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ORIGINAL ARTICLE

Challenges for local adaptation when governance scales overlap. Evidence from Languedoc, France

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Abstract

In coastal areas around the world, actors are responding to multiple global changes by implementing adaptation plans, often confined within a single-focal perspective with few explanations of targeted changes and cross-scale interactions. To better anticipate the raising coordination issues and the potential feedbacks generated by adaptation in these complex social-ecological systems where governance scales overlap, we used the robustness framework (Anderies et al. 2004; Anderies 2015). We analyzed a case study along the Languedoc coastline in southern France, where governance is organized in multiple jurisdictions which we considered as interlinked adaptation situations. We identified three interacting changes impacting adaptation: demographic growth, climate change, and large-scale political changes, such as decentralization. We used the examples of land-use planning and coastal management to illustrate the major coordination challenges facing the implementation of adaptation plans in coastal areas by various intertwined communities. In the example of land-use planning, adaptation is impacted by miscoordination between multiple sectors that all rely on a shared resource, land, thus putting more pressure on the decision-makers to make explicit trade-offs between multiple issues. Coastal management illustrated how emerging adaptation strategies created new interdependencies in the system and how these were hardly considered due to confusion in the devolution of responsibility between multiple jurisdictions. In both examples, using coupled and evolving robustness diagrams was helpful in revealing renewed fragilities, foreseeing consequences of adaptation in inter-related decisional contexts, and promoting collective action to redefine the boundaries of adaptation situations and their coordination to cope with converging changes along coastlines.

Keywords Adaptation · Coastal areas · France · Multi-scale governance · Robustness · Social-ecological systems

Introduction

Challenges linked to global change are leading to the emergence of a specific field of action and research on 'adaptation to climate change', which can be limited by the fact that it is often confined to a single-focal perspective: one actor adapting to one change, often climatic, in one place at one moment. This restricted vision tends to under-estimate

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interconnectivity, feedback processes, and complexity (Pielke et al. 2007; Adger et al. 2011; Bassett and Fogelman 2013). For example, Turner et al. (2010) illustrate how people's adaptation to climate change can have impacts that even exceed the direct effects of climate change on ecosystems. In eastern England, investments in 'hold-the-line' policies to address local erosion affect erosion rates down the coast and reduce adaptive capacity to future sea level rise (Milligan et al. 2009). Hence in this globalized world (Steffen et al. 2004), multiple changes and interconnectivity emerge as critical elements when implementing adaptation. Current research emphasizes the co-occurrence of 'multiple stressors' or 'double exposure' (O'Brien et al. 2004; Klein et al. 2014): adaptations are not isolated from other decisions dealing both with global change (e.g., structural changes associated with economic globalization) and with socio-economic and environmental changes occurring in a specific context (Adger et al. 2005a). Moreover, the process of globalization is increasing the speed of interaction and multiplying the connectedness within and among coupled social-ecological systems (SES) (Young et al. 2006; Liu et al. 2013), i.e., integrated systems of ecosystems and human society with reciprocal feedbacks and interdependences (Gallopín et al. 1989; Berkes and Folke 1998). It has thus been recognized that adaptation needs to be understood as a cross-scale and multilevel process (Klein et al. 2014): diverse elements (places, people, species, timings…) that are considered and managed as disconnected can in reality be strongly interconnected and will likely be even more so in the future. More trade-offs have to be expected between robustness, performance and flexibility, and between different types of robustness in the face of different types of change. Society has to make choices and is facing dilemmas: improvements to SES robustness in one area could result in 'hidden fragilities' in other areas (Anderies et al. 2013).

Integrating the domino effect associated with the parallel implementation of several adaptation strategies is a wicked challenge (Moser et al. 2012). It requires a cross-scalar analysis of interactions and feedbacks that reshape linkages within a SES and among interconnected SES submitted to multiple changes. Here, scale refers to analytical dimensions used to study adaptation: spatial, temporal, institutional, or jurisdictional (Cash et al. 2006). Each scale is composed of multiple internal levels (e.g., municipality to central government in the context of jurisdictional scale). This reshaping of the interconnectivity within and among systems at multiple scales must be translated into governance responses. According to Berkes (2002), a failure to recognize cross-scale linkages is a central reason for some unsuccessful interventions in resource systems and the persistence of resource degradation may be in part related to 'cross-scale institutional pathologies'. Recent meta-analysis underlines the importance of institutional constraints on adaptation (Biesbroek et al. 2013), asserting issues of miscoordination and mismatch when institutional procedures that coordinate actions are in misfit with the interdependencies between actors and with the resources (Oberlack 2017). Hence, adaptation strategies have to simultaneously address: (i) the constraints and opportunities represented by cross-scale implementation dynamics (Klein et al. 2014), (ii) the consequences of implementation on others at diverse scales and levels (Adger et al. 2005b), (iii) the archetypal scale challenge of the mismatch when the authority or jurisdiction of the management institution is not coterminous with the problem or the resource (Cash et al. 2006).

Doing so requires using frameworks developed to analyze the linkages between the interconnected pieces of the SES puzzle, including actors, their system of concern, and the larger context in which they act (Moser and Ekstrom 2010). Among the diversity of conceptual tools developed to address these pieces, the robustness framework was designed by Anderies et al. (2004) to focus on the interactions that arise from dynamics within key elements of the SES—the resource system, resource user, public infrastructure provider, and public infrastructure—as described in the methods section. However, the use of the robustness framework to analyze multi-functional coastal SES, where actors organized at multiple scales are pursuing a diversity of objectives and are facing diverse and growing changes, may be challenging. In this paper, we suggest some adaptations to the robustness framework to cope with interacting coexisting governance levels and to discuss cross-scale processes occurring when adaptation is implemented. What are the cascade of changes induced by adaptation patterns due to interactions within multiple SES facing concomitant challenges? Using the Languedoc coastline in southern France as a case study, we discuss how adaptation reshapes linkages in a complex coupled infrastructure system subject to multiple changes and composed of multiple issues, scales, and levels of organization. We use two examples, land-use planning and coastal management, to highlight (1) how multiple adaptation strategies interact through cross-scale processes, (2) the trade-offs involved by these interactions, and (3) the underlying issues of governance coordination and reorganization.

Materials and methods

Presentation of the case study

In France, the investigation took as its case study the area between Montpellier and Nîmes, influenced by these two main cities and organized around four watersheds from the interior lands to the coastline (Fig. 1). This area is located along a major European axis connecting Spain and northern Europe. It is characterized by a Mediterranean climate, with major climate change effects expected (ONERC 2015). The

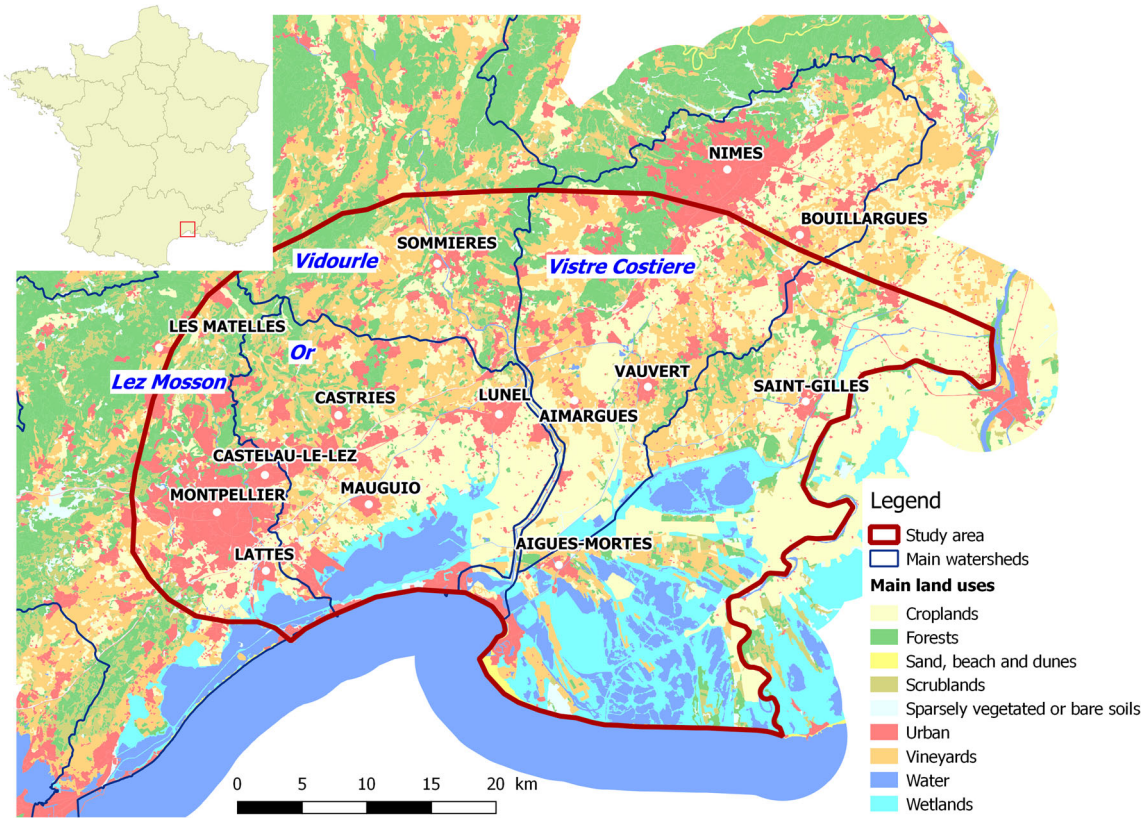

Fig. 1 Magic study area, Languedoc-Roussillon, France. *Data: Corine LandCover 2006*

area's sandy coastline is very sensitive to sea level rise and to submersions along the coast, and interior lands are impacted by extreme events such as violent flashfloods in the plains, and by fires in the interior scrublands. Accordingly, there has been a historical focus on risk management policies. The Mediterranean basin is also considered a global biodiversity hotspot that is particularly sensitive to global changes (Myers et al. 2000). Coastal wetlands, lagoons, and Mediterranean cultural landscapes, shaped by an age-old history of human presence, are characterized by high levels of complexity and diversity. Agriculture, mostly viticulture, is still important in the area, shaping the landscapes and contributing to the local economy. In the 1960s, state-mandated mass market tourism development led to the construction of seaside resorts along the coast (Klemm 1996). Today, tourism represents the major industry in Région Languedoc contributing 15% of the regional GDP and almost 60,000 jobs. Sixty percent of regional tourism is concentrated along the coastline (Région Languedoc-Roussillon 2013). Moreover, the region developed a 'host county' policy which actively solicits in-migration resulting in a rapid demographic growth rate with newcomers coming from other parts of France and settling mainly in cities, along the main roads and next to the shoreline. This generates an important urban sprawl and artificialization process. A large part of the regional economy can be characterized as a 'presential' economy driven by inhabitants' day-to-day needs. We observe a fragile economic development, with a high level of inequity, low average income levels, and a high rate of unemployment. This study area was chosen for analysis to illustrate the reshaping of the linkages emerging through adaptation processes along a gradient of diverse natural habitats, species, human activities, and institutions that could be identified as multiple SES with fuzzy borders defined according to sectoral perspectives. Meanwhile, this diversity of possible SES is interlinked through the watersheds and the process of metropolization.

The use of the robustness framework

To analyze the Languedoc case study, we use the robustness framework (Anderies et al. 2004; Anderies 2015), which is an extension of the Institutional Analysis and Development (IAD) framework (Ostrom 2011) (see also, this issue's editorial). A challenge associated with the use of the robustness framework is that multi-functional coastal SES are composed of multiple resources, resource users, infrastructures, and infrastructure providers (see Online Material 1 for a summary of the Languedoc system). The robustness framework requires a focus on specific characteristics of the study area, including parsing the whole territory into sub-systems for analysis. Indeed, the governance of human-environment problems in the Languedoc case study is structured in a polycentric system

characterized by modularity: management and decision-making processes are organized around diverse more or less inter-related 'system modules' (Anderies 2013). The French government structure is organized sectorally and across space with multiple levels of jurisdictions, beginning with the municipal (local government level), to the intercommunality level (voluntary cooperation of a group of municipalities), regional (including county and province), and national. Modules can thus be defined as clearly bounded and organized jurisdictional units with linkages between them (Cash et al. 2006), defined by their spatial extent (e.g., regional, intercommunal, municipal) and by the issue they address (e.g., flood management, biodiversity conservation, or land-use planning). Certain jurisdictional units are concerned with a single issue (for example, an intercommunality managing a watershed), while others integrate several issues (like a municipality in charge of land-use planning and flood prevention). It should also be noted that some governance mismatch might occur: landscape units and watersheds can be managed by a single jurisdictional unit, but most of the time, several units that are not necessarily coordinated are involved. We distinguish three types of cross-scale interactions between multiple jurisdictional units: (1) overlapping—meaning that different, spatially overlapping jurisdictional units address different issues (flood risk management, land-use planning, biodiversity conservation); (2) horizontal interplay—meaning that equivalent jurisdictional units dealing with the same issue are right next to one another in space (e.g., several municipalities in charge of land-use planning); (3) vertical interplay (Young 2006)—meaning that jurisdictional units dealing with the same issue represent multiple levels along a single spatial scale (e.g., municipalities and intercommunalities in charge of land-use planning).

Our analysis focused on the interplay between these institutionalized jurisdictional units, i.e., between different levels of social organization that are recognized by law. These units can be defined as action situations which consist of strategic interactions between participants, rules, norms, and attributes of the physical world that generate outcomes. Following the suggestion of Oberlack (2017), we define these action situations as adaptation situations: a stimulus (climatic or other) influences an exposed unit (or system) where participants implement adaptation actions. Participants have the ability to design, build, and maintain hard (roads, dikes, bridges) and soft (rules, regulations, norms, e.g., to establish a protected area) infrastructures to reduce losses or increase benefits from these influences. These infrastructures will affect the target adaptation situation, but also other interconnected adaptation situations through the outcomes generated. These adjacent adaptation situations combine to create networks of adjacent action situations (NAAS) (McGinnis 2011), or in our case, networks of adjacent adaptation situations.The analysis of the system is based on diverse sources: literature review, content analysis of diverse policy documents, and stakeholder interviews, including strategic decision makers representing the main organizations. A total of 29 interviews were conducted lasting 90 min on average. We met with representatives of State services, regional and local authorities, and of other public policy organizations. The interviews were recorded with a tape-recorder, transcribed, and thematically analyzed. This general framework of analysis allowed for an explorative and inductive approach. Interviewees were asked to talk about four main topics: the missions and objectives of the represented organization; the changes and drivers affecting these missions and objectives; the actions taken to account for these changes; and the outcomes of their responses across scales. We used the robustness framework associated with the concept of NAAS to analyze two examples of nested feedback systems: (1) land-use planning management and the growing scarcity of land and (2) evolution of coastal area management. These examples illustrate two major challenges linked to cross-scale interactions when implementing adaptation in coastal areas: miscoordination and mismatch in a polycentric system and fuzziness in the devolution of responsibility.

Results

Main changes in the Languedoc case study

The question of adaptation in land-use planning and in coastal management comes from the exposure of the study area to several changes which 'is more than climate change' (Steffen et al. 2004, p.4). The robustness framework considers such changes as 'exogenous drivers' that can impact the resource system (RS) and the infrastructures (PI) (*link 7*) or the users (RU) and the infrastructures providers (PIP) (*link 8*). As detailed in Online Resource 2, multiple changes were identified through the interviews and the literature review. Among them, we distinguish three main types of change:

(1) Demographic growth due to in-migration and changing lifestyles (*link 8 on RU*) has a direct impact on the users and an indirect consequence on resources (*link 1 of RU on RS*). This growth also calls into question the suitability of local political choices and public infrastructures (*link 2 of PIP on RU; links 4, 5, and 6 of PI on RU and RS*). Languedoc is one of the most attractive French regions and subject to rapid demographic growth (see Online Resource 2). This growth phenomenon is due to a voluntary interregional net migration linked to the coastal zone attractiveness, to heliotropism, but also to the active recruitment of new residents by regional policymakers and Montpellier city officials (*link 2 of PIP on RU*) who pursue a persistent ideology that

equates progress with growth. In this case, demographic growth is facilitated through local political choice and infrastructure implementation. New inhabitants need water, housing, transport infrastructures, and services, leading to an important demand upon resources, particularly land (*link 1 of RU on RS*), and to the artificialization of agricultural and natural land into urban areas. Changes in family structure (e.g., increase in single-parent families) and the fact that many newcomers prefer living in single-family residences are trends which further exacerbate the need for land. The space-saving political effort indicated by a decreasing urban sprawl indicator cannot compensate for the concomitant increase in demand for land spaces to accommodate the needs of such a rapidly growing population. Moreover, due to the geographical location of the Languedoc (France–Spain cross-border traffic hub), the study area is also subject to 'external' land-consuming forces linked to the development of transportation drivers, such as the high speed rail or the A9 freeway projects. Artificialization is recognized as one of the main drivers of biodiversity loss (see Online Resource 2) and as an aggravating factor in flood and submersion risk management, an exacerbated trend since most development occurs in coastal areas which are more vulnerable to the adverse impacts of climate change. Hence, demographic growth and changing lifestyles place an additional strain on finite resources which are already struggling to adjust to changing climate conditions.

(2) Languedoc is predicted to experience major climate change effects, especially along the coast. Climate change is and will continue to impact directly both resource availability which is expected to become less abundant (*link 7 on RS*) and infrastructures, which will be subject to more extreme events and pressures (*link 7 on PI*). Manifestations of climate change in Languedoc include rising sea levels, temporary marine submersions, accentuated coastal erosion, rising temperatures, and more extreme rainfall events (see Online Resource 2). Aside from creating new environmental conditions, climate change will also magnify well-known risks such as flash floods, erosion, and submersion, as well as resource scarcity, especially water. It will also have major consequences for biodiversity with changes in species distribution or phenological decoupling. As depicted earlier, climate change effects are exacerbated by other ongoing changes such as demographic growth. Climate change calls into question the suitability of current policy orientations and public infrastructures. Under future climatic conditions, the robustness of infrastructures (*link 7 on PI*) is challenged, i.e., will the dykes and risk prevention plans be adapted to more extreme events (*links 4, 5, and 6 of PI on RS and RU*)? Is the current network of protected areas sufficient to allow continued species migration (*link 4 PI on RS*)? And how will decision-makers adapt their strategies (*link 3 of PIP on PI*)? Hence, climate change raises the question of adapting infrastructures and who will be responsible to do so.

(3) Last, decentralization, neo-liberalism, and increasing environmental concerns among policymakers and the public (*link 8 on PIP and RU*, see Online Resource 2) call into question the devolution of responsibilities between multiple governance levels to implement infrastructures (*links 2, 3, and 6 between PI, RU, and PIP*) and the choice between various adaptation strategies, notably infrastructures (*evolution of link 3 of PIP on PI, having consequences for links 4, 5, and 6 of PI on RS and RU).* The emergence of a neoliberal paradigm is associated with an increase in individual responsibility, a call for greater efficiency, and budgetary restrictions. Moreover, the State's withdrawal from local affairs since the 1980s has led to greater decentralization of authority to the local arena. For example, decentralization processes provided local authorities at the municipality and intercommunality levels with more power over land-use planning, particularly through tools such as municipal land-use plans and intercommunal land-use recommendations. Decentralization is still ongoing, for example in 2014 with the launching of a law regarding the management of flood prevention, empowering intercommunalities instead of the State. A key issue related to this change is the devolution of responsibility among multiple users and infrastructure providers as well as their coordination: who is in charge of what, who will pay for what, and how are multiple jurisdictional levels coordinated? Lastly, a new political paradigm, defined as the greening or sustainable paradigm, sustains the integration of multiple issues in policies, notably with the inclusion of rules and norms to ensure environmental sustainability. This shift pushes stakeholders to rethink management in a more integrated way, leading to different types of infrastructure implementation, for example natural-infrastructures such as dune ridges to face erosion, and renewed coalitions of actors.

Some of these changes are already well known and have led to the development of long-standing policies (e.g., hosting policies, biodiversity conservation policies, risk management policies), others are currently ongoing (e.g., decentralization, strengthening of the sustainability paradigm), and others are expected and associated with a high level of uncertainty (e.g., climate change). They interact in complex ways, now translating into a period of instability where stakeholders are subject to several disturbances, pursuing multiple sometimes contradictory objectives, in a context of fuzziness in the devolution of responsibilities among scales. We use the example of land-use planning and of coastal management to illustrate how

these changes lead to multiple adaptation strategies that redefine cross-scale interactions and raise new coordination challenges. Both policies, currently high on the political agenda, are essentially cross-sectoral and concern the diversity of resources and people that have to work together in the same network of connected places.

Land-use planning

The example of land-use planning, summarized in Fig. 2 and in Online Material 3, illustrates how ongoing changes described in section "Main changes in the Languedoc case study" worsen a situation of competing planning agendas and miscoordination in a context of cross-scale governance, which are two major institutional constraints for adaptation (Oberlack 2017).

As mentioned earlier, because of the multiple changes occurring in the Languedoc case, land-use control is a crucial issue. Land appears as a precious resource upon which there is a growing demand to respond to well-known issues (housing new residents, preserving biodiversity) and to anticipate sea level-rise, more extreme flooding events, and future repartitioning of biodiversity under changing climatic conditions. Land-use planning is under the influence of multiple interconnected adaptation situations, in which a large set of regulations focusing on these issues is developed and is evolving with renewed climatic and governance conditions. The coordination between these regulations is thus a major challenge, illustrated in our example by three interacting issues: land-use planning of urbanization, flood risk prevention, and biodiversity conservation.

First, urbanization is mostly driven by demographic growth and changing lifestyles, slowly increasing the demand upon agricultural and natural land to develop urban areas. This growth, at the heart of the local economic model, is amplified by the hosting policy that has been cultivated since the 1960s. Land-use plans are the main infrastructure used to control the growing demand for land. Their implementation is decentralized between multiple levels along a jurisdictional scale, and more particularly between the municipality and the intercommunality, with a municipal land-use plan (PLU) and intercommunal land-use recommendations (SCOT). Even if we focus here on a single issue (urbanization), challenges of coordination emerge at two levels: between municipalities or between intercommunalities (horizontal interplay) and between multiple municipalities and the overarching intercommunality (vertical interplay). Sometimes, the lack of coordination between the different jurisdictions where the PLU or SCOT are implemented, and the fact that these tools remain planning documents that decision-makers are not strictly obliged to implement, raises several problems: 'the [communal] economic competition is exacerbated, land consumption is not optimized…'.[1]

Second, land-use plans interact with risk management policies by identifying flood risk or submersion risk areas, leading to zones where construction is not allowed. These zones are defined through an independent flood risk management policy implemented by specific intercommunalities in liaison with the State. Implemented infrastructures include flood risk prevention plans, no-build zones, dykes, retention dams, and warning systems. These infrastructures and their implementation are now challenged both by an evolving paradigm in flood prevention, climate change, and governance modifications. Based on climate change scenarios, both soft and hard infrastructures are now evolving, increasing the spatial expansion of risk areas, and therefore increasing constraints on land use. For certain stakeholders, a forward-looking vision of coastal risks management is also leading to the consideration of relocation policies which question the availability of land reserves (see the coastal management example). Paradoxically, the construction of important hard infrastructures for risk protection, associated with the development of temporary and/or resilient urbanization, can also favor the expansion of urbanization in risky areas. This situation is well illustrated in Lattes and Sommières, two municipalities historically subjected to major flood risks. In Lattes, the construction and reinforcement of an important flood protection system (including dykes) facilitated urbanization: residential areas are now built 'safely behind the dyke'[2] in areas that were previously considered at risk of flooding. In this context, a dyke failure would have catastrophic consequences. In Sommières, we observe a continuing urbanization on the hills and the development of different infrastructures (retention dams, hill reservoirs, a warning system, and buildings adapted to flood risk) that do not prevent people from living in flood areas—sometimes in unsanitary conditions.

Third, biodiversity conservation is another policy that has an important impact on land-use planning. Biodiversity is strongly impacted by urban land-use change, by the transformation of agriculture (intensification and decline), and by climate change. To respond to these threats, environmental stakeholders, especially at the national and regional levels, are mobilizing a large diversity of infrastructures such as protected areas, but are also trying to influence land-use planning through new soft infrastructures such as ecological network and compensation policies. While the ecological network policy (SRCE) aims to identify and preserve ecological continuities through their incorporation into land-use planning documents, compensation policies are also contributing to more pressure upon land since any destruction of a protected

[1] All quotes from local stakeholders have been translated from French to English by authors.
[2] Internship report: Sougrati (2015).

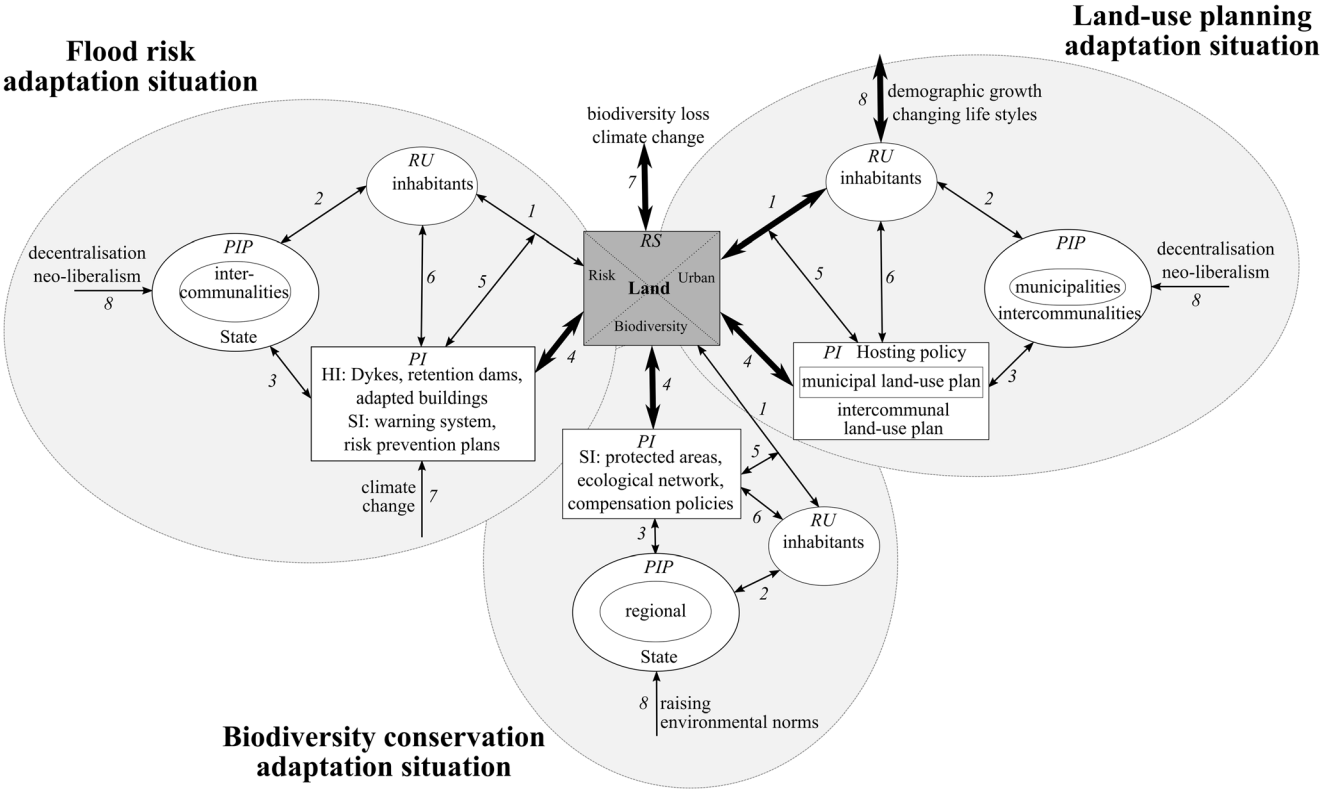

Fig. 2 A robustness diagram for the land-use planning example. Land is a resource (RS) that is managed in several adaptation situations that can be overlapping (flood risk management, land-use planning, biodiversity conservation), in a horizontal (several municipalities) or vertical interplay (municipalities and intercommunalities). The main issue is in the coordination between these adaptation situations, and more specifically between multiple users (RU), infrastructure providers (PIP), and infrastructures (PI) that can be hard (HI) or soft (SI). Thick arrows represent the most important interactions in the system. The numbers alongside the arrows fit the robustness framework classification (Anderies et al. 2004) and are detailed in Online Resource 3

natural habitat has to be compensated by protection or restoration measures in another area. In a forward-looking vision that includes climate change, environmental stakeholders are beginning to think about extending land tenure to the ecological habitats of the future, even if the social acceptability of this option is now non-existent.

As summarized in Online Material 3, the example of land-use planning illustrates the coordination challenge occurring between inter-related adaptation situations and regulations around the management of a shared and coveted resource: land. It reveals the interplay between multiple providers pursuing diverse objectives through infrastructures implementation (*link 3 of PIP on PI*), and organized in overlapping, horizontally, and vertically linked adaptation situations. These infrastructures influence the control of land (*links 4 and 5 and 6 of PI on RU and RS*): access to land is necessary to many adaptation strategies in the face of climate change, narrowing options for the future and putting more pressure on the infrastructure providers to make trade-offs. As discussed in the last section, power relationships between the State and local authorities, between local authorities and between sectorial issues, play an important role in this negotiation.

Coastal management

This second example about coastal management illustrates how multiple adaptation strategies involve renewed cross-scale interactions and governance challenges through time (see Fig. 3 and Online Material 3).

In Languedoc, the coastal area is of importance for several reasons: most of the growing number of inhabitants are concentrated along the coast where there is a high density of economic activities, particularly tourism. At the same time, lagoons and coastal natural habitats are recognized as hotspots for biodiversity conservation, leading to a high concentration of conservation measures. This area is also particularly sensitive to climate change. Historically, the main challenge in coastal management was the equilibrium between development and conservation issues, which are unequally distributed along the coastline. In the 1960s, the State promoted the economic development of the region through tourism development and the preservation of the coastline in a logic of spatial segregation. As a legacy of this policy, the study area in the east around the Camargue is dominated by several conservation measures (nature reserves and a regional nature park) and has remained fairly

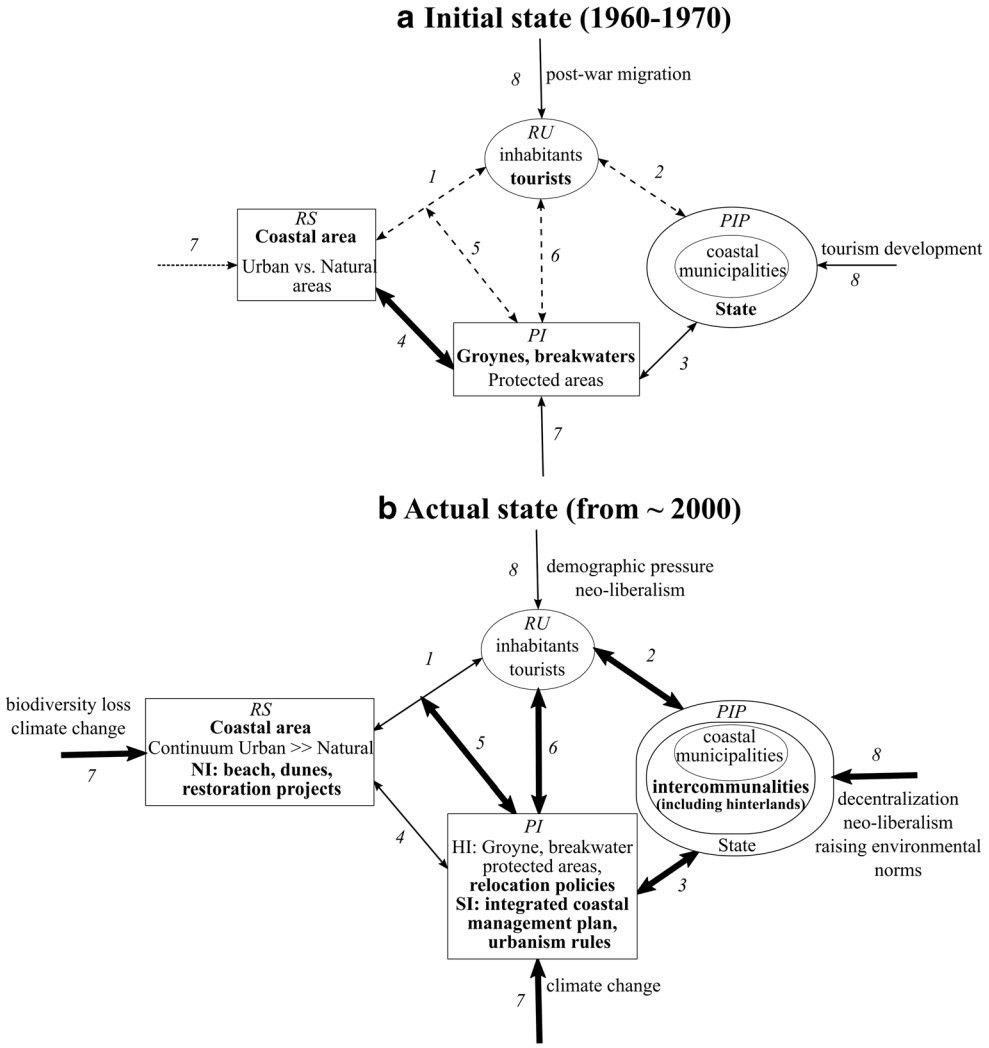

Fig. 3 A robustness diagram for the coastal management example: **a** initial state (1960–1970) and **b** today (from ~2000). The resource system (RS) is the coastal area, shared and managed by several users (RU) and infrastructure providers (PIP) through infrastructures (PI) that can be hard (HI), soft (SI), or natural (NI). Regarding adaptation in coastal management, two issues emerge: (1) the definition of which strategy to adopt, and which type of infrastructure to mobilize; (2) the question of responsibility and coordination among multiple users and/or different types of infrastructure providers. Thicker arrows represent the most important interactions in the system, bold text represents the most important components in the system, and dotted arrows represent the less important interactions in the system. The numbers alongside the arrows fit the robustness framework classification (Anderies et al. 2004) and are detailed in Online Resource 3

protected from damaging practices such as artificialization. Conversely, the western part is dominated by seaside resorts concentrating important tourism and residential issues, separated by coastal natural habitats and protected from erosion by hard infrastructures such as groynes and breakwaters. Mass tourism along the beaches and transport infrastructures in the middle of the thin dune ridge that separates the sea from the lagoon are strongly reducing the buffering capacity of the remaining coastal natural habitats. This situation has come under increasing scrutiny in recent years for several reasons: (i) the unsustainability of the management model due to tourism's impact on the environment (*link 1 of RU on RS*) and the risk of reduced attractiveness of the coast; (ii) growing environmental and sustainability concerns in the management of erosion (e.g., through the European Integrated Coastal Zone Management Directive, *link 8 on PIP*) and its transposition into French national policy (e.g., national strategy for integrated coastline management); (iii) a growing recognition of the adverse effects associated with hard infrastructure defenses against coastal risks, especially their impact on transit in sediment cells that alter the adaptive capacity to future sea level rise (*link 4 of PI on RS*); (iv) a decentralization and local empowerment process (*link 8 on PIP and RU*) that has led to an increase in individual and local level decision-making responsibility; and (v) the exacerbation of already existing risks and pressures on resources and infrastructures due to climate change (*link 7 on PI and RS*).

These changes are pushing towards a paradigmatic shift, from a command and control approach (Fig. 3a) to an integrated and flexible approach (Fig. 3b) which blurs the boundaries between development and conservation areas, and between the coastline and the interior lands. The historical approach of coastal risk management using hard human-made infrastructures (*link 4 of PI on RS*) is called into question. The degradation of dune ridges due to overcrowding as well as the renewed vulnerability of hard protection infrastructures due to increasing erosion and submersion risks is leading a growing number of national and regional authorities to call for investment in adaptation policies. Depending on the local setting, proposed adaptation responses include the development of urbanization rules to preserve the coastline (*link 5 of PI on link 1 between RU-RS*), beaches, or dune systems maintenance or restoration and revegetation projects to promote sand-trapping capability and resilience of flexible natural infrastructures (*link 4 of PI on RS*), or relocation policies in the most critical cases (*link 5 and 6 of PI on RU-RS and on RU*). These options are presented by regional authorities as more adaptive than hard human-made infrastructures, and their maintenance represents a way to preserve the ecological integrity of the environment and a way to respond to economic and safety issues while coping with climate change. These management options introduce new cross-scale interactions and governance challenges. For example, supplying sand for beach maintenance raises questions about its long-term sustainability, and the potential impact of such activity on the sea bed and marine environments. Relocation policies raise the issue of where to relocate the population, and the condition of land reserves away from the coast. Coastal municipalities without land reserves will be highly dependent on neighboring interior municipalities:

> 'It is very difficult for municipalities with small territories, which do not have any possibility for retreat on their territory. They are squeezed (…), especially for the municipalities on the shoreline where there is a pond, and which do not have land beyond. They are in a very difficult situation in terms of local development' (Languedoc Region, 2014)

This situation creates new interactions between municipalities and requires adapted soft infrastructure to enable coordination between the interior municipalities and the coastal municipalities. But at the same time, the coastal governance is challenged by two changes: (1) decentralization and neo-liberalism are affecting the distribution of governance responsibility and funding availability (*link 8 on PIP and RU*); (2) the context of climate change (uncertainty, long-term process) is raising difficulties in terms of decision-making. Historically, the State played a key role in implementing risk policies; however, now, this responsibility lies within the competence of intercommunalities which are experiencing a budgetary crisis. As a representative of the Languedoc regional council explained about adaptation policies: 'It will be expensive, it will be difficult to support, we risk to lose some feathers. So it is complicated. If there is a problem, we will be responsible if we fund this policy. So we consider the State is responsible, but that is not necessarily the case'. Some adaptation strategies also involve responsibility devolution to the users themselves (*evolution of link 2 between PIP and RU*), for example by modifying insurance arrangements: 'People who are buying houses just along the seafront, I think they should be responsible for it. We need to make people more responsible'. Moreover, most of the institutional representatives at the regional level recognize climate change denial among residents and local decision-makers, trapped in short-term temporalities: 'Local elected officials are here for 5 years! Here we talk about land-use planning on a longer term (…) So it is difficult, we talk about a 50-60 years' time period… It is not their decision scale, it is difficult to take a decision for something that will happen in 50 years (…) and maybe it will never happen!'. They wonder whether this resistance to change can be overcome by devolving the responsibility across scales and infrastructure providers: should a regulatory framework be imposed by the State (top-down perspective)? Or should individuals and local decision-makers be encouraged to take responsibility and assume the consequences (both human and financial) of their choices?

As summarized in Online Resource 3, this fuzziness in the devolution of responsibility among different users and infrastructure providers (*link 2*) reveals uncertainties and power issues about who is in charge of what, and who will take the responsibility to manage coastal risks through infrastructure implementation (*links 3 and 6*). Considering the diversity of local settings along the Languedoc coastline, as well as the diverse representations of best ways to manage coastal risks, it seems that various strategies will be adopted. The main issue to consider is how the choices made in particular adaptation situations will involve new cross-scale interactions and affect the options of others along the coast or in the interior lands.

Discussion

Analysis of cross-scale interactions with the robustness framework

The examples of land-use planning and coastal management in Languedoc demonstrate the usefulness of the robustness framework to analyze the dynamic linkages

between the pieces of the SES puzzle in the face of multiple changes. The fact that governance scales overlap raised some concerns in using the robustness framework, which had not been originally designed to represent interactions among multiple inter-related adaptation situations, each one being characterized by a specific set of resources, actors and infrastructures. Associating the robustness framework with the NAAS (McGinnis 2011), as featured in Fig. 2, allowed us to grasp the propagation of consequences of changes in mental frames, as well as the allocation of responsibilities in the entire feedback loops that ensure robustness of these complex coastal systems. Identification of key resources or infrastructures that bridge SES and connect feedback loops identified through the robustness framework provided a means to delineate the system meaningfully from a resource or infrastructure point of view. In Fig. 3, we connect two robustness diagrams to illustrate significant changes across time, especially in terms of renewed cross-scale interactions. This adaptation of the robustness diagrams entails the representation of evolution of a coastal system which is compulsory in the context of multiple changes and adaptation to these. External changes such as in link 8 have direct consequences for infrastructure providers or users, but also indirect consequences through link 2 concerning the relations between users and providers, as well as on link 3 and the capacity of providers to implement infrastructures, or their choice between several types of infrastructures. Hence, second-order indirect consequences will concern the interaction between these renewed infrastructures and their target, either users, resources, or the interaction between the two (*links 4, 5, and 6*). Similar patterns can be drawn from the example of link 7. Through an identification of these major changes in the system and the representation of separated robustness diagrams, we are able to better identify the cascade of changes and consequences due to local adaptation patterns.

The use of coupled and evolving robustness diagrams also revealed contradictory policies and hidden fragilities, as well as the need to redefine the boundaries of adaptation situations and their coordination. These fragilities can be explained by cross-scale interactions and trade-offs between interlinked adaptation situations (Oberlack 2017) and allow us to discuss factors that make it harder to plan and implement adaptation actions, or adaptation constraints (Klein et al. 2014). There are multiple co-occurring and reinforcing constraints acknowledged in the literature (Moser and Ekstrom 2010; Eisenack et al. 2014). Our study discusses 'how and why' some of these constraints emerge and reinforce each other (Biesbroek et al. 2013), and particularly: miscoordination, competing planning agendas, unclear responsibility distribution, mismatch in time scales, and path dependency.

Miscoordination when adaptation relies on a shared resource

Miscoordination traps, a frequent institutional barrier, are explained by institutional fragmentation and a lack of coordination due to a spatial mismatch between institutions and the stimuli, or by a silo effect (Oberlack 2017). It has been recognized that if the system of concern extends across multiple jurisdictions, adaptation requires coordination and collaboration across jurisdictions (Moser and Ekstrom 2010). The land-use planning example illustrates how multiple actors, organized in multiple jurisdictions, facing diverse changes and pursuing multiple objectives rely on the same resource (land) to face short-term challenges and to adapt in the long run. They try to control land by implementing infrastructures, especially land-use plans, in adaptation situations that can be overlapping (same space, diverse sectorial interests), or related through horizontal or vertical interplay (same sectoral interest, different jurisdictional, and spatial levels). Coordination mechanisms among these situations have limited efficiency because of power relationships (Adger et al. 2005b) among actors defending competing values and interests (Klein et al. 2014), disregard of the effects of their policy implementations on other situations, and lack of long-term projections on the availability of land resources.

First, some soft infrastructures leave room for interpretation and flexibility which can lead to negotiations constrained by power relationships. Although municipal land-use plans are framed by intercommunal masterplans, intercommunal guidance is ambiguous and malleable leaving room for interpretation: some regulations have to be strictly applied (e.g., risk prevention plans), whereas others just have to be considered (e.g., the ecological network regional plan). This enables opportunistic municipal land-use plans that seek to increase local revenues through new urbanization projects, but contribute to a greater vulnerability at the intercommunal level. Second, with the building of additional hard infrastructures for flood management (dikes, hill reservoirs) and the development of 'resilient' houses that are adapted to flooding, short-term trade-offs facilitate access to land in flood plains or other sensitive areas that were previously considered too risky to develop. In the long run, doing so may contribute to greater local vulnerability to severe weather events and fail to address the unsustainability of the Languedoc economic development model. Yet, we know that sustainable economic development is a critical foundation for the creation of adaptation opportunities (Klein et al. 2014). This illustrates the reinforcing interaction between path dependency, historical and unresolved conflicts between the involved actors' goals and miscoordination (Eisenack et al. 2014), thus reducing the

capacity of Languedoc to switch from one model of development to another. The current situation may have been considered acceptable when resources were available, infrastructures adapted, and extreme events were limited; however, this is no longer the case given the pressure and growing interactions imposed by multiple changes.

Renewed boundaries and responsibilities

The coastal example illustrates a possible shifting pathway from one management strategy (command and control ordered by the State) to another (flexibility, live with change, local responsibilities). This shift calls for a renewal of the scale where adaptation is implemented, the actors responsible for its implementation, the needed resources and the related cross-scale trade-offs. It echoes well-known constraints such as fragmented and unclear responsibilities, or temporal and spatial mismatch (Eisenack et al. 2014; Oberlack 2017). Some proposed adaptations are not implementable at the scale of the concerned adaptation situation, such as relocation policies in coastal municipalities that lack land reserves and that must design relocation at a larger spatial scale, including municipalities that are not located along the coast. Other adaptations rely on new external resources, such as sand extraction for beach nourishment to face erosion and submersion along coastlines. This option requires the enhancement of knowledge of a new interlinked environment, the seabed, and of the potential consequences of sand extraction on marine environments. In both cases, these options question the boundaries of the current adaptation situations and involve future trade-offs that will have to be considered during the decision-making process. These situations correspond to a spatial mismatch since the authority or jurisdiction of the management institution is not coterminous with the problem. Resolving this type of mismatch requires reinforced coordination and responsibility sharing (Cash et al. 2006). However, these resolutions are constrained by the direct impact of ongoing changes in environmental governance (e.g., decentralization) and by indirect impacts linked to the specifics of climate change (e.g., uncertainty and temporal mismatch). We illustrated in the results section how multiple changes are leading to a fuzziness in responsibility distribution among several infrastructure providers and users. Despite tendencies that favor a changing devolution of responsibility from the State to the local level, Languedoc is trapped in a path dependence where French citizens are accustomed to the national government being the main provider of many local services. Moreover, in a context of budgetary crisis, authority is transferred to the local level without the necessary financial support to take on such responsibility. Decentralization implementation efforts are hampered by confusion as to who has authority to take what action locally, and who will assume the cost of infrastructures. As a result, an institutional framework that likely was intended to transfer power to citizens and local policymakers in order to create more adaptive governance structures and to reduce costs at the national scale, appears as a disruptive factor, marred by power struggles, thus greatly reducing the possibility to implement adaptation responses. Lastly, taking on the responsibility of coastal risk management in the face of uncertain and long-term climate changes is not an attractive option for many local decision-makers. This temporal mismatch, when short-term electoral cycles conflict with long-term planning needs, is described in the literature as a major adaptation constraint which is specific to climate change (Cash et al. 2006; Eisenack et al. 2014).

Conclusion

Addressing the robustness of coastal systems in the face of multiple changes raises the issue of analyzing cross-scale interactions in multi-functional SES characterized by overlapping and inter-related decisional contexts. Applying the robustness framework to the Languedoc case, we demonstrate that the presence of multiple and interacting changes and local adaptation to these are critically impacting coastal systems, leading to growing pressures upon resources and infrastructures, and to a redefinition of social organization. This situation increases cross-scale interactions and cascade effects among multiple adaptation situations, blurring their frontiers as well as the relevance of pre-existing infrastructures and policies, and raising the issue of responsibility devolution and of coordination between multiple users and infrastructure providers. As a consequence, the main collective action problem in the study area is to define adaptation situations and their coordination with regard to the growing interactions created by multiple changes. In our case study, one strength is the trend towards integrative management, sharing responsibilities, and shifting paradigms that promote sustainable management practices. However constraints exist in practice, including a cultural and institutional inertia related to path dependency, power struggles between participants, and a network of adjacent adaptation situations that are more and more interrelated and not adequately coordinated. In this context, the lack of efficient coordination rules is a serious concern for the long-term sustainable management of coastal areas. To conclude, the use of the robustness framework associated with the concept of networks of adjacent action situations as we have done in this work provides tools to elucidate the cascading effects of adaptation patterns and bring them into the debate provided that suitable arenas exist to organize them.

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