in their specific localities [16, 35, 39–41]. While planning processes must necessarily be coordinated at multiple scales [11, 42], it is widely recognized that interventions are successful only to the extent that they align with challenges and opportunities of complex production systems [21, 22, 32]. Local actors often have existing practices to mitigate risk rooted in practical knowledge and experience, which can help in developing locally-appropriate responses to climate threats [43–45]. Policy strategies for 'community-based adaptation' and 'bottom up' climate assessments are both premised on the belief that local input in planning processes is necessary to develop interventions that align with local needs and context-specific conditions [23, 46, 47].

A burgeoning body of scholarship has investigated the factors that enable effective responses to challenges faced by households and communities in different contexts [48, 49]. Households' ability to cope with stressors or undertake responses to mitigate future threats is structured by assets and resources, personal capabilities, the ability to gain access to external support, and other factors [8, 34, 50, 51]. Social networks, norms of reciprocity, and traditions of collective action often play a crucial role in helping to coordinate collective responses to local challenges or disseminating new technology and knowledge [31, 52, 53]. Local institutions can serve as crucial channels to leverage resources and programs from higher levels of government and connect them to local needs [13, 54, 55]. Knowledge of climate threats and response alternatives is itself an important prerequisite for vulnerable groups to decide what kinds of actions to undertake [8, 49]. Broader policy frameworks play a significant role in shaping the kinds of resources and support given to local and meso-level governance structures, which may both extend and constrain the range of local responses that are available [12, 26, 28].

Yet although such work has made important progress toward the identification of factors conducive to locally-coordinated climate responses, a majority of social science literature has continued to focus on the determinants of individual decision-making, with far less attention to how social interactions and institutions structure adaptation of agricultural systems, as two recent large-scale reviews note [15, 56]. Moreover, there remains only limited empirical evidence of how individual decision-making unfolds in tandem with shifts in broader production systems, even despite important theoretical progress in conceptualizing the interplay between individual responses and system transformation [7, 30, 32]. Building upon these scattered threads of scholarship, our account of self-organized adaptation sheds light on how pathways of transformation come about as a result of farmers' incremental decisions, structured by variegated state support and ongoing interaction and diffusion within household social networks.

2. Study background: agricultural transformation in the Kullu Valley

Our study of agricultural transformations in the lower middle Himalayas over the past two decades provides one such example of successful long-term, self-organized adaptation. Our analysis focuses on the Takoli panchayat, which is located in India's northern state Himachal Pradesh at the lower reaches of the Kullu Valley. Our analysis is built upon detailed household surveys undertaken in 2011 complemented with secondary data on climate and agricultural changes in the area as well as intensive qualitative enquiry and semi-structured interviews (see full details on materials and methods in the SI available online at stacks.iop.org/ERL/16/104002/mmedia).

In the early 1980s, local agricultural production was oriented around two dominant agricultural strategies: subsistence crops and apples. As the primary cash crop of the region, apple was the backbone of the rural economy, comprising over 50% of private land under cultivation and 80% of income for the average household in 1985 (figure S1).

Rising winter temperatures and declining snowfall (figure S2) significantly diminished apple productivity and commercial value, a pattern observed across the Himalayan region as the apple belt has gradually shifted to higher elevations [57, 58]. In Takoli, mounting losses from several years' bad harvests led most farmers to abandon apples by the early 1990s.

Since this time, however, agricultural practice has undergone a remarkable transition. As apples declined, they were replaced by a panoply of other cash crops—46 varieties in total (SI section 3). Our analysis of cropping patterns within present-day Takoli finds significant clustering of households according to the crops that they grow, represented by five distinct 'agricultural profiles'. While some farmers prefer to grow a variety of crop types, others focus their attention on crops within one type—fruits, vegetables, or food grains. The agricultural landscape is not just diverse; there is a diversity of ways that different farmers have responded to climate challenges in developing the agricultural strategies they now pursue.

Today, apples constitute a negligible proportion of land under cultivation and household incomes, yet agriculture remains profitable while standards of living are high for the Himalayan region. Importantly, these outcomes were not the effect of any coordinated climate adaptation project or policy; climate change was not even on the state's agenda.

3. A history of agricultural change

For farmers, apple was itself an adaptation to new opportunities, enabled by the growth of state support during the post-colonial era. In the 1960s, the state of Himachal Pradesh began to invest heavily in agriculture—and apple in particular—through the establishment of the Agriculture Department and Horticulture Department as well as strategic interventions in subsidized inputs and access to credit. As the Kullu apple economy grew, so did trading networks, expanding opportunities for farmers to market high value cash crops to more distant urban centers [59]. These changes did not just support the widespread adoption of apples; increasing availability of state support and market integration fundamentally reoriented rural production systems, thus providing a foundation for further changes to occur.

The widespread adoption of apple increased incomes substantially, leading to a growth in disposable incomes and an overall increase in well-being for many farmers through the 1970s and 80s. Yet slow changes in climate began to undermine the viability of apple throughout Kullu [57, 60]. In Takoli, apples peaked at the lower reaches of the valley in the 1980s, and by the early 1990s they were in decline across the upper reaches of its range (figures S1 and S2).

While some farmers already grew other fruits and select vegetables, typically in small amounts, several infrastructural interventions helped to expand the viability of a wider variety of crops. In year 1983, a satellite agricultural and horticultural research center linked to state agricultural universities opened in the area, which has focused on setting up demonstration plots for different crops and disseminating knowledge about new varieties of vegetables and fruit. At the same time, the expansion of irrigation—through both subsidized credit for borewells as well as a lift irrigation scheme built by the Irrigation Department in year 1998—provided more secure access to water during the summer, enabling farmers to scale up production of high value vegetable crops. Finally, the establishment of a state-run marketing facility at the southern end of Takoli in 1998 created a central location for farmers to sell their produce through open auction to traders that specialize in different crops and transport them to lowland cities for sale.

All the while, increasing demand for fresh vegetables and fruit among India's growing middle classes in north Indian urban centers steadily expanded opportunities for farmers in mountain regions to grow these crops during their comparatively moderate summers, when they are out of season elsewhere. The gradual diversification of production practices also brought new opportunities for small-scale entrepreneurs—owners of seed shops and fruit tree nurseries, for example—who make a living by disseminating new varieties and knowledge of how to grow them. Thus, aside from the negative impacts of changing climate conditions on apple production, numerous other developmental and economic shifts helped to expand farmers' opportunities. All of these factors combined to create a broad set of enabling conditions for farmers to diversify production through different agricultural portfolios.

4. The five agricultural portfolios

Drawing on our survey data, we classified crops presently grown into five main categories—fruit,

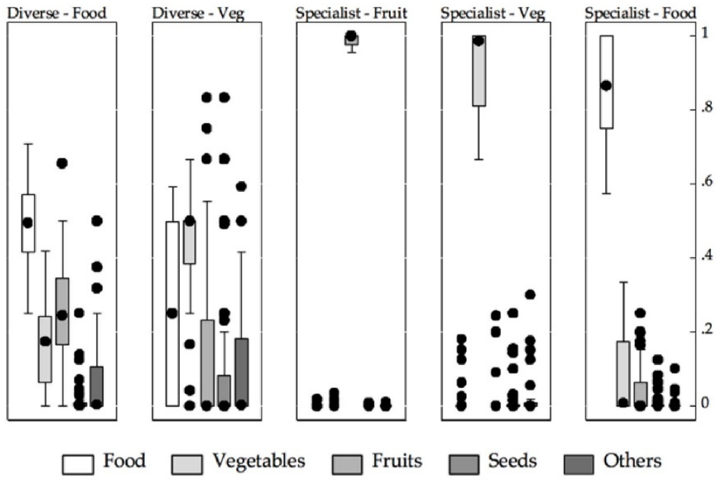

Figure 1. Boxplots show the proportion of agricultural land households devoted to five categories of crops: food grains, vegetables, fruits, seed crops, and others. The 273 households in the sample cluster into five distinct profiles. Two of the clusters diversify across crop types with an emphasis on food grains (Diversified Food Grains Profile; $n = 61$) or on vegetables (Diversified Vegetables Profile; $n = 79$). Three other clusters privilege one crop type over all others: Specialized Fruit ($n = 14$), Specialized Vegetable ($n = 32$), and Specialized Food Grain Profiles ($n = 87$). The profiles represent distinct cropping strategies that different households pursue.

Table 1. Summary of landholding size, irrigation, and caste status by agricultural profile.

	Profile 1: 'Diversified Food Grains'	Profile 2: 'Diversified Vegetables'	Profile 3: 'Specialized Fruit'	Profile 4: 'Specialized Vegetables'	Profile 5: 'Specialized Food Grains'
Total households	61	79	14	32	87
% Low caste	23%	51%	46%	81%	53%
Mean landholding	.47 hectares	.29 hectares	.71 hectares	.16 hectares	.21 hectares
% Households with irrigation	68%	82%	24%	94%	34%

vegetables, seeds, subsistence food grains, and others. These categories face different kinds of risks, require different inputs, and operate on different temporal scales. Fruit trees, for example, are long term investments that take years to mature. Vegetable crops can be reevaluated seasonally, and they typically require intensive irrigation. Seed crops are produced through buy-back agreements with seed companies. Food grains typically require limited chemical inputs and are produced for subsistence consumption. 'Other' crops comprise those which do not fit neatly into other categories (SI section 3).

Almost all households in Takoli grow at least some crops from multiple categories, suggesting that most famers prefer to embrace livelihoods with a range of characteristics. To better understand which crops farmers tend to adopt together, we undertook a hierarchical cluster analysis on the proportion of land farmers devote to each crop type [24]. The cluster analysis reveals distinct combinations of crop types across different groups of farmers (figures 1 and S3). Some farmers are highly diversified across crop types, with a primary emphasis either on food grains (Profile 1, Diversified Food Grains Profile) or on vegetables (Profile 2, Diversified Vegetables Profile). Others tend to focus on one crop type over all others (Profiles 3, 4, and 5—Specialized Fruit, Vegetable, and Food Grain Profiles respectively).

These profiles are the emergent outcome of ongoing and incremental decisions of individual farmers within an evolving agricultural system. Although the data does not allow us to trace the development of these portfolios since the decline of apple in the late 80s and early 90s, it does provide evidence of some factors that have structured these processes. First and foremost, we find an association between farmers' productive assets—especially land and irrigation (including borewells, the state-sponsored lift irrigation scheme, or mountain streams)—and their agricultural strategy (table 1). Overall, farmers that specialize in subsistence food grains (Profile 5) tend to lack access to irrigation and have limited land. In contrast, those with limited land but access to irrigation tend to invest in vegetables (Profiles 2 & 4). Social status does not itself appear to be an impediment for adopting new strategies; while households in Profile 4 have less land overall (a reflection of historical inequities for lower castes), they nonetheless have

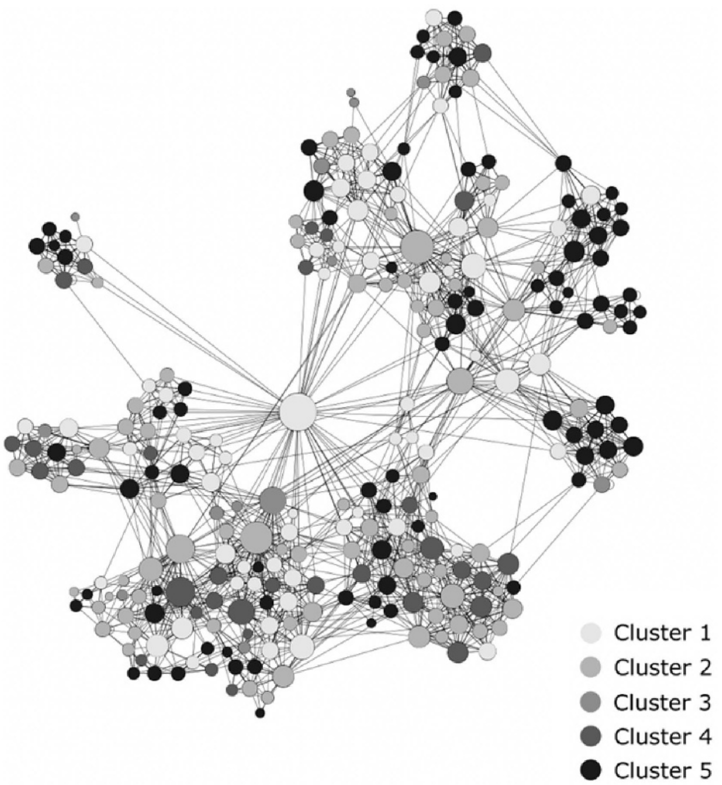

Figure 2. Graph depicts the network of social interaction among 273 households. The nodes are households, while each link represents interaction between households for information and advice regarding agricultural decisions. The size of nodes is proportionate to the number of households they interact with ('degree') and relative position of a node in the graph reflects common links in the network. Households with diversified crop portfolios (Clusters 1 & 2) and vegetable producers (Cluster 4) are located more centrally in the network and have higher degree, suggesting these households are better connected on average within the network.

been able to adopt intensive vegetable production—a comparatively lucrative strategy where land is a constraint. Unsurprisingly, farmers with substantial investment in fruit production, usually low-density orchards, tend to be those with more land (Profiles 1 & 3).

We also find evidence that decision-making is structured by broader flows of agricultural information in Takoli. Our survey data asked households to identify the other households in the village from which they seek information concerning crop choice, techniques, equipment, inputs, pest control, and any other aspect of agricultural production. We used this data to construct a social network for the diffusion of agricultural knowledge in the village (figure 2). We find that a household's position within the network is predictive of cluster membership: both diversified profiles (Profiles 1 & 2) and specialized vegetable farmers (Profile 4) tend to have greater centrality in the network, while fruit and food grain specializers tend to have less (Profiles 3 & 5) (figure 3; tables S4 and S5). This correlates with the greater intensity of knowledge exchange necessary to sustain more diversified profiles and of vegetable production. The latter in particular is characterized by a high degree of experimentation and adjustment compared to fruit and food grain production which remains far more static between seasons and across years.

Significantly, there are no self-contained cliques within the network; overall, it has a high degree of integration among farmers with different strategies (figure 2). However, the density of interaction between different profiles varies. Our measure of cross-cluster connectivity—calculated as the proportion of actual linkages to the total possible linkages between households in each profile (figure 4 and table S1)—shows that the more diversified profiles tend to have particularly strong relationships both with each other and the other profiles. While the more diversified profiles require a broader catchment of knowledge to sustain their diversity, these households may also play an important role in extending knowledge and experience of different varieties in the village. At the aggregate, heterogeneous social connections between the profiles imply that farmers have access to knowledge and information far beyond what they presently grow—an important prerequisite for experimenting with and adopting new strategies to best fit changing constraints and opportunities—climate, market, or otherwise.

These endogenous processes of diffusion are also patterned by interaction with a broader set of state institutions. Although comparatively few farmers

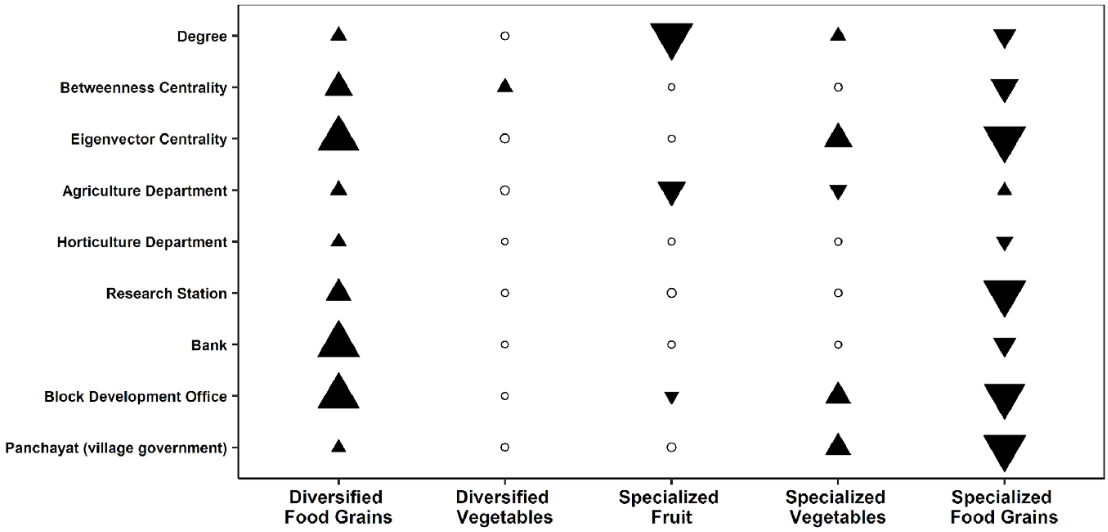

Figure 3. Marginal effects from bivariate multinomial logistic regressions of network variables on each of the five agricultural profiles. The upward triangle represents a positive and significant effect (higher network centrality; closer network distance to institutions) and downward triangle represents a negative and significant effect (lower network centrality; greater network distance to institutions). Hollow circles imply associations that are not statistically significant at a 95% level of confidence. Size of the triangle correspond to the p-value on marginal effects from the regression model (table S4).

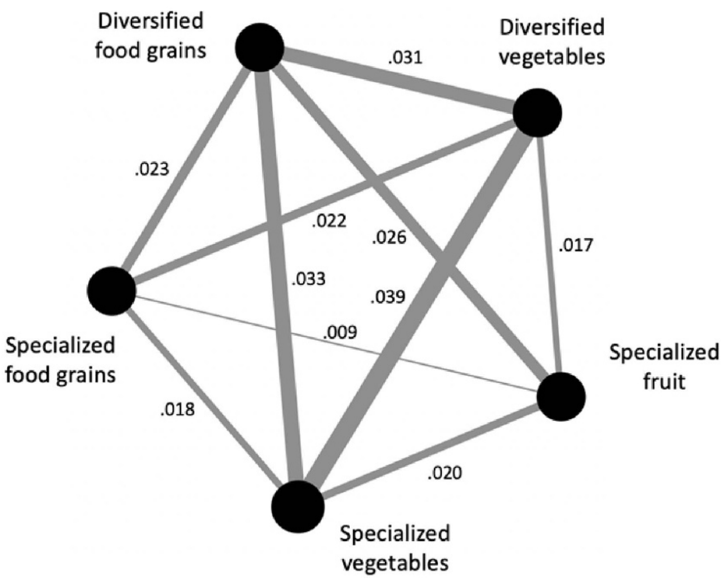

Figure 4. The interaction of households across profiles shows the strength and diversity of sources of information. Values are calculated as the proportion of observed linkages to the total possible linkages between households in each profile pair. Edges are scaled to the strength of the connection; thicker lines represent a stronger connection and thinner lines represent a weaker connection. Households in the two diversified portfolios and the specialized vegetables portfolio show the strongest connection to households in other clusters, reflecting both a greater need for information as well as their role in disseminating information to other profiles.

interact with these institutions directly (SI section 5), we used our household social network to construct the network distance ('shortest path') between households and state institutions—in short, the number of links that a household needs to reach a given institution in the network. Our analysis shows that cluster membership is associated with different kinds of support (figure 2(a)). Food grain specializers (Profile 5) tend to have a shorter network distance to the Agricultural Department—a reflection of the Department's longstanding support for subsistence food production. In contrast, vegetable specializers (Profile 4) tend to be more distant from the Agricultural Department, yet have a shorter network distance to both the Block Development Office and the elected village government (panchayat), both of which are critical gateways for learning about and gaining access to a range of state support for farmers, for example subsidies for farm inputs, equipment or irrigation. Diversified food producers (Profile 1) tend to be close to each of these institutions, but also to the Horticulture Department and the nearby Research Station at Bajaura linked to the state Agriculture and Horticulture Universities, which focuses on experimenting with, introducing, and training farmers in the cultivation of niche crops varieties. Indeed, farmers in this profile are not just diverse in their cropping strategies, their network position suggests that they access the greatest diversity of information and support among farmers in the village. These farmers may thus play an important role in adopting new varieties and techniques that are then available for further diffusion within the village network as a whole.

5. Building policy support for self-organization

The case of Takoli provides an example of successful, long-term self-organized adaptation. While state interventions—for irrigation, marketing, and institutional support—have helped to expand the range of options available to farmers, ultimately it was farmers' individual decisions to experiment with and refine their own cropping portfolios that determined how local adaptation trajectories have unfolded. Today, agriculture remains not only profitable, but exceptionally diverse—providing ongoing opportunities for farmers to continue to calibrate their cropping portfolios according to the changing constraints and opportunities that they face.

While notions of self-organization are invoked in discussions of adaptation [39, 40, 61], the mechanisms that underlie such processes are not well understood, while there continues to be an analytical gap in determining how to support such objectives through specific policy interventions [36]. Our analysis shows how an interplay of state support, local social interactions, and individual, distributed, decision-making can serve as complementary parts of transformation. While much existing research has focused extensively on determinants of individual decision-making processes [15], our analysis of network interaction shows how farmers' responses are structured by ongoing processes of exchange and diffusion embedded within a broader set of local social relationships. This suggests that simply better targeting of climate support to address pre-identified vulnerabilities is not enough—or even 'bottom up' assessments of local adaptation priorities [23, 37]. Equally important may be to ensure that households have the opportunity to undertake ongoing responses in alignment with their specific needs and challenges, and to build linkages with diverse forms of knowledge and support that expand the range of opportunities to do so [8, 31]. More broadly, our work reveals adaptation as an inherently collective process, where individual, decentralized decisions are not just a significant determinant of household vulnerability, but constitutive of broader adaptation trajectories for the system as a whole [7, 25, 32].

Critically, state interventions have played a central role in enabling these processes to occur. Existing responses to address climate risks may be an important factor in climate adaptation in many contexts, as other scholars have observed [16, 43, 45], yet our analysis suggests that self-organized adaptation may often require more than farmers' practical knowledge or intrinsic ingenuity alone. In Takoli, present-day cropping strategies have been structured by a history of state interventions dating over the past half-century, which have provided critical inputs of knowledge, resources, infrastructure and other support. Such interventions are purposeful policy choices, which structure how processes of self-organization ultimately occur.

Most strikingly, although climate has been a central driving factor of agricultural change, the large-scale transformations in Takoli's agricultural system has not occurred as part of any specific 'adaptation' plan. The nature of state support has co-evolved with household agricultural decisions, as farmers have adopted a wider range of crops, and agricultural institutions have, in turn, devised new strategies to cater to their needs. At a time of ongoing discussions about how best to incorporate adaptation into development planning [6, 8, 62], our analysis suggests that the range of available institutions, their resources, and their capacities may be more important than any specific 'adaptation' policies that such institutions are called upon to carry.

Of course, the positive outcomes observed in this case are not inevitable; there is no guarantee that available support will be enough to support self-organized adaptation in many contexts, while a large and growing body of research warns about the risk of maladaptation—where actions to respond to climate risk may even exacerbate long-term vulnerability [63, 64]. Still, this case aligns with a growing body of work that highlights the importance of learning from examples of successful transformation in order to build knowledge of how best to facilitate adaptation over the long-term [7, 13, 16]—especially in the case of successful local actions that might otherwise fall under the radar of adaptation policy [65].

While much research on climate change has focused on areas of perceived urgency to avoid future calamity, rural livelihood systems have never been static to begin with, but have constantly evolved to face a wide range of challenges and opportunities—well before climate change was on the policy agenda. Takoli is but a single case, but we do not believe it is unique; it is simply an instance where state support has worked in a way that one might hope that it would. Cases without dramatic 'red flags' and planned interventions to address them are more likely to be invisible in present debates, but they may nonetheless provide valuable insight into the policy mechanisms that enable successful adaptation over the long-term.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://doi.org/10.17632/prs95bn8wj.1.

Acknowledgments

The authors would like to thank Satya Prasanna, Vijay Guleria, Rajesh Rana, and Sriharitej Kolagani for assisting in data collection and analysis, and two anonymous reviewers for their insightful comments on the manuscript. We especially thank our research participants for taking the time to share information about their agricultural strategies with us during the course of fieldwork. This research was very generously supported by Swedish Research Council (Vetenskapsrådet) research project 2018-05875 and a University of Illinois Academy of Entrepreneurial Leadership research grant.

ORCID iDs

Harry W Fischer https://orcid.org/0000-0001-7967-1154
Ashwini Chhatre https://orcid.org/0000-0002-5374-7867
Sripad Devalkar https://orcid.org/0000-0002-3708-9104
Milind Sohoni https://orcid.org/0000-0003-0510-7109

References

[1] Adger W N, Huq S, Brown K, Conway D and Hulme M 2003 Adaptation to climate change in the developing world *Prog. Dev. Stud.* **3** 179–95
[2] Mearns R and Norton A 2010 *Social Dimensions of Climate Change: Equity and Vulnurability in a Warming World* (Washington, DC: The World Bank) (https://doi.org/10.1596/978-0-8213-7887-8)
[3] Karki S, Burton P and Mackey B 2020 The experiences and perceptions of farmers about the impacts of climate change and variability on crop production: a review *Clim. Dev.* **12** 80–95
[4] Agrawal A and Carmen Lemos M 2015 Adaptive development *Nat. Clim. Change* **5** 185–7
[5] Grigss D 2013 Sustainable developmnet goals for people and planet *Nature* **495** 305–7
[6] Ayers J and Dodman D 2010 Climate change adaptation and development I the state of the debate *Prog. Dev. Stud.* **2** 161–9
[7] Wise R M, Fazey I, Stafford Smith M, Park S E, Eakin H C, Archer Van Garderen E R M and Campbell B 2014 Reconceptualising adaptation to climate change as part of pathways of change and response *Glob. Environ. Change* **28** 325–36
[8] Eakin H C, Lemos M C and Nelson D R 2014 Differentiating capacities as a means to sustainable climate change adaptation *Glob. Environ. Change* **27** 1–8
[9] Rigg J and Mason L R 2018 Five dimensions of climate science reductionism *Nat. Clim. Change* **8** 1030–2
[10] Molenveld A, Van Buuren A and Ellen G J 2020 Governance of climate adaptation, which mode? An exploration of stakeholder viewpoints on how to organize adaptation *Clim. Change* 162 233–54
[11] Huitema D, Adger W N, Berkhout F, Massey E, Mazmanian D, Munaretto S, Plummer R and Termeer C C J A M 2016 The governance of adaptation: choices, reasons, and effects. Introduction to *Ecol. Soc.* **21** 37
[12] Urwin K and Jordan A 2008 Does public policy support or undermine climate change adaptation? Exploring policy interplay across different scales of governance *Glob. Environ. Change* **18** 180–91
[13] Agrawal A, Perrin N, Chhatre A, Benson C S and Kononen M 2012 Climate policy processes, local institutions, and adaptation actions: mechanisms of translation and influence *WIREs Clim. Change* **3** 565–79
[14] Lemos M C, Boyd E, Tompkins E L, Osbahr H and Liverman D 2007 Developing adaptation and adapting development *Ecol. Soc.* **12** 26
[15] Davidson D 2016 Gaps in agricultural climate adaptation research *Nat. Clim. Change* **6** 433–5
[16] Osbahr H, Twyman C, Adger W N and Thomas D S G 2010 Evaluating successful livelihood adaptation to climate variability and change in Southern Africa *Ecol. Soc.* **15** 22
[17] Adamson G C D, Hannaford M J and Rohland E J 2018 Re-thinking the present: the role of a historical focus in climate change adaptation research *Glob. Environ. Change* **48** 195–205
[18] Mehta L, Adam H N and Srivastava S 2019 Unpacking uncertainty and climate change from 'above' and 'below' *Reg. Environ. Change* **19** 1529–32
[19] James R, Washington R, Schleussner C F, Rogelj J and Conway D 2017 Characterizing half-a-degree difference: a review of methods for identifying regional climate responses to global warming targets *Wiley Interdiscip. Rev. Clim. Change* **8**
[20] Kuhl L 2021 Policy making under scarcity: reflections for designing socially just climate adaptation policy *One Earth* **4** 202–12
[21] Hill A 2021 COVID's lesson for climate research: go local *Nature* **595** 9
[22] Williams L J *et al* 2015 Household types as a tool to understand adaptive capacity: case studies from Cambodia, Lao PDR, Bangladesh and India *Clim. Dev.* **5529** 1–12
[23] Conway D *et al* 2019 The need for bottom-up assessments of climate risks and adaptation in climate-sensitive regions *Nat. Clim. Change* **9** 503–11
[24] Fischer H W and Chhatre A 2015 Assets, livelihoods, and the 'profile approach' for analysis of differentiated social vulnerability in the context of climate change *Environ. Plan. A* (https://doi.org/10.1177/0308518X15623278)
[25] Naylor A, Ford J, Pearce T and van Alstine J 2020 Conceptualizing climate vulnerability in complex adaptive systems *One Earth* **2** 444–54
[26] Lemos M C, Lo Y J, Nelson D R, Eakin H and Bedran-Martins A M 2016 Linking development to climate adaptation: leveraging generic and specific capacities to reduce vulnerability to drought in NE Brazil *Glob. Environ. Change* **39** 170–9
[27] Davies M, Béné C, Arnall A, Tanner T, Newsham A and Coirolo C 2013 Promoting resilient livelihoods through adaptive social protection: lessons from 124 programmes in South Asia *Dev. Policy Rev.* **31** 27–58
[28] Fischer H W 2019 Policy innovations for pro-poor climate support: social protection, small-scale infrastructure, and active citizenship under India's MGNREGA *Clim. Dev.* **0** 1–14
[29] Mapfumo P *et al* 2017 Pathways to transformational change in the face of climate impacts: an analytical framework *Clim. Dev.* **9** 439–51

[30] Termeer C J A M, Dewulf A and Biesbroek G R 2017 Transformational change: governance interventions for climate change adaptation from a continuous change perspective *J. Environ. Plan. Manage.* **60** 558–76

[31] Barnes M L, Bodin Ö, Guerrero A M, McAllister R R J, Alexander S M and Robins G 2017 The social structural foundations of adaptation and transformation in social–ecological systems *Ecol. Soc.* **22**

[32] Burnham M and Ma Z 2018 Multi-scalar pathways to smallholder adaptation *World Dev.* **108** 1–3

[33] Swanson H A, Svenning J, Saxena A, Muscarella R and Tsing A L 2021 History as grounds for interdisciplinarity: promoting sustainable woodlands via an integrative ecological and socio-cultural perspective *One Earth* **4** 226–37

[34] Ramprasad V 2021 Institutional benefit pathways in development *World Dev.* **142** 105453

[35] Tschakert P and Dietrich K A 2010 Anticipatory learning for climate change adaptation and resilience *Ecol. Soc.* **15** 11

[36] Preiser R, Biggs R, De Vos A and Folke C 2018 Social-ecological systems as complex adaptive systems: organizing principles for advancing research methods and approaches *Ecol. Soc.* **23**

[37] Smit B and Wandel J 2006 Adaptation, adaptive capacity and vulnerability *Glob. Environ. Change* **16** 282–92

[38] Osbahr H, Twyman C, Neil Adger W and Thomas D S G 2008 Effective livelihood adaptation to climate change disturbance: scale dimensions of practice in Mozambique *Geoforum* **39** 1951–64

[39] Dorsch M, Flachsland C and Polycentric A 2017 Approach to global climate governance *Glob. Environ. Polit.* **17** 45–64

[40] Hamilton M L and Lubell M 2019 Climate change adaptation, social capital, and the performance of polycentric governance institutions *Clim. Change* **152** 307–26

[41] Hahn T and Nykvist B 2017 Are adaptations self-organized, autonomous, and harmonious? Assessing the social–ecological resilience literature *Ecol. Soc.* **22**

[42] Adger N, Arnell N W and Tompkins E L 2005 Successful adaptation to climate change across scales *Glob. Environ. Change* **15** 77–86

[43] Nyong A, Adesina F and Osman Elasha B 2007 The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel *Mitig. Adapt. Strateg. Glob. Change* **12** 787–97

[44] Adger W N, Barnett J, Brown K, Marshall N and O'Brien K 2013 Cultural dimensions of climate change impacts and adaptation *Nat. Clim. Change Gr.* **3** 112–7

[45] Naess L O 2013 The role of local knowledge in adaptation to climate change *Wiley Interdiscip. Rev. Clim. Change* **4** 99–106

[46] Kirkby P, Williams C and Huq S 2018 Community-based adaptation (CBA): adding conceptual clarity to the approach, and establishing its principles and challenges *Clim. Dev.* **10** 577–89

[47] Fischer H W 2021 Decentralization and the governance of climate adaptation: situating community-based planning within broader trajectories of political transformation *World Dev.* **140** 105335

[48] Lemos M C *et al* 2013 Building adaptive capacity to climate change in less developed countries *Climate Science for Serving Society: Research, Modeling and Prediction Priorities* ed G R Asrar and J W Hurrell (Dordrecht: Springer) pp 437–57

[49] Cinner J E *et al* 2018 Building adaptive capacity to climate change in tropical coastal communities *Nat. Clim. Change* **8** 117–23

[50] Jain M, Naeem S, Orlove B, Modi V and DeFries R S 2015 Understanding the causes and consequences of differential decision-making in adaptation research: adapting to a delayed monsoon onset in Gujarat, India *Glob. Environ. Change* **31** 98–109

[51] Goldman M J and Riosmena F 2013 Adaptive capacity in Tanzanian Maasailand: changing strategies to cope with drought in fragmented landscapes *Glob. Environ. Change* **23** 588–97

[52] Adger W N 2003 Social capital, collective action, and adaptation to climate change *Econ. Geogr.* **79** 387–404

[53] Agrawal A 2010 Local institutions and adaptation to climate change *Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World* ed R Mearns and A Norton (Washington, DC: World Bank Publications) pp 173–98

[54] Rodima-Taylor D, Olwig M F and Chhetri N 2012 Adaptation as innovation, innovation as adaptation: an institutional approach to climate change *Appl. Geogr.* **33** 107–11

[55] Amaru S and Chhetri N B 2013 Climate adaptation: institutional response to environmental constraints, and the need for increased flexibility, participation, and integration of approaches *Appl. Geogr.* **39** 128–39

[56] Totin 2018 Institutional perspectives of climate-smart agriculture: a systematic literature review *Sustainability* **2018**

[57] Rana R S, Bhagat R M, Kalia V and Lal H 2011 Impact of climate change on a shift of the apple belt in Himachal Pradesh *Handbook of Climate Change and India: Development, Politics and Governance* ed N K Dubash (Routledge) pp 51–62

[58] Rahimzadeh A 2017 Political ecology of climate change: shifting orchards and a temporary landscape of opportunity *World Dev. Perspect.* **6** 25–31

[59] Vedwan N 2008 Apple Growers' associations in Northwestern India: emergence, success, and limitations in the context of state-society interactions *Hum. Organ.* **67** 86–96

[60] Vedwan N 2006 Culture, climate and the environment: local knowledge and perception of climate change among apple growers in northwestern India *J. Ecol. Anthropol.* **10** 4–18

[61] Hahn M B, Riederer A M and Foster S O 2009 The Livelihood Vulnerability Index: a pragmatic approach to assessing risks from climate variability and change—a case study in Mozambique *Glob. Environ. Change* **19** 74–88

[62] Runhaar H, Wilk B, Persson Å, Uittenbroek C and Wamsler C 2018 Mainstreaming climate adaptation: taking stock about "what works" from empirical research worldwide *Reg. Environ. Change* **18** 1201–10

[63] Schipper E L F 2020 Maladaptation: when adaptation to climate change goes very wrong *One Earth* **3** 409–14

[64] Magnan A K, Schipper E L F, Burkett M, Bharwani S, Burton I, Eriksen S, Gemenne F, Schaar J and Ziervogel G 2016 Addressing the risk of maladaptation to climate change *Wiley Interdiscip. Rev. Clim. Change* **7** 646–65

[65] Rahman H M T and Hickey G M 2019 What does autonomous adaptation to climate change have to teach public policy and planning about avoiding the risks of maladaptation in Bangladesh? *Front. Environ. Sci.* **7** 1–14