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ORIGINAL ARTICLE

Nurturing ecosystem-based adaptations in South Africa's Garden Route: a common pool resource governance perspective

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Abstract

Increasing human demands for ecosystem services due to climate change, population growth, poverty, lack of employment, tourism, and concomitant coastal property development threatens adaptive capacity in South Africa's coastlines. Adaptation strategies frequently propose ecosystem-based adaptation (EBA) as a model for transformative change. However, several studies point to difficulties implementing EBA across the world. The aim of this paper is to assess to what extent social-ecological systems approaches and common pool resource (CPR) governance theories could inform EBA. Data obtained from interviews and surveys with policy makers and residents in South Africa's Garden Route District were interpreted using the robustness framework (RF) and the design principles (DPs), two common tools for analyzing CPR governance. We found that the Garden Route coast is threatened by negative interactions between hard public and private infrastructures and ecological infrastructures (the cornerstone of EBA) which are driven by weak local government bodies and asymmetrical power relations. By coding the data for elements/interactions within the RF and then identifying and mapping the DPs onto the RF, we also revealed ways to leverage transformative EBA in the Garden Route. Our analyses suggest that the interactions between human-made and ecological infrastructures, as well as power relation, should be at the core of any development debate. Trade-offs should aim for maximum congruence between sustainability and equity in ecosystem services provisioning. This paper provides some considerations for researchers and decision makers to leverage transformative EBA that could potentially apply to areas experiencing similar challenges.

Keywords Coastal resilience · Climate change adaptation · Design principles · Robustness framework · Ecological infrastructure · Congruence · LTSER

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Introduction

Coastal zones are particularly vulnerable to climate change, but adaptation planning has mostly been haphazard, with many unintended negative consequences (Carey et al. 2012). Success stories are scarce because managing coastal systems places great demands on organizational capacity and leadership and, even in developed countries, stretches their knowledge and insights to the limit (Measham et al. 2011). Planners are therefore challenged to balance the need for complexity, holism, and integration with the realities and practicability of adaptation plans. Most adaptation plans for coastal areas promote development and economic activity, even in vulnerable areas, instead of pursuing long-term objectives such as ecosystem-based adaptation (EBA) (Young et al. 2006; Barbier et al. 2008; Temmerman et al. 2013; Nel et al. 2014). Uncertainties, economic pressures, and political turmoil constitute "wicked" problems that hamper adaptive

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capacity and add to the difficulties of implementing climate change policies (Moser et al. 2012; Pasquini et al. 2015). Hence, the need for decision support tools to aid in marine and coastal EBA, in particular to explore the linkages and feedbacks between social and ecological systems across different geographic and temporal scales (Leslie and McLeod 2007).

There is broad agreement that adaptation planning needs to embrace an integrated, cross-sectoral approach (Ziervogel et al. 2014; Reyers et al. 2015) and that this necessitates the adoption of a complex adaptive systems perspective (Timmermans et al. 2012). Theories on the governance of social-ecological systems (SES) have flourished over the past 30 years and include resilience, sustainability, and other holistically integrated approaches. Building upon common pool resource (CPR) theories, Ostrom and colleagues' research on the sustainable governance of SES suggest that particular types of governance systems are more robust to change than others (Ostrom 1990, 2009; Anderies et al. 2004). However, because of the difficulties of linking theory and practice in complex adaptive systems, there is a paucity of information on the governance challenges of implementing these strategies in practice (Anderies and Janssen 2013). A research agenda focusing on coupled infrastructure systems has been proposed as an appropriate unit of analysis to overcome the difficulties of operationalizing the SES frameworks and to encourage comparative analyses (Anderies et al. 2016). Here, we propose to test the use of CPR ontologies to explore transformative pathways to global change adaptation in coastal areas within a South African context of political and environmental uncertainties.

South Africa's scenic coastline is affected by intensifying human impacts on the natural environment, rising demand for services due to in-migration of people searching for work, poverty, tourism growth , and concomitant increases in urban development, including converting coastal lands into suburban areas (Crisp 2015). Many parts of the coast have been impacted by climate change in the form of droughts, fires, and floods that threaten human infrastructure and biodiversity (Nel et al. 2014; Reyers et al. 2015). Policy makers have responded to these threats by focusing on coastal adaptation plans at provincial and district levels, but these plans are rarely implemented at the municipal level (Sitas et al. 2014a; Pasquini et al. 2015; Pasquini and Cowling 2015). For the past 10 years, environmental forums have flourished, motivated by awareness of unsustainable trajectories and short-term threat perceptions (Western Cape Province 2017). However, reactive responses and poor integration across sectors and scales (Sitas et al. 2014a; Ziervogel et al. 2014) present obstacles which are exacerbated by historical inequalities—the legacy of race-based policies–shortages in time and funding, as well as weak human capacity (Faling et al. 2012; Sitas et al. 2014a; Pasquini et al. 2015; Mudombi et al. 2017). Many organizations and individuals support learning, knowledge co-production, collaboration, and partnership (Reyers et al. 2015). While some adaptive responses are emerging, the adaptation challenge is enormous and often requires not just incremental but also transformative changes (Moser et al. 2012).

A first challenge is to provide more practicable approaches that allow developers, planners, and policy makers to adopt a complex systems approach by proactively considering the outcomes on the social and environmental structures within which they are embedded, as well as across scales, and where necessary adjust these. A second challenge is that complex systems management necessitates adaptive transformative approaches and constant value judgment. The assumption of rational actors responding wisely to carefully constructed models seldom holds, no matter how good their empirical and scientific foundations. Hence the need to provide common tools to visualize the state of the system, its diverse components, and how decision making and rules may affect them. A third challenge is that collaborative governance means building trust, learning, co-creating solutions, and finding common ground (Baird et al. 2014; Reyers et al. 2015). Several authors reckon that transformative change requires actors to have a common intent or, at least, a collective vision (Abson et al. 2017; Colloff et al. 2017). All of this should also be supported by regional and national policies encouraging collaborative management efforts (Armitage et al. 2009). A SES lens that views adaptation as a common pool governance challenge might shed new light on these challenges.

Here, we adopted two CPR governance tools to analyze and understand the factors affecting proactive adaptation to global change in the Garden Route coast (South Africa). The robustness framework which was originally conceptualized in 2004 (Anderies et al. 2004) and modified to a coupled infrastructure perspective in 2015 (Anderies 2015) emphasizes that operational and collective-choice levels must be analyzed together in order to assess the system's vulnerability and adaptive capacity. The coupled infrastructure perspective of the 2015 iteration of the robustness framework (hereinafter "RF") extends the notion of infrastructure to various system components, allowing the analyst to focus on the feedbacks generated among these linked infrastructures (Anderies 2015). The RF, thus, represents an ontology that allows an analyst to identify key elements in a system of interest and the interactions among those elements that are salient to the social dilemma/resource problem of interest. In doing so, it helps identify a general set of variables that can be used to analyze various types of similar settings within the system of interest and across other similar systems. It also provides a way to identify relevant theories that can then be used to hone in on particular aspects of interest within the system (Ostrom 2005).

The design principles (DPs) were often found to be present in long-enduring small-scale CPR governance regimes and help explain key governance components (Ostrom 1990; Ostrom 2009). This includes the conditions under which trust and reciprocity can be built and maintained in order to sustain collective action in the face of social dilemmas, such as resource overexploitation (Cox et al. 2010). The DPs provide a complementary methodology to determine whether the results

of the interactions among the elements in the RF are robust or not (Ostrom 2009). For instance, one could utilize the RF to determine interactions that work or do not work well within the Garden Route SES, and then use the DPs as an additional tool to determine whether the presence or absence of particular DPs may be contributing to the weakness/strength in the interaction.

In essence, the RF and the DPs represent different, yet complementary, lenses with which to analyze a particular issue of interest. The RF provides a broader more general oversight of the system and key interactions within it. The DPs are higher-level theories of key criteria that have been found to aid in overcoming social dilemmas related to resource over-appropriation or under-provisioning of infrastructure.

We utilized a mixed-methods approach to animate the interactions within the Garden Route SES, as described by interviewees, by coding the descriptions to the relevant feedbacks in the RF. We then separately analyzed whether those interactions represented evidence of DPs or not and then compared our findings to those outlined in the literature.

Data sources and analyses

Mixed-methods research involves combining elements of qualitative and quantitative approaches to promote breadth and depth of understanding through corroboration (Johnson et al. 2007). Data to populate the RF were collected using aerial photographs, ecosystem surveys, and in-depth interviews with private and public sector decision makers from all three tiers of government, as well as surveys with residents (Table 1). For a given set of interviews, the same guide was used with all informants and, when purposive sampling was conducted, the sample was closed when collected information indicated saturation (Guest et al. 2006).

As outlined in the "The Garden Route social-ecological system, South Africa" section, we used the modified RF (Anderies 2015) to outline the core elements of the Garden Route SES context, to examine the interactions/processes among these elements, and to explore the influence of exogenous drivers based on the data generated by our mixed-methods approach (Fig. 2). In order to unite the RF and the EBA approaches, we adjusted some of the vocabulary. Ecological infrastructure, i.e., "a network system of natural lands and waters that provides ecosystem services" (sensu Lee et al. 2014, P. 764; also see SANBI 2014), was employed instead of the term "natural infrastructure." This allowed us to better incorporate ecological processes which represent not only the state of the natural assets but also the functionality of the coastal ecosystems and ecosystem services they provide (Reyers et al. 2015; Reid 2016).

Table 1 Mixed methods applied to perform the analysis of the resilience of the Garden Route social-ecological system to environmental changes

Protocol	Study site	Aim	Methods	Focus and sample size
A	Garden Route District Coastline from Gouritzmond to Nature's Valley	Determine the rate of development on coastal sand dunes.	Inspection of 31 aerial photographs from 1935 to 2007.	Ecological Infrastructure (I_E) (Foredunes)
B	Suburbs of Hartenbos, Bothastrand, Outeniqua Strand, Glentana, Wilderness West, Wilderness East, Buffelsbaai along the coastline	Determine to what extend coastal landowners are exposing themselves to sea-level rise along the Garden Route.	Stratified random sampling of properties along the coast, record p hysical characteristics of property, structures and dune, descriptive statistics based on observations (2015).	Private human infrastructure ($I^{PRh}{}_{HM}$) (Properties on foredunes, $n = 130$)
C	Development role players (environmental consultant, developers, and architects) who have worked on projects on Eden District's coastline	Identify the knowledge and practices of development practitioners towards ecological infrastructure.	Purposive sampling and snowballing, full transcription and coding, content analysis (2014).	Resource users (RUs) (Private decision makers and consultants, $n = 37$)
D	Residents living on coastal foredunes in the suburbs of Wilderness, Buffalo Bay, Grootbrak, and Hartenbos	To assess the perception of risk, sense of water, and the sense of place of people living in coastal areas.	Survey questionnaire, stratified random sampling, descriptive statistics (2016)	Resource users (RUs) (Residents of the foredunes, $n = 66$)
E	Government representatives working on the Garden Route District with ties to coastal adaptation (at local, district, or provincial level)	Explore the processes sustaining the adaptive management of coastal areas in policy implementation agencies	Purposive sampling and snowballing, semi-structured interviews, full transcription and coding, content analysis (2016)	Public infrastructure providers (PIPs) ($n = 13$) including provincial government, district municipality, local municipality, SANParks, and Cape Nature representatives

The software NVivo (Woods et al. 2015) was used to code the interview transcripts for the institutional discourses used that related in particular to the following: (i) the interactions and feedbacks between different infrastructure types (Links#1–6 of the RF), and (ii) the presence/absence and nature of Ostrom's DPs (Table 2). The DPs that were identified during coding were then manually added onto the RF in order to provide complementary details about the characteristics of the infrastructures, the interactions among them, and the exogenous drivers influencing them. Once coding was completed, 20% of the coded interviews were double checked for coding accuracy by other members of the research team.

The Garden Route social-ecological system, South Africa

The Garden Route District (formerly known as Eden District) is situated in the Western Cape Province of South Africa. Our study focuses specifically on its coastline extending from Vleesbaai in the west to Nature's Valley in the east (Fig. 1).

The resource system and biophysical conditions

Ecological infrastructure

The study area's coastline is a mosaic of rocky headlands interspersed with soft features (beaches, dunes, salt marshes, freshwater systems, deltas, lagoons, and estuaries), dunes and beaches being the most abundant. Rocky shores are interspersed with dune systems stabilized by coastal vegetation that act as sediment traps (Tinley 1985). The ecological infrastructure (I_E) provides numerous ecosystem services, including coastal protection, erosion control, water catchment, water purification, wildlife refuge, tourism, raw materials, food, and recreation, and is rich in biological diversity (Barbier et al. 2011; Sitas et al. 2014a; Nel et al. 2014).

Private hard (human-made) infrastructure

Since 1930, the number of suburbs and residences within the study area has grown dramatically with a peak in the 1960s (Crisp 2015). This coincided with the drive by the South

Fig. 1 Garden Route coast and associated ecological infrastructures. Top left: The white rectangle shows the location of the study area in relation to South Africa. Bottom: Extent of study area showing Vlessbaai to the west and Nature's Valley to the east (Source: Google Earth Pro v.7.3.1). The picture on the top right was taken from Wilderness' Dolphin's point and illustrates an iconic section of the coast (© C. Fabricius/Sustainability Resource Unit, Nelson Mandela University, George Campus)

African government to increase revenue through purchases of land to make up for revenue lost through the reduction in tourism. Development of the foredunes continued well into the 1990s, even after South Africa implemented new environmental legislation in 1996. During the 1990s, there was an upsurge in the development of golfing estates and other high-security ("gated") developments, but the rate of development started flattening off in the mid-1990s due to a more stringent application of environmental legislation and public resistance (Crisp 2015).

Public hard (human-made) infrastructure

Key hard public infrastructures include gabions and engineered constructions to protect coastal properties, roads, drainage lines (gray and storm water drains), transport network, and carparks, as well as pathways and staircases to access beaches. They can be developed and maintained by local municipalities, provincial, or national government services.

From an RF perspective, the SES's biophysical conditions are determined by the network of ecological and hard (public and private) infrastructures (IPUhHM and IPRhHM), meant to deliver affordances (resources) to community members (Link#1) (Anderies 2015) (Fig. 2). For example, freshwater is collected, stored, and distributed to individual households.

Attributes of the community

The resource users

According to the 2011 National Census, there were 453,475 people living in the Garden Route District with an annual population growth rate of 2.9% (2001–2011) and pockets of 5% growth in some local municipalities. Within local municipalities, almost 80% of the population is of previously disadvantaged racial groups, i.e., African, Colored, and Asian people, who could not participate in elections prior to democracy in 1994. In George Municipality, 52% of household fall within the low-income bracket (less than 50,616 ZAR/year) with an

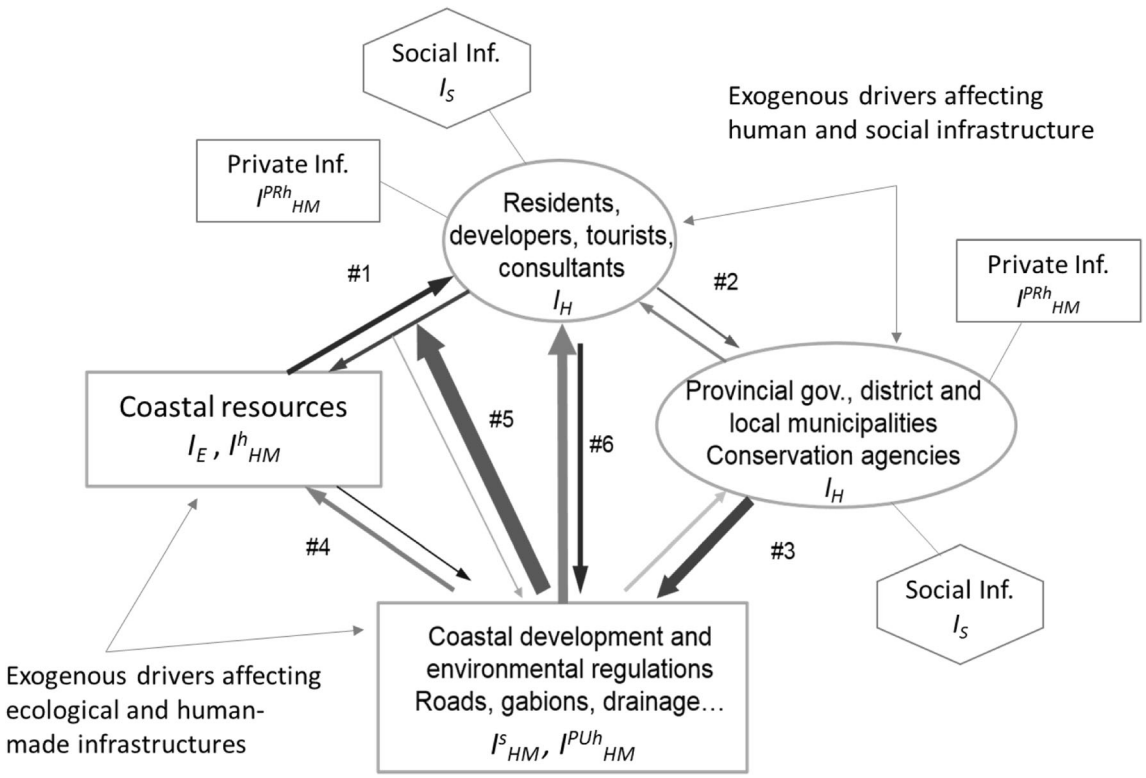

Fig. 2 Ecosystem-based adaptations from a modified robustness framework perspective (adapted from Anderies 2015). The 5 main types of infrastructures ("Inf.") include the following: ecological infrastructure I_E which provides the foundations for ecosystem-based adaptation; hard infrastructure I^h_{HM} which is human-made structures that are either public (I^{PUh}_{HM}) (such as bridges, roads, beach accesses) or private (I^{PRh}_{HM}) (houses), soft infrastructure (I^s_{HM}) which are collections of human-made "instructions" for using other types of infrastructure; human infrastructure (I_H) which refers to knowledge, capacity and value systems, and social infrastructure (I_S) which refers to the relationships we have with others. The thickness of the arrows represents the number of segments coded per interaction (i.e., Links#1–6) in the public infrastructure provider interview transcripts. The darker the link's color the less functional the interaction, and the greater the potential for maladaptive processes to emerge from the interaction

unemployment level of 25%. A total of 16% of the population lives in informal settlements (George IDP 2017–2022). The local economy is driven by the service industry and manufacturing, but tourism is believed to provide an important contribution to local informal employment. The properties on the foredunes are mostly owned by retired (63%), white South-Africans (89%), or Europeans (10%), 43% are seasonal residences and 62% of the owners possess other properties (protocol D). The land uses and spatial development schemes bear the stigmata of apartheid, and the population remains segregated by race and social class with a majority of the private land owned by the white community. The segregation also transpires in the social infrastructure, e.g., the human network and collaboration structure, especially for proactive risk management (crime, fire) and nature conservation (Heider 2018).

Public infrastructure providers

Three spheres of government are influencing ecological infrastructure management: national government, provincial government, and district/local municipalities. At the national level, the Department of Environmental Affairs (DEA) oversees the management of the coastal zone, and the implementation of the Coastal Management Programme (CMP) and the National Environmental Management Act (NEMA). The Western Cape Provincial Department of Environmental Affairs and Development Planning (DEADP) and the office of Environmental Management within the Garden Route District maintain local control over coastal management through provincial legislation and by-laws, for example spatial development plans, climate change adaptation plans, and coastal management strategies. National and provincial conservation bodies assist with monitoring and compliance and offer advice and scientific services to inform the CMP. In terms of social infrastructure, Municipal Coastal Committees (MCC) including members from different government bodies and resident representatives are held quarterly at district level. However, previous studies highlight the lack of resources, knowledge, and capacity at the municipal level which undermines transformative response to global change (Pasquini et al. 2015; Sitas et al. 2014b). Local municipalities are mandated to develop and enforce the Spatial Development Frameworks and Planning in accordance with national, provincial, and district policy contexts.

From an RF perspective, the attributes of the community are characterized by the capacity of resource user (RU) and public infrastructure provider (PIP) to generate and process information, as well as transfer and transform the produced knowledge into decisions and actions (human infrastructure I_H) (Anderies 2015). These capacities inform their interactions with each other through information sharing and inclusion in decision making (Link#2). They also determine the ability of PIPs to allocate/coordinate public infrastructure assets, such as budgets, rulemaking, and coordination (Link#3) (Fig. 2). Both RU and PIP also draw on a web of relationships to connect to others in order to exchange materials and information (I_S) (Anderies 2015). This social infrastructure can have an important influence on decision making (Links#1, #2, #3, #6). For example, PIP may draw on information received from fishers to assess fishing stocks in a particular region. Community members may be influenced by the information received from civil society organizations to support environmental protection efforts.

Rules and regulations

Current environmental legislation in South Africa forms a solid foundation from which policies and implementation plans can be developed. The chief piece of legislation is the National Environmental Management (NEM) Act (107 of 1998) which informs its associated Acts, and the Integrated Coastal Management Act (ICMA) (NEM:ICM Act 24 of 2008) (Celliers et al. 2009).

ICMA is meant to control inappropriate development and improve governance, maintain the natural attributes of coastal landscapes and seascapes, and to promote ecologically, socially, and economically sustainable development and resource use (Glavovic 2006). The National Coastal Management Programme of 2014 was followed by a Provincial Management Programme in 2016, followed by the Garden Route Coastal Management Programme, updated in 2017.

From an RF perspective, the soft human–made infrastructure (IsHM) represents the collection of rules, norms, and shared strategies that provide instructions or decision-making guidance to the social components of the RF (community members and PIPs) as to how to engage and interact with each other and the environment (Anderies 2015). These soft infrastructures also guide the development of hard public infrastructure by the government in order to facilitate functional communities within given biophysical conditions that are embedded within and connected to the ecological infrastructure, such as a coastal system.

External drivers

Extreme weather events and an increase in the frequency of disasters have drawn attention to the climate change vulnerability of the region (RADAR 2010; Nel et al. 2014). Informants expressed concerns about flooding, sea-level rise, fires, freshwater shortages, and increased instances of disasters related to changes in global climate patterns. In-migration and increased urbanization are key

exogenous drivers on communities which are affecting policy maker decision making. "Many people coming in and move [sic] out because there's a perception that there's enough money in the Garden Route" (PIP 6). The desire to attract outside investors to bring businesses and jobs to the region to improve job opportunities and lift people out of poverty often overrides local policy maker concerns about the environmental impacts of those developments. "Obviously the politicians' agenda is largely focused on the poor, poverty or whatever… they will always tell you that if you come with green arguments or whatever that is not our focus." (PIP 6).

From an RF perspective, assessing the influence of external drivers and/or shocks on the social, ecological, and hard/soft human–made infrastructure components of the SES specifically acknowledges that the SES is not a closed system but is subject to and influenced by exogenous forces that introduce additional unpredictability into the system. Recognizing these exogenous drivers facilitates a more holistic assessment of SES robustness, including ways to buffer the effects of those drivers and shocks.

Institutional strengths and weaknesses of climate change adaptation in the Garden Route

Based on the coded interview data, we found that policy makers (PIPs) tended to reference negative interactions (55%) related to climate change adaptations within the Garden Route SES more than positive interactions (21% of coded segments) (Fig. 2). The most noticeable narratives related to the ability of current and emerging policies (soft public infrastructure) to regulate the interaction between resource users (RUs) and resources (Link#5, PI to Link#1). While this link, which is at the heart of adaptive management policies, was viewed mostly negative, it also provided some promising positive elements (Table 2). The weak capacity of local PIPs to implement pro-adaptation policies (Link#3, PIP to PI) also stood out, as did the problematic relationship between policies and RUs (Link#6, PI to RU).

Analysis of the PIPs' interview data was augmented by and triangulated with results from other research protocols described in Table 1. Four narratives emerged from the mixed-methods approach: (1) On-going negative impacts of development on ecological infrastructure; (2) ecosystem-based adaptations (EBAs) are generally supported as a feasible adaptive response; (3) there is a need for improved governance of ecological infrastructures; and (4) positive signals towards more collaborative governance of ecological infrastructure. These four narratives are described in more detail below.

Impacts of development on ecological infrastructure

While sections of the coastline remain unmodified, property owners and developers have transformed most of the coastal foredunes in the study area (Crisp 2015). In the densely developed coastal settlements, 60% of the properties surveyed showed intentionally degraded coastal foredunes, flattened to facilitate construction and improve sea views, while another 22% showed signs of erosion. Sea-facing properties had become more exposed to erosion and flooding than before through modification of the ecological infrastructure by resource users (Link#1 RU to R). These changes created a cycle of maladaptation between the RUs and their environment (including human-made hard infrastructures) in response to perceived (and real) risks from coastal storms (Link#1 R to RU in Fig. 2). Risks are exacerbated by poor communication between RUs and PIPs (Link#2) and weak implementation and oversight of existing policies mentioned earlier (Link#5 PI to Link#1, and Link#6 PI to RU in Fig. 2). "The big goose that lays the golden egg has been killed in the process… People want to come here because of the natural beauty and by putting their houses where it shouldn't be, they're killing the goose…" (PIP 7).

Respondents mentioned that the increase in holiday accommodations along the coast is also impacting the livelihoods of other RUs (notably fishers and recreational beachgoers) by limiting their access to beaches, fishing grounds, and shellfish stocks (PIP 12). Besides programs like *Working for Water* and *Working for the Coast*, government subsidies for ecological infrastructure management, private and public infrastructures (including the Marine and Terrestrial Protected Areas) on the foredunes and along the estuaries, also limit access to people relying on natural resources for subsistence living (PIP 9). The fish stocks have been drastically reduced as a result of intentional estuary transformations and the increase in recreational and commercial fishing (PIP 12). In 2019, the municipality of Knysna is experiencing massive water pollution and sanitation issues as a result of increasing estuary development (PIP 9) and outdated or inadequate sanitation systems (PIP 10). Flood mitigation measures, for example artificial breaching of the river mouth to protect flood-prone properties when the water exceeds a predetermined level, also have long-term negative effects on the ecological infrastructure (PIP 2). PIPs also mentioned that over-consumption and population growth, as well as the expansion of invasive exotic tree species with higher water requirements than native ones, were causing drastic water shortages (PIPs 9, 10, and 11) in the Garden Route catchments.

Support for ecosystem-based adaptations

Residents living near the ocean were strongly aware and supportive of the value of the ecological infrastructure to

reduce flood risk. For developers, coastal defenses (both ecological and hard physical infrastructure) were the primary adaptation to sea surges although they also recognized the consequences of these adaptations, e.g., exacerbated erosion of coastal foredunes and compounded risk to neighboring properties. Most residents on the dunes (77%) strongly supported restoring ecological infrastructure as a strategy to reduce their exposure to risk from surges or sea-level rise. Thirty-five percent were already investing in ecological infrastructure, compared to 26% who had invested in hard infrastructure and 27% who relied on insurance. Local developers were equally aware of the importance of ecological infrastructure in protecting built infrastructure: 63% had a good understanding of the services they provide. In the words of an interviewed engineer: "I think the first thing that comes to my mind is that it [coastal foredunes] protect whatever happens at the back, if it's residential development it protects that, if it is other vegetation it protects that, if it's whatever's ecosystem it's a protection barrier, mainly as far as I'm concerned." PIPs also valued the services provided by ecological infrastructure: only 7% of the coded text referred negatively to it. Ecological infrastructure was also closely linked to recreational opportunities and place meaning, e.g., "Eden District [now Garden Route District] is like the main part of the Garden Route which is a beautiful natural environment largely, lots of tourism and sort of smaller urban areas that are becoming increasingly important. It's also under a lot of threat" (PIP 6).

Desire for improved governance of ecological infrastructure

There was consensus that a holistic approach to coastal management necessarily means incorporating the need to reinvest and protect the ecological infrastructure through improved governance, implementation and oversight, and stakeholder awareness. Almost 18% of the coded segments of PIP interviews referred to failures in soft public infrastructure in regulating the interactions between the RUs and the resource (Link#5) (Fig. 2). Most of the criticism related to the way soft public infrastructure (e.g., policies such as the National Environmental Management Act NEMA, and Integrated Coastal Management Act ICMA) were implemented, rather than the policies themselves (dysfunctional Link#3 PIP to PI). Respondents complained about contradictions in the way various departments and sectors implemented environmental acts "We've got many policies and many great laws… I don't see it coming together" (PIP 7). A similar sentiment was echoed by PIP 3, who stated "There are millions of plans but do those plans ever get executed?" leading to frustration among public sector employees. PIPs frequently mentioned their low capacity (particularly related to funding and personnel) and weak policy implementation (dysfunctional Link#3). There were several comments that short-term economic development and poverty alleviation were being prioritized over ecological infrastructure management in government budget allocations. The long-term benefits of investing in ecological infrastructure deterred politicians interested in immediate results. Delays in resource allocation were also cited as a capacity-related challenge. "Legislation mandates municipalities to include disaster risk reduction in their spatial planning and IDPs, but there is no funding to do disaster risk reduction. …We know what's supposed to be done, but even in the amended disaster management act, the funding part is not even addressed. So, everything stops there." (PIP 8). There were, however, many positive comments among PIPs on the potential of existing laws, regulations, and policies (soft public infrastructures) to enhance change and promote transformation to sustainability by protecting ecological infrastructure, if implemented properly (PIPs 4, 9, 11, 12). Interviewed officials were positive about new legal requirements to include climate change and biodiversity considerations in municipal spatial development frameworks (PIP 11).

Warnings and positive signals towards a collaborative governance

Most residents living on the coast strongly agreed that the responsibility to reduce flood risk rests at multiple levels with the highest responsibility falling on local government (88%) and with the least responsibility falling on the residents. Although many respondents commented that they frequently felt disempowered when dealing with PIPs, there were a number of promising positive signals from the PIP perspective. Some PIPs acknowledged the dysfunctionality of their relationship with civil society (Link#2) and recognized the need to build trust. The leading conservation agency in the Garden Route has adopted the vision "connecting society" and is investing in forums and appointing staff whose job it is to strengthen the connection between people and their organization (PIPs 4 and 5). Coastal management committees, mandated by environmental legislation, are starting to provide the impetus for collaborative management of coastal ecological infrastructures (Link#5 and Link#6). While residents and subsistence users of the coast remain under-represented in forums, interviewed residents were willing to volunteer time to assist flood victims (88%), attend information sharing meetings (71%), and share information they have

acquired through learning (74%). Some officials mentioned that engaging collaboratively with other stakeholders (Link#2) and within the community of PIPs on coastal protection appears to have other benefits for sustainability. Examples include (1) landowners and developers agreeing to protect the coast using environmental friendly sand-bags and replanting vegetation instead of using concrete- or stone-filled gabions that damage dunes (PIP 7) (improved Link#1); (2) agencies and NGOs aligning their public works programs, such as *Working for Water*, *Working for the Coast*, and *Working on Fire* to prioritize areas covered by invasive alien plants, thus improving ecosystem functioning and water storage capacity—when well implemented (improved Link#4) (PIP 8); (3) agreements between local communities and the provincial environmental affairs department (DEADP) to ensure continued access to fishery resources for small-scale and subsistence fishers while implementing coastal and estuary management plans (improved Link#5 and Link#6) (PIP 12); and (4) delineation of coastal setback lines that take sea-level rise and episodic events into account, and require property developers to consider these setback lines in their development plans (Link#1) (PIP 6). Another promising example is the emergence of integrated climate change, mitigation, and adaptation strategies in municipal Integrated Development Planning (IDP) processes (PIP 7).

Our results suggest overall support for EBA in the Garden Route; however, as depicted in Fig. 2, the governance system is triggered by social and economic realities that are framed as antagonistic. Budget shortfalls, manpower losses, and ambiguous rule coordination contribute to a weakened Link#3 interaction which impacts negatively on other components and interactions in the SES.

Ecosystem-based adaptation or the collaborative governance of ecological infrastructure as a common pool resource

The favoring of individual property rights over collective rights to a healthy environment seems to lie at the heart of the commons' dilemma of collaborative ecological infrastructure management (PIPs 3, 7, 8, 12), hence the emphasis on EBA. Rights to develop and use ecological infrastructure on private land has undermined the rights of other users. Many respondents commented on the clash between environmental protection laws and individual property rights which, they believe, have favored coastal development for the affluent (Link#6 and Link#5 interactions). The emphasis on private property rights in coastal development decision making has for example led to exclusion of coastal access rights for fishers from their traditional fishing grounds (PIP 3), as well as private infrastructure development in pristine natural areas, which should have been zoned for conservation (PIP 7). The designation of ecological infrastructure as common pool resources instead of private resources might avert many unintended consequences.

In this section, we shed light on the strengths and weaknesses of EBA in the Garden Route (Table 2) using common pool resource theory and the DPs developed by Ostrom (1990) and others. The main common pool resource management challenges highlighted from the PIP interviewees were as follows: (1) unclear boundaries (DP 1) with encroachment of private properties onto public land due to ineffective regulation; (2) degradation of the state of ecological infrastructures and service provisioning as a result of increasing demand (DP 2), and unequal sharing of the benefits of ecological infrastructure and ecosystem services which affects governance and trust building among stakeholders (DP 2); (3) weak capacity of authorities to facilitate fair and equitable public participation processes (e.g., involving the poorer communities as well) and unequal power relations among self-organizing groups (DP 3); (4) lack of cooperative monitoring and data sharing (DPs 3 and 4), ineffective law enforcement which endorses abuse of ecological infrastructures (DP 5), and weak coordination between different tiers and government levels (DP 8).

These challenges are however mirrored by opportunities for transformation to sustainability which until now have been hampered by a lack of integrated systems perspectives and approaches to governance, the legacy of single-sector, siloed land use planning, and deeply rooted inequality. Some of the more affluent RUs and certain PIPs, catalyzed by a shared desire to manage ecological infrastructure more sustainably, expressed eagerness to cooperate. New mapping initiatives have been launched to more clearly specify boundaries between private and state land (PIP 1), and resource users have started making use of legal provisions to report transgressions (PIP 7). Many RUs have also created their own rules to collectively protect ecological infrastructure, thus improving congruence between local rules, resource benefits, and responsibilities. New self-organized forums and organizations are being established for the co-management of ecological infrastructures. Platforms for collaboration are being strengthened to facilitate collective-choice arrangements. An emerging long-term monitoring program, underpinned by a combination of citizen science and formal research, will make reliable monitoring data more freely available and, linked to this, environmental authorities are gradually sanctioning resource users who fail to manage invasive alien plants and damage valuable ecological infrastructure, such as sensitive coastal vegetation. New and more integrated planning processes and approaches will promote coordination between nested spheres of government. These finding are systematically described in Table 2.

Table 2 Summary of the challenges and opportunities for ecosystem-based adaptation in the Garden Route based on the robustness analysis and the design principle theory

Design principle	Examples of challenges	Opportunities for transformation to sustainability through ecological infrastructure management
1.Clearly defined boundary	- Private property encroaching on public land (Link#6). - Lack of oversight and enforcement (ineffective Link#5).	-Boundaries, ownership, and responsibility for the management of state and municipal land is being clarified and enforced (strengthened Link#3). - Recently published coastal setback lines and a land ownership mapping project initiated by the Western Cape government and local authorities are a step in the right direction.
2. Congruence between appropriation and provision rules and local conditions	- Unequal access to land and ecosystem services (attributes of the community) - Inequality in investments for disaster risk reduction and unequal distribution of benefits (weak Link#6). - Private rights serve to undermine ecological integrity (Link#1 and interactions among resource users).	- Increasing research on place meanings and forms of attachment/dependence, as well as the interactions between different uses or activities. - Emerging collaborative governance structures such as estuary and coastal management committees or the newly established Garden Route Environment Forum hold promise (Link#2 and Link#3). - Emerging landowners' groups calling irresponsible landowners to task for not managing ecological infrastructures properly (Link#2 and Link#3 PIP to PI), with recourse to recently amended legislation. - Emergence of self-organized task group for disaster risk reduction at neighborhood scale (dunes restoration, invasive alien clearing, fire management).
3. Collective-choice arrangements	- Lack of funding is undermining the ability of public infrastructure providers to facilitate effective public participation (Link#2). - Lack of consensus/ignorance about appropriate resource governance leading to non-compliance (Link#6).	- Integrated development plans and spatial development framework processes are promising platforms for functional participation by all, provided that adequate budget amounts and time are allocated for dialog. - Meaningful public participation processes will foster compliance with the principle of collective-choice arrangements. Ecological infrastructure management could provide the impetus for this: many interviewees were eager to share knowledge and skills with disadvantaged groups.
4. Monitoring	- Monitoring of ecological conditions (Link#4) and natural resource extraction (Link#5) is being conducted but the generated data are poorly shared (Link#3) which undermines feedbacks and self-regulation (Link#6).	- "Developing robust, locally relevant and maintainable monitoring and evaluation mechanisms for the key ecosystem services flowing from ecological infrastructure" (SANBI 2014, p. 17) - Designing long-term social-ecological research in the Garden Route (as currently discussed with the South African Environmental Observation Network (SAEON) could be a catalyst for formal monitoring systems with accountable monitoring that includes citizen's science, thus improving the functionality of Links #4, #5, and #6.
5.Graduated sanctions	- Ineffective sanctioning of community members' actions (Link#5) serves to legitimize rules-in-use (Link#6), thus failing to mitigate inappropriate interactions with the resources (Link#1).	- Public infrastructure providers commented positively on the potential of existing laws, regulations, and policies (soft public infrastructures) to enhance change and promote transformation to sustainability. - Department of Environmental Affairs' (DEA's) approach to resource users contravening the invasive plant regulations in the National Environmental Management Biodiversity Act (NEMBA). DEA initiates sanctions by issuing directives to transgressors. If these are not heeded, officials clear the invasive plants and recover the costs from culprits. This is another way to strengthen Link#5.
6. Conflict resolution mechanisms	- A low-cost and accessible court system (attributes of public infrastructure providers) fosters effective interactions in Link#6 but due to Link#3 weaknesses can be ineffective to protect and preserve the integrity of the ecological infrastructure (Link#5).	- SAEON's plea or an environmental ombudsman, if heeded, might provide an impetus for conflict resolution.

Table 2 (continued)

Design principle	Examples of challenges	Opportunities for transformation to sustainability through ecological infrastructure management
7. Minimal recognition of rights to organize	- This design principle is entrenched in the South African constitution, but its application is hampered by its asymmetrical application, affecting Link#1 via Link#5 and Link#6.	- National Environmental Management Biodiversity Act (NEMBA) encourages self-organization through conservancies, forums, and stewardship organizations. The Garden Route Biosphere Reserve has brought together environmental role players under one umbrella and could, if appropriately governed, become a unifying initiative around a common vision.
8. Nested enterprise	Multiple governance levels are indeed present and active, but communication and coordination among departments, agencies, and which rules apply when is problematic (human infrastructure of public infrastructure providers, Link#3).	- Emerging spatial development frameworks, mandated by the Western Cape Land Use Planning Act, are showing promise as platforms for coordination between municipal, provincial, and national processes and are mandated to take ecological infrastructure into account in decision making.

Discussion

Ecological infrastructure and ecosystem-based adaptations as rallying points for sustainability transformation

Ecological infrastructure management has the potential to compensate for the numerous shortcomings in CPR management evident in the Garden Route by refocusing policy considerations on the effects of decision making on congruence (DP 2-proportionality of benefits received from and investments made into the ecological infrastructure) and related social and environmental justice, as mentioned above. Ecological infrastructure might provide a useful common focus to bring organizational actors together, especially in vulnerable or scenic areas and biodiversity hotspots characteristic of coastal areas (Reyers et al. 2015; Reid 2016).

Firstly, we have found that RUs and PIPs can relate to the value and importance of ecological infrastructure, compared to, e.g., abstract concepts such as "biodiversity," "ecosystem-based adaptation," and "climate change" which they find difficult to visualize (Pasquini and Cowling 2015). Secondly, Garden Route residents and officials share a strong place attachment and a sense of place galvanized by beautiful landscapes and scenery with ecological infrastructure at the core. Place attachment and meaning also interact with risk perception (Quinn et al. 2018), thereby influencing adaptation strategies. Ecological infrastructure thus provides the common ground for individual and collective action towards EBA. Thirdly, ecological infrastructure mobilizes actors around two common goals: averting natural hazards and benefiting from nature in a sustainable manner, thus changing the nature of the relationship between residents and resources (Link#1). The resulting collective action fosters better oversight and implementation mechanisms. For example, the self-organization of RUs in conservancies, environmental interest groups, and home owners' associations, aimed primarily at managing ecological infrastructure, is promoting the establishment of internal rules with buy-in from members, thus compensating for the shortcomings of PIP implementation of existing rules. Ecological infrastructure enables the expression of stewardship that can change patterns of interactions among key actors and allow for new forms of management and governance to emerge in response to environmental change (Olsson et al. 2006). This is, however, no panacea (sensu Ostrom et al. 2007): environmental stewardship can be motivated by self-protection and the exclusion of the poorer segments of the society (Heider 2018), thus reinforcing existing socio-economic divides and affecting adaptive capacity.

The leverage point to conserving the proverbial goose that lays the golden egg and supporting ecosystem-based solutions is to mitigate the dysfunctionality in the relationship between RU and R by repairing or strengthening Link#5, i.e., rules that mediate the common pool resource dilemma in Link#1. The dysfunctionalities in this link, mentioned by many, can be overcome through achievable strategies such as improving coordination and information sharing between actors (individuals and institutions); strengthening the capacity of PIPs to implement and enforce laws, rules and policies, including involving citizens in reporting transgressions and training of officials. This has been highlighted by previous studies on mainstreaming EBA (Pasquini and Cowling 2015) and ecosystem services (Sitas et al. 2014b) in the Garden Route. Other opportunities may be created by giving greater delegated authority to by-laws and locally appropriate institutions emerging from the bottom up via home owners' associations, conservancies, and community-based organizations; and using multi-faceted strategies that include information campaigns, the media, and law enforcement with graduated sanctions. Communication and monitoring programs could draw on the wide variety of citizen's science projects already present in the area (Irlich et al. 2017). Ecological infrastructure could indeed by a viable rallying point for EBA in the Garden Route through collective management and knowledge co-

production (Reyers et al. 2015), e.g., for managing invasive alien plants.

At an upper scale, South Africa's National Adaptation Strategy (DEA 2016) identifies capacity development and training, knowledge sharing, research, and monitoring as enabling mechanisms. The Strategy prioritizes EBA, which it defines as "adaptation that supports the inherent ability of ecosystems, including their human inhabitants and organisms, to adapt to climate change, principally by reducing the other stresses which might impede that capacity, and restoring ecosystem function where it has been damaged, thus providing services on which people can depend" (DEA 2016). The document highlights the importance of ecological infrastructure, defined as "naturally functioning ecosystems that deliver valuable services to people" which are regarded as "the asset, or stock, from which a range of valuable services flow" by the South African National Biodiversity Institute (SANBI 2014). The implementation of the new national framework in South Africa emphasizes the need to invest in ecological infrastructure as a stepping stone to consolidating Link#3 interactions.

A lasting solution would be to legally define ecological infrastructures (like clean air, wildlife, and water) as common pool resources, considering not only the private costs and benefits, but also the spillovers and externalities, when permitting its alteration or removal in private and state-owned land. In the interim, it is however possible to experiment with and learn about workable alternatives, inspired by the DPs for common pool resource management (Ostrom 1990).

Rethinking ecosystem-based adaptation: incorporating ecological infrastructure in the robustness framework

The utilization of the modified RF (Anderies 2015) allowed us to productively use multiple sources of qualitative, yet rigorously collected data, to assess the underlying institutional influences on maladaptation. By linking the DPs to the components and interactions within the RF, our study provides further empirical evidence of the usefulness of the DPs as categories of robust institutional structures. However, some negative interactions emerging from the narratives were difficult to illustrate via the RF; for example, there were many negative comments about the maladaptive relationship between resource users and ecological infrastructure, mainly through the inappropriate use and placement of hard engineered infrastructure (public or private). The case of the Garden Route further

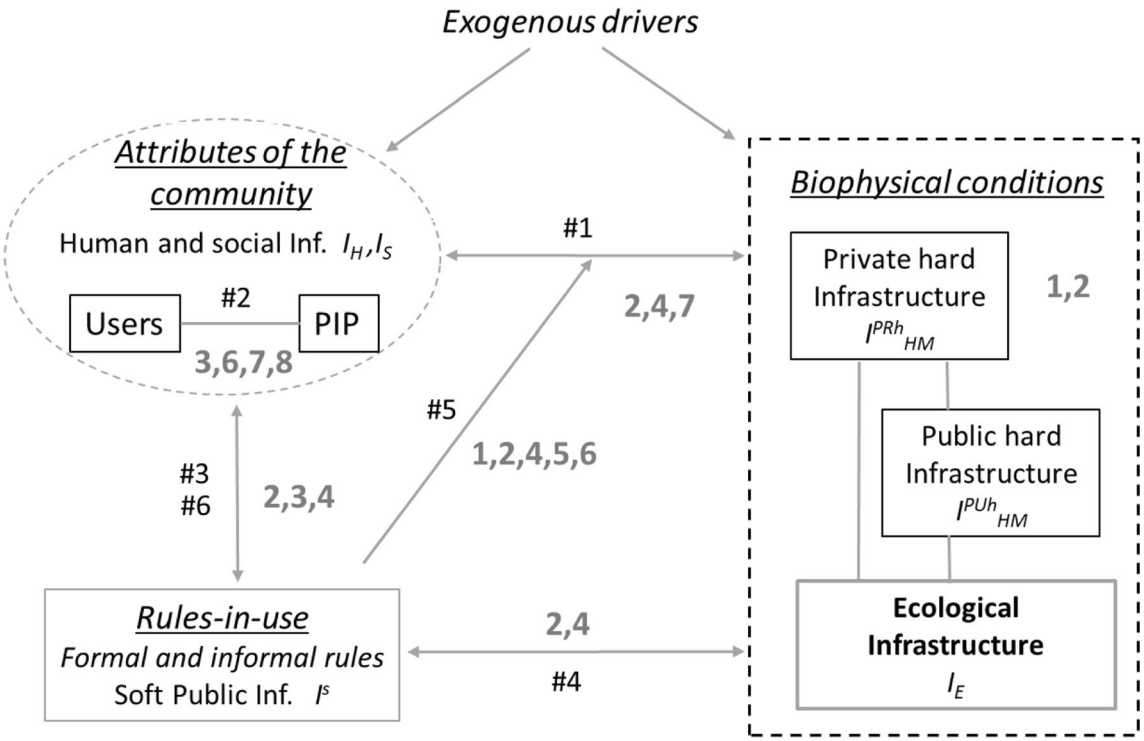

Fig. 3 The modified robustness framework revisited as an attempt to nurture ecosystem-based adaptation in the Garden Route. The arrows represent expected feedbacks or potential spillovers within and across the infrastructure ("Inf.") elements (users, public infrastructure providers (PIPs)), and hard and soft infrastructures ("Inf."). The links (#1 to #6) correspond to those described in Fig. 2. Bold gray numbers refer to the design principles (1 through 8) and are mapped onto the robustness framework to provide a synthesis of our results. Congruence between uses and the state of the social-ecological system (design principle 2) and long-term social-ecological monitoring (design principle 4) are two critical interdependent governance principles to successful ecosystem–based adaptation

suggests that making explicit the interactions between ecological and hard human–made infrastructures (public or private) from a SES perspective facilitates the assessment of the robustness of EBA, i.e., its ability to cope with the uncertainty of global climate change. In fact, analyzing the Garden Route system from a RF perspective forced us to shift our focus from how a particular component in the system may be modified to become more adaptive to looking at the problem from a system-level perspective (Colloff et al. 2017; Few et al. 2017). The RF could, however, benefit from modification (as proposed in Fig. 3) to make it more applicable to EBA.

First, we explicitly acknowledge that interactions between ecological infrastructure, public and private hard human–made infrastructures define the biophysical environment, thereby creating three types of interdependent and non-substitutable hard infrastructures ($I^{PUh}{}_{HM}$, $I^{PRh}{}_{HM}$, and I_E). Defining these connections allows the analyst to explicitly examine the effect of one specific hard infrastructure management decision on the management options of the others. Second, the attributes of and connections between the community of RU and PIP (human and social infrastructure) become key elements of the adaptation process. For instance, social arrangements that conform to particular DPs, which promote trust and reciprocity, may enhance social robustness to change. DPs 3 (collective-choice arrangement) and 7 (recognition of rights) have been found to be important to the successful engagement of stakeholders (Baggio et al. 2016). This, in turn, could reduce the risk of unintended negative impacts of EBA on vulnerable or marginalized people (Few et al. 2017). Colloff et al. (2017) emphasize that values and knowledge (both contributing to I_H), and rules provide a dynamic decision–making context. We concur and argue that the social arrangements (i.e., governance network, power relations, I_S) will also condition the adaptation pathways as illustrated in our example. Third, DPs 2 (congruence with local conditions, state of the resource, and the provision and appropriation rules) and 4 (monitoring) are fundamental to robust adaptation. This is corroborated by Baggio et al.'s (2016) findings that the absence of DP 2 and DP 4 greatly increased the odds of failed CPR governance systems. We found these elements to be dysfunctional in the Garden Route, despite the emergence of recent opportunities. To mitigate this dysfunctionality, decision makers in government, NGOs, and researchers need to collaborate to monitor ecological infrastructure, as well as the impacts of adaptation measures (Leslie and McLeod 2007).

Conclusion

In order to evaluate EBA strategy for its robustness to cope with change, we used the robustness framework and the design principles to map the interactions in the Garden Route as expressed by PIPs and local residents. Doing so allowed us to emphasize potential strengths and weaknesses within the Garden Route SES. For example, our key finding that the congruence DP is not adequately represented in the Garden Route SES was based on the fact that the interactions in Links #2, #4, and #6 created negative feedbacks that undermine coastal adaptation rules. Analyzing the attributes of the community of RUs and PIPs pushed us to consider the historical context of apartheid and the interplay between different economic spheres of society and their impact on policies and decision making and further improved our understanding of the overall robustness of the system. South Africa's National Adaptation Strategy (NAS) is sufficient to inform and guide EBA strategies, particularly around ecological infrastructure management. If implemented properly, it can restore the inherent ability of the ecosystem to provide adaptation services and promote more robust and equitable adaptations to global change.

It should be noted that our assessment is based on the perceptions of adaptation processes and their effectiveness as reported by the policy makers and residents we interviewed. This data provided a basis for the mapping of reported interactions onto the RF and subsequent identification of DPs that were present or absent within the Garden Route SES. While our analysis is limited to our sample set, our findings provide a useful ontology for policy makers and researchers to analyze and assess core interactions within their given SES. Our findings also provide insights as to potential strengths and weaknesses within the Garden Route SES which may be useful to policy makers and civil society in their attempts to increase coastal adaptation effectiveness.

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