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Twenty priorities for future social-ecological research on climate resilience

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Abstract

Faced with the global climate crisis and the inevitability of future climate shocks, enhancing social-ecological resilience has become an urgent area for research and policy internationally. Research to better understand the impacts of, and response to, climate shocks is critical to improve the resilience and well-being of affected people and places. This paper builds on the findings of a focus collection on this topic to provide a concluding and forward-looking perspective on the future of social-ecological research on climate resilience. Drawing on an expert workshop to identify research gaps, we distinguish 20 priorities for future research on climate resilience. These span four key themes: Systems and Scales, Governance and Knowledge, Climate Resilience and Development, and Sectoral Concerns. Given the need and urgency for evidence-based policies to address the climate crisis, the analysis considers the importance of understanding how findings on social-ecological resilience are used in policy, rather than solely focusing on how it is generated. Many of the priorities emphasise the governance systems within which climate research is produced, understood and used. We further reflect on the state of current evidence generation processes, emphasising that the involvement of a wider range of voices in the design, implementation and dissemination of climate resilience research is critical to developing the efficient and fair interventions it is meant to support.

1. Introduction

The scientific community has invested considerable effort over the past 50 years in studying extreme climate events and the scale of their impacts on people and the physical and biological systems they inhabit (Mcphaden 2015, Hallegatte and Rozenberg 2017). In 2017, global economic losses attributed to climatic disasters were estimated at over $300 billion (UNSD 2019). However, aggregated estimates of economic loss mask the fact that impacts disproportionately affect low income countries, and within them, the poorest people and especially resource dependent communities (Mendelson *et al* 2006, Morton 2007, Mertz *et al* 2009). Climate shocks—extreme events such as droughts, flooding and storms—are predicted to increase in magnitude and frequency under a changing climate, exacerbating long-term climate change trends (Yeh *et al* 2009, Cai *et al* 2015). Developing a robust understanding of the resilience of ecosystems and societies is therefore an essential and urgent task.

Research to better predict when, where and how climate shocks will occur is critical to reducing their adverse effects. Yet faced with the inevitability of future shocks, enhancing social-ecological resilience has become an pressing focus of research and policy internationally (Stone-Jovicich *et al* 2018). This is reflected in clear provisions under the 2015 Paris Agreement, the Global Stocktake exercise and in global climate financing structures such as the Green Climate Fund, which aims to fund mitigation and adaptation measures (GCF 2018).

The most recent global climate shock was the 2015/16 El Niño South Oscillation. This provided an opportunity for innovative empirical research on climate shocks and changes. The collection, 'Focus on

Resilience to Climate Shocks in the Tropics', for which this article provides a closing comment, presents multidisciplinary research that analyses resilience from a variety of perspectives and scales in the context of the 2015/16 El Niño event (see appendix A). Its magnitude was comparable to the 1997/98 El Niño event (Paek *et al* 2017), and the availability of predictive systems and meteorological technologies made the 2015/16 event a critical research opportunity to improve our ability to reduce the negative impacts of future events (Cai *et al* 2015). While we recognize the importance of spontaneous and curiosity-driven research, the urgency of the climate challenge means targeted research is an important tool for developing effective policies, for example identifying best practices for interventions, highlighting areas at high risk, or addressing poorly known but potentially critical issues (Rudd *et al* 2011).

This paper is based primarily on an expert workshop designed to identify key gaps in knowledge which need to be addressed through future research on social-ecological climate resilience. It also reflects on the insights arising from papers in this special issue (identified in bold in our citations) and the wider literature.

Climate resilience is the capacity of a system to adapt, reorganize, and evolve into more desirable configurations in face of climate shocks, leaving it better prepared for future climate change impacts (Adger 2000, 2006, Folke 2006). This definition highlights the intertwined nature of the social and environmental dimensions of resilience. A system is defined appropriately to the research or policy question, for example as a location, an ecosystem, an institution, a person, or animal population. Importantly, resilience is highly context-dependent (Gallopín 2006, Marshall *et al* 2010) and socially contingent (Fortnam *et al* 2020). This is illustrated by papers in this issue demonstrating how the 2015/16 El Niño impacted different parts of the world in fundamentally different ways (Anyamba *et al* 2019, Whitfield *et al* 2019). While the concept of resilience itself is free from norms, discipline and scale, we recognize that it has taken on a normative connotation when applied in climate change and international development, where increased resilience is almost universally viewed as beneficial (Brown 2016). But the concept is increasingly contested, as questions *of what, for whom*, and *how* resilience occurs have divergent answers for different groups. The priorities identified below reflect important current conceptual and practical preoccupations for climate resilience research.

2. Methods

In May 2018, a two-day conference on *Building Resilience to the Impacts of El Niño—Lessons from the Field* was held at the Royal Society of London. This conference was the closing event for the £4 million programme *Understanding the Impacts of the Current El Niño* funded by NERC[5] and DFID[6] and brought together the 14 projects funded under this programme. On Day 2, a workshop session was held with the objective of identifying research gaps that need to be addressed in future multidisciplinary academic research. Participants were briefed to generate responses to the prompt: '*What are the top fundamental questions for social-ecological climate resilience research? This discussion will be framed as research questions that can be realistically answered by a £1-2 million project on a 3–5 year timescale*'. Similar to other 'key questions exercises', this framing was designed to generate questions that were sufficiently specific to be answerable within a reasonable and realistic time and financial frame, yet ambitious enough to significantly progress the field (2009, Sutherland *et al* 2013, Pretty *et al* 2010). An iterative and consultative process of consolidation of the original questions has led the identification of 20 priorities which are presented here, along with why these areas are of importance, why they remain open, and examples of existing work of relevance.

To embrace the universality of contemporary and future climate issues, the workshop prompt was not focused on specific geographies. Rather, the focus was on the multidisciplinarity of research areas, and on the consideration of emerging issues and potential new collaborations to deal with climate shocks and changes. The priorities emerging from this exercise are globally relevant even if their application may be specifically related to the Tropics, which are disproportionately impacted by climate change and shocks.

The participants were split into three multidisciplinary groups that addressed the prompt, and in turn built on the previous groups' responses. This allowed priority areas to be iteratively refined and the work from each group to be reviewed by peers. The discussion surrounding each priority was captured by minute-takers and the facilitators. Forty participants took part in the exercise: 72% were academics from a range of natural and social science backgrounds, including anthropology, economics, social ecology, hydrology, conservation and entomology among others. We recognize that expertise was primarily focused on terrestrial ecosystems, although marine experts were also present. Twenty percent of participants were senior representatives of UK and international non-governmental partners, and 8% were from policy-making bodies and research funding agencies. While the majority of participants were based in European institutions, all those involved had worked in-depth in the Tropics carrying out research and building collaborative partnerships. The mix of

[5]Natural Environment Research Council (UK).
[6]UK Department for International Development.

disciplinary backgrounds and professional contexts was intentional, to ensure a broad lens was applied to the topic and the priorities identified were not dominated by a particular framing or geography (Fleishman *et al* 2011, Rudd *et al* 2011). Gender balance was an objective of the conference organisers and 53% of participants were women (Hawkins and Power 1999). Precise data on nationality and age were not collected for this exercise, but there was an emphasis on supporting developing-country participants to attend the workshop and take part in this exercise. The group included people with 30+ years of experience in the field, as well as early-career participants.

Analysis of the data was conducted by the authors of the paper. Two authors (EB, MH) independently coded the collated themes and the related contextual discussion data inductively to thematically categorise discussions and identify common and overlapping thematic research areas. There was then an iterative process of synthesising the independent analysis, involving refining themes, which resulted in the final list of priorities.

During this process, we considered that just because a theme receives less attention during discussion does not necessarily mean it is less significant, but attention may simply be reflective of the biases present in any particular group of people. Therefore, themes and priorities were not ranked. The list of themes and priority areas was then circulated to all participants of the workshop and to all project PIs for validation and revisions (40% response rate). This approach differs from other global systematic exercises that involve voting (2009, Sutherland *et al* 2013, Pretty *et al* 2010).

Expert consultation represents a useful exercise to synthesize knowledge and guide decision-making on issues where a high level of uncertain and when availability of data is poor (Knol *et al* 2010, Usher and Strachan 2013, Morgan 2014, Hemming *et al* 2018). There are nonetheless many challenges to undertaking a consensus-based 'key research questions' exercise. In particular, the final set of priorities tends to reflect the perspectives, including biases, of the groups involved in generating them. Additionally, striking a balance between developing questions that fit with a broadly framed area of research and questions that are sufficiently specific that they could be practically implemented in research projects is difficult (Hemming *et al* 2018).

The priority areas presented here are thus broad, and some have been the subject of considerable research effort. Nonetheless, these questions retain their importance, relevance and novelty due to continuously evolving global and local social and environmental contexts. This exercise intends to succinctly present priority areas for research that emerged from the recent social-ecological research under the '*Understanding the Impacts of the Current El Niño*' programme. Our results reflect the collective reflection of the participants and should be viewed as guidance for future investigations, rather than a systematic and comprehensive literature review.

The issues regarding bias are particularly relevant for work on a topic as broad as climate resilience, which entails engaging with numerous areas of contestation. These include the conceptual framing of the issue, the characterisation of what is problematic, and for whom, as well as the political dimensions of the potential approaches to addressing problems (e.g. emphasising financial value, the role of the market or state). We mitigated these issues to the extent possible, by convening a group which reflected a diverse range of views and interests and by providing a well-defined prompt. We also consciously kept the framing of resilience open, so that it applied to the variety of disciplines involved in this field, to avoid imposing our own biases on the process. The priorities identified here are therefore the synthesised product of expert engagement during the workshop and the research produced under the El Niño NERC-DFID funded programme.

3. Results

The priorities are presented within four themes: System and Scales; Governance and Knowledge; Climate Resilience and Development; Sectoral Concerns. These themes overlap and are interconnected, providing a useful way of organising and indicating the major priorities which emerged from the analysis. For each of these themes we briefly explain the importance of the theme before presenting the priority areas, framed as questions, with a brief contextual discussion that aims to highlight the importance of the area, suggest novel analyses and illustrate existing work on each area.

3.1. Systems and scales

This first theme emphasizes the theoretical and conceptual dimensions of resilience. Priorities for this theme underline how resilience can be conceptualised and framed differently across academia, policy and practice, and highlight the need for analysis of how different framings shape and influence findings and action.

1. What are the key resilience properties and definitions applicable across systems and scales?

Whilst resilience has been applied and studied across many fields, this has resulted in multiple definitions of the core concepts in resilience research (Martin-Breen and Anderies 2011). This priority recognises the need to develop meta-analyses of currently available data to synthesise lessons across diverse contexts and support operationalisation of resilience interventions in the context of climate shocks. This will enable the identification of which frameworks can best support intervention

design (Chelleri *et al* 2015). For example, several climate adaptation frameworks applied in international development assume linear linkages between resilience as an outcome, and well-being as a long-term impact—which empirical analyses dispute (Jones and Tanner 2017, Beauchamp *et al* 2019a). Better understanding of linkages between core aspects—such as vulnerability, exposure, and sensitivity—is also necessary to better plan for future disasters and enhance climate resilience.

2. How can local and contextualised approaches to resilience be reconciled with global dynamics and processes?
3. How can responses to short-term events be balanced with responses needed to long-term change?

The second and third priorities concern feedbacks and thresholds across scales. Change at one temporal or spatial scale has impacts on others, which might be amplified or made irreversible if the entire system transforms when it reaches a particular threshold (Reyers *et al* 2018). Given the context-specific nature of resilience, the second priority underlines the difficulty of managing trade-offs and dynamics between geographically connected spaces. For example, the extent to which resilience lessons from one community, region or country can be applicable to other areas remains largely unanswered to date. This is important for cross-country and global cooperation on climate policy and the management of transboundary climate risks.

Similarly, resilience to short-term shocks is often grounded in long-term historical trends (Whitfield *et al* 2019); and, adaptation from a shock can also lead to long-term maladaptation (Adger *et al* 2011, Magnan *et al* 2016). For example, increased drought and climate shocks can threaten the recovery of tropical forests over decades unless forest management practices are adapted appropriately (Qie *et al* 2019). Long-term, granular resolution datasets that include periods of shocks, and integrated modelling (for example with climate data integrated into social-ecological models), can play a critical role in predicting potential leverage points for resilience across time and space (Hirons *et al* 2020).

4. How can resilience be measured across spatial and temporal scales to get contextualized and meaningful indicators?

Measuring resilience across multiple scales is identified as a priority (Vincent 2007, Levine 2014, Schipper and Langston 2015, Sharifi 2016). A wealth of data generated in different programmes exist, but often in closed datasets. As new data emerge from adaptation research, there is no strong consensus on the general validity of resilience indicators—specifically on how to aggregate measures into single metrics (Ifejika Speranza *et al* 2014, Clare *et al* 2017, Jones and Tanner 2017). With global-scale aggregation of resilience indicators being methodologically difficult and providing limited contextual relevance, researchers should consider how they frame resilience in order to effectively support climate resilience policies in specific contexts (Beauchamp *et al* 2019 b).

5. How can interdisciplinary research be used to generate new knowledge on cross-scale interactions?

Finally, working across scales and different types of systems requires interdisciplinary research involving a broad range of expertise. One priority concerns how to better collaborate to answer issues of cross-scale interactions, and move towards decompartmentalising knowledge within disciplines and in particular, entrenched research perspectives and paradigms (Moon and Blackman 2014, Stone-Jovicich *et al* 2018). This issue also relates to the next theme on governance and knowledge.

3.2. Governance and knowledge

Governance encompasses the norms, institutions, and systems that shape how power and responsibilities are exercised, and how decisions are taken. Knowledge is central to governance and of critical importance to contestations around decision-making associated with climate resilience. Research can engage with governance in at least three ways; it can be done with intention of informing, evaluating or understanding governance processes (Mcdermott and Hirons 2018). All three of these modes of climate resilience research are important, but the third mode—understanding how and why governance processes operate as they do—is fundamental to efforts to address normative concerns regarding climate resilience (Cote and Nightingale 2012, Bulkeley and Newell 2015, Eriksen *et al* 2015). The priorities under this theme are applicable globally and should be considered when designing and implementing research on resilience to climate shocks and slower onset climate change.

6. How can producers and users of research findings integrate different forms of knowledge into their research and decision-making?
7. How are trade-offs and related political contestations regarding climate resilience acknowledged and accounted for in governance processes and related research?

Existing power dynamics mean that some forms of knowledge or ways of knowing (including decisions on what is important or should be prioritised) are

privileged over others, often to the detriment of poorer and more marginalised groups (Mccusker and Carr 2006, Berbés-Blázquez *et al* 2016, Myers *et al* 2018, Hirons *et al* 2018a). This has been the topic of considerable research to date (e.g. Berkes *et al* 2000, Arora-Jonsson 2016, Bremer and Meisch 2017). Yet priority six reflects the fact that challenges associated with integrating different types of knowledge remain. This includes combining conventional ecological and traditional knowledge (particularly where they do not agree), and challenges are exacerbated by ongoing structural issues and inequalities, e.g. around accessing and financing academic research, which remain unresolved.

Priority 7 highlights the importance of understanding how power operates in governance processes (Boonstra 2016). This is critical if knowledge generated by research, e.g. climate information or understanding of soil degradation, is going to be incorporated into decision-making (Lemos and Rood 2010, Cote and Nightingale 2012, Morrison *et al* 2019). These areas of research (Lukes 2004, Scoones 2016, Morrison *et al* 2017) remain open and retain novelty because they are dynamic in both time and space, and because they can be approached from a number of theoretical perspectives, that are themselves evolving over time. For example, the role of law (a cornerstone of governance processes) is increasingly the subject of research in resilience, development and sustainability in general (e.g. Arnold and Gunderson 2013, Lesniewska and Mcdermott 2014, Garmestani *et al* 2016, Cosens and Gunderson 2018). Laws and other institutions, such as policies around climate financing, are rooted in trade-offs and political contestations. Side-lining such contestations risks research on resilience either being seen as irrelevant or being used to entrench existing unequal power relations (Nightingale *et al* 2020).

8. What weather and climate information (including forecasts) is needed for resilience decision-making by different actors and in different contexts?
9. What forms of knowledge concerning risk and uncertainty are used within governance processes, by whom, and why?

Two further priorities relate to governance and are more specific in scope. With respect to priority 8, research is necessary to address issues such as appropriate forecast lead times and methods of communicating forecasts by climate information services. These are vital elements that shape people's ability to use weather and climate information and adapt appropriately. This has been a key topic of research for the last decade (see e.g. Feldman and Ingram 2009, Kirchhoff *et al* 2013, Weaver *et al* 2013, Prokopy *et al* 2017), however, there are many contexts which remain poorly understood. Recognition of the important concept of 'climate services'[7] is growing, and research is beginning to engage in detail with this topic in historically under-researched areas. For example, (Nkiaka *et al* 2019) in their review of climate services in sub-Saharan Africa show how climate information services can dramatically improve the livelihoods and resilience of farmers and pastoralists during climate shocks if designed well.

The ninth priority highlights the importance of risk and uncertainty (Pidgeon and Fischhoff 2011, Renn 2012), issues raised in numerous ways during the workshop. These play a central role in framing much policy work on resilience, yet influential governance actors or institutions either may not adequately understand probabilistic information or prefer, for political reasons, to side-line complexity and uncertainty and promote simplistic, monocausal explanations with unwarranted confidence (Bulkeley and Newell 2015, Brown *et al* 2018, Cumming *et al* 2020, Morrison *et al* 2020). Despite an increase in model and methodological complexity over the years, more research—and consensus—is needed on the classification of, and inference from different approaches to confidence and uncertainty (Stainforth *et al* 2007, Knutti 2008).

10. How do different intermediaries build climate knowledge and communication capacities in relevant governance institutions?

The links between knowledge and communication and are particularly important in light of the growing role of intermediaries, such as knowledge brokers, in bridging different communities of knowledge and practice. Despite knowledge systems and science communication being a well-established field (e.g. Cash *et al* 2003, Bielak *et al* 2008) better communicating uncertainty, underlying scientific assumptions and effective communication delivery pathways are still a recent innovation in science communication. A priority for research is better evaluative understanding of the role of knowledge brokers in governance for resilience (Cash *et al* 2003, Dilling and Lemos 2011, Jones *et al* 2016).

3.3. Climate resilience and development

Recognition that the poorest will be most adversely affected by climate change means there is a focus on the linkages between climate resilience and development (Cannon and Müller-Mahn 2010, Béné *et al* 2014, Tanner *et al* 2015). Although an existing body of literature highlights the potential for resilience research and interventions to maintain the status quo, in effect protecting the existing social, political and economic relationships that cause poverty (Cote and Nightingale 2012, Warner and Kuzdas 2017, Hirons

[7] For example, a dedicated journal—Climate Services—launched in 2016.

et al 2018b), there is still a need for research on how to avoid and mitigate these risks.

11. How does research on climate resilience risk entrenching inequalities associated with existing social, political and economic relations, and how can this risk be mitigated?
12. How do development agendas constrain or enable the pursuit of climate resilience relative to other forms of specific and general resilience?

Priority 11 addresses this concern and is related to vital questions such as 'who is involved?' and 'whose voice is listened to?' in ongoing efforts to pursue climate resilience (Marino and Ribot 2012). These questions are important both normatively, because equity is a central moral consideration, but also instrumentally, since inequality can undermine the effectiveness of resilience and other interventions (Pascual *et al* 2014, Hamann *et al* 2018, Corbera *et al* 2020). Although there is a significant body of work engaging with these topics, for example in political ecology, the persistent and changing dynamics of inequality (e.g. under the new wave of authoritarianism—see Neimark *et al* 2019) means it is an important topic, with emerging aspects of novelty applied to climate shocks.

Priority 12 captures the importance of framings in development agendas, as normative concepts like 'climate-resilient development pathways' and 'transformative adaptation' (Pelling 2010, Kates *et al* 2012) may be uncritically adopted in research, policies or development projects. As existing research demonstrates, short donor project cycles and related policies have tended to stress short-term gains at the expense of long-term benefits; this is likely to have impacts on vulnerable groups (Brooks *et al* 2009, Adger *et al* 2011). Novelty is to be found in synthesising natural and social sciences and increasing the resolution of findings across scales. Drury O'Neill *et al*, 2019 demonstrate this in their explanation of how access to credit for small-scale fishers through patronage with traders increases short-term and individual adaptability during climate shocks, yet leads to extractive fishing behaviours that undermine the ecological base of fisheries and long-term resilience of the social-ecological system.

13. How can better contextual understandings of the lives and agency of people affected by climate shocks be integrated in research, policy and practice concerning climate resilience?

This priority draws on concerns that policy discourses and interventions are too detached from people's everyday lives and actions. It is important because understanding the experiences of people, and the role of human agency in determining the effect of policies to increase resilience is critical to developing appropriate policies likely to have their intended impact (Broto and Bulkeley 2013, Brown 2016). Existing work on 'everyday resilience' addresses these issues (Harris *et al* 2017, Ziervogel *et al* 2017, Wakefield 2018, Betteridge and Webber 2019), but much could be done to extend this work in a wider range of contexts and draw on interdisciplinary approaches. For example, in Ethiopia, climate shocks and related water scarcity can lead to violent conflicts, malnutrition, reductions in livelihood options and health impacts. Macdonald *et al* (2019) show how a detailed understanding of communities and their local environments can inform decisions regarding the type and location of water source infrastructure in order to minimise collection time during times of water stress.

14. How can climate information be better embedded into resilience decision-making to balance short-term priorities with long-term development requirements?

The lack of integration of climate information into resilience and development decision-making and planning remains both a policy and a methodological gap. While data and forecasts are available, the credibility and trust required for the information to be used in making informed planning decisions is limited largely by institutional, organisational and cultural obstacles (Zebiak *et al* 2015, Buizer *et al* 2016, Singh *et al* 2018).

15. How can climate financing mechanisms and governance systems be created, that are sustainable, socially-inclusive and fair?

Financing mechanisms are key in shaping how power dynamics are embedded into resilience policies and processes. Existing work reveals that accessing contemporary global climate finance is a complex process and funds remain limited (Soanes *et al* 2019). With the burden of impacts being felt in poor communities in developing countries with low access to assets and resources, research towards developing innovative, efficient and fair financing mechanisms is a priority (Hallegatte and Rozenberg 2017). This remains an open topic for research because of ongoing shifts in geopolitics shaping international climate-financing mechanisms. For example, as global powers fail to commit to climate financing (GCF 2018), increasing attention is given to the role of private investment, from both individuals and corporates (Pauw *et al* 2016, Bowman and Minas 2019, Caravani *et al* 2016).

3.4. Sectoral concerns

The final theme highlights particular sectors and systems that were identified as research priorities given their complexity and potential response to climate change risks. Complexity stems from the high density

of interlinkages between sectors, actors and processes; for example, overlaps between social, natural, economic and political factors. They are systems in which climate impacts, and the inequality of impacts between actors, are high, yet where future resilience pathways are still poorly understood (Chelleri *et al* 2015, Meerow *et al* 2016). Each system or sector has its own established literature, yet each remains of key importance and novelty due to constantly evolving social and ecological dynamics that keep presenting new challenges.

16. How will climate change and shocks affect complex interacting marine systems and the people who depend on them?

Marine and coastal systems are particularly geographically interconnected, which results in management challenges ranging from the governance of high seas to highly complex contextualised local livelihoods (Hughes *et al* 2005). They are also particularly sensitive to climate change, due to the anticipated increase in sea surface temperature, changes in pH and sea level rise (Harley *et al* 2006). Yet the scale of changes is difficult to predict in marine systems, and so are the adaptive capacities and responses to climate change and shocks of both humans and marine species. The effects of these responses will feed back into further impacts and changes both within marine systems and in linked terrestrial and atmospheric systems, with trade-offs between social groups (Cinner *et al* 2015, 2018, Maina *et al* 2016). This will affect coastal communities due to sea level rise but also in terms of loss of livelihoods and reduced food security. For example, climate shocks such as drought can reduce fish catchability despite having little ecological effect on the species themselves (Wilkinson *et al* 2019).

17. How can the world's growing population be fed without exacerbating the changing climate and undermining the ecological integrity of production landscapes?

Agricultural and food systems, where climate-induced changes in crop patterns and productivity already affect the biodiversity and food security of people across global food supply chains, were identified as a priority for further research (Lobell *et al* 2008, Godfray *et al* 2010). Climate resilience interventions in agricultural systems have been identified in the literature, yet measures for adaptation are still not widely implemented (Pretty *et al* 2010). New research should focus on exploring feedbacks between agriculture and other climate impacts, along with on how best to operationalize measures for societal uptake. These measures can range from diversifying local livelihoods to large-scale changes in crops and farming methods (Boillat *et al* 2019), development of improved seeds and soils (Smith *et al* 2019), and advancing research into alternative production methods such as aquaculture or lab-based food.

18. What is required to create urban living conditions that are low-carbon and resilient to climate shocks while also providing a good quality of life for all urban residents?

Over half of the world's population currently lives in urban areas, projected to increase to 75% by 2050 (Giles-Corti *et al* 2016, Hugo 2017). Priority 18 aims to address the serious impact that that climate change and shocks have on quality of life, energy consumption and health of urban citizens, with current infrastructure largely unable to withstand climate shocks and variability (Santamouris and Kolokotsa 2015). While these questions have been addressed by the social and physical sciences and engineering, integrating perspectives to assess the multifaceted resilience needs of densely populated areas is still required.

19. What are priority areas for investment in global health measures and systems for climate resilience, including hot spots and overlooked issues?

Climate changes and shocks related to extreme events such as drought, floods, wildfires, and storms all directly affect human health (Keim 2008). Increased exposure to shocks means research must focus not only on emergency preparedness and response to disasters, but also on public health systems to build human resilience to the consequences of climate change, such as shortages of water for hygiene and sanitation (Frumkin *et al* 2008, Watts *et al* 2015, Satterthwaite 2016). The impacts of climate shocks on existing and new diseases are still not well understood, both communicable (e.g. vector and water-borne) and non-communicable, including mental health (Altizer *et al* 2013, Berry *et al* 2018). For example, climatic variations driven by climate shocks such as the 2015/15 El Nino have not been well linked to micro-climatic conditions that influence mosquito behaviour; a critical consideration for understanding the future dynamics of insect-borne diseases such as malaria (Kreppel *et al* 2019).

20. What methods and models can lead to better predictions for emerging large-scale migration dynamics in fair and just ways?

The final priority concerns migration, by both animals and humans. Migration is in itself a form of adaptation to climate change and shocks, recorded for plants, animals, and humans (Walther *et al* 2002, Black *et al* 2011). The resultant changes in social-ecological systems at a range of scales could produce ripple effects for biodiversity, health, food security and livelihoods worldwide; yet changes in migration and mobility are still poorly anticipated. For example, fish populations are shifting due to changing sea temperature and acidification, with particularly striking impacts in the Tropics where marine ecosystems and livelihoods will be undermined (Doney *et al* 2012). Climate change and shock-related human migration is further constrained by political and institutional

boundaries. There is a critical need for analysis in order to holistically understand and anticipate the scale and direction of human and non-human movements. This will support society to prepare and adapt to these global changes that are already occurring and will inevitably continue (Grecequet *et al* 2019).

4. Conclusion

The 20 research priorities and four themes identified in this paper highlight several overlapping and complementary topics for organising future research in climate resilience. This exercise was based on the principle that expert and group elicitation can be effective in developing novel solutions to tackle wicked problems in climate and resource management (Vercammen and Burgman 2019). While articles in this special issue and research from the NERC-DFID programme, and hence the background of most participants, were focused on the Tropics, the priorities identified here are articulated as broader research priority areas which are more universally valid. We found that group deliberations are susceptible to trade-offs between the range of expertise involved and the precision of solutions proposed (here, the research priorities). The outcome of such group discussions crucially depends on who is included or who is 'in the room'. The design and protocols for expert elicitation must thus carefully balance the diversity of participants and the framing of the discussion prompt, and acknowledge the implications of the choices made for the outcome of the exercise (Kynn 2008, Hemming *et al* 2018). Expert consultation is nonetheless a useful means of synthesizing knowledge when limited information is available, providing guidance for the production of robust evidence (Choy *et al* 2009, Knol *et al* 2010).

The priorities identified through this process highlight the governance systems within which climate research is produced, understood and used. This is partly a reflection of the fact that, while innovative research is essential, it takes considerable time for new knowledge and evidence to shape policy, and this process of change will be subject to political contestations. Climate change is a global challenge, so the research priorities derived through this exercise are pertinent to international agendas and future funding priorities set by research councils, environmental and climate agencies, and international donors. However, many of them require cross-scale perspectives, as resilience varies according to the impacts of climate shocks and/or slow onset changes, which are felt most acutely in particular places. The broad nature of the priorities identified through this process means that the areas chosen represent both areas of established work and also cutting-edge research frontiers, particularly where research topics are considered in new contexts or using novel combinations of methods. As well reflecting scientific advances in understanding complexity and shedding light on some of the new methods being developed across diverse disciplines and fields, the priority areas highlight the emergence of new challenges due to the overwhelming scale and urgency of the climate change problem.

The final challenge emerging from this Focus Collection and this list of 20 priorities remains: by whom and how will this agenda be delivered? Climate shocks and impacts inevitably cross geographical, jurisdictional and institutional boundaries, and so should the research process underpinning the evidence being produced. Ensuring the involvement of a wider range of voices in the design, implementation and dissemination of climate resilience research is critical to developing the efficient and fair interventions it is meant to support (Anderson 2013, Fisher 2015). Including local voices is especially critical for research under the themes of Governance and Knowledge and Climate Resilience and Development, as the design of research processes inherently influences the results from which policy recommendations are drawn, thereby potentially replicating unequal power dynamics. This points specifically to moving beyond knowledge exchange towards co-generation and more inclusive research agendas, which incorporate perspectives from the Global South, including marginalised groups such as women and youth, and those whose lives the resilience interventions aim to improve. There is a continuing need to bridge the disciplinary divides between the social and natural sciences and to develop inter- and trans-disciplinary collaborations (e.g. Moon and Blackman 2014, Bennett *et al* 2017).

Research that involves closer and more reflexive collaborations with implementing organisations across a range of sectors and scales is essential to addressing the challenges of climate change and shocks. Many of the priorities identified here, for example around policy making, agricultural, health and financial systems, require closer science, policy and civil society interactions in order for research to lead to positive societal impacts (Glaser *et al* 2016; Hall *et al* 2018). The process of undertaking the research—through engagement and partnership—is therefore as important as the topic of the research itself. Ultimately, the challenge and novelty of addressing these priorities for climate resilience research are fundamentally linked to understanding the uncertain dynamics of environmental and societal change under the climate crisis.

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Data availability statement

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Data statement

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