Earth's Future

RESEARCH ARTICLE
10.1029/2022EF003012

Key Points:

- The study presents an approach for assessing governance performance and identifying leverage points in social-ecological systems
- The approach combines three different methods: a capital approach framework, fuzzy cognitive mapping, and a leverage points analysis
- The study advances methodological and theoretical knowledge on how to operationalize transformation toward climate resilience

Supporting Information:

Supporting Information may be found in the online version of this article.

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Citation:
Rölfer, L., Abson, D. J., Costa, M. M., Rosendo, S., Smith, T. F., & Celliers, L. (2022). Leveraging governance performance to enhance climate resilience. *Earth's Future*, *10*, e2022EF003012. https://doi.org/10.1029/2022EF003012

Received 28 JUN 2022
Accepted 28 SEP 2022

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Leveraging Governance Performance to Enhance Climate Resilience

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Abstract Enhancing the resilience of complex social-ecological systems (SES) to climate change requires transformative changes. Yet, there are knowledge gaps on how best to achieve transformation. In this study, we present an approach for assessing governance performance in SES and identifying leverage points to ultimately enhance climate resilience. The approach combines three different methods including a capital approach framework, fuzzy cognitive mapping, and a leverage points analysis. Using a coastal case-study in Algoa Bay, South Africa, the performance of governance processes contributing to different forms of capital is assessed. Subsequently, leverage points - where a small shift may lead to transformative changes in the system as a whole - are identified based on measures of centrality and performance. Results suggest that a range of leverage points can improve governance performance and therefore climate resilience in the case-study. Leverage points include improving (a) support from the provincial government; (b) priority given to climate change in the integrated development plan; (c) frequency of collaborations; (d) participation in the implementation of climate action plans; (e) allocation of funding to climate change actions; (f) the overall level of preparedness in terms of staff with relevant expertise; (g) public awareness and understanding of climate change. The approach can also be used to analyze and model the relations and interactions between capitals. The study advances methodological and theoretical knowledge on the identification of leverage points for enabling transformations toward climate resilience and broader sustainability goals in SES.

Plain Language Summary Climate change has severe impacts on both people and nature. Enhancing the ability to persist and adapt to climate change requires transformative governance of social-ecological systems. However, more knowledge is required on how to enable such transformations. In this paper, we present an approach to measure the performance of different governance processes, such as decisions and actions for climate change adaptation made by public and governmental organizations. The approach aims to identify key processes, where a small intervention may improve overall performance for climate change adaptation, and therefore transformation. We apply the approach in a real-world example in Algoa Bay, South Africa. Results suggest that different processes in the case-study can be changed in order to enhance the ability to persist and adapt to climate change. This includes seven actions: (a) more support from governmental organizations; (b) greater priority given to climate change in relevant policies; (c) increasing the frequency of interactions between organizations; (d) enhancing the participation in the implementation of climate action plans; (e) better allocation of funding to climate change actions; (f) training staff within organizations to enhance their climate expertise; (g) improving public awareness and understanding of climate change.

1. Introduction

Climate change presents a major challenge to the resilience of social-ecological systems (SES) (IPCC, 2021). Given the complexity, uncertainty, and trajectory of change, recent studies have highlighted the need for transformations to achieve a desirable state for nature and society (Rölfer et al., 2022; Rosenzweig & Solecki, 2018; Steffen et al., 2018). During the last decade, the notion of transformation has also gained importance for sustainability research and ecosystem management (e.g., Abson et al., 2017; Folke et al., 2021; O'Brien & Sygna, 2013; Westley et al., 2013). Yet, knowledge gaps exist in how to best achieve transformation, calling for new approaches

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for its operationalization. Several authors have argued that leverage points in complex systems - where a small shift may lead to fundamental changes in the system as a whole - help to facilitate transformation (e.g., Abson et al., 2017; Meadows, 1999; Smith et al., 2013). Governance systems play a major role in building capacities for enhancing climate resilience and achieving broader sustainability goals in complex SES. Therefore, an assessment of the governance performance and the identification of leverage points that can enable transformation may be necessary (Abson et al., 2017; Berbés-Blázquez et al., 2017; Thonicke et al., 2020).

A variety of different methods to assess the governance performance of SES already exists. One such method is the assessment of forms of capitals (a capitals approach) that underpin adaptive capacity in SES (Jarzebski et al., 2016; Stotten et al., 2021). Capitals can be understood as the capacities that enable individuals of institutions to act. Whereas the application of a capitals approach has been developed in various contexts, a 'capital approach framework' (CAF) has been adapted specifically to the context of climate change adaptation (e.g., Carmona et al., 2017; Celliers et al., 2020; Máñez et al., 2014). The CAF includes environmental, social, political, financial, and human capital (see Section 2.1 for more details) capturing both social and ecological components of SES. However, previous applications of the CAF typically reflect an aggregate assessment of governance performance, without exploring the potential interactions between capitals. In other words, how do different forms of capital, or capital held by different actors, interact to determine overall governance performance in complex SES? In addition, while the performance of one form of capital may be low, it might not be feasible to enhance that capital, but a small intervention that increases another form of capital may improve the performance of the entire governance system.

To understand how governance of SES contributes to developing adaptive capacity for climate resilience, it is necessary to study the performance of and interactions between individual governance processes that contribute to different forms of capital. Therefore, we combine the CAF with fuzzy cognitive mapping (FCM), as proposed by Williams et al. (2020), giving special attention to connectivity from a complex system perspective. Such a systems perspective is important but rarely applied in the context of climate resilience management or analysis (Berbés-Blázquez et al., 2017; Giordano et al., 2017).

In this study, we (a) present an approach to assess governance performance and identify leverage points to enhance the climate resilience of SES, (b) apply the approach in a case-study of the coastal SES of Algoa Bay, South Africa, and (c) discuss the implications of the case-study findings and the broader applicability of our approach for assessing climate resilience and broader sustainability goals in SES. The paper presents the application of a step-wise approach combining the CAF and FCM with a leverage points analysis for the first time. Additionally, the proposed approach facilitates the exploration of the interactions between different forms of capital. The paper, therefore, advances methodological and theoretical knowledge on the identification of leverage points for enabling transformations toward climate resilience and broader sustainability goals in SES.

2. Assessment Approach

The approach presented in this study adapts the work of Williams et al. (2020) and combines three different methods in a step-wise approach to first identify governance processes and assess their performance using the CAF (Step 1, Figure 1); then map the relationships between governance processes using FCM (Step 2), and finally, apply a leverage points analysis based on centrality measures and performance of individual governance processes (Step 3). In this paper, we define *governance processes* as system-level variables, which describe the effectiveness and recognition of policies, strategies, and actions that enable climate change adaptation at the intersection with coastal and ocean governance, and therefore enhance climate resilience across both the social and environmental dimensions of SES. Examples of governance processes are: 'participation in the implementation of climate action plans' (social capital), 'support from provincial government' (political capital), and 'enforcement of environmental legislation' (environmental capital). In the following sections, the methods used in this approach and the implications for enhancing the climate resilience of SES are described in detail. More details on the step-wise implementation of the approach are explained in Section 3.2.

2.1. Capital Approach Framework

Assessments of individual capitals are used to reflect the current state of a social and/or ecological system, or the requisite elements needed for the improvement and resilience of those systems (Plummer et al., 2018).

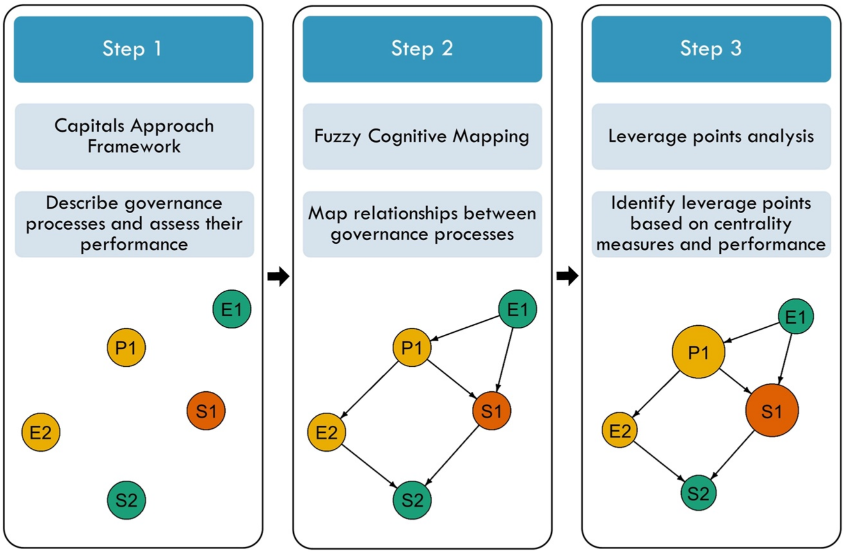


Figure 1. Illustration of the step-wise approach and its implementation. Letters in the nodes indicate the type of capital (E = environmental, S = social, P = political) to which different governance processes contribute. Numbers denote different processes. Colors indicate the performance of governance processes as 'high' (green), 'medium' (yellow), and 'low' (orange). Nodes with increased size in step 3 visualize governance processes with higher centrality and therefore potential leverage points.

Indicator-based capital assessments have been shown to provide a valuable indication of the strengths and weaknesses of governance systems or specific institutions for climate adaptation. A capitals approach framework (CAF) has been developed, which uses indicators and factors to describe the status of different capitals (Carmona et al., 2017; Celliers et al., 2020; Máñez et al., 2014; Williams et al., 2019). The CAF proposes that five capitals underpin governance performance for climate change adaptation: environmental, human, social, political, and financial capital (see Table S1 of Supporting Information S1 for detailed descriptions of the capitals). The CAF was used to identify and assess indicators in the form of governance processes contributing to different levels of adaptive capacity, and therefore to climate resilience across an SES. For assessing the performance of different forms of capital, the governance processes contributing to different forms of capitals are evaluated by actors within the SES.

2.2. Fuzzy Cognitive Mapping

FCMs enable a systems perspective and present a useful method to capture people's perception of the causal relationships between parts of the system they inhabit. This approach has already been applied in the context of climate change adaptation and coastal management including various case-studies (e.g., Giordano et al., 2020; Gómez Martín et al., 2020; Gray et al., 2015; Solana-Gutiérrez et al., 2017). In this study, variables used in the FCM are the same as the capital indicators previously identified using the CAF. These variables represent governance processes as nodes of the system. The relationships between governance processes are indicated by edges (connections as lines between nodes) and their weight describes the strength of the relationship. This is useful for identifying system components using formal and non-formal knowledge, as well as to find leverage points for change.

2.3. Leverage Points Analysis

Since the introduction by Donella Meadows in 1999, various approaches have been developed to characterize and identify leverage points in complex systems. Here, we apply a systems analysis using graph/network theory for analyzing the governance system. This type of analysis is typically used for social network analysis (e.g., Bodin & Crona, 2009; Lam et al., 2020), and is increasingly applied for studying human-nature relationships (Kluger et al., 2020). Leverage points, in this study, are described as points in the FCM representation of the system (a node with high centrality and medium to low performance) which, upon intervention, will cause systemic and positive change. Thus, systems functioning can be enhanced by both improving the performance of individual nodes and establishing or strengthening connections between nodes. This is important for the resilience of SES, as 'connectivity' has been suggested as an important principle of resilience (Berbés-Blázquez et al., 2017; Biggs et al., 2012, 2015; Chapin et al., 2009; Walker & Salt, 2006). There leverage points can be used to identify priority management actions in order to transition the governance system to higher degrees of climate resilience.

3. Implementation Phase

Coastal SES are particularly impacted by climate change, on top of other environmental and socio-economic pressures (IPCC, 2019; Jouffray et al., 2020). Local governance, defined as the political and institutional process of management, shared between government and civil society, is recognized as a suitable administrative level for responding to, and managing for enhanced climate resilience in coastal SES (Celliers et al., 2020; Rölfer et al., 2022). A representative coastal SES was used as a case to test and validate the step-wise approach proposed in this paper.

3.1. Case-Study Area: Algoa Bay, South Africa

Algoa Bay in South Africa is an important ecological and socio-economic hub on the east coast of South Africa and a good example of an urban coastal SES. It is home to the Nelson Mandela Bay Municipality, which includes the city of Gqeberha, and two smaller towns, Despatch and Kariega, collectively inhabited by more than 1.3 million people. The metropolitan area is characterized by strong growth in urban and peri-urban development with exaggerated social-economic inequality resulting in high levels of poverty and informal settlement. The natural and relatively protected bay is resource-rich, both on the coast and in the marine environment. Two economically important industrial ports are located in the bay. Algoa Bay is a popular tourist destination, especially for water sports and recreation. The area is home to several national parks and (marine) protected areas, which support many marine organisms and seabirds, several of which are of conservation concern (Theron & Rossouw, 2008).

Algoa Bay is also at risk from climate change and development pressures on coastal and marine ecosystems (Dorrington et al., 2018). Multi-faceted and uncoordinated management objectives of coastal management (at the local administrative level) are separate from those for marine planning (national administration). Currently, the SES is not managed as a single connected system across the land-ocean interface. This is largely due to effective but disconnected legislation (i.e., National Environmental Management: Integrated Coastal Management (ICM) Act No. 24 or 2008; Marine Spatial Planning (MSP) Act No. 16 of 2008; National Environmental Management: Protected Areas Act No.57 of 2003) resulting in a variety of separate management tools. Some of these management tools include national to local level coastal management plans, regional marine spatial plans, and Marine Protected Areas (MPA), which are managed at different administrative levels of government. A lack of coordination between these management approaches presents a challenge to climate change adaptation, and ultimately to the sustainability of Algoa Bay (Celliers et al., 2022).

Relevant actors in the ocean and coastal governance of the Algoa Bay SES are from the public sector (national to local government, government agencies), non-government organizations, civil society organizations, university and research institutes, and business and industry. Important sectors and activities in the SES range from tourism to nature conservation, sport and recreation, development, and private businesses. Actors and stakeholders already perceive climate change as a serious to a very serious problem, with droughts, sea-level rise, and coastal erosion being the most recognized climate-related threats (results from a survey conducted as part of the CAF; data not displayed). While some organizations already respond to the impacts of climate change, collective governance action across the land-ocean continuum in Algoa Bay is still conceptually abstract. The objective of applying the approach in this study was to identify leverage points for enhancing climate resilience in the integrated SES of Algoa Bay at the intersection of climate change adaptation and coastal and ocean governance (including ICM, MSP, and MPA).

3.2. Implementation of the Approach in the Case-Study

3.2.1. Step 1: Describe Governance Processes and Assess Their Performance

The CAF was adapted to the local context of the Algoa Bay SES. A literature review by the research team was used to identify relevant elements (factors) of five forms of capital (environmental, social, human, political, and financial; see Table S1 of Supporting Information S1). These were further validated with local stakeholders. In total, 18 factors were identified. For example, human capital was informed by six factors describing the state of the accessibility of information; human resources; knowledge and information; organizational structure and leadership; and technical knowhow and expertise. The literature review also identified and informed key governance processes that contribute to each factor. In total, 45 key governance processes were identified. Each governance process (represented by a node in the FCM) was coded by the form of capital to which it belongs, the factor, and a number, for example, HAc1 for **H**uman (capital), **Ac**cessibility of information (factor), and **1** (governance process number).

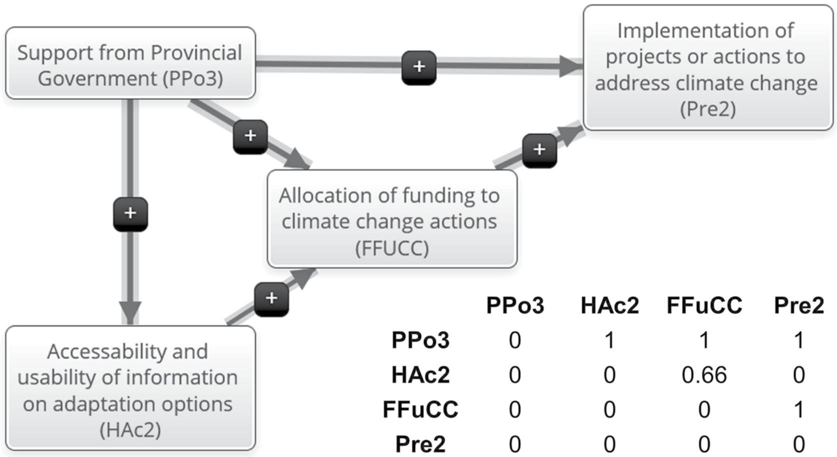
To assess the performance of the 45 governance processes, an online survey and online interviews of 39 relevant organizations within the Algoa Bay SES were carried out. Organizations were identified from a review of the literature and online resources, environmental impact assessments, and provincial and local coastal working groups, and included representatives from all interested/affected stakeholder groups. The performance of each governance process was evaluated by participants on a 5-point Likert scale and later grouped into 'low' (1–2 on the Likert scale), 'medium' (3 on the Likert scale), and 'high' (4–5 on the Likert scale). Performance, thereby, was defined as the capacities of different organisations to engage with the issues of climate change and its impacts on the Algoa Bay SE. For example, in order to assess the performance of the governance process 'accessibility and usability of information on how climate is changing' (HAc1), participants were asked to rate - between 1 (low accessibility/usability) to 5 (high accessibility/usability) – how accessible and useable information on climate change are. If a question was not applicable to a stakeholder, or the stakeholder was not knowledgeable about a specific governance process, they were given the option to choose "don't know/not applicable".

A value representing a system-level, average rating of the performance of each governance process between −1 and 1 was then calculated as a weighted function of the sum of low, medium, and high performance ratings. Therefore, 'high' performance was weighted with 1, 'medium' performance with 0.5, and 'low' performance with −1. Medium performance was assigned a 0.5 instead of 0, because it still represents some degree of performance, instead of no performance at all. In the aggregated performance, values between −1 and <−0.25 represent 'low performance', between −0.25 and 0.25 represent 'medium performance', and between >0.25 and 1 represent 'high performance'. A full list of capitals, factors, governance processes, and performance ratings can be found in the Supporting Information S1 (Table S2).

3.2.2. Step 2: Map Relationships Between Governance Processes

In the next step, governance processes were mapped using the online fuzzy cognitive mapping tool Mental Modeler (Gray et al., 2013). In this map, governance processes were depicted as nodes, and relationships between governance processes were depicted as edges (connections between nodes) (Figure 2). Relationships were given a numerical weight between 0 and 1 in 0.33 increments, depending on the existence and strength of the relationship. The relationships between governance processes were evaluated by five scientific experts from the project Cities and Climate Change in the Western Indian Ocean. Experts consisted of researchers from the region of Algoa Bay, bringing in the local knowledge, and researchers with expertise in coastal governance in South Africa more broadly. Such an expert-led approach was chosen because the limitations of the COVID-19 pandemic restricted the ability to co-develop the FCM with stakeholders from the case-study area.

The FCM software produces an adjacency matrix that includes data on the direction and strength of relationships between nodes. An adjacency matrix shows all nodes as both columns and rows and indicates the relationships for each pair of nodes according to the numerical weight that was given (0, 0.33, 0.66, 1) (see Figure 2). The adjacency matrix was imported to *R* (R Core Team, 2021) and analyzed using the package *FCMapper*. The package is specifically designed for analyzing FCMs by calculating matrix indices that provide more information about system characteristics (Wildenberg et al., 2010) (see Table 1).



	PPo3	HAc2	FFuCC	Pre2
PPo3	0	1	1	1
HAc2	0	0	0.66	0
FFuCC	0	0	0	1
Pre2	0	0	0	0

Figure 2. Example of four governance processes (boxes) that were mapped using Mental Modeler, including the relationships between them (depicted as arrows), and the adjacency matrix for this example.

3.2.3. Step 3: Identify Leverage Points Based on Centrality Measures and Performance

The R-package *igraph* was used to analyze the centrality of governance processes from the adjacency matrix, which in turn, enabled the identification of leverage points. *igraph* is typically used for social network analysis but allows for a more in-depth analysis of the relationship between the structure and process of complex governance systems (Bodin & Crona, 2009). The centrality measures *in-* and *out-degree, strength, and betweenness* were calculated for each governance process. *In-* and *out-degree,* thereby, refer to the sum of in-coming and out-going weights of relationships connected to a node. *Strength* specifies the total sum of the weights connected to a node and therefore presents the sum of *in-* and *out-degree* (Freeman, 1979). *Betweenness* indicates the number of shortest paths that go through a given node, which connects nodes that would otherwise be disconnected. Therefore, governance processes (nodes) with higher betweenness can be interpreted as 'bridges' between different clusters of processes that exert more control over the system (Freeman, 1979; Lam et al., 2020). At the same time, a node with high betweenness may also function as a 'bottleneck' of the system, if the performance of the governance process is low and hence may block flows between connected governance processes. An overview of the centrality measures for each governance process can be found in the Appendix (Table S2 of Supporting Information S1). As suggested by Williams et al. (2020), nodes with a high centrality, but low/medium performance were identified as leverage points. Governance processes were ranked by the centrality measures of strength and betweenness, respectively, and the highest-ranking quartiles with medium or low performance were selected as leverage points.

Table 1
Matrix Indices Output From R Package FCMapper With Descriptions

Matrix index	Description	Value
Number of connections	Total number of connections (relationships between governance processes) in the FCM	125
Connection density	Number of actual connections divided by the possible number of connections.	0.062
Number of nodes	Number of nodes (governance processes) within the FCM.	45
Number of transmitters (T)	Number of nodes with only out-going connections, which are considered to drive the system	5
Number of receivers (R)	Number of nodes with only in-going connections, which can be viewed as end-points of the system	4
Number of ordinary (O)	Number of nodes with both in- and out-going connections	36
Connections/node	Number of in- and out-going connections per node	2.78
Complexity (R/T)	Ratio of receivers to transmitters, which indicates the degree of resolution of the FCM	0.8
Hierarchy	Structural measure indicating whether the FCM is hierarchical (close to 1), or democratic (close to zero)	0.00063

Note. Interpretation of the values are explained in the discussion.

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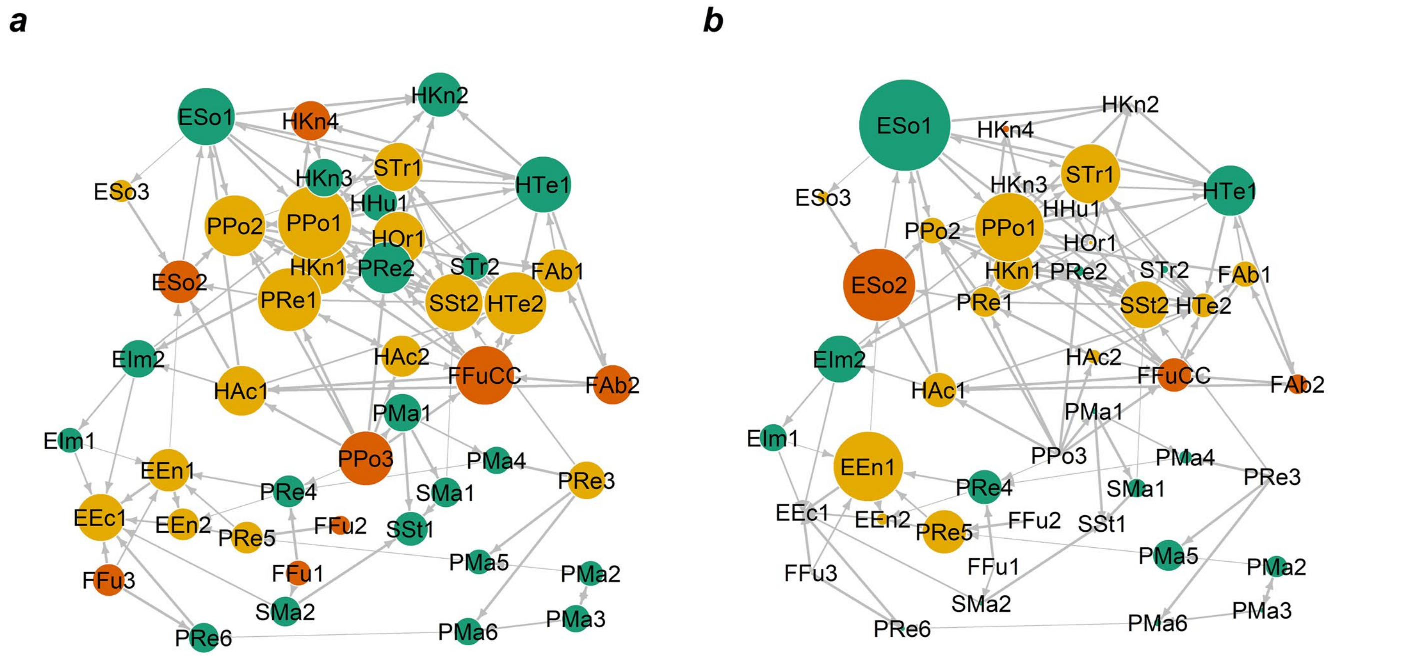

Figure 3. System with nodes representing governance processes and edges representing relationships between governance processes. Arrows indicate the direction, and the width of arrows indicates the weight of relationships. Nodes are sized to the centrality measures (a) strength and (b) betweenness as the square root of values. Colors indicate the performance of governance processes as 'high' (green), 'medium' (yellow), and 'low' (orange).

3.3. Results

The CAF was used to assess the performance of individual governance processes of the SES that enable climate change adaptation at the intersection with coastal and ocean governance. Based on the stakeholder survey ($n = 39$), performance ratings for each governance process were calculated. Subsequently, average performance values between 1 and -1 were calculated for each capital. Results show that political capital scored highest with a rating of 0.29, followed by environmental capital (0.26), social capital (0.25), and human capital (0.14). Financial capital, the lowest rated, was the only capital that had a negative score of −0.35, and therefore showed low performance.

The complete FCM, visualizing the relationships between individual governance processes of the Algoa Bay SES, is provided in the supplementary information (Fig. S1). From the FCM adjacency matrix, different matrix indices were calculated using *FCMapper* (Table 1). Five transmitters (nodes with only out-going connections) were considered to drive the system, and these were: 'general level of funding for ICM' (FFu1), 'general level of funding for MSP' (FFu2), 'general level of funding for MPA' (FFu3), 'support from Provincial Government' (PPo3), and 'awareness of key planning instruments' (PRe3). Four receivers (nodes with only in-coming connections), were 'protection of natural ecosystems (EEc1)', 'intent to find information on how the climate is changing' (HKn2), 'intent to find information on adaptation options' (HKn3), and 'participation in coastal forums' (SSt1). The relatively high number of transmitters and receivers indicates a high resolution and therefore complexity of the model. See Table S2 in the Supporting Information S1 for a full list of all governance processes indicating their node type (e.g., transmitter, receiver, ordinary).

The centrality measures of strength (in-degree plus out-degree) and betweenness were calculated for each governance process (Table S2, Figure 3). In terms of strength, 'priority given to climate change within organizations' (PPo1) clearly ranked highest with 13.32 (Figure 3a) and also showed the highest out-degree (10.66). The transmitter (driving) governance process with the highest out-degree was 'support from provincial government' (PPo3, 7.33). 'Participation in the implementation of climate action plans' (SSt2) showed the highest in-degree (7.98). Betweenness was 0 for all transmitters (driver) and receivers and values ranged between 0.001 and 0.255 for ordinaries. Interestingly, the top three governance processes in terms of betweenness (0.255–0.150) were all governance processes supporting environmental capital, namely - in decreasing order – 'recognition of climate

Table 2
List of Governance Processes Identified as Leverage Points Based on the Centrality Measure Strength and Medium to Low Performance (<0.25)

Capital	Governance processes (nodes)	Strength	Performance
Political	Priority given to climate change within organizations (PPo1)	13.32	0.06
Political	Existence of climate change action plan/strategy (PRe1)	9.98	0.13
Human	Preparedness in terms of staff with relevant expertise (HTe2)	9.64	−0.14
Political	Priority given to climate change in the Integrated Development Plan (IDP) (PPo2)	9.33	−0.11
Financial	Allocation of funding to climate change actions (FFuCC)	8.66	−0.54
Social	Participation in implementation of climate action plans (SSt2)	8.31	−0.11
Political	Support from Provincial Government (PPo3)	7.33	−0.31
Human	Embeddedness of climate change in organisational structures (HOr1)	6.98	−0.04

change as a problem by organization' (ESo1), 'public awareness and understanding of climate change' (ESo2), and 'enforcement of environmental legislation' (EEn1) (Figure 3b).

Overall, performance of individual governance processes ranged between 0.99 for 'recognition of the importance of ecosystems for protection against climate change' (EIm2) and −0.79 for 'need for more information on climate change' (HKn4). In fact, the top three governance processes in terms of performance all contributed to environmental capital, namely - in decreasing order – 'recognition of the importance of ecosystems for protection against climate change' (EIm2, performance of 0.99), 'recognition of the importance of ecosystems for the economy' (EIm1, performance of 0.92), and 'recognition of climate change as a problem by organizations' (ESo1, performance of 0.79). However, only ESo1 also showed a high centrality in terms of betweenness.

Leverage points were then identified based on a combination of high centrality (strength and betweenness) and medium to low performance (<0.25). An overview of the first quartile ($n = 8$) of governance processes with these criteria for strength and betweenness are shown in Tables 2 and 3, respectively. In total, 14 leverage points were identified, with only PPo1 and SSt2 identified as leverage points for both centrality measures. Most of the leverage points fell under political and human capital, with five and four leverage points, respectively. For social and environmental capital there were two leverage points each and only one in the financial capital.

4. Discussion

In this study, we presented and applied a step-wise approach combining a capital approach framework (CAF) with fuzzy cognitive mapping (FCM), which enabled the identification and analysis of leverage points for enhancing climate resilience in SES. By doing so, we analyzed the governance performance for climate change adaptation at the intersection with coastal and ocean governance in a case-study in Algoa Bay, South Africa. The results have

Table 3
List of Governance Processes Identified as Leverage Points Based on the Centrality Measure Betweenness and Medium to Low Performance (<0.25)

Capital	Governance processes (nodes)	Betweenness	Performance
Environmental	Public awareness and understanding of climate change (ESo2)	0.160	−0.45
Environmental	Enforcement of environmental legislation (EEn1)	0.150	−0.22
Political	Priority given to climate change within organizations (PPo1)	0.145	0.06
Social	Frequency of collaborations (STr1)	0.109	0.04
Social	Participation in implementation of climate action plans (SSt2)	0.069	−0.11
Political	Degree of implementation of MSP (PRe5)	0.059	0.22
Human	Vulnerability assessment (HKn1)	0.051	0.21
Human	Accessibility and usability of information on how climate is (HAc1)	0.038	0.10

implications for enhancing climate resilience across the land-ocean interface in the case-study, and we argue for the broader applicability of the approach.

4.1. Implications for Enhancing Climate Resilience in the Case-Study

The assessment of forms of capitals (using a CAF) is useful for identifying specific governance processes for climate change adaptation at the intersection with coastal and ocean management in Algoa Bay (e.g., Celliers et al., 2020; Máñez et al., 2014; Ojwang et al., 2017). The interpretation of the results, however, is highly contextual. For example, even though environmental capital shows a relatively high aggregate performance of 0.29 compared to other capitals, there were considerable differences between the performance scores of individual governance processes. This is demonstrated by the 'recognition of the importance of ecosystems for the economy' (EIm1) and 'recognition of the importance of ecosystems for protection against climate change' (EIm2), which received extremely high scores (0.99, 0.92), whereas the actual 'enforcement of environmental legislation (EEn1)' and 'protection of natural ecosystems' (EEc1) scores were low (−0.22, −0.10). When thinking about the resilience of the Algoa Bay SES to climate change, then a simple aggregate evaluation of the performance of capitals is not sufficient. This example emphasizes the need to view the governance system as a set of interacting governance processes, and hence with a systems lens.

The FCM depicts relationships between governance processes and thus provides a systems view. This has been shown in other case-studies analyzing the dynamics in policy processes and environmental governance (e.g., Gray et al., 2015; Solana-Gutiérrez et al., 2017). The matrix indices of the FCM (Table 1) play an important role in describing different system characteristics and subsequently for interpreting the result of actions or interventions in the system. While some indices are self-explaining (e.g., number of nodes and connections), others are not as easily interpretable. *Complexity*, for example, represents the ratio of receivers to transmitters and indicates the degree of resolution of the FCM. The comparably high ratio of 0.8 indicates a higher complexity, because the number of possible outcomes of policy intervention increases with the number of receivers. At the same time, a high number of transmitters increases the number of possible management policies through hierarchical top-down interventions (Özesmi & Özesmi, 2004; Williams et al., 2020). With a hierarchy index of close to zero, the Algoa Bay SES represents a highly integrated democratic system (as opposed to being hierarchical). Because of the high integration and dependence of nodes, democratic systems, such as presented here, indicate a much higher potential for adaptation to environmental changes (Özesmi & Özesmi, 2004). This means that system interventions have a high potential to leverage change in the system, but they have to be chosen carefully in order to avoid unintended system responses (e.g., maladaptation or lock-ins).

This means that the results of the three methods have to be interpreted together in order to identify the most important leverage points at which policy and management interventions are likely to result in enhancing climate resilience in the Algoa Bay SES. For example, if only viewing the results of the CAF, financial capital scored lowest in the overall performance of capital and one could conclude, that intervention in financial capital is needed. However, only 1 out of 14 leverage points was related to processes supporting financial capital, namely 'allocation of funding to climate change actions' (FFuCC). Thus, an integrated view of the three methods including different measures of centrality and performance of governance processes, and the connectivity between them was applied. For interpreting leverage points with the highest centrality of strength, it is particularly important to consider the out-degree of those governance processes (Solana-Gutiérrez et al., 2017). The higher the out-degree, the higher is the impact on connected governance processes. In this study, the governance processes 'priority given to climate change within organizations' (PPo1) and 'support from Provincial Government' (PPo3) showed the highest out-degrees (10.66 and 7.33, respectively). The latter (PPo3) presents a transmitter (driver) variable, which was rated with low performance and additionally affects the 'allocation of funding to climate change actions' (FFuCC), which showed the lowest performance of all leverage points. It thus presents an important intervention point in the system. Furthermore 'priority is given to climate change within organizations' (PPo1) and 'participation in the implementation of climate action plans' (SSt2) returned high scores for both strength and betweenness, and therefore are considered important.

Due to the high interconnectedness and dependence of governance processes, it makes sense not only to improve the performance of one or two individual leverage points but a combination of several leverage points together with their connectivity (Figure 4). One set of leverage points could be the improvement of 'support from provincial government' (PPo3), which facilitates the 'priority given to climate change in the Integrated Development

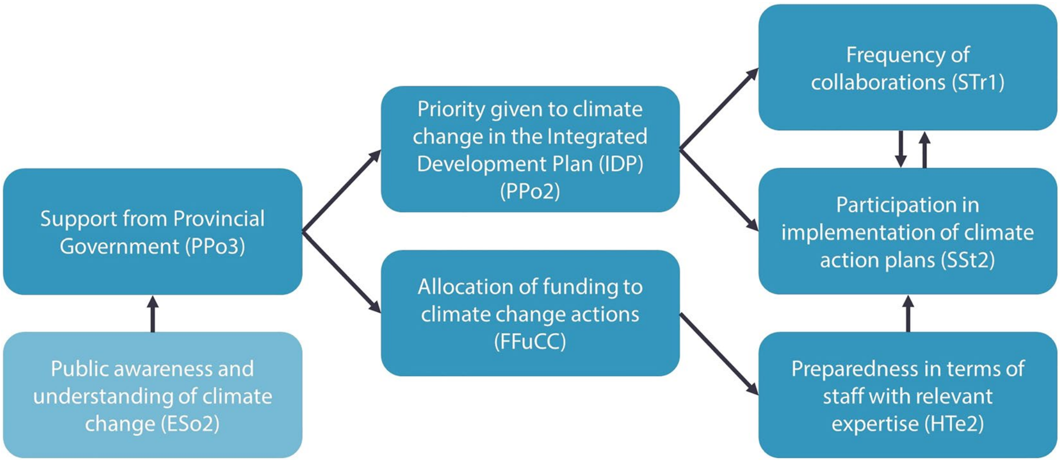

Figure 4. Suggested set of leverage points (policy interventions) that can enhance climate resilience across the social-ecological system of Algoa Bay. Arrows indicate systemic interdependencies between leverage points.

Plan (IDP)' (PPo2), which in turn increases both the 'frequency of collaborations' (STr1) and the 'participation in the implementation of climate action plans' (SSt2) (Figure 4, top row). The latter also creates an important bottleneck to other governance processes, which is why an improvement of its performance is essential to enhance capacities across the system. Similarly, improved 'support from provincial government' (PPo3) will also have flow-on benefits to the 'allocation of funding to climate change actions' (FFuCC). This in turn is linked to the 'overall level of preparedness in terms of staff with relevant expertise' (HTe2), which, to some degree, enables the 'participation in the implementation of climate action plans' (SSt2) (Figure 4, bottom row). To enable these changes, it is also necessary to improve overall 'public awareness and understanding of climate change' (ESo2). ESo2 not only scored highest in terms of betweenness and showed a low performance, but also influences the 'support from provincial government' (PPo3). Initiating such a change not only requires top-down (e.g., support from the provincial government), but also bottom-up (e.g., increased public awareness) transformations, as recognized in recent studies (e.g., Reed & Fazey, 2021; Rölfer et al., 2022).

Improved management for enhancing climate resilience in the Algoa Bay SES also includes a better integration between climate change adaptation and coastal and ocean governance, including different management approaches such as ICM, MSP, and MPA. For example, even though the 'relevance of the ICM Act for organizations' (PMa1) is high (see Table S2 of Supporting Information S1, Appendix), the 'awareness of a coastal working group or committee' (SMa1) and the 'participation in coastal forums' (SSt1) is comparably low. This is probably due to a lack of 'funding for ICM' (FFu1), which is a transmitter (driver) variable in the system. Similar patterns exist for MSP and MPA. Improving the connectivity between climate change adaptation at the intersection with coastal and ocean governance can, similar to the above-mentioned processes, be leveraged by enhanced 'support from provincial government' (PPo3). Therefore, relationships between the governance processes have to be strengthened, and missing links between climate change adaptation, coastal zone management, marine planning, and ecosystem protection and management (e.g., ICM, MSP, and MPA) are to established (see Figure S1 of Supporting Information S1). Separation of management approaches, as described in the case-study area, is very common to coastal SES and has been described as a challenge to the resilience and overall sustainability of such systems in many other regions of the world (e.g., Lazzari et al., 2019; Maragno et al., 2020; Pittman & Armitage, 2016; Schlüter et al., 2020; Van Assche et al., 2020). Hence, Algoa Bay presents an appropriate case-study for transferring the approach and its results and implications to other areas.

4.2. Applicability of the Approach

The approach presented here of assessing relationships between governance processes within a SES (rather than for a specific initiative or policy) may be particularly useful for identifying places to intervene in complex SES. It is useful to support enhancing general climate resilience – the capacity to buffer all system perturbations, including unforeseen ones, while continuing to provide essential functions (Folke et al., 2010; Walker & Salt, 2006).

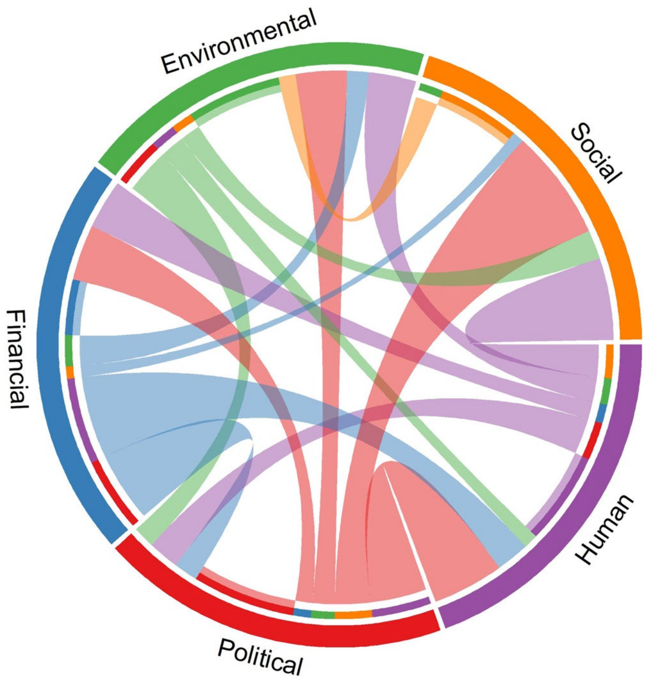

Figure 5. Chord diagram visualizing flows between capitals as sum of weighted relationships between governance processes contributing to different forms of capital (scaled to the sum of total flows within capitals). The direction of flow is indicated by its color, for example, all red strings originate from political capital and flow to the other four capitals. Flows within capitals are symbolized as blank spaces.

FCMs are very useful in this context, as they do not necessarily require large volumes of data. The focus of FCMs is less on the parametrization itself, but mostly on the qualitative outcomes of the relationships between different system nodes (Kosko, 1986). This is particularly important in areas, where data are poor and non-formal knowledge is of upmost relevance. Additionally, the evaluation of individual governance processes instead of capitals advances previous approaches of the CAF. Such a subdivision is of particular importance as multiple interlinked processes contribute to the performance of capital. The subdivision into different governance processes can also support the self-assessment of organizations by making the underlying concept of capital more tangible for stakeholders. Furthermore, governance processes are rarely linear, as visualized by the example under 4.1. This means that relationships such as benefits and trade-offs between different capitals may remain unrecognized, if not disaggregated to individual governance processes.

Furthermore, the notion of the capital approach framework originates from livelihood at the 'household level' as the unit of analysis (e.g., Adger, 2009; Elrick-Barr et al., 2016). If applied to the governance level, however, the outcome depends on the interaction of multiple stakeholders within the governance system. Therefore, in this study, the performance of individual governance processes is measured as an aggregate across relevant organizations at the 'system level'. Different from the household level, in a governance system, various stakeholders may need to intervene at different system points (governance processes) in order to enhance adaptive capacity. In the case-study, this is demonstrated by the integration of stakeholders from different scales and administrative levels, for example, individual local organizations and provincial government.

The proposed approach can also be applied in other case-studies.In this case, the governance processes (system nodes) need to be adapted to the case-specific context and the study objective, for example, climate change adaptation, sustainable development, or environmental governance. When possible, the CAF and FCM should therefore be co-produced with stakeholders who are part of the governance system (Williams et al., 2020). Different stakeholders may perceive the functioning and interplay of different governance processes differently. Such a co-production exercise can facilitate a process that enables stakeholders to reflect on their own role within the broader system and to take ownership of the results (Brouwer et al., 2016; Williams et al., 2020). Whereas the number of governance processes in an expert-led process - such as performed here - was quite high, reducing the number of FCM variables in participatory approaches may be necessary. The assessment of relationships between governance processes can be very time-intensive, especially when engaging stakeholders with different perceptions. Reducing the number of governance processes will therefore also reduce complexity, increase transparency, and maintain practicality.

When interpreting the results of the proposed approach, one should consider, that an aggregated performance rating at the systems level may hide the divergence in individual stakeholder ratings and therefore can involve false conclusions. For example, the 'recognition of climate change as a problem by organizations' (ESo1) received a performance score of 0.79 and shows the highest centrality in terms of betweenness for the whole system (Table S2 of Supporting Information S1). Even though it was evaluated as very effective, it may present a bottleneck for individual organizations that do not recognize climate change as a problem to be addressed within their organization. In this case, such organisations may also lack 'priority given to climate change within their organization' (PPo1), which is strongly influenced by ESo1. A closer look at organizations with high agency and central role in such governance systems may still be necessary, in order to identify such problematic bottlenecks (Lyon et al., 2020). Such an analysis can additionally help to identify the needs for empowerment and capacity building of particularly marginalized stakeholders (Williams et al., 2018).

Finally, the approach of combining a CAF with FCM can also be used to analyze flows in form of relations and interactions between capitals (see Figure 5). Mapping the relationship between capitals is crucial because they are likely to be complementary. This means that capitals are not substitutable for each other in building resilience (Daly, 1995; Rouhi Rad et al., 2021). From an ecological-economic and strong sustainability perspective, financial, social, political, and human capital can be considered as the basis for creating benefits from natural capital with which to enhance human well-being (Daly, 1980; Ekins et al., 2003). Therefore, a focus on the centrality of natural capital in relation to other capitals might warrant further investigation. A deeper analysis and interpretation of the flows between capitals are possible but beyond the scope of this paper.

5. Conclusions

In this study, we presented and applied an approach for assessing governance performance based on forms of capital and identifying leverage points to ultimately enhance climate resilience in SES. The combination of a capital approach framework and fuzzy cognitive mapping and a subsequent leverage points analysis has proven useful to describe and analyze a governance system across both the social and environmental dimensions of SES. Leverage points were identified based on a combination of centrality measures (strength and betweenness) and low to me performance of 45 governance processes.

Results suggest that a range of leverage points exist that could potentially improve governance performance and therefore climate resilience of the SES in the case-study of Algoa Bay, South Africa. These leverage points include improving (a) the support from Provincial Government; (b) the priority given to climate change in the Integrated Development Plan (IDP); (c) the frequency of collaborations; (d) participation in the implementation of climate action plans; (e) the allocation of funding to climate change actions; (f) the overall level of preparedness in terms of staff with relevant expertise; (g) public awareness and understanding of climate change. It also includes a better integration between different coastal and ocean management approaches (ICM, MSP, MPA) in the Algoa Bay SES to integrate climate change adaptation into these processes. Besides these leverage points at which changes are required, well-performing governance processes with high centralities also need to be maintained in their functioning for managing climate resilience.

We also discussed and emphasized the need to evaluate governance processes instead of capitals itself. An evaluation at the systems level (instead of the household level) facilitates the integration of complexity and interdependence between different governance processes because processes in governance are rarely linear. We propose to co-develop the CAF and FCM together with stakeholders of the governance system to facilitate a process that enables stakeholders to reflect on their own roles within the broader system and to take ownership of the results. The approach can also be used to analyze flows in form of relations and interactions between form of capital, for example, to analyze systems in relation to the concepts of strong sustainability and critical natural capital.

Finally, the approach advances methodological and theoretical knowledge on modeling flows between forms of capital and the identification of leverage points for enabling transformations toward climate resilience and broader sustainability goals in SES. Further research may include further analysis combining the approach with a stakeholder analysis of the agency of individual stakeholders of the governance system to identify key actors and capacity-building needs of marginalized stakeholders.

Acknowledgments

We would like to thank Eulalia Gómez Martín and Meredith Fernandes for their support in mapping the governance processes and relationships between them in a FCM. We also acknowledge the participation of all stakeholders in the CAF interviews. The authors acknowledge funding from the I2B Program of the Helmholtz-Zentrum Hereon, Germany, and from the WIOMSA-MASMA Cities and Coast Program Grant. Citiesand-Coasts/OP/2018/02. This work contributes to Future Earth Coasts, a Global Research Project of Future Earth. Open access funding enabled and organized by Projekt DEAL.

Data Availability Statement

The data generated and analyzed in this study are available in the Supporting Information stored in the public repository figshare, available under https://doi.org/10.6084/m9.figshare.20732788.

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