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Synthesis

Resilience and coastal governance: knowledge and navigation between stability and transformation

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ABSTRACT. Several intergovernmental agreements highlight the need for resilience in the face of environmental and societal challenges. Coastal systems are particularly complex and susceptible to global climate change, and building human resilience to future changes is of high priority. While the concept of resilience has historically been associated with stability to perturbations, the notion of transformation within the social-ecological resilience (SER) approach has recently gained importance in ecosystem management. In order to operationalize resilience in the context of coastal governance in a changing climate, a better understanding of the concept is required. This paper provides an overview of different approaches to resilience, including stability and transformation, in order to understand resilience as a concept in a coastal governance context. Subsequently, we propose five steps and three types of knowledge (system, target, transformative) with which to embed SER in coastal governance. In addition, we consider scale and system boundaries; identify (un)desirable system characteristics and the role of normative goals and common visions in resilience management. Finally, we highlight the central role that local actors and information services play in fostering a two-way exchange between science and society and tailoring solutions for establishing or enhancing SER to the needs of local actors. We conclude that the navigation between stability and transformation within the concept of resilience is central to finding sustainable future pathways in the face of climate change.

Key Words: *climate change; ecosystem management; information services; knowledge co-production; social-ecological systems; sustainability*

INTRODUCTION

Coasts are of high social, economic, and environmental value (Martínez et al. 2007), yet significantly impacted by population growth (Neumann et al. 2015), increasing economic activities (Jouffray et al. 2020), and environmental change (IPCC 2019). Coastal systems are particularly vulnerable to climate change due to impact caused by rising air and seawater temperatures, ocean acidification, sea-level rise, changed precipitation, wind and wave conditions, and subsequent coastal erosion (IPCC 2019). Increasingly, environmental drivers combined with local economic impacts, such as eutrophication or sedimentation, pose critical challenges to both fragile coastal ecosystems (Halpern et al. 2015) and communities depending on those ecosystems (Selig et al. 2019).

In the face of these challenges, a variety of global agreements emphasize the need for resilience, e.g., the Sustainable Development Goals (SDGs), Paris Climate Agreement, Aichi Biodiversity Targets, and the Sendai Framework for Disaster Risk Reduction (Convention on Biological Diversity 2010, Roberts et al. 2015). Of particular interest is the emphasis to include resilience to climate change as part of national and international strategies, missions, and fora. For example, the new EU Strategy on Adaptation to Climate Change aims at increasing the resilience of European coastlines to climate change (European Commission 2021), and the EU International Ocean Governance Forum (December 2020) has called for action in making (climate) resilience a greater priority in ocean governance.

These international agreements, that promote resilience, are often formulated at intergovernmental levels without specific recommendations for specific courses of action. Indeed, the operationalization of resilience at the local level remains challenging (de Bruijn et al. 2017, Hernantes et al. 2019, Weise et al. 2020, Thonicke et al. 2020), raising concerns that resilience may become “a buzzword devoid of meaning” (Masselink and Lazarus 2019). However, the concept of resilience supports a holistic management approach, integrating non-linearities and complexity, which may support coastal governance to respond to urgent issues in the face of uncertain change (Tompkins and Adger 2004, Brown et al. 2014, Mulrennan and Bussières 2018). At the local level, there is a variety of area-based management approaches for coastal governance, such as Integrated Coastal Zone Management (ICZM), and Marine Protected Areas (MPA) in which the concept of local coastal resilience to climate change can be embedded (Fletcher et al. 2018). The notion of transformation within resilience management has gained particular prominence over the last years (Folke et al. 2021), but the implications of this shifting focus are often not intuitive when attempting to operationalize resilience in relation to coastal governance under climate change.

First, we provide an overview of social-ecological resilience and desirable system states, and specifically highlight the tensions associated with transformation and adaptation at different scales and in relation to local coastal governance. Secondly, we propose five steps for navigating the tensions between adaptation and transformation in complex social-ecological systems, such as coasts, by co-producing system, target, and transformative knowledge (ProClim 1997) together with relevant actors in coastal governance. This includes addressing scale and system boundaries, (un)desirable system characteristics, and the role of normative goals and common visions in resilience management. This synthesis is mainly addressing an academic audience and can be used as a starting point for developing transdisciplinary approaches for the operationalization of the concept of resilience

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within sustainability research. We argue that researchers placing greater focus on target and transformative knowledge (which are currently underrepresented in the literature), particularly in relation to transformative change, is a crucial first step for understanding and enacting effective management of resilience in coastal social-ecological systems (SES).

UNDERSTANDING RESILIENCE AS A CONCEPT FOR COASTAL GOVERNANCE

Social-ecological resilience and desirable system states

Resilience, as a multi-disciplinary concept, has existed for decades and is understood differently by various disciplines. In order to operationalize resilience in environmental management - and specifically coastal governance - a thorough understanding of the concept of resilience and its different approaches is indispensable. Within environmental and sustainability science, resilience thinking is often rooted in ecology and is referred to as a systems characteristic. Ecological resilience refers to a system with multiple (potential) stable states (Holling 1996). Engineering resilience more often refers to one single steady state and therefore stability (Holling 1973).

Over the past decades, the definition of ecological resilience has evolved to integrate the degree to which humans intervene in ecological systems. It acknowledges the intertwined relationship between society and nature as an integrated social-ecological system (SES), and is hence referred to as *social-ecological resilience* (SER). SER has been defined as the "capacities of a system to persist, adapt and transform in face of change through human intervention" (Folke et al. 2010, 2016). In this context, *persistence* means that shocks are absorbed, adaptability is the capacity of components in a system to adapt to gradual change, and transformability is the capacity of a system to evolve into a fundamentally new system (Walker et al. 2004, Folke et al. 2010). Within the Folke et al. (2010, 2016) definition of SER, *adaptability* and *transformability* play a critical role to sustain human well-being in face of uncertain change (e.g., climate change) (Chapin et al. 2010, Biggs et al. 2015, Folke et al. 2016). The distinction between adaptation and transformation is sometimes vague, but a definition for SES has recently been proposed by Garmestani et al. (2019, p. 1): "Adaptive capacity describes the potential a SES has to alter resilience in response to change and maintain the current social-ecological regime; a system with high adaptive capacity is more likely to remain resilient given substantial episodes of change. Transformative capacity describes the potential of a SES to shift to a different, but still productive and socially desirable, regime that is again resilient to disturbance." Accordingly, there is a clear distinction between the two by identifying the key functions of a given SES and whether they are maintained or changed. The SER approach offers an appropriate lens through which to understand and address the dynamics of complex adaptive systems and the role of human intervention and agency in such systems.

The notion of transformation within SER has gained importance in ecosystem management throughout the past decade. This is due to an increasing recognition of the need to manage human-nature relationships toward a more desirable and healthy system state (Biggs et al. 2010, Westley et al. 2011, 2013, Olsson et al. 2014, Glaser et al. 2018, Grafton et al. 2019). The transformation of a system, "is considered desirable or necessary when existing ecological, economic, and social structures become untenable" (Walker and Salt 2006, Resilience Alliance 2010). Figure 1 shows that humans often try to increase the stability of one steady state (engineering resilience, Fig. 1a), or prevent a system to move to a less desirable system state, such as a coral reef moving from a healthy ecological state to a degraded state (ecological resilience, Fig. 1b). Figure 1c visualizes that in the SER approach, human intervention (such as coastal governance) is a choice between stabilization (preventing the system to move to a less desirable system state) and the transformation to a more desirable system state.

We conceptualize resilience as both a descriptive and a normative concept. Thereby, the descriptive component describes resilience as a system's state (e.g., Fig. 1), however, the management of coastal systems for resilience is inherently normative (Thorén and Olsson 2018) as it requires a socially constructed (rather than purely scientific) understanding of what a desirable resilient system could look like (Brown 2014). The concept of resilience, therefore, does not only bridge the social and environmental sciences, but also establishes a common ground between science and policy and a more diverse set of knowledges (Cote and Nightingale 2012). For navigating systems toward a desirable system state, a discussion about the implications of, and tensions between, stabilization and transformation of system states in social-ecological systems is necessary.

Fig. 1. Different approaches of systems resilience: a) engineering resilience, b) ecological resilience, and c) social-ecological resilience, illustrated by the ball-and-cup heuristic (Walker et al. 2004); a and b are adapted from Liao (2012, Fig. 2). The cup represents the "basin of attraction" in which the system tends to remain, including all of the system's characteristics. The ball represents the state of the system at a given time. The perturbation affecting the system can be both natural, e.g., climate extremes, or anthropogenic, e.g., human intervention driving change (both positive and negative). While within engineering and ecological resilience human intervention is associated with stabilization, in the social-ecological resilience approach the human intervention is a choice between stabilization (preventing the system from moving to a less desirable system state) and transformation to a more desirable system state.

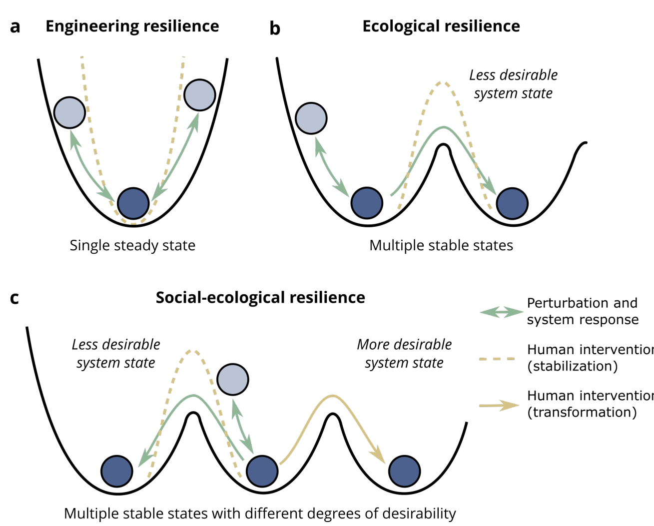


Table 1. Desirable and undesirable characteristics in coastal social-ecological systems with regard to stabilization and transformation, and examples (Oppenheimer and Glavovic 2017, Mcleod et al. 2019, Masselink and Lazarus 2019, Bonnett and Birchall 2020, Dornelles et al. 2020, Thonicke et al. 2020).

	Stabilization	Transformation
Desirable	'Fast' solution Maintains current state structures and functions (preserving status quo) Integrates future drivers in form of scenarios	Flexible and adaptive Integrated systems view (sustains both ecosystems and human well-being) May support sustainable development (social, economic, and environmental) Sustainable state for coupled SES Integrates future drivers in form of scenarios Acknowledges and addresses uncertainty by offering multiple pathways of development
Undesirable	Static, not flexible Danger of 'lock-ins' Short-term perspective (Economic) benefits may become negative	'Slow' solution, requiring change at multiple levels Change to a completely new system not necessarily desired by those affected
Examples	Resist occasional flooding Coastal defence - 'hold the line' Aided recovery of a coral reef after a heat wave	Incentives to couple subsidies to the maintenance of ecosystem services Ecosystem-based management Shift to a different livelihood to reduce impact on the ecosystem (e.g., coral reef) Shift fishing grounds based on migration of species due to climate change Retreat or advance

Tensions between stabilization and transformation

Even though the acknowledgment of (social) transformation as a prerequisite for enabling more desirable system states is not new (e.g., in the field of sustainability transitions, Westley et al. 2013, Olsson et al. 2014, Abson et al. 2017, Scoones et al. 2020, Folke et al. 2021), the implication and consideration in complex social-ecological systems is not trivial. There is still a largely unresolved tension between seeking to manage SES for "stabilization" and "transformation" focused resilience. Three factors make resolving this tension challenging.

Firstly, stabilization (short-medium) and transformation (long) have different temporal scales. This is compounded by the negative effect of "locking-in" systems through stabilization (Dornelles et al. 2020), thereby limiting their potential for transformative change. Thus, stabilizing or preserving the current system state is often not a desirable outcome. For example, this is the case where an ecosystem has tipped toward a degraded ecological system state and is unable to recover, which is often observed on coral reefs under pressures of climate change and eutrophication (Mcleod et al. 2019).

Secondly, while in resilience thinking it has been suggested that one must ask resilience "of what," "to what," and "for whom" (Carpenter et al. 2001, Davoudi et al. 2012), with regard to "transformative" resilience an additional question arises: "transformation to what (state)?". What constitutes a "desirable alternative system state" for coastal SES is likely to be highly contested, due to diverse interests and objectives of actors, and must consider their political, cultural, and historical values (Cote and Nightingale 2012), as well as their agency and existing power relations between them (Béné et al. 2012, Cretney 2014). However, without a clear alternative normative vision, intentional transformative change is problematic (Abson et al. 2014) and the default may be to stabilize the current state regardless of the long-term feasibility or even the short-term desirability of such an outcome. Therefore, if building resilience requires transformative change then, difficult as it may be, resilience thinking needs to engage with the development of socially acceptable visions of what that transformed state is, and why changes need to be enacted to move toward such a desirable and resilient future.

Finally, in complex SES it is likely that there are components of the current system that are desirable and feasible to stabilize and other components that require transformation. This, in turn, has implications for the relevance of temporal scales. While managing for resilience requires the accommodation of adaptation to current challenges, it also has to consider other future, long-term climatic and environmental changes (Torabi et al. 2018, Folke et al. 2021). The resulting uncertainty about possible future impacts will inevitably and increasingly complicate agreeing on a common normative vision of which components are desirable and feasible to stabilize or transform. Therefore, it is necessary, when thinking about managing for SER in coastal SES, that one clearly conceptualizes and differentiates between stabilization and transformation (e.g., Table 1).

The relationship between social-ecological resilience and coastal governance

Coastal SES compass a particularly diverse environmental resource base (Glaser and Glaeser 2014), but over-exploitation and increasing urbanization reduce the resilience in coastal areas, which is further exacerbated by climate change (Motta Zanin et al. 2021). Governance systems are often decentralized (Boyes and Elliot 2014, de Alencar et al. 2020) and management activities are fragmented, due to different interests and conflicts of actors, as well as a separation into land and ocean (Nursey-Bray 2014, de Alencar et al. 2020). This complicates the navigation between stabilization and transformation toward desirable system states and overall resilience management of coastal SES.

In order to enable SER in coastal systems, some area-based management (ABM) approaches can facilitate effective governance in face of climate change. A variety of ABM approaches exist to manage the coast at the local scale (Dunstan et al. 2021). For example, Integrated Coastal (Zone) Management (ICZM) is "a dynamic process for the sustainable management and use of coastal zones, taking into account at the same time the fragility of coastal ecosystems and landscapes, the diversity of activities and uses, their interactions, the maritime orientation of certain activities and uses and their impact on both the marine and land parts" (European Commission 2009). ICZM provides for a structured approach for preparing, implementing, and evaluating strategies to achieve policy objectives. The management process integrates different actors and institutions from different levels in an adaptive and participative approach, including climate adaptation planning (Tobey et al. 2010, O'Mahony et al. 2020, Ojwang et al. 2017).

Such participatory processes for governing coastal systems at the local scale may also support the navigation between stabilization and transformation in the face of climate change. For example, in the case of transformation, Scoones et al. (2020) draw on human agency and propose three distinct but complementary approaches to transformation, namely structural, systemic, and enabling approaches. While structural approaches require fundamental shifts in ecosystem governance, systemic approaches target specific interdependencies of institutions, technologies, and actor constellations to achieve a normative goal in complex systems. Enabling approaches, on the other hand, aim at "fostering human agency, values and capacities necessary to manage uncertainty, act collectively, identify and enact pathways to desired futures" (Scoones et al. 2020). While structural approaches relate to the global scale, an enabling approach refers to a more endogenous, bottom-up transformation at the local scale, such as enabled through local coastal governance.

Even so, the implementation of resilience remains a challenge in coastal governance. In order to facilitate bottom-up approaches within local coastal governance processes, more collaborative research including approaches for co-producing knowledge together with actors from policy and society are necessary. In the next section, we propose a process that can be applied by researchers to support the operationalization of SER through coastal governance.

ENABLING SOCIAL-ECOLOGICAL RESILIENCE THROUGH COASTAL GOVERNANCE

In recent literature, the need for "actionable knowledge" has been highlighted, e.g., within environmental sustainability science (Caniglia et al. 2020, Mach et al. 2020, Wong-Parodi et al. 2020) and climate science in particular (Bremer et al. 2019, Daniels et al. 2020, Celliers et al. 2021). It draws on the importance of increasing the uptake of scientific evidence through knowledge co-production with society, often in form of transdisciplinary approaches (e.g., Norström et al. 2020, Folke et al. 2021), rather than the simple provision of data and information. This requires knowledge of actors and governance systems, as well as a facilitation of knowledge exchange between actors. This points to various types of knowledge that must be considered in the local coastal resilience debate. We propose the use of the "three types of knowledge" typology often applied when framing a system in sustainability science (based on ProClim 1997, further developed in Pohl et al. 2017). The typology includes "systems" knowledge (what is?), "target" knowledge (where to?), and "transformative" knowledge (how to get there?). There is an existing body of scientific literature on coasts as "systems," and specifically SES (e.g., reviewed by Refulio-Coronado et al. 2021). However, "target" and "transformative" knowledge are still underrepresented in literature. "Target" and "transformative" knowledge of actors within governance processes involves aspects such as visioning (of the future) and goal setting, as well as pathways and trajectories for achieving those visions and goals (Spangenberg et al. 2015).

When considering SER to climate change of coastal systems, the entangled concepts of stability and transformation, different scales, vague system boundaries, and questions of normativity need to be navigated. Within the context of the knowledge typology, we propose a five-step approach for addressing SER in coastal SES according to systems, target, and transformative knowledge (Fig. 2). Steps 1 and 2 thereby contribute to the systems knowledge, and Step 3 to the target knowledge. For implementing and enhancing transformative knowledge in coastal SES, we consider two key mechanisms including the adaptive capacity and agency of local actors (Step 4) and scientific information services for informed decision-making (Step 5). Consequently, local actors and information services are to be integrated into all of the steps in order to both foster two-way exchange between science and society and to tailor solutions to the needs of the local actors.

Systems knowledge

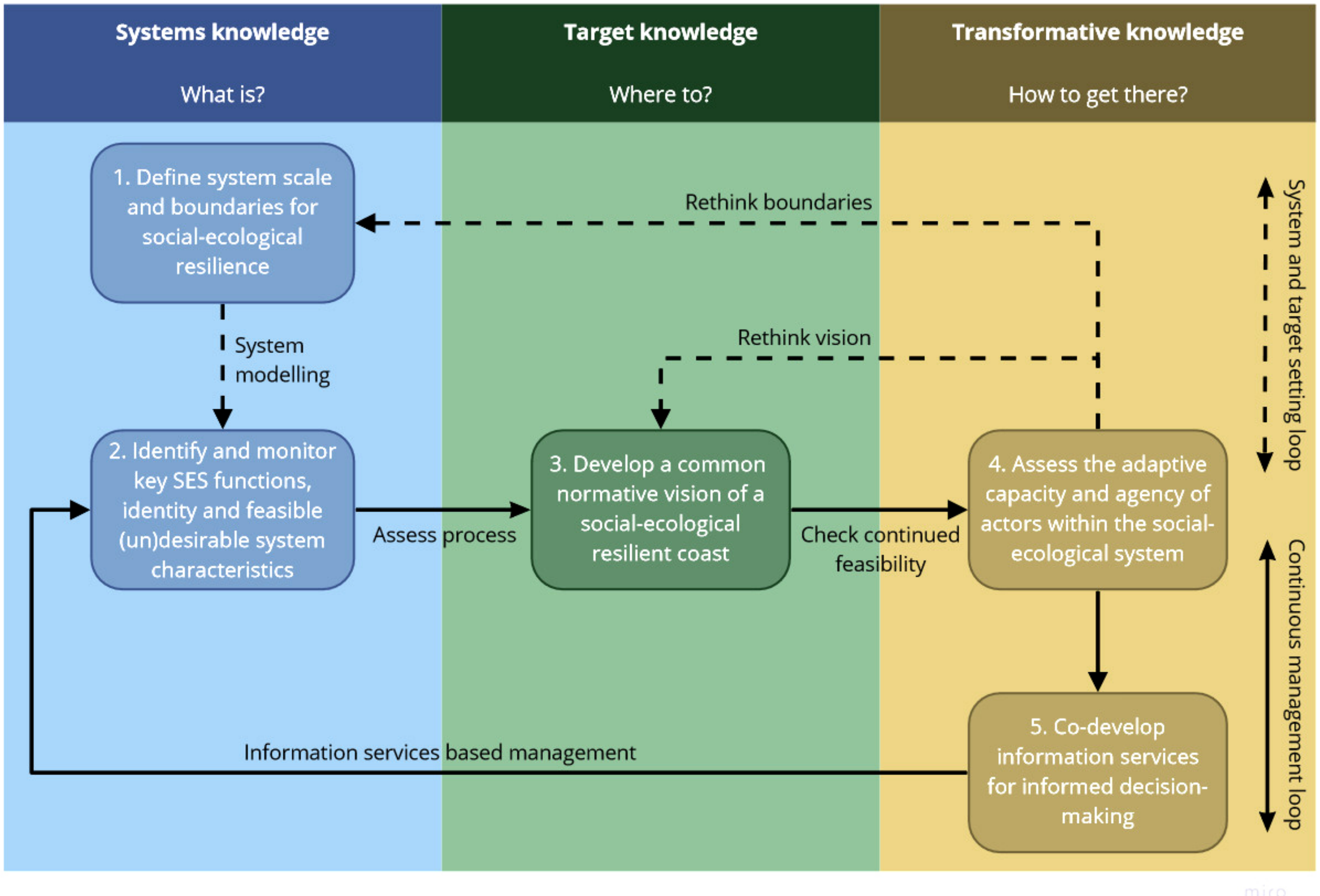
Step 1: Define system scales and boundaries for SER in coastal systems

Coastal systems are particularly dynamic and complex, and different administrative levels, spatial (land-ocean interface, extent of SES), and temporal scales of change need to be considered (Fig. 3).

Determining the administrative scale and level at which to operationalize resilience is not trivial, and what constitutes its appropriate boundaries is dependent on the (local) context and the objective (target knowledge), as well as on cross-level and cross-scale interactions (Carpenter and Turner 2000, Gunderson and Holling 2001, Cash et al. 2006). However, complex multi-scale interactions (Levin 1998) make defining clear system boundaries in relation to SES challenging. Especially when managing for transformation, the local level cannot be isolated from larger scales and levels. For example, where a whole coastline is under threat of flooding due to sea-level rise, local action may not be sufficient to maintain SER.

The landscape-scale has been suggested as a useful operational scale for studying such interactions and assumes that local action drives change in SES (Wu 2013). The extent of the landscape-scale can range from 10 to 100 km, depending on the associated physical processes and anthropogenic actions within the focal system. Even though it is spatially restricted, choosing the landscape-scale also recognizes the dynamical interlinkages in the face of uncertain changes from internal feedbacks and external disturbances (Wu 2013). Landscapes are hence social constructs that are shaped by the actions of a variety of actors (Sayer et al. 2015, Köpsel and Walsh 2018), and what constitutes the "landscape scale" is often vague. Determining the scale for dealing with issues of managing SES, therefore, is not trivial and needs to reflect the mandate of actors and agency to act (Garmestani and Benson 2013). Moreover, both practicality and the unique "local" characteristics and key functions of SES suggest that local governance administrative boundaries are likely to provide a vital scale for addressing bottom-up approaches toward enabling SER.

Fig. 2. Addressing social-ecological resilience in coastal SES, based on systems, target, and transformative knowledge. The order of steps is indicated by numbers, and iterative learning cycles are indicated by straight and dashed lines.

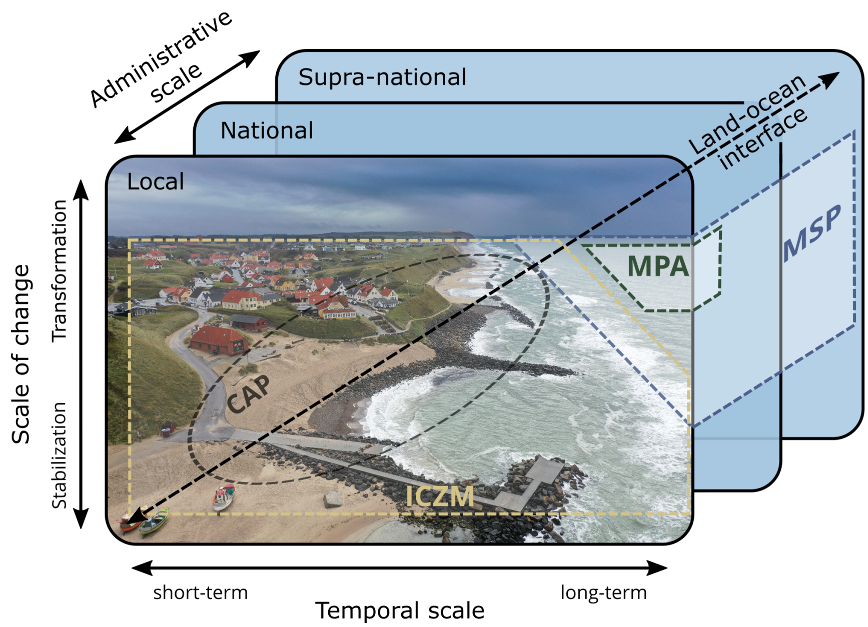


Local coastal governance is defined as place-based political and institutional processes of coastal management and the implementations of related decisions. It creates the conditions for ordered rules and collective action and encompasses actors from government, the private sector, and civil society (Adger 2003, Shah and Shah 2006, Ojwang et al. 2017, Celliers et al. 2020). Governance, in this context, also includes the key institutions for addressing environmental and climate change challenges (Celliers et al. 2020). Therefore, local coastal governance results in the establishment and implementation of local policies, which affect (to a limited extent) and are affected by national to international policy regimes.

In defining the scale at which SER is operationalized there are likely to be trade-offs between agency to effect change, on the one hand, and the ability to tailor solutions to the unique characteristics of different SES, on the other. Fine scale governance for climate resilience in coastal systems means that some system characteristics (such as rate of sea-level rise) have to be adapted to but may simultaneously allow for transformative changes in relation to livelihoods or governance structures that are facilitated by localized system characteristics. Therefore, a key consideration is the interplay between the governance scales and clear understanding of agency and transformative change.

Furthermore, coastal management approaches have to acknowledge the integrated nature of coastal systems across the land-ocean interface (Rölfer et al. 2021) (Fig. 3). The bio-physical features of land and ocean are seamlessly connected and as such the landscape scale should ignore the “boundary” created by the shoreline. This is necessary to avoid a mismatch between scales of change and scales of management, or in other words, between the “governing system” and “the system-to-be-governed” (Jentoft 2007). While ICZM offers a process for the governance across the land-ocean interface, it overlaps with other ABM approaches, such as Marine Spatial Planning (MSP). MSP, however, is often applied at a larger spatial scale (of the ocean) and often applied at the national and regional (international) scale (Fig. 3). A subsequent fragmentation into different management approaches has, to date, complicated the integration between different policies and a consistent management across the land-ocean interface at different spatial scales (Maragno et al. 2020, O’Hagan et al. 2020). Defining system boundaries by integrating different ABMs,

Fig. 3. Identifying key scales and boundaries in coastal social-ecological systems across which resilience has to be managed. The spatial scale includes both the land-ocean interface, as well as the connection between SES along different spatial scales. Different area-based management approaches such as Marine Spatial Planning (MSP), Integrated Coastal Zone Management (ICZM), and Marine Protected Areas (MPA) are thereby applied within different spatial extents and at different administrative levels (local, national, supra-national). Additionally, Climate Adaptation Planning (CAP) is of relevance for coastal governance at the local scale. The temporal scale is dependent on the system's characteristics and target and may vary between short- and long-term planning. Linked to the temporal scale is the scale of change, which is characterized by a navigation between stabilization and transformation. Aerial photograph used with permission by Lisa Röpke.



therefore, may facilitate the implementation of coastal resilience across boundaries.

Additionally, the temporal scale is particularly important with regard to stabilizing and transformational trajectories (scale of change, Fig. 3). There may be different trade-offs between the long-term feasibility and the short-term desirability of different management approaches, which are further complicated by the uncertainty about future climatic and socio-economic changes. Managing for a state of the SES that is resilient in face of multiple environmental and anthropogenic stressors requires using the knowledge of current and future drivers that influence ecosystem function, in order to prioritize, implement and adapt management actions that sustain ecosystems and human well-being (Mcleod et al. 2019).

Finally, the selection of appropriate planning and management frameworks (such as MSP and ICZM), as well as appropriate scales for conceptualizing and managing SES for resilience, then also relate to the agency and adaptive capacity of actors (Step 4) at different scales to both decide upon what constitutes desirable (and possible) change, and to nudge systems toward a desirable state (Step 2 and 3).

Step 2: Identify key SES functions, identity, feasible and (un) desirable characteristics

Managing for a state that is social-ecologically resilient to climate change requires the management of different system characteristics and their adaptive capacity of both the social and ecological system. Increasing the resilience of coastal areas to climate change has mainly been associated with climate adaptation practices for coastal communities that maintain present conditions and system functions (IPCC 2014). Even though stabilization is not undesirable *per se*, at some point in time the economic benefits of stabilization practices may become negative, e.g., in the case of coastal defense through dikes (de Bruijn et al. 2017, Masselink and Lazarus 2019). An assessment of feasible characteristics should therefore include the consideration of stabilizing and transformational approaches, which also recognizes environmental characteristics (Petersen et al. 2018). While stabilization or a transformation toward a more desirable system state may be desired, it might be restricted by system characteristics that are not possible/feasible to alter.

The definition of feasibility and desirability of a system should be informed by both local actors and information services (provision of context specific information for evidence-based decision-making). Participatory stakeholder mapping and other knowledge co-production methods are critical to identifying system components and their relationships, in order to model the SES (Giordano et al. 2020, Williams et al. 2020). System boundaries may also be identified using such knowledge co-production approaches. Information services can further contribute to identifying environmental characteristics, such as climate characteristics, ecosystem attributes and processes, or landscape compositions and configurations (Chambers et al.

2019). Desirable and undesirable characteristics within the SES can thus be identified. Other desirable characteristics, such as cultural values, should be identified and included in modeling as they contribute to the systems identity.

It is necessary for there to be an iterative process between identifying (un)desirable system characteristics and the definition of system boundaries, and therefore the scale of management (top loop, Fig. 3). This in turn will influence the normative goals on which SES resilience management should be focused (Step 3).

Target knowledge

Step 3: Develop a common normative vision of a social-ecological resilient coast

Humans and their activities drive major changes in coastal SES - both positive and negative. As such, humans are, to some extent, capable of steering the trajectory of change. The trajectory also depends on both the adaptive capacity and the intended or desired outcome. Planning with regard to managing the impact of climate change at the local level, thereby, depends on the concerns, preferences, perceptions, and knowledge of local actors (Tyler and Moench 2012, Torabi et al. 2018, Hoerterer et al. 2020) as well as the location-specific context (Glaser et al. 2012, Lorenz et al. 2017, Birchall 2020).

Management goals in coastal areas are multi-faceted and sector-dependent, including a variety of actors with different resources, power, and at different local to national levels (Celliers et al. 2012). Managing for a state of the coast that is social-ecologically resilient, therefore, requires the integration of multiple values and interests to fully understand benefits and trade-offs (Chakraborty et al. 2020), especially in a changing climate. This could potentially reduce both conflicts between different actors and the vulnerability of SES to multiple, often conflicting, activities, e.g., for fishing and tourism activities (Lazzari et al. 2021). Such a common normative vision is fundamental to a cross-sectoral approach and to agree on coordinated actions. Consequently, when managing for SER, agreement and coordination between often-siloed ABM approaches, e.g., integration between ICZM and MSP is required. This is particularly true for climate adaptation planning (O'Hagan et al. 2020, Schlüter et al. 2020). Such coordination between ABMs will assist management of the system across predefined boundaries, such as the land-to-ocean interface. This, in turn, may be required to negotiate new system boundaries (Step 1).

The navigation between stabilizing adaptation vs. transformation can become central to finding a common normative vision of a social-ecological resilient coastal future and is highly dependent on the scale at which (un)desirable and feasible characteristics can be managed and on actor perceptions on desirable change, as described in Step 2. A desirable system state should also be informed by the goals and targets set out in intergovernmental frameworks, especially the SDGs and the Paris Agreement, in order to identify possible solutions for reaching these goals in the future. The role of scientific research is to play an important role in informing possible pathways with which to achieve normative visions in the local context and to catalyze action and transformative change (Ramesh et al. 2015, Norström et al. 2020, Rudolph et al. 2020). This may include an exploration of collective action and institutional changes, and broadening of adaptation options including more environmentally sustainable and ecosystem-based approaches, given the uncertainty about future climate impacts. For example, ecosystem-based "soft" solutions in favor of engineered "gray" solutions are more flexible and can often provide co-benefits by acting as natural buffers and simultaneously providing ecosystem services to society (Bonnett and Birchall 2020, Thonicke et al. 2020).

The question of how to generate a common vision for a resilient future in coastal systems is not trivial, as previously discussed in the section - Tensions between stabilization and transformation. However, if resilience scholars are serious about including transformation in resilience thinking, then methods for developing normative visions are needed. While it is beyond the scope of this paper to address this point in detail, there are a number of promising approaches that could be applied to facilitate such visioning. These include conflict management as part of management processes, e.g., within ICZM (Westmacott 2002) in conjunction with methods for co-production e.g., participatory action research (Keahey 2021), anticipation and foresight for governance (Vervoort and Gupta 2018, Levin et al. 2021), and futures thinking (Stoddart et al. 2020, Wyborn et al. 2021). The participatory "three horizons approach" to scenario development and back-casting (Sharpe et al. 2016) may provide another useful approach for developing normative visions for coastal systems. The *three horizons approach* is particularly promising with regard to implementing SER. It focuses on mapping desirable and undesirable system characteristics, and the agency required to alter such characteristics in relation to purposeful transformative change. Using such approaches to build a future vision that is co-produced with local actors will consequently be more socially acceptable for the actors involved (Caniglia et al. 2020). Such an approach may also support deliberate transformations by actors endogenous to the system, as they can better understand the value of such change through their participation (O'Brien 2012, Charli-Joseph et al. 2018).

Given the scale dependency of setting meaningful target knowledge in relation to SER management, further iteration between shared normative visions and the setting of appropriate system boundaries is necessary (Fig. 2). Where the normative goals may have to be "scaled" to match the management scale, or the management scale adjusted to match the desired system goal. A final step (Step 4) in this iterative learning loop (top loop in Fig. 2) is to understand which (un)desirable system characteristics are endogenous to the system, and can therefore be (potentially) transformed by actors within the system, and which are exogenous and can only be adapted to.

Transformative knowledge

Step 4: Assess the adaptive capacity and agency of actors within the SES

Human agency is the driving force for managing social-ecological systems and therefore SER. Local actors, for example, play a critical role in transformation to climate resilience (Torabi et al. 2018, Williams et al. 2020) and sustainability (Abson et al. 2017, Lyon et al. 2020). In the case of poverty alleviation, effective transformation has been shown to be led by actors endogenous to the system, involving priorities different from the status quo, and leading to change across multiple levels of society (Lade et al. 2017). In order to contribute to SER in coastal areas, a bottom-up approach including collective action of local actors may be required to drive (transformative) change in current management systems.

Therefore, the actors of the system of interest have to be identified, which in turn re-defines system scale and boundaries (Step 1). Actors, thereby, can be both actors that are physically placed within the system but also actors at other levels, e.g., national level that have agency in the local system. This means that actors that fall outside system boundaries may still need to be integrated into the process. Social experiments and participatory planning approaches are appropriate for determining both the social and ecological adaptive capacity of coastal systems at the sub-national to local scale (Whitney et al. 2017, Celliers et al. 2020). Place-based research will be necessary to investigate how local coastal governance can contribute to the SER and sustainability of coastal systems (Wu 2013), including identifying where power relations within institutional arrangements may block transformational processes (Béné 2012, Cote and Nightingale 2012, Brown 2014). This may include empirical and quantitative research on the role of local actors by identifying their adaptive capacity, agency, and ability to leverage change through individual and collective action, which is currently underrepresented in climate adaptation research (Cárcamo et al. 2014, Ziervogel et al. 2017). Suitable methods are stakeholder and network analyses (Cárcamo et al. 2014, Ziervogel et al. 2017, Ahmadi et al. 2019, Kluger et al. 2020) for identifying key actors that can enhance change within the system (Gain et al. 2019).

Step 5: Co-develop information services for informed decision-making

After defining system boundaries, identifying shared normative goals, and the agency of actors, active management is still required to make the system more resilient (bottom loop in Fig. 2). Such active management as part of local coastal governance and by local actors requires science-based information. This includes information about external drivers, such as climate and environmental change, as well as economic development, but also internal drivers such as local information including Indigenous and traditional knowledge about experienced change or cultural values (Rölfer et al. 2020). Even though there may be much data and information available for coastal systems, its integration into local planning remains challenging. This is due to a lack of appropriate "translation" of data into information then into knowledge and wisdom at the local level (Celliers et al. 2021). This means, that more co-developed information services are required that foster two-way exchange between science and society and which are responsive to the needs of decision-makers.

Climate information services, in particular, can be useful for enabling the SER to climate change, if they are tailored to the framing of coastal SES. The concept of "climate services" has been established throughout the last decade as a means for science- and action-based participatory solutions to climate change (Hewitt et al. 2017). It is defined as the "transformation of climate-related data into customized products such as projections, forecasts, information, trends, economic analysis, assessments, counseling on best practices, development and evolution of solutions, and any other service in relation to climate that may be of use for the society at large" (Street et al. 2015). The terminology of "coastal climate services" has just evolved throughout the last few years, with only a few studies referring to the specific term (Le Cozannet et al. 2017, Hinkel et al. 2019, Breili et al. 2020, Khan et al. 2020, Stephens et al. 2020). All of those studies relate to adaptation to sea-level rise and predominantly address the physical aspect from a social perspective. However, a broader definition may be necessary to integrate also the ecological components of SES.

For such services to be fit for purpose, the considerations introduced in all of the prior steps, and hence all three types of knowledge, should be integrated into their design in order to be applicable to coastal SES. In order to empower local actors to manage for SER and facilitate sustainability and transformation, more research and development of effective and co-produced information services are needed. In the field of climate services, more research is needed on the provision of climate information that is tailored to the specific challenges in coastal systems, as well as to the implementation cycles of local coastal governance systems facing climate change (Tribbia and Moser 2008, Hinkel et al. 2019).

As with the system and target-setting loop (Fig. 2), the management loop also requires a continued iterative process and changing circumstances may require further reassessment of system boundaries, adaptive capacity, and normative goals in managing coastal SES for resilience to climate change.

Iterative learning cycles

Even though we present the approach using numbered steps, iterations between the steps will be necessary. This is indicated with straight and dashed arrows (Fig. 2) for the target-setting and management loop, respectively. The starting point of the approach may also not always be at Step 1. This may be most apparent in the questions, whether one first needs to define the current system including its identity and characteristics or whether a normative vision of the future state and the adaptive capacity and agency of actors defines the scale and boundaries of the system of interest in the first place (dashed-line cycle). Finally, resilience is not a static condition but rather a characteristic of systems that are adaptive, flexible, and constantly evolving (Folke et al. 2016). Constant reflection and re-evaluation between the target system and the current system will therefore be necessary (Whitney et al. 2017). This is indicated in our approach by the iterative cycle between Steps 5 and 1 (straight-line cycle).

Iterations of the target-setting and management loop facilitate a structured learning process, similar to double- or triple-loop learning. Such learning cycles relate to a reflection of the design of the process (double-loop) and the reconsideration of underlying values and beliefs (triple-loop), which is considered important in environmental governance (Pahl-Wostl 2009). Therefore, the suggested approach does not only focus on achieving a goal but also on adjusting the target to continuously manage for resilience.

While elements of the proposed approach may correspond to the adaptive cycle or policy pathways (e.g., Haasnoot et al. 2013), this approach should be viewed as complementary; emphasizing a transdisciplinary bottom-up approach at the local level. Developing such a transdisciplinary approach is particularly important for the creation of a normative vision given diverse objectives. It integrates adaptation but also draws particular attention to possible system transformations driven by local actors to enhance SER. Furthermore, adaptive cycles tend to underrepresent conflicts between actors in face of uncertain change, which the proposed approach accounts for by focusing on the identity of the current system, as well as finding a common normative vision between diverse actors.

CONCLUSION

Climate change and other environmental stressors pose serious threats to coastal and marine ecosystems and coastal communities depending on them. The concept of resilience facilitates a holistic approach for flexible and adaptive coastal management, yet the operationalization at the local level remains challenging. Researchers still need to develop a better understanding of what constitutes resilience in particular contexts. The SER approach provides an appropriate lens for researchers to integrate the human dimension and their agency to manage coastal social-ecological systems toward a systems state that is desirable for humans and nature.

The navigation between stability and transformation within the concept of resilience is thereby central to finding sustainable future pathways in the face of climate change. We propose the application of three types of knowledge (system, target, and transformative) in an iterative learning process to support the identification of (un)desirable and feasible system components and characteristics of the current system, the development and continuous reflection of a common normative vision of the future, as well as solutions on how to move toward that envisioned systems state. We further propose the application of various approaches for co-producing knowledge between scientists and societal actors in coastal governance, that are responsive to the agency of actors and the power relations within institutional arrangements. We also highlight the role of both local actors and information services and the need for participatory approaches to foster two-way exchange between science and society, and approaches that are responsive to the needs of decision-makers. This may enable decision-makers within local coastal governance to manage for SER more effectively. While the paper concentrates on coastal systems, the proposed approach may also be applied to other social-ecological systems.

Further research is required to develop approaches for assessing the adaptive capacity and agency of local actors within place-based research. In the provision of information services, services need to be further developed that are tailored to the needs of local actors in, and policy implementation cycles of, coastal governance.

Responses to this article can be read online at:
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Data Availability:

Data/code sharing is not applicable to this article because no data/code were analyzed in this study.

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