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ORIGINAL ARTICLE

A multiscale analysis of social-ecological system robustness and vulnerability in Cornwall, UK

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Abstract

Understanding social-ecological system (SES) feedbacks and interactions is crucial to improving societal resilience to growing environmental challenges. Social-ecological systems are usually researched at one of two spatial scales: local placed-based empirical studies or system-scale modelling, with limited efforts to date exploring the merits of combining these two analytical approaches and scales. Here, we take a multiscale interdisciplinary approach to elucidate the social dynamics underpinning cross-sectoral feedbacks and unintended consequences of decision-making that can affect social-ecological system vulnerability unexpectedly. We combined empirical place-based research with the Robustness Framework, a dynamic system level analysis platform, to analyse the characteristics and robustness of a coastal SES in Cornwall, UK. Embedding place-based empirical analysis into a broader institutional framework revealed SES feedbacks and "maladaptations". We find that decentralisation efforts coupled with government austerity measures amplify second-order (reputational) risks. This prompted temporal policy trade-offs, which increased individual and community vulnerability and reduced social-ecological system robustness, impeding local adaptation to climate change. We identify opportunities to ameliorate these maladaptations by (1) implementing coordination rules that can guide policymakers in instances of conflicting coastal management pressures, and (2) recognising how second-order risks influence decision-making. This work demonstrates the strengths of combining local and regional analyses to assess the robustness of social-ecological systems exposed to environmental changes, such as climate change and sea level rise. Our results show how analysis of the multiscale effects of climate policies, decision-making processes and second-order risks can usefully support local climate change adaptation planning.

Keywords Social-ecological systems · Vulnerability · Adaptation · Robustness framework · First- and second-order risks · Coastal management · Climate change

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Introduction

Global climate change is underway, and nowhere is this more evident than in densely populated coastal areas (Moser et al. 2012). Population projections predict that the number of people living in coastal regions will continue to rise throughout the remainder of this century (Neumann et al. 2015) and risks associated with flood exposure and subsidence will grow (DeConto and Pollard 2016). From a policy and economic perspective, rising sea levels will increase costs associated with providing flood and storm alleviation (Hallegatte et al. 2013). At the same time, many national strategies emphasise government decentralisation efforts and concomitant devolution of authority and responsibility from the national to the local level, whilst simultaneously performing deep local budget cuts (Ayres et al. 2013; Den Uyl and Russel 2018). This often leads to policies and actions that emphasise short-term social and economic benefits instead of decisions that support long-term ecological and social resilience[1] (Adger et al. 2011). This includes investing in hard infrastructure, such as reinforcing dikes and sea walls that protect economic activity and assets in vulnerable coastal areas instead of pursuing long-term solutions that limit the risks posed to society, for example, relocating communities inland and strengthening the natural buffering capacity of the coast (Hino et al. 2017). These shifts in coastal vulnerability, coupled with governance pressures, add further complexity to contemporary governance challenges in coastal areas.

Since few adaptation plans account for cross-scalar dynamics and therefore overlook the multiscale and cascading effects of these policies (Adger et al. 2005), there is increased likelihood of perverse outcomes from climate change interventions (Bunce et al. 2010). Although adaptation plans and policies to address coastal climate change vulnerability have proliferated, many policies fail to consider the interconnected processes and feedbacks inherent in coupled social-ecological systems (SES) and, instead, view climate change, vulnerability, and adaptation planning in isolation. This has led to policy responses that fail to address underlying problems and may exacerbate vulnerabilities (Hallegatte et al. 2015). As a result, there are unexamined connections between policies at one scale and maladaptations and unintended consequences at other scales.

Risks of climate change include the physical and economic impacts and the probability of harm, but also the perceived dangers associated with these impacts and the uncertainty surrounding them; what Dessai et al. (2004) distinguish as external and internal risks, or what are commonly understood as objective and subjective risks. Decisions on how to manage risks associated with climate change and adaptation are critically influenced by organisational concerns. Renn (2010) refers to this as risk perception, where physical risks can be attenuated or amplified by social processes. Kuklicke and Demeritt (2016) suggest that risk has ceased to be simply an object to be managed and has become an organising principle in climate change adaptation. They identify two distinct types of risk, or orders of risk in adaptation management. First-order risks refer to both the physical risks to society such as flooding or storm events, and the explicit societal obligation or responsibility of an organisation or individual to reduce uncertainty or harm—for example building flood defences. Second-order risks refer to the risks to the organisation relating to legitimacy and blame, namely reputation management, that the individual and organisation need to manage in order to maintain the successful continuation of the organisation (Power et al. 2009). The general trend for increased public accountability means that managers are increasingly integrating second-order risk concerns into their decision-making processes (Rothstein et al. 2006). This can lead managers away from adaptive management when second-order risks require particular responses or defensive actions, for example focusing more on predictive statistics rather than probabilistic approaches in order to manage interactions with the public (Kuklicke and Demeritt 2016). Adaptation decisions involve a range of socio-cognitive factors (Grothman and Patt 2005) and understanding how these influence adaptive management is important for policymaking. The interaction between first- and second-order risks is experienced at the individual scale but are emergent in a system of interacting interests where decision-making typically occurs. Combining place- and system-based approaches is thus particularly useful to identify second-order risks and, importantly, how they interact and impact on decision-making.

In this paper, we apply a multi-scale, multi-method, interdisciplinary approach that combines empirical place-based research with a dynamic systems perspective using the Robustness Framework (Anderies et al. 2004; Anderies 2015). This analysis represents a novel attempt to systematically apply the Robustness Framework as a tool to embed local, place-based analyses, i.e. the formal and informal human decision-making processes, within a formal context that connects these processes to the hard and soft (e.g. rules, regulations) infrastructure and the natural system. Doing so reveals crucial interactions between first- and second-order risks and how these interactions influenced maladaptive[2] decision-making in response to a series of intense storms but also

[1] In this context, we define resilience as building fail-safe systems that have the "capacity to sustain a shock and continue to function" which is similar to the concept of robustness, except that resilience relies on learning, self-organization and adaptation whereas robustness relies on backup sub-systems and feedbacks (Anderies et al. 2013).

[2] Maladaptation is where adaptation to climate change decisions may "fail to meet their objectives, and they may even increase vulnerability" Barnett and O'Neill (2010, 211).

created spaces for potential proactive adaptation[3] (Brown et al. 2017b). We focus our analysis on the coastal county of Cornwall, United Kingdom (hereafter, UK).

Our work builds upon and extends studies of disconnected and disparate policy processes, such as coastal development and environmental conservation, that have argued for the need to integrate stakeholders at all governance levels in coastal decision-making processes (Brown et al. 2001; Few et al. 2007). We use coastal systems as an exemplar in this paper, but the principles developed here could be applied to other resource-constrained systems, including communities affected by other resource pressures (e.g. acute water shortages) and/or environmental hazards, such as landslides, floods and wildfire.

Why Cornwall?

Cornwall has many contextual factors that make it a good example of many global tourist hotspots which are geographically isolated, economically disadvantaged, and have dispersed populations with substantive coastal climate change risks. Cornwall is located on the southwestern tip of the UK, where there are limited transport networks into and out of the region—two highways and one railway line, and no ferry transport connecting the region to the rest of the country. Second, it is one of the most economically deprived, post-industrial regions in the UK and one of the poorest regions across Europe. Third, the community is dispersed and isolated with strong localised prioritisation of place embedded within a wider Cornish identity that unifies and distinguishes them from other areas of the country. There is a mixture of long-term and new residents, and Cornwall has the largest number of second homeowners in England and Wales (Office for National Statistics 2012). It has long been a tourist and retirement destination, and the pressures and opportunities these places on local resources continue to grow. This makes it a good site to study the interaction of multiple stressors and changes and their outcomes for adaptation and vulnerability.

These social and geographical pressures are amplified by the rule structures operating in the UK, where there is a shift from centralised financing for coastal flood and erosion risk management to partnership funding models that require financial contributions from local regions (Begg et al. 2015). Local regional budgets have also been reduced by the central government, leaving fewer resources for local governments at a time when their burden of responsibility for coastal protection is growing. These financial and governance pressures are positioned against a rule structure for coastal climate change adaptation that is non-statutory. Shoreline Management Plans (SMP) in England and Wales are used to assess current and future risks for coastal communities due to erosion and flooding over three time periods until 2100 (Ballinger and Dodds 2017). They make recommendations on current and future approaches to managing these risks, such as when and where to "hold the line" of current defences, and when and where to realign areas (such as moving roads and other infrastructure in land). Whilst these policies are adopted locally, they are non-statutory, so there is no requirement to follow the recommendations they make.

[3] Proactive adaptation "denotes actions undertaken to reduce the risks and capitalize on the opportunities associated with global climate change" (Wamsler et al. 2014, 265).

Methodology

System-level analyses, such as the Robustness Framework (Anderies et al. 2004; Anderies 2015) have been applied to develop formal models of common pool resource systems (Anderies 2006; Cifdaloz et al. 2010; Barnett and Anderies 2014) with limited studies applying these frameworks to local, place-based issues in a resource governance context. In contrast, place-based analyses are typically undertaken in more depth in a smaller geographic region, where interviews are often carried out to gain perspectives on a particular issue (Balvanera et al. 2017).

There are at least three formal conceptual frameworks commonly applied to study a SES: the Institutional Analysis and Development (IAD) (Kiser and Ostrom 1982; Ostrom 2005, 2011), the Robustness (Anderies et al. 2004; Anderies 2015), and the Social-Ecological Systems (SES) Frameworks (Ostrom 2007, 2009). Both the Robustness and the SES framework are extensions of the IAD framework and provide complementary means to a systematic SES analysis. The Robustness Framework is designed to allow the analyst to explore feedbacks, flows, and nonlinearity in a SES which helps provide a dynamic systems view that addresses the uncertainty and connectedness of a complex coupled human-natural system (Sterman 2002). It is also a means to uncover hidden assumptions and biases by providing a common tool to look at the Cornish SES from a social researcher's perspective and from the perspective of the systems analyst. The back and forth interactions between researchers made our research more robust and helped uncover hidden assumptions and biases that directly influenced our findings. The influence of second-order risks on governance processes emerged from interactions between social researchers and analysts. The literature review that the analyst conducted did not identify the second-order risks, and the local interviews would not have necessarily revealed the broader implications, embeddedness of the second-order risks and their implication on other governance processes that directly affect coastal adaptability to change.

We use the Robustness Framework for three reasons. First, a shortcoming of the IAD and SES frameworks is that they code key conditions within a SES at a given point in time creating a static analysis. The Robustness Framework is

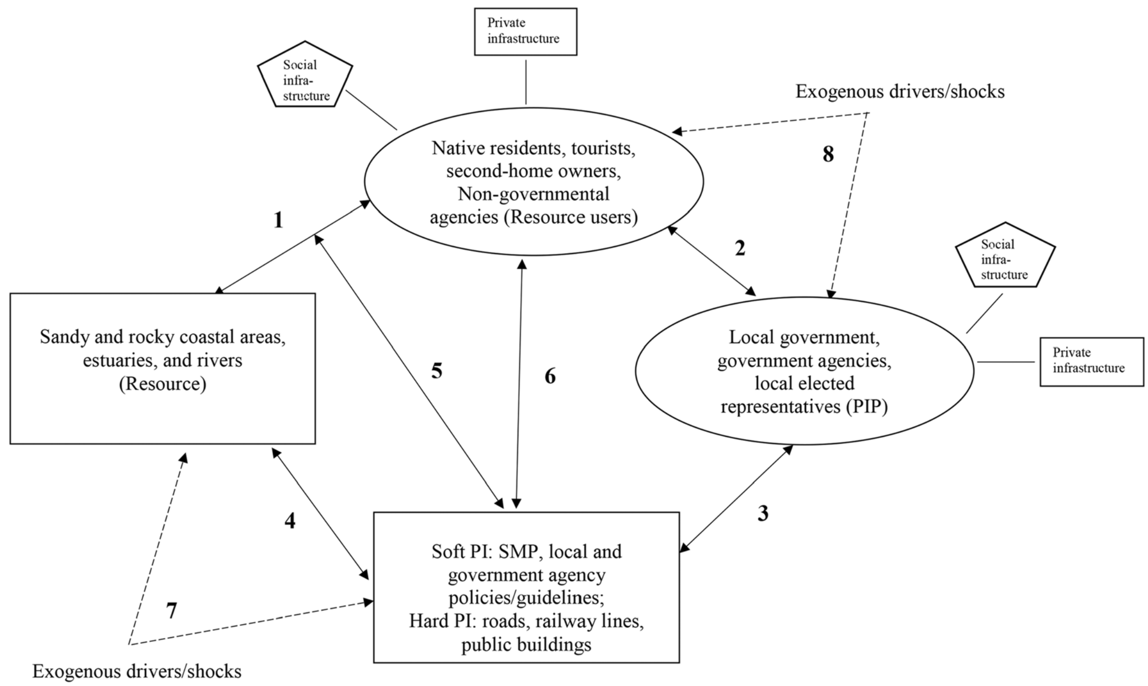

Fig. 1 The Robustness Framework adapted from Anderies (2015) to reflect the Cornwall context. The boxes represent natural infrastructure (resource, R), hard and soft human made public infrastructure (PI), the ovals represent the attributes of the local population and community members (resource users, RU) and civic agencies (i.e. the public infrastructure providers (PIP)). Arrows 1–6 represent the feedbacks between the four elements in the system, whilst arrows 7–8 represent exogenous drivers that affect infrastructure and human elements. Social and private infrastructure (e.g. personal financial assets) can affect these interactions

designed to address this by creating a conceptual platform within which the dynamic interactions and feedbacks between key components of the SES of interest can be analysed and presented visually. Second, the Robustness Framework takes the IAD concept of an action arena—a theoretical space in which participants interact in an action situation, e.g. international policymakers discuss global climate policy at a biennial meeting—and expands it to four individual components: (1) natural infrastructure (the resource system, R), (2) the resource users (RU, i.e. local people who draw affordances from the resource system), (3) the public infrastructure providers (PIPs, e.g. civic agencies at various levels of government, hereafter civic agencies), and (4) the hard (physical) and soft (rules, regulations) human-made public and private infrastructure (Anderies 2015, Fig. 1). In doing so, it illuminates the interactions and feedbacks between the four elements, and the exogenous drivers that exert pressure on the social and the coupled natural/human-made hard and soft infrastructure within the SES (Anderies et al. 2004; Anderies 2015). Lastly, the Robustness Framework is designed to allow for multi-scale governance analysis (e.g. Morrison et al. 2017). It allows examination of the interactions and decision-making that occurs at the operational governance level—where local peoples' daily decision-making directly affects the resource—and the collective choice level where public infrastructure providers create rules that govern the behaviour that takes place at the operational choice level (Anderies et al. 2004; Barnett and Anderies 2014). The Robustness Framework also analyses two types of human subsystems: local people (i.e. resource users (RU)) and civic agencies (i.e. Public Infrastructure Providers, PIPs) allowing the interactions between these groups to be identified and related to the wider pressures influencing decision-making. This can be coupled with an assessment of the polycentricity of the system[4] by focusing on the composition within the PIP element and how it is connected to PIPs at other scales by creating networks of adjacent action situations (McGinnis 2011; Therville et al. this volume).

Our analysis focuses on a series of storms that caused widespread disruption in Cornwall during 2013–2014.

One criticism of systems analyses is that they tend to rely on secondary data. Our method extends the usefulness of the Robustness Framework by examining place-based primary data alongside secondary data derived from policy documents and published sources.

An important criticism of the Robustness Framework, as with any generalisation method, concerns the inherent trade-offs in translating rich place-based data into more

[4] Polycentricity is a governance theory that has a multiplicity of definitions. Here, we adopt Ostrom's definition of polycentricity as a governance system that consists of multiple governing authorities at differing governance scales in which independent governance units are independent and exercise within a specifically described domain of authority but remain interconnected with each other (2005)

generalisable findings. There is the risk that place-based findings that point to larger phenomena may not be included in a systems analysis or that local findings are viewed as generalisable when they really are not (Ratajczyk et al. 2016). Meanwhile, place-based actor analyses can often miss crucial temporal, spatial and governance interactions (Balvanera et al. 2017). Our study involved iterative data exchange and cross check between researchers immersed in the place-based data and researchers using a systems approach to develop those findings into generalisable patterns. The two approaches are complementary and allowed us to populate the system-scale framework analysis with local data and situate the place-based actor analysis in the wider social-political and institutional context.

The Robustness Framework was initially populated with secondary data (e.g. from government reports) to gain an overview of the context and dynamics within the Cornish SES. The preliminary results were shared online at Arizona State University's Social-Ecological Systems Library (SES Library 2016). In parallel with the preliminary robustness framework analysis, primary data were generated over 18 months through a workshop and three stages of interviews over 18 months with managers in the environment sector (from civic agencies, non-governmental organisations, civil society and the private sector) involved in environmental issues (coastal management, conservation, and climate change) at the Cornwall county scale, to explore these individuals' perceptions of coastal management and adaptive capacity (Gallopin 2006) to address global change. An initial round of interviews (n = 9) was conducted in 2014 following a series of storms in the winter of 2013/2014 (first-order risk) where environmental managers from civic bodies and NGOs with operational and strategic roles in coastal flooding and risk management were selected to explore individual and organisational responses to the storms. The interview protocols were semi-structured, and questions centred on how individual managers experienced and handled coastal management decisions. The findings from the first round of interviews shaped the research questions for the second stage of data collection involving a creative participatory workshop on risk management in Cornwall along with a second (pre-workshop) and third (post-workshop) round of interviews with PIPs. Interviewees from the initial round were invited to the workshop, as well as additional managers involved in sustainability management in Cornwall (Table 1 shows the range of organisations involved in the workshop and second and third round of interviews).

All interviews were recorded and transcribed. Purposive sampling is appropriate for studies that require expert information that cannot be obtained by randomly sampling the population (Bernard 2011).

Central to our data collection was the creative participatory workshop to the professional and personal negotiation of risks. The workshop complemented the other data collection methods and aimed to identify and characterise multiple and complex risks in a creative and playful way. Participatory and creative methods are increasingly advocated to enable wider engagement in the subjective and emotional dimensions of climate change risk and resilience (Brown et al. 2017a, b; Heras and Tàbara 2014). Working in partnership with designers specialising in creative participatory research techniques, we developed a narrative workshop informed by social and cultural geography participatory research methodologies (Davies and Dwyer 2007). The workshop incorporated a series of playful linked activities through which participants were empowered to explore the interplay of first- and second-order risks in decision-making scenarios, and the effect of second-order risks on their decision-making practice and wider risk management. Five activities used creative and participatory techniques, including making physical representations of risk, generating and co-constructing future scenarios of risks, and co-creating risk definitions. These activities invited participants to move beyond organisationally normative definitions of risk that typically focus on first-order risks such as flooding. This was achieved by encouraging participants to acknowledge their personal identities and experiences, and by co-producing a definition of risk appropriate in both commonplace and professional risk contexts. The approach provoked participants to make salient any personal or professional assumptions that shape their first-order risk-related decision-making. Discussions at each table were recorded and transcribed and analysed alongside interview data.

For the pre- and post-workshop interview data, transcripts were also coded using a set of coding variables developed using Anderies' (2015) revised Robustness Framework (Fig. 1) to test for interactions between individual elements in the Cornish SES (see Supplementary Materials for a copy of the coding manual). This coding framework was reviewed across the research team to ensure context-specific validity. The data clearly identify first- and second-order risks that influence how coastal adaptation to climate change is managed. The coded primary interview data were then integrated to enrich and calibrate the Robustness Framework analysis. This provided additional insights into the nature of the interactions within the SES, helping us better understand the effects of second-order risks. Lastly, the Robustness Framework was used to help interpret the effects of second-order risks on risk management and adaptation practice in the Cornish SES, using responses to severe storms as the case study.

Analysis

Our analysis focuses on understanding how first- and second-order risks affect adaptive capacity within a SES. The secondary data analysis of the Robustness Framework (SES Library 2016) indicated that efficiency

Table 1 Summary of participant organisations and sectors in interviews and the workshop

Sector	Participant organisation	Sector represented
Public	Local government	Environment
	National government agency	Environment
Civic	Environment and culture non-profit organisation	Environment and Culture
	Conservation area non-profit organisation	Environment
	Environmental energy non-profit organisation	Environment
	Economic non-profit organisation	Social
	Civil non-profit organisation	Economy

and cost-driven restructuring efforts by the UK government in 2008 and 2011 transferred more coastal governance responsibility to the Environment Agency (EA) in 2008 and then in 2011 shifted again to a partnership funding model. These changes in governance created weaknesses in Robustness Framework Link 3 between public infrastructure (PI) and those that provide the infrastructure (i.e. Civic agencies, referred to as public infrastructure providers (PIPs) in the Robustness Framework) and Link 5 (Fig. 1). The secondary data review also indicated that more recent local budget cuts, lack of coordination rules, and the non-statutory nature of coastal change guidelines (the SMPs), were leading to temporal policy trade-offs in which policymakers were implementing short-term hard infrastructure fixes, instead of long-term adaptation strategies.

Identifying second-order risks in the Cornish social-ecological system

Analysis of the first round of interviews found that the interaction between first- and second-order risks emerged as a significant driver of adaptation management choices. This helped to explain a core weakness in the Robustness Framework interactions, which was then further investigated. The second round of pre-workshop interviews thus focused on issues related to second-order risks and institutional rules, providing data to populate the links between the PIPs (PIP in Fig. 1) and the other elements of the Robustness Framework. From the first and second set of interviews, it became clear that whilst the first-order risks (e.g. managing roads, biodiversity, floods) that individuals managed across the sectors were distinct—the second-order risks were largely similar across the sectors interviewed. Six of the 15 workshop participants highlighted this as the main learning for them, with one participant stating that they were most surprised by how much similarity and agreement there was amongst workshop participants from diverse organisations. In terms of how risk was conceptualised, participants often highlighted second-order risks as being as significant as statutory obligations, as demonstrated in the following exchange during the workshop:

> Our issue with [specific role] is they're [local authority] very risk averse. All the time. Every time when they say you can't do that we say why not. Sometimes we're not managing the individual's risk we're managing the council's risk. It's corporate risk, it's a nightmare and it kills everything we do.
> (R14, Workshop transcript)

From these interviews, we were able to clearly identify a series of second-order risks that were influencing the decision-making of PIPs and allied groups (e.g. non-governmental organisations) (Table 2). These second-order risks exerted pressure on decision-making where PIPs worked to contain and manage the uncertainties they created. One participant in the workshop described the most challenging issue as "How to keep the main thing the main thing". Pressure to respond to public and central government demands or priorities (reputational risk) was discussed by participants as the main driver for the technical and engineering response to the storm events. They openly acknowledged that these actions did not align to longer-term coastal change guidance such as the SMP. In this situation, it is difficult to avoid being reactive and to negate the impacts of second-order risks if adaptive planning guidance is not statutory. We sought to explore how this influenced the dynamics at the system scale and decision-making in response to extreme storm events.

Impacts of second-order risks on system dynamics

Our place-based insights on second-order risks were used to improve our understanding of the nature of the interactions in the Robustness Framework which visualise the system dynamics in the Cornish SES. The interactions in the Framework are numbered from 1 to 6 and colour-coded as blue = positive or red = negative for internal SES processes; and green = positive and orange = negative for external drivers, where a black arrow indicates no interaction or driver) between the four key aspects of systems frameworks: the

Table 2 Summary of second-order risks identified from the place-based actor interviews

Second-order risk and (Robustness Framework link)	Illustrative example from our interviews	Response and implication
Reputation (link 6, RU to PI)	Collapse of harbour wall following storms Storm-induced collapse of road near coast—where non-statutory coastal adaptation policy (the SMP) suggests realigning the road to be further from the coast.	Public support for Mullion harbour to be rebuilt after the storms meant inaction would undermine trust in the organisation. In response harbour was built back (against National Trust policy) in consultation with public and a conversation that if it happened again that wall would be left to natural forces. Pressure from locals means that the road it is built back as before rather than it being realigned future inland to reduce long-term risk.
Funding cuts leads to changes in funding structure (link 3)	Funding cuts to charitable organisations	Changing funding structure puts a charitable organisation in a difficult situation—it is a partnership of several organisations—some of whom now regard them as competitors. This impacts relationships and social capital.
Funding uncertainty (link 6)	Funding uncertainty for civic organisation (renewable energy network)	Organisation chose to align with larger public sector organisation in order to gain legitimacy and capture more funding. Organisation seeks collaborative partnerships. Sometimes this results in organisations having to change how they manage risk—e.g. they become more risk averse—to align with public sector standards.
Funding mismatch between emergency funding and existing plans and policy. (link 3)	Funding mismatch around response to severe events	Respondents in the public authorities demonstrated two responses to this changeability. Injections of money after events did not align with planned spending and so often were spent quickly but in a manner that diverged from long term adaptive planning. Respondents with experience in injections of money after severe events started to anticipate this change, and so the authority of documents such as the SMP was undermined.
Devolved responsibility (links 2 and 3)	Council and Environment agency (formal PIPs) devolve responsibility of assets and flood risk management to NGOs/civic organisations (informal PIPs) in response to funding cuts.	Intensive time and investment are required in the handover period to ensure partnerships between public and private organisations function effectively, which are hard to find during a period of severe job loss. In the long run, it should reduce the exposure of some organisations to certain place based risk and increase the adaptiveness of small communities that are able to respond to risks in context sensitive manners.

resource (R), local people (i.e. resource users (RU)), civic agencies (i.e. public infrastructure providers (PIPs)) and public infrastructure (PI) which can either be soft (e.g. policies, rules, norms) or hard (engineered systems, such as dikes, levees, roads)) forms of infrastructure. These interactions are expressed in terms of their colour, as outlined above, direction (of the interaction) and scale of impact (e.g. the size of the arrow corresponds with the number of coded interview segments discussing this particular interaction in the SES—the more text segments, the larger the arrow). Arrows 7 and 8 represent exogenous drivers or shocks that exert persistent or rapid pressure on R and/or PI (link 7) or the PIP and/or RU (link 8). Mapping the interactions described by interview participants onto the Robustness framework allowed us to visualise and animate the interactions as they flowed through the SES. For example, civic agency staff concerns for second-order risks (a link 2 interaction) generated a decision-making context in which they were less likely to follow coastal change guidelines when faced with re-development requests after severe flooding events (a link 3 interaction).

Figure 2a and b depict the negative and positive interaction (respectively) in the Cornish SES based on the number of coded segments identified in the civic agency interviews. It shows a general trend of negative interactions between different aspects of the SES outweighing the positive ones, in all but two instances (links 2 and 6). Links 1, 3 and 5 emerged as particularly strong with the addition of interview data; for example, the highest number of negative interactions was reported for public infrastructure allocation via link 3 from the public infrastructure providers to public infrastructure (11

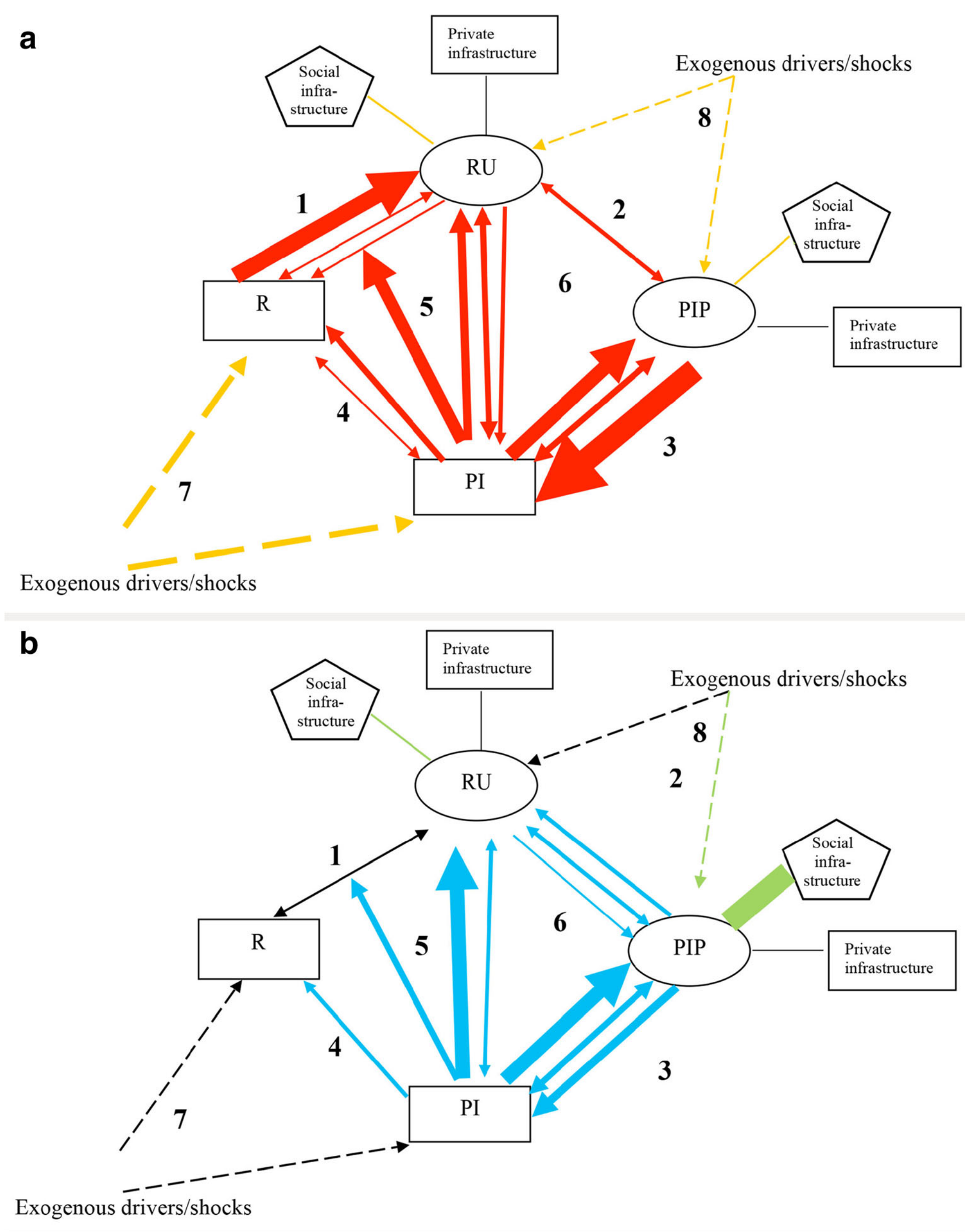

Fig. 2 **a**, **b** Robustness Framework layout and abbreviations as in Fig. 1. This figure identifies positive and negative interactions within the Cornish social-ecological system: Solid red arrows indicate negative interactions/feedbacks; dashed yellow arrows indicate negative exogenous drivers; solid blue arrows indicate positive interactions/feedbacks; dashed green arrows indicate positive exogenous drivers/connections and black arrows indicate neutral (neither positive no negative) interactions. The thickness of the arrows indicates the degree of interaction—the thicker the arrow, the stronger the interaction—and is based on the number of text segments that identified a negative interaction in a particular link

coded text segments; 14.47% of negatively coded responses). The addition of these data allowed us to better assess the direction and scale of impacts, and thus determine where the key stressors are in the Cornish SES. For example, exogenous drivers (link 7 in Fig. 2a) such as climate change and flood risks were clearly identified as major risk factors influencing Cornish communities and decision-makers. Conversely, link 6 emerged as a positive interaction (Fig. 2b) where interviewed policymakers identified public infrastructure production to resource users (7 coded text segments; 11.86%) as governance strengths.

Resources provide affordances, such as freshwater, flood alleviation, land for roads and buildings (link 1 R to RU). These affordances are reduced and threatened by exogenous drivers (link 7), like climate change, which exert pressure on resources (R), (e.g. increased severe storm and flooding events, coastal erosion and hard infrastructure (PI) (e.g. damage to public buildings, roads). This leads to an increase in vulnerability of public and private property, communities, ecosystems, the economy (e.g. agricultural practice), as well as damage and harm (link 1 R to RU and link 4 R to PI). Many of the coded segments referenced a negative interaction between R and RU in link 1 (Fig 2a). Link 1 RU to R outlines the economic asset allocation and coordination of materials that are extracted from and/or the investment back into the resource. Here, one policymaker mentioned the effect of people's perceptions and use of resources (link 1, RU to R) and funding availability (link 3, PIP to PI) were as significant as environmental constraints on the ability of communities to adapt to changing environmental conditions (link 1, R to RU).

Interactions between civil society (i.e. resource users (RU)) and civic agencies (i.e. public infrastructure providers (PIP)) (Link 2) show the degree to which civil society is included or considered in civic agency decision-making processes (PIP to RU), as well as the degree to which civil society is able to influence civic officials or agencies through lobbying and petitioning efforts (RU to PIP). We found that this link usefully highlights the transition of NGOs from organisations that represent citizens' interests and are part of the civil society (i.e. RU) to de facto civic agencies who are increasingly assuming government responsibilities, due to decentralisation efforts and budget cuts. This shift is emphasised in the concern about (second order) reputational risks expressed by members of civic organisations who report having to protect their reputation with high standards and a heightened concern about public perception: "When dealing with the public, their perception is the truth we have to deal with…" (R08, workshop).

Link 3 of the Robustness Framework outlines the interaction between the civic agencies and public infrastructure (PI hard, physical and soft, rules/norms) in which the civic agencies engage in public infrastructure asset allocation/coordination (interaction between the PIP and the PI) and the hard/soft infrastructure facilitates information sharing and flows to civic agencies (Anderies 2015). Based on the interviews, this link represented the strongest interaction/feedback, both positive and negative, within the Framework. Interviews with civic agency representatives suggest a negative feedback in link 3 in which civic agency employees strategically align with existing policy processes instead of being more visionary and adapting policies to match that vision. Second-order risks may be stifling innovation, vision and thus the ability to meet coastal environmental challenges. Again, there is evidence that the implementation of policies affecting existing rules, regulations or procedures that reduce risk are governed by second-order reputational risks:

> …about assessing risk and a lot of what we do is governed by 'where does that fit within the policies that allow us to do those things' what is the risk attached to that decision-making process. That's the first thing
> (R15, Pre-workshop interview).

The interactions between the resource and the hard and soft public infrastructure in Link 4 contribute to economic production (PI to R) in two ways: Either hard or soft rules serve to protect a resource, e.g. creation and maintenance of a protected area (investment in the infrastructure) or the hard infrastructure is utilised to modify the resource for the benefit of consumption, e.g. building an access road into an area for tourism. One civic agency interviewee described the collapse of the seawall at Coverack on south coast of Cornwall as an example of a negative Link 4 feedback in which a lack of proactive government intervention or investment into public infrastructure, i.e. regular monitoring and maintenance of the seawall [or managed retreat] led to catastrophic failure of the seawall during a storm event (Link 4 R to PI hard) which, in turn, left the village cut off and necessitated emergency (i.e. re-build) interventions. Other link 4 (PI hard to R) weaknesses included a lack of funding for long-term solutions to coastal community risk resulting in "tweaks and mitigation" efforts that made "incremental gains", rather than long-term proactive adaptive solutions.

Link 5 represents "governance production, i.e. monitoring, sanctioning, conflict resolution, coordination… of resources for economic production" (Anderies 2015, p. 271). In Cornwall, non-statutory coastal governance (the SMP policy) is in place that could potentially limit the development in areas that are prone to flooding and rising seas. However, this guidance is not always heeded, as exemplified in the storm example below and Table 2.

Funding shortfalls create negative link 5 feedbacks in which uncertainty of support from government agencies brings a renewed focus on financial efficiency and a strong economic framing around adaptation decisions. One workshop participant described the salience of the financial bottom line:

> I think the problem we've got now for those that are involved in the sort of things we're involved in is every decision feels like it's that way. So, you know, the triple aim stuff, the experience, then the last one is the impact, financial. Because of financial cut backs that now is the first consideration. So, you know we're looking at saving money. You know that's where we're starting from…
> (R15, Workshop transcript)

Some respondents describe a "relaxation of planning" and regulation that is undercutting conservation actions taken over the past three decades. Austerity measures (budget cuts) lead to prioritisation of hard infrastructure improvements that might increase short-term protection but can increase long-term community and ecosystem vulnerability to climate change.

The interaction between the public infrastructure (hard/physical and soft rules or norms) and local people (i.e. resource users, link 6 PI to RU) is characterised by the production of public infrastructure for the benefit of local people. In Cornwall, civic agency interviewees report that the link 6 feedback loop (PI to RU and RU to PI) is negatively affected by a lack of investment and austerity driven cuts which have led to the removal or downgrading of services and devolved governance of public infrastructure across a range of sectors (Link 6 PI to RU).

Civil society (such as community groups) and non-government organisations (NGOs) (as informal or de facto PIP) are attempting to fill the social service gaps created by financially inhibited formal PIPs (Table 1), expressed as a link 6 interaction. NGOs increasingly provide economic safety nets by assuming the role of informal PIPs, where they apply for funding and collaborate with formal PIPs to fill in the gaps left by stretched government organisations in order to provide flood risk infrastructure, clean energy and community support services. For example, a formal PIP interviewed remarked that,

> 20 years ago, we would have never thought that we would give authority for flood gates to local communities. Now it is part of the general strategy. Collaboration is becoming a reality. (R02, post-workshop interview)

In doing so, civil society organisations and NGOs assume the de facto role of PIP but without the statutory obligation that is attached to civic agencies. This has several implications. Whilst NGOs or civil society can act quickly, there is no guarantee that they will be able to continue to provide services as they are often wholly dependent on grant, donor or voluntary contributions. Citizens may also not have legal recourse if actions taken by NGOs or civil society organisations lead to negative outcomes.

The interaction in link 6 highlights an interesting development resulting from the sustained funding cutbacks that financially struggling regions in the UK have been experiencing.

For NGOs, funding uncertainty causes respondents to strategically focus on alignment with bigger public organisations to try to ensure security. For example, a manager from an environmental charity described their strategy in an increasingly uncertain political environment:

> Yes, but an unsympathetic political climate, whether it's at the national or the regional or local makes it increasingly challenging [funding]. And we have to be realistic about that, but if we can join forces with others, again then the chance of success becomes greater (R13, post-workshop interview).

This alignment prompts shifts in second-order risks, where NGOs choose to adhere to statutory guidelines and public perception risk management strategies used by the civic agencies. For example, reputational management in terms of public perceptions of accountability become more important and require increased attention and investment. This represents a shift from formal civic agency responsibility to informal non-government bodies such as NGOs or civil society organisations filling these roles. This negatively influences the Robustness Framework (Fig. 2b), demonstrating the dynamic interplay between individuals and institutions at different scales and the role of second-order risks (Termeer et al. 2016).

Discussion

We applied our analysis of the SES system to examine local scale responses to managing the effects of intense storms on the local community. This allowed us to examine interactions between different parts of the SES (nexus section), to identify strategies to improve system robustness (strategies section) and explore these through a scenario analysis (scenarios section), discuss which governance changes in response to storms may improve system robustness and lead to more proactive adaptation decisions when recovering from storms.

The risk—decision-making nexus

By mapping coded interviews onto the Robustness framework, we were able to visualise and animate the feedbacks generated by a series of storm events over one winter. This helped us gain a greater understanding of the underlying drivers of decision-making and how interactions between various endogenous and exogenous elements combine to create maladaptive decisions. We found that second-order risks became especially significant and influenced decision-making in relation to severe storms experienced in Cornwall in 2013–14 (Fig. 3a–c). Here, non-statutory policy was overruled by rebuilding roads post-storm in their existing locations, which are known to be vulnerable to coastal climate change. Why did this happen? A series of dynamic interactions influenced decision-making resulting in rebuilding, rather than a proactive adaption decision in line with non-statutory coastal change guidance (the SMP). This example provides further evidence of the import of second-order risks known to influence flood risk decision-making in the UK (Kuklicke and Demeritt 2016).

One of the civic agencies attending the workshop was working with a local community that had recently suffered from a severe flooding event that destroyed a main road (Fig. 3, exogenous driver 7 on PI hard) requiring both emergency and long-term repairs. The loss of the road (and associated repairs) interfered with local people's access to vital services, such as food and healthcare, thus restricting contribution to economic production and use (Fig. 3, link 4 hard PI to R); this reduced the local population's ability to access these services (Fig. 3, link 1 R to RU).

The SMP recommended that the road be realigned inland in the current planning timeframe (to 2025) due to its at-risk location and the anticipated climate-change related risks such as sea level rise and increased occurrence of extreme flooding events (Fig. 3, link 3 PI soft to PIP). This requirement should have guided civic decision-making towards a more adaptive

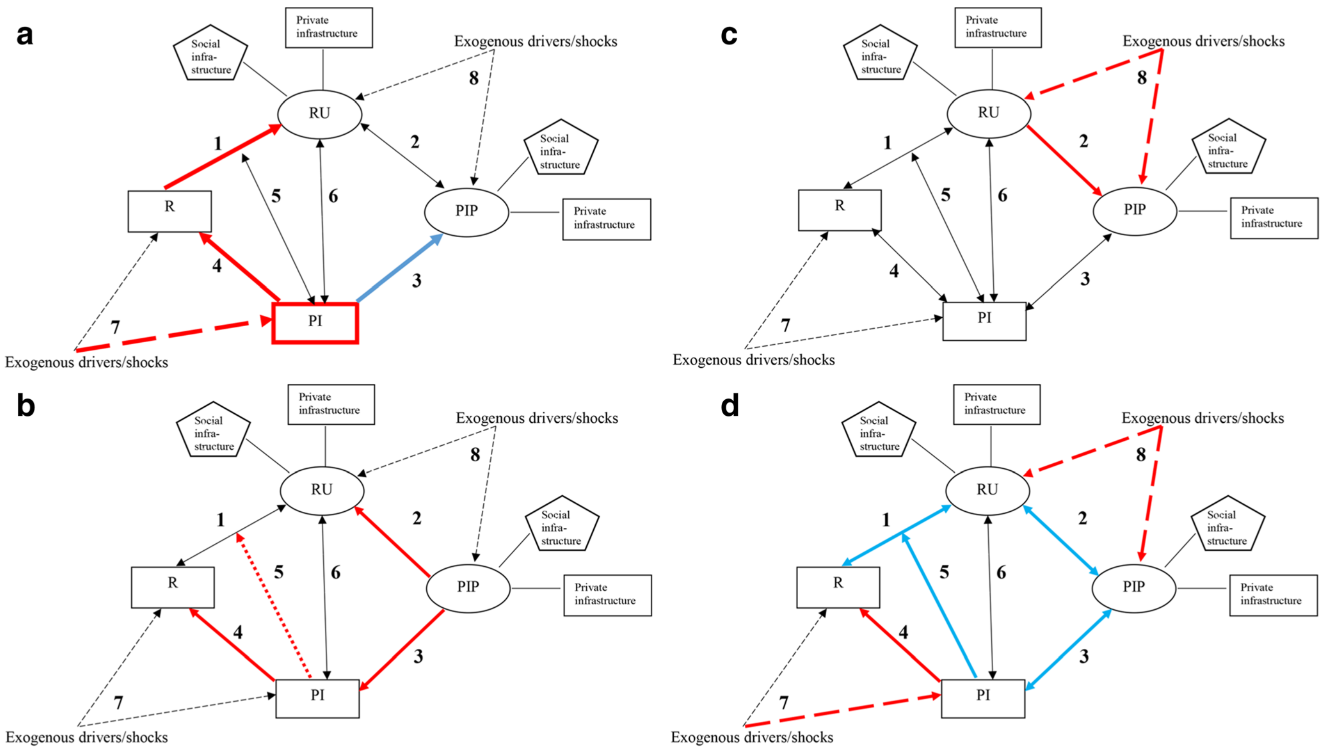

Fig. 3 **a- d** Robustness Framework layout and abbreviations as in Fig. 1. In this figure, the risk-decision-making nexus of one response to the 2013–14 floods was mapped where 3a–c provides a step-by-step illustration of the how the decisions taken post-storm increased second-order risks and led to re-building a road in an area identified for realignment and 3d illustrates how changes in exogenous drivers may have reduced second-order risks and led to a more proactive adaptation response post-storm. Links are detailed in the main text

approach that included considering realigning road access. However, two forces were acting against this. The Prime Minister responded to the storms with a clear message that the government would actively support rebuilding of affected communities and hard infrastructure assets (link 8, exogenous political driver). Meanwhile, local people pressured the civic agencies to rebuild the road, despite the coastal change recommendation (Fig. 3b, link 2 RU to PIP). A civic elected official was interviewed and their connectedness to the local community and desire to support their constituency's views (second-order risks) (Fig. 3b, link 2 PIP to RU), led them to ignore the non-statutory coastal change guidelines recommendation (Fig. 3c, link 3 PIP to PI). This, along with second-order risks led civic agency staff and civic elected officials to allow the road to be rebuilt "one more time" (Fig. 3c, link 4 PI hard to R). However, the contribution to economic production and private consumption that rebuilding the road represents comes at a cost. By overruling the coastal change guidelines (i.e. soft public infrastructure), the decision-maker undermined their capacity to effectively mitigate the interaction in link 1 between the resource and local people in the future (Fig. 3c, link 5 soft PI to link 1). This decision not only represents an inefficient use of funds (Fig. 3c, link 3 PIP to PI—public infrastructure asset allocation), but it also has the potential to perpetuate a cycle of risk (see Figs. 3a–c) where the next severe flooding event may expose the community to repeated interruptions of vital services, instead of mitigating such risks in a more resilient manner.

This example also illustrates how the Prime Minister's response to rebuild after the storms undermines the ability of local civic agencies to make the decisions most appropriate for the specific locality. For example, recent correspondence between the research team and the minister for floods confirms that decision making after storm events is the responsibility of local civic agencies:

> Any special funds for recovery following severe events are coordinated by the Department for Communities and Local Government. Decisions about the focus and nature of any recovery funding will be made in light of the circumstances following an event. Government departments will set objectives for how any funding they make available is used by local authorities. How spending on flood risk and coastal erosion management is prioritised is a matter for the [local] risk management authorities. They are best placed to identify local priorities. (Coffey pers. comm. 2017).

We posit that it would be difficult for local civic officials or civic agency staff to contradict the Prime Minister's "rebuild" in favour of a decision with more reputational risk—to oppose the Prime Minister and follow non-statutory government guidelines instead. Whilst the example in Fig. 3c only represents one example of a civic official and civic agency response to storms, many local decision-makers elsewhere in the UK and further afield will likely face similar challenges in response to future storms.

Strategies to ameliorate second-order risks to allow more resilient decisions in response to storm events

Our results demonstrate how second-order risks have a strong influence on decision-making in response to storm events. Decisions were taken to manage second-order risks such as reputational risks instead of using storm events as catalysts for proactive adaptation to climate change. This finding prompts many questions about how to better acknowledge, account for, and manage second-order risks when dealing with the immediate effects of first-order risks (i.e. storm damage) on society. These include the following:

1. What local governance systems (i.e. coordination rules) and funding mechanisms may best support identifying and managing second-order risks?
2. How do second-order risks propagate across scales of governance? For example, what national scale political factors and government policies amplify second-order risks for local civic agencies and how might these be ameliorated?

For example, may an increase in funding and/or further decentralisation of funding and local empowerment enhance or reduce capacity of civic agencies, NGOs, civil society and local people improve resilience to coastal issues such as increasing risk and impact of storms and floods? Or would risk registers assist in identification and mapping of second-order risks (e.g. Demeritt and Nobert 2011), so that they are more explicitly part of risk management decision-making? In this paper, we evaluate one of these questions, question 2, to explore how changes in governance may improve SES robustness.

Scenarios to evaluate the effects of governance changes on social-ecological system robustness

By incorporating coded primary data into the Robustness Framework, we can identify weaknesses in governance processes where exogenous drivers (e.g. central government undermining long-term policy in favour of fixing things in the here and now) and second-order risks destabilise decision-making. We tested question 2 by changing inputs to the Robustness Framework to see if changes to national political and policy frames could affect local-scale second-order risks. The coastal road rebuilding example described above identifies two places in the Robustness Framework (link 8 and link 3, Fig. 3c) where post-storm decisions appeared to amplify second-order risks faced by local civic agencies (Renn 2010). We adjusted those two factors whereby: (1) the Prime Minister and central government respond to storm event recovery in line with their coastal change guidelines, instead of publicly supporting rebuilding post-event in places of known high erosion and flood risk (link 8 on PIP) (2) making the existing non-statutory coastal change guidelines statutory (i.e. a change to the conditions of the soft PI) would help reduce reputational risk—one of the key second-order risks identified.

Figure 3d shows how adjusting these two Framework inputs (central government stance and statutory policy levers) may reduce second-order risks locally by strengthening links between the civic agencies and local people and reducing reputational pressure. This would provide stronger political and policy positions upon which civic agencies and civic officials can make more proactive adaptation decisions after storm events (such as not rebuilding the road in the same, at risk, location). These strengthened links indicate reduced pressure from second-order risks on local civic agencies (Fig. 3d, link 2) compared with the links based on our empirical data discussed above (Fig. 3c). These changes, alongside other measures to acknowledge and manage second-order risks such as risk registers (Demeritt and Nobert 2011) may empower them to make space for more proactive adaptation in response to storm damage (Brown et al. 2017b), improving the long-term resilience of the Cornish SES. One example of fostering proactive adaptation might be to make SMPs mandatory so that in effect, they shield decision-makers from second-order risks.

Policy recommendations

The CCC (2018, chapter 3) report cites complex governance arrangements as a key impediment to effective management of coastal erosion and flood risks. Our research confirms this and shows how multiple stakeholders and actors, with differing and often conflicting policy goals affect our ability to adapt to coastal climate change. Identifying areas where different governance levels and areas can align (as Fig. 3c–d illustrate) will help reduce these conflicts, would improve our ability to manage coastal risks.

The analysis also demonstrates that second-order risks (i.e. individual reputational risks) are often prioritised over first-order risks (i.e. storm risk to communities) in adaptation decision-making. To address this, sustained engagement with diverse stakeholders is necessary to identify, and deliberate, second-order risks. This, we argue, will help "facilitate change in social attitudes" that are needed to deliver "sustainable coastal adaptation" (CCC 2018, p.9).

Finally, the findings underscore the need for a shift to proactive rather than reactive responses to extreme events. Adaptation planning requires that strategies are agreed in advance of extreme events such as intense storms or floods, rather than worked out in response. Storms and floods might then represent event-based thresholds or triggers for implementing adaptation plans. This approach would allow shoreline planning policies (designed to identify and alleviate first-order risks) to be implemented instead of rebuilding of at-risk assets. Our research shows why it is important to shift to event-based decision-making (CCC 2018), so that storm events become windows of opportunity (Brown et al. 2017a, b) for proactive adaptation. Reforms to policy are needed to deliver this.

Conclusions and perspectives

Through this analysis of the Cornish SES, we have demonstrated how the integrated and iterative analysis of place-based empirical data within the Robustness Framework can help identify key feedbacks and interactions with second-order risks. The multiscale, mixed methods approach used here shows how the Robustness Framework can be used dynamically to identify the cascading effects of second-order risks and decisions on SES resilience. It exposes how second-order and first-order risks interact, providing three novel insights for coastal climate change adaptation. First, collaboration between different agencies–including civic agencies, NGOs and civil society–as a risk-spreading strategy to manage complex multi-sectoral problems, may exacerbate and amplify some second-order risks. Second, we identified how second-order risks emerge, interact, and propagate across governance scales. Third, our data demonstrates that second-order risks strongly influence decision-making and in doing so, increase maladaptive responses to coastal climate change risks.

This type of analysis can be applied to better identify how first-order risks interact with the second-order social, political and governance risks act to produce maladaptation. Policymakers can use this approach to adapt and strengthen multi-scale governance systems to aid delivery of proactive adaptation to climate change.

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