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System and transformative knowledge for enhancing the resilience of coastal social-ecological systems to climate change

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"There is a compelling need for new trajectories of coastal research that transcend disciplinary boundaries and the barriers between science, policy, and practice in order to facilitate transformative changes necessary to transition toward safer and more resilient and sustainable pathways."

(Ramesh et al. 2015)

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Abstract

Climate change presents a major sustainability challenge to coastal social-ecological systems (SES). The integration of climate change adaptation into processes or structures for coastal governance, however, has been described as challenging. Resilience presents a suitable concept to approach this problem, as it facilitates bridging between the natural and social sciences, as well as between science and policy in an inter- and trans-disciplinary approach. The Intergovernmental Panel on Climate Change also makes use of the concept of resilience and confirms that recent literature increasingly suggests that transformative changes in SES are required to enhance their resilience to climate change. Yet, knowledge gaps still exist on how to enable effective coastal governance to enhance the climate resilience of coastal SES. To address this problem, the importance of actionable knowledge is growing in climate change adaptation, environmental governance, and broader sustainability research. Actionable knowledge refers to knowledge that contributes to solving societal problems and points to actions and processes of change. One way of generating actionable knowledge is the co-production of knowledge with societal stakeholders. Yet, knowledge gaps exist in what methods and approaches may contribute to generating actionable knowledge and what obstacles to knowledge co-production exist especially for early-career researchers (ECRs).

This dissertation contributes to research on generating actionable knowledge for coastal governance to enhance the resilience of coastal SES to climate change. It does this by providing theoretical, methodological and empirical insights on three research questions (RQs), laid out in Chapter I. These are: 1) what is a more actionable concept for applying the concept of resilience in coastal governance?; 2) what methods and approaches are suitable to generate actionable knowledge for coastal governance?; and 3) what obstacles to knowledge co-production exist for ECRs and how can they be overcome? The RQs are addressed in five publications, each presenting one chapter of this dissertation. For answering RQ1, Chapter II applies a research synthesis to bring together common themes and challenges documented in resilience, climate change and environmental governance literature. For answering RQ2, in Chapter III-V different methods and approaches for generating actionable knowledge are proposed and tested using a case-study in the SES of Algoa Bay, South Africa. These include i) the analysis of stakeholder agency as an indicator of the ability of stakeholders to act in governance processes; ii) the application of a stakeholder analysis to gain an improved understanding of the current degree of knowledge exchange for climate change adaptation; and iii) the combination of a capital approach framework, and fuzzy cognitive mapping, which shed light on the governance performance for climate change adaptation and on leverage points that can enhance climate resilience. Finally, for answering RQ3, Chapter VI provides a perspective on the obstacles that especially ECRs face, and actions that are needed to create the conditions under which knowledge co-production processes can be successful. This is done by applying a multi-method approach combining an online survey and workshop targeted at ECRs in the marine sciences.

Key findings suggest that system and transformative knowledge are particularly important when applying the concept of resilience in coastal governance to generate actionable knowledge. The different methods and approaches that are proposed and tested contribute to generating both system and transformative knowledge. Firstly, they provide an overview of the capacities of different stakeholders to act, shed light on current collaboration and knowledge exchange, and enable the identification of different governance processes for coastal governance and climate change adaptation (system knowledge). Secondly, results have implications for how to improve knowledge exchange and identify leverage points that can enhance overall governance performance, thus providing recommendations on actions and processes that can enhance climate resilience in the case-study area (transformative knowledge). It is also highlighted how knowledge co-production can

contribute to generating system and transformative knowledge together with stakeholders, and what actions are needed to build the capacities to translate knowledge into action. Additionally, the findings of this dissertation put forward actions that are needed at different organisational levels of the academic system to facilitate knowledge co-production processes with stakeholders involved in coastal governance.

The results of this dissertation have implications for stakeholders and decision-making in the case-study area, as well as for environmental governance, climate change adaptation and broader sustainability research. Implications for stakeholders include recommendations for implementing formal commitments to share climate information across levels and sectors, establishing the role of information providers in the municipality, and reinforcing human capital within the local municipality in Algoa Bay. It also requires more support from the provincial government, such as addressing funding issues, offering training focusing on stakeholders with lower agency and capacities, and improving the overall availability and accessibility of climate information, as well as the priority given to climate change in the Integrated Development Plan. Findings also suggest the need for a more integrated approach to climate change adaptation in coastal planning and management frameworks. It also suggests that the conservation of environmental assets presents an important bottleneck for resilience management and needs to be further prioritised within decision-making. Implications for research include the applicability of methods beyond the context of this dissertation; a more actionable concept for approaching resilience in (coastal) governance systems that can be applied for achieving broader sustainability goals; and a more critical reflection on how transformative research is conducted, and what academic foundation is needed so that it can fulfil its societal goal.

Future research may include a combination of the methods applied in this dissertation; qualitative applications of the stakeholder network analysis; and an application of the proposed approach to other case-studies using real-world laboratories. Overall, this dissertation provides theoretical, methodological, and empirical implications and insights into pressing SES problems. It also contributes to advancing the field of transformative research for more societally relevant outcomes in face of climate change and broader sustainability challenges.

Zusammenfassung

Der Klimawandel stellt eine große Herausforderung für die Zukunftsfähigkeit von sozial-ökologischen Küstensystemen dar. Die aktuelle Forschungsliteratur beschäftigt sich mit der Herausforderung, wie die Anpassung an Klimawandelfolgen in die Prozesse der Küstengovernance integriert werden kann. Resilienz ist ein geeignetes Konzept, um sich diesem Problem zu nähern, da es eine Verbindung zwischen den Natur- und Sozialwissenschaften sowie zwischen Wissenschaft und Politik in einem inter- und transdisziplinären Ansatz ermöglicht. Der Weltklimarat (IPCC) verwendet ebenfalls das Konzept der Resilienz und bestätigt, dass die aktuelle Fachliteratur zunehmend darauf hindeutet, dass transformative Veränderungen in SES erforderlich sind, um deren Resilienz gegenüber dem Klimawandel zu verbessern. Dennoch gibt es immer noch Wissenslücken darüber, wie eine wirksame Küstengovernance ermöglicht werden kann, um die Resilienz von sozial-ökologischen Küstensystemen gegenüber dem Klimawandel zu verbessern. Um dieses Problem anzugehen, wird handlungsorientiertes Wissen in den Bereichen Klimawandelanpassung, Umweltmanagement und Nachhaltigkeitsforschung im Allgemeinen immer wichtiger. Unter handlungsorientiertem Wissen versteht man Wissen, das zur Lösung gesellschaftlicher Probleme beiträgt und auf Maßnahmen und Veränderungsprozesse hinweist. Eine Möglichkeit, um handlungsorientiertes Wissen zu erzeugen, ist die Ko-Produktion von Wissen mit gesellschaftlichen Akteuren. Es bestehen jedoch Wissenslücken darüber, welche Methoden und Ansätze zur Generierung von handlungsorientiertem Wissen beitragen können. Außerdem besteht die Frage, welche Hindernisse insbesondere für Nachwuchs-wissenschaftler*innen bei der Wissens-Ko-Produktion bestehen.

Diese Dissertation trägt zur Forschung über die Generierung von handlungsorientiertem Wissen für die Küsten-Governance bei, um die Resilienz von sozial-ökologischen Küstensystemen gegenüber dem Klimawandel zu verbessern. Hierzu liefert diese Arbeit theoretische, methodische und empirische Antworten auf die folgenden drei Forschungsfragen, welche in Kapitel I dargelegt sind: 1) Was ist ein handlungsfähiges Konzept für die Anwendung des Konzepts der Resilienz in der Küstengovernance? 2) Welche Methoden und Ansätze sind geeignet, um handlungsorientiertes Wissen für die Küstengovernance zu generieren? und 3) Welche Hindernisse bei der Wissens-Ko-Produktion bestehen für Nachwuchswissenschaftler*innen und wie können sie überwunden werden? Die Forschungsfragen werden in fünf Veröffentlichungen aufgegriffen, welche jeweils ein Kapitel der vorliegenden Dissertation darstellen. Zur Beantwortung von Forschungsfrage 1 wird in Kapitel II eine wissenschaftliche Synthese angewandt, um gängige Themen und Herausforderungen zusammenzuführen, welche in der Literatur zu Resilienz, Klimawandel und Umweltmanagement dokumentiert sind. Zur Beantwortung von Forschungsfrage 2 werden in den Kapiteln III-V verschiedene Methoden und Ansätze zur Generierung von handlungsorientiertem Wissen vorgeschlagen und anhand einer Fallstudie in Algoa Bay, Südafrika, getestet. Dazu gehören i) eine Analyse der Handlungsfähigkeit von Stakeholdern als Indikator für die Fähigkeit von Stakeholdern in Governance-Prozessen zu agieren; ii) die Anwendung einer Stakeholder-Analyse, um ein besseres Verständnis des aktuellen Wissensaustauschs für die Anpassung an den Klimawandel zu erlangen; und iii) die Kombination eines Kapitalansatzes (Capital Approach Framework) und einer partizipativen Kartierung (Fuzzy Cognitive Mapping), welche Aufschluss über die Governance-Leistung für die Anpassung an den Klimawandel und Hebelpunkte zur Verbesserung der Klimaresilienz geben. Zur Beantwortung von Forschungsfrage 3 bietet Kapitel VI schließlich eine Perspektive auf Hindernisse für Nachwuchswissenschaftler*innen bei der Wissens-Ko-Produktion, und schlägt Lösungen vor, welche die erforderlichen Bedingungen für eine erfolgreiche Wissens-Ko-Produktion schaffen können. Dies geschieht durch die Anwendung eines Multi-Methoden-Ansatzes, der eine Online-Umfrage und einen Workshop für Nachwuchswissenschaftler*innen in den Meereswissenschaften umfasst.

Die Schlüsselergebnisse deuten darauf hin, dass System- und transformatives Wissen bei der Anwendung des Konzepts der Resilienz in der Küstengovernance besonders wichtig sind, um handlungsfähiges Wissen zu generieren. Des Weiteren, tragen die verschiedenen hier vorgeschlagenen und getesteten Methoden und Ansätze dazu bei, die beiden Wissenstypen zu generieren. Erstens geben sie einen Überblick über die Handlungsfähigkeit der verschiedenen Akteure, die aktuelle Zusammenarbeit und den Wissensaustausch, womit sie die Identifizierung verschiedener Governance-Prozesse für die Küstenpolitik und die Anpassung an den Klimawandel ermöglichen (Systemwissen). Zweitens bieten die Ergebnisse Implikation dafür, wie der Wissensaustausch verbessert und Hebelpunkte identifiziert werden können, um die Gesamtleistung der Governance zu verbessern. Damit liefern die Ergebnisse Empfehlungen für Maßnahmen und Prozesse, die die Klimaresilienz im Untersuchungsgebiet erhöhen können (transformatives Wissen). Es wird auch aufgezeigt, wie die Wissens-Ko-Produktion dazu beitragen kann, gemeinsam mit den Akteuren System- und Transformationswissen zu generieren, und welche Maßnahmen erforderlich sind, um die Kapazitäten zur Umsetzung von Wissen in Maßnahmen zu schaffen. Darüber hinaus werden in dieser Dissertation Maßnahmen vorgeschlagen, die auf verschiedenen organisatorischen Ebenen des akademischen Systems erforderlich sind, um Prozesse der Wissens-Ko-Produktion mit den relevanten Akteuren zu ermöglichen.

Die Ergebnisse dieser Dissertation haben Implikationen für Akteure und Entscheidungsfindung im Fallstudiengebiet, sowie auf die Umweltgovernance-, Klimawandelanpassung- und allgemeinere Nachhaltigkeits-Forschung. Zu den Implikationen für die Akteure gehören Empfehlungen zur Umsetzung formeller Verpflichtungen zum Austausch von Klimainformationen über alle Ebenen und Sektoren hinweg; Festlegung der Rolle von Informationsanbietern in der Stadtverwaltung; und Stärkung des Humankapitals innerhalb der lokalen Stadtverwaltung in Algoa Bay. Darüber hinaus ist mehr Unterstützung durch die Bezirksregierung erforderlich, wie z. B. durch die Klärung von Finanzierungsfragen; dem Angebot von Schulungen, die sich an Akteure mit geringerer Handlungsfähigkeit und Kapazitäten richten; der Verbesserung der allgemeinen Verfügbarkeit und Zugänglichkeit von Klimainformationen; sowie der Priorisierung des Klimawandels im integrierten Entwicklungsplan. Die Ergebnisse deuten außerdem darauf hin, dass ein stärker integrierter Ansatz zur Anpassung an den Klimawandel im Rahmen der Küstenplanung und des Küstenmanagements erforderlich ist. Zudem ist wichtig, dass die Erhaltung von Umweltgütern einen wichtigen Engpass für das Resilienzmanagement darstellt und daher bei Entscheidungsfindungen stärker priorisiert werden muss. Implikationen für die Forschung beinhalten über den Kontext dieser Dissertation hinaus anwendbare Methoden; ein handlungsfähigeres Konzept für den Umgang mit Resilienz in (Küsten)-Governance-Systemen, welches auch zur Erreichung allgemeiner Nachhaltigkeitsziele angewandt werden kann; sowie eine kritischere Reflexion darüber, wie transformative Forschung durchgeführt wird und welche akademische Grundlage erforderlich ist, damit sie ihr gesellschaftliches Ziel erfüllen kann.

Zukünftige Forschungsarbeiten könnten eine Kombination der in dieser Dissertation angewandten Methoden, qualitative Anwendungen der Stakeholder-Netzwerkanalyse, sowie die Anwendung des vorgeschlagenen Ansatzes auf andere Fallbeispiele unter Verwendung von Real-Laboren umfassen. Insgesamt bietet diese Dissertation theoretische, methodische und empirische Implikationen und Einblicke in drängende Probleme sozial-ökologischer Systeme. Sie trägt außerdem dazu bei, das Feld der transformativen Forschung voranzubringen, um angesichts des Klimawandels und allgemeiner Nachhaltigkeitsherausforderungen gesellschaftlich relevantere Ergebnisse zu erzielen.

List of publications

The following list includes the five research publications that contribute to this dissertation. They are referred to as Chapters II-VI. Chapter I is the framework chapter of this dissertation and thus not included in the list.

Chapter II: Resilience and coastal governance: knowledge and navigation between stability and transformation
Rölfer, L., Celliers, L., & Abson, D. J. (2022)
Published in *Ecology and Society*

Chapter III: Stratification of stakeholders for participation in the governance of coastal social-ecological systems
Celliers, L., **Rölfer, L.,** Rivers, N., Rosendo, S., Fernandes, M., Snow, B., Máñez Coast, M. *(in print)*
Published in *Ambio*

Chapter IV: Assessing collaboration, knowledge exchange and stakeholder agency for enhancing climate resilience of coastal social-ecological systems
Rölfer, L., Celliers, L., Rivers, N., Fernandes, Snow, B., M., Abson, D. J. *(submitted)*
Manuscript under review

Chapter V: Leveraging governance performance to enhance climate resilience
Rölfer, L., Abson, D. J., Máñez Costa, M., Rosendo, S., Smith, T., Celliers, L. (2022)
Published in *Earth's Future*

Chapter VI: Disentangling obstacles to knowledge co-production for early-career researchers in the marine sciences
Rölfer, L., Elias Ilosvay, X.E., Ferse, S.C.A., Jung, J., Karcher, D.B., Kriegl, M., Nijamdeen, T.M., Riechers, M., Walker, E.Z. (2022)
Published in *Frontiers in Marine Science*

List of abbreviations

ABM	Area-based management
AR6	Sixth Assessment Report of the Intergovernmental Panel on Climate Change
CAF	Capital Approach Framework
ECR	Early-Career Researcher
FCM	Fuzzy Cognitive Mapping
HCA	Hierarchical Cluster Analysis
IC(Z)M	Integrated Coastal (Zone) Management
IPCC	Intergovernmental Panel on Climate Change
MPA	Marine Protected Areas
MSP	Marine Spatial Planning
SA	Stakeholder Analysis
SDG	Sustainable Development Goal
SER	Social-ecological resilience
SES	Social-ecological system
SNA	Stakeholder Network Analysis

Chapter I: System and transformative knowledge for enhancing the resilience of coastal social-ecological systems to climate change – a synthesis

Lena Rölfer

Framework chapter and synthesis

1 Introduction

1.1 Motivation and problem framing

Social-ecological systems (SES) are comprised of different, intertwined human and environmental elements and constantly shaped by multiple social and ecological processes. Such processes interact and reinforce each other on multiple levels and at multiple scales (Cash et al. 2006, Folke et al. 2016, Biggs et al. 2021). A SES approach applies a complex adaptive systems view (Levin 1998, Preiser et al. 2018), emphasizing the often non-linear and dynamic interplay, adaptiveness and evolving nature of its component parts (Preiser et al. 2018, Biggs et al. 2021).

Coastal areas are complex SES that span the land and ocean interface, are resource-rich, and are occupied by a multitude of different stakeholders (Pittman and Armitage 2016, Schlüter et al. 2020, Refulio-Coronado et al. 2021). Furthermore, coastal SES are characterized by high social, economic and institutional diversity (Partelow et al. 2020). Governance systems are often decentralised, and management activities are fragmented, due to different stakeholder interests and conflicts, as well as a separation into land and ocean management units (Boyes and Elliott 2014, Nursey-Bray et al. 2014, de Alencar et al. 2020). Tools and approaches to manage the coastal space include Integrated Coastal (Zone) Management (IC(Z)M), Marine Spatial Planning (MSP), and Marine Protected Areas (MPA) management. Even though such area-based management approaches spatially overlap, they are still lacking integration at the operational level (Celliers et al. 2022b). Simultaneously, coastal SES increasingly face challenges brought on by resource overuse, coastal development, pollution and environmental change (Nash et al. 2017, IPCC 2019, Jouffray et al. 2020). As a result, the state of the world's coastal ecosystems is cause for concern (Halpern et al. 2015, Nash et al. 2017, UN 2021).

Especially climate change presents a major challenge for coastal SES. Climate impacts are caused by rising air and seawater temperatures (including climate extremes such as marine heatwaves), ocean acidification, sea-level rise, changed precipitation, wind and wave conditions, and subsequent coastal erosion (IPCC 2019). These impacts, combined with other socio-economic pressures, pose severe challenges to coastal ecosystems and the people depending on them (Halpern et al. 2015, Selig et al. 2019). Coastal governance includes the key institutions for addressing environmental and climate change challenges in coastal SES (Celliers et al. 2020). It is defined as place-based political and institutional processes of coastal management and the implementation of related decisions. It creates the conditions for ordered rules and collective action and encompasses actors from the government, private sector, and civil society (Adger et al. 2003, Shah and Shah 2006, Ojwang et al. 2017, Celliers et al. 2020). Even though area-based management approaches, such as ICZM and MSP, have the potential to play a major role in adapting to climate change impacts, the integration of climate change adaptation into processes or structures for coastal governance has been described as challenging (Tobey et al. 2010, Frazão Santos et al. 2020, Gissi et al. 2021).

Resilience presents a suitable bridging concept between environmental governance and climate change adaptation in (coastal) SES. It facilitates bridging between the natural and social sciences, as well as between science and policy in an inter- and trans-disciplinary approach (Davoudi et al. 2012, Deppisch and Hasibovic 2013, Baggio et al. 2015). Resilience as a scientific concept related to environmental management came to prominence at the turn of the 21st century and is now used as a multi-disciplinary concept applied in various disciplines. While different definitions of resilience exist in environmental research, e.g., engineering and ecological resilience (Holling 1973, 1996), *social-ecological resilience* refers to the "*capacities of a system to persist, adapt and transform in the face* *of change through human intervention*" (Folke et al. 2010, 2016). While Holling's definition of engineering resilience (Holling 1973) is associated with stability and incremental adaptation, the notion of *transformation* has gained importance in environmental governance facing sustainability challenges (Walker et al. 2004, Westley et al. 2013, Folke et al. 2021). Transformation refers to "*the potential of a SES to shift to a different, but still productive and socially desirable, regime that is again resilient to disturbance*" (Garmestani et al. 2019).

The Intergovernmental Panel on Climate Change (IPCC) also makes use of the definition of social-ecological resilience in its Sixth Assessment Report (AR6) and confirms that recent literature increasingly suggests that transformative changes in SES are required to enhance their resilience to climate change (Ara Begum et al. 2022). Governance systems have been highlighted to play a major role in building the capacities for adaptation and transformation towards climate resilience in coastal SES (Celliers et al. 2020, Jozaei et al. 2022, Pörtner et al. 2022). Managing towards climate resilience, in this context, can be understood as actions and processes (adaptive and transformative in nature) that enable stakeholders involved in coastal governance to maintain a functioning and sustainable SES in face of climate change. Yet, it remains unclear how to enable effective coastal governance to build the capacities that are needed to enhance the resilience of coastal SES to climate change.

To address this problem, the importance of *actionable knowledge* is growing in climate change adaptation, environmental governance, and broader sustainability research. Actionable knowledge (also called action-oriented research or actionable science) refers to knowledge that contributes to solving societal problems and points to actions and processes of change (Arnott et al. 2020, Mach et al. 2020, Wong-Parodi et al. 2020, Caniglia et al. 2021). To generate actionable knowledge for coastal governance, an improved understanding of different elements of the governance system is required. Firstly, it requires an understanding of the *agency* of different stakeholders to act in coastal governance. *Agency* can be defined as "*the capacity of individual and collective actors to change the course of events or the outcome of processes*" (based on Pattberg and Stripple 2008, Otto et al. 2020). It has been highlighted as an important element for transformative change in resilience and sustainability research (e.g., Brown and Westaway 2011, Westley et al. 2013, Otto et al. 2020). Secondly, an improved understanding of the current degree of knowledge exchange for climate change adaptation can help to reduce vulnerability within SES and thus enhance the resilience to climate change (Bodin and Crona 2009, Prell 2011, Weiss et al. 2012). Thirdly, an identification of leverage points in the governance system - where a small shift may lead to fundamental changes in the system as a whole and thus can facilitate transformation - may shed light on actions that are needed to transform towards climate resilience (e.g., Meadows 1999, Smith et al. 2013, Abson et al. 2017).

One way of generating actionable knowledge for more evidence-informed decision-making is the *co-production of knowledge* with stakeholders from policy and society (Wyborn et al. 2019, Norström et al. 2020, Chambers et al. 2021). *Knowledge co-production* can be defined as "*iterative and collaborative processes involving diverse types of expertise, knowledge and actors to produce context-specific knowledge*" (Norström et al. 2020 p. 183). It ensures that relevant stakeholders are included in the research process, facilitates them to legitimise and take ownership of the outcomes, and increases the uptake (Lang et al. 2012, Brouwer et al. 2016, Chambers et al. 2022). However, researchers engaging with knowledge co-production face specific challenges, such as structural issues of the academic system, practice orientation vs. scientific excellence, or limited access to stakeholder networks for turning research into action (Armitage et al. 2011, Cvitanovic et al. 2015, Oliver et al. 2019). Such obstacles are often amplified for early-career researchers (ECRs) due to common limitations such as lack of funding, experience, and access to networks (Haider et al. 2018, Schrot et al. 2020, Fam et al. 2020, Strand et al. 2022).

Considering the literature presented above, three research gaps arise for generating actionable knowledge for coastal governance to enhance the resilience of coastal SES to climate change. Firstly, there is a need to develop a more actionable concept of resilience for application in coastal governance. Secondly, there is a need for methods and approaches that can generate actionable knowledge for coastal governance. Thirdly, there is a need to identify and overcome obstacles to knowledge co-production, especially for ECRs, as a process for generating actionable knowledge in coastal SES.

1.2 Research aim and objectives

This dissertation aims to contribute to research on generating actionable knowledge for coastal governance to enhance the resilience of coastal SES to climate change. It does this by providing theoretical, methodological and empirical insights on the three identified research gaps in five research publications. The five research publications contributing to this dissertation are attached to this framework chapter as chapters II-VI.

In the following sections, I first describe my research approach by formulating the research questions, establishing how the different chapters are linked in the broader frame of this dissertation, and introducing the case study chosen for the place-based empirical research (Section 2). I then present the key findings for each of the five chapters (Section 3), synthesize the main findings and discuss the internal coherence in a unifying concept, highlight the implications for the case study and research, and point to future research needs (Section 4). Finally, I draw the conclusion in Section 5.

2 Research Approach

2.1 Research questions

The overarching aim of this dissertation is explored by three research questions (RQs), which each address one of the research gaps highlighted in the introduction. The RQs are:

RQ 1: What is a more actionable concept for applying the concept of resilience in coastal SES through coastal governance?

RQ 2: What methods and approaches are suitable to generate actionable knowledge for coastal governance?

RQ 3: What obstacles to knowledge co-production exist for ECRs and how can they be overcome?

2.2 Research design and chapter overview

For answering the research questions, RQ1 and RQ3 are addressed by one publication each (Chapters II & VI) and RQ2 is addressed by three publications (Chapters III-V), summing up to a total of five chapters (Table 1). Chapter III-V follow a place-based research approach for advancing methodological and empirical research in a coastal case study. Each of these chapters addresses a sub-research question contributing to RQ2, which is presented in Table 1. The following section provides a short introduction to each chapter, the methods used, and how the (sub-)research questions are addressed. The individual chapters partly build upon each other and a unifying concept illuminating the internal coherence of this dissertation is presented in the synthesis section.

Table 1. Overview of the overarching aim, (sub-)research questions and chapters addressing them.

<table>
<tr><th colspan="3">Overarching aim: Contribute to research on generating actionable knowledge for coastal governance to enhance the resilience of coastal SES to climate change.</th></tr>
<tr><th colspan="2">Research and Sub-Research Question</th><th>Chapter</th></tr>
<tr><td colspan="2">RQ 1: What is a more actionable concept for applying the concept of resilience in coastal governance?</td><td>Chapter II: Resilience and coastal governance: knowledge and navigation between stability and transformation</td></tr>
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Chapter II: Resilience and coastal governance: knowledge and navigation between stability and transformation

RQ1 seeks to provide a more actionable concept of resilience for application in coastal governance. Given the already broad literature about resilience and coastal SES, I used a research synthesis to answer this research question. Research syntheses are comprehensive and facilitate the creation of a new understanding of problems for research, policy and/or practice by bringing together different bodies of knowledge (Wyborn et al. 2018). For this study, I brought together common themes and challenges documented in the resilience, climate change and environmental governance literature. Based on the literature, I provided an overview of different approaches to resilience, desirable system states, and highlighted tensions associated with adaptation and transformation at different scales and in relation to coastal governance.

In a second step, I proposed a five-step approach based on three types of knowledge, including system, target and transformative knowledge (ProClim 1997). The three types of knowledge typology is often applied when framing a system in sustainability science (Abson et al. 2014, Pohl et al. 2017). The typology addresses the question of 'what is?', 'where to?' and 'how to get there?', each addressing one of the three knowledge types (ProClim 1997). The findings can be seen as a starting point for developing research approaches that are targeted at generating actionable knowledge for coastal governance and for operationalising the concept of resilience in coastal SES. Thus, Chapter II builds the conceptual groundwork for this dissertation and the place-based research approach applied in Chapters III-V.

Chapter III: Stratification of stakeholders for participation in the governance of coastal social-ecological systems

RQ2 seeks to enhance the understanding of what methods and approaches are suitable to generate actionable knowledge for enhancing the resilience of coastal SES to climate change. SRQ2.1, more specifically, is targeted at how organisations involved in coastal governance can be classified by dimensions of agency for better selection and representation of stakeholders in research processes. Agency, in this context, is understood as the ability of different stakeholders to act in governance processes and was identified as an important driver for enhancing resilience in Chapter II. For answering RQ2 and SRQ2.1 I proposed and tested i) a classification of organisations involved in coastal governance by their agency to act, and ii) a subsequent grouping into organisational archetypes for representation and selection in research processes.

The classification by agency builds on previous work by Celliers et al. (2012) that identifies and defines three dimensions required for effective coastal management in South Africa. These dimensions are scale, power, and resources, which are each informed by a set of indicators. For application in Chapter III, the dimensions and indicators were tailored to the case study context and used as an assessment scheme for agency of organisations involved in coastal governance. Organisations were identified from a review of the literature and online resources, Environmental Impact Assessments, and provincial and local coastal working groups, as well as using snowball sampling (Leventon et al. 2016). In total, 113 organisations involved in aspects of coastal governance of the Algoa Bay SES were evaluated. Given the restrictions brought about by the COVID pandemic, an expert-driven approach was applied. Experts include researchers knowledgeable of the coastal and ocean domain in Algoa Bay.

Normalized scores for each indicator were aggregated per dimension, and the arithmetic mean across all indicators is referred to as the agency of the organisation. The resulting scores ranged from 1 (highest) to 0 (lowest). An agency of 1 would be an institution that has a physical presence in Algoa Bay with a high institutional mandate and constituency, which is highly resourced and has the highest power. Subsequently, a hierarchical cluster analysis (HCA) is performed using 'complete-linkage clustering' to identify clusters of organisations that have a similar scoring for indicators internally but are distinct from other clusters externally, using the maximum Euclidian distance (dissimilarity). I chose to use a dissimilarity clustering approach because I was seeking to identify distinct archetypes. The HCA resulted in 5 distinct groupings of organisations with similar characteristics. Each group was then categorized into organisational archetypes based on organisational types and their scoring for indicators. The empirical results of this chapter build the basis for the stakeholder selection in Chapters IV and V.

Chapter IV: Assessing collaboration, knowledge networks and stakeholder agency for enhancing the climate resilience of coastal social-ecological systems

SRQ2.2 seeks to contribute to a better understanding of stakeholder networks regarding collaboration, knowledge exchange and the role of stakeholder agency and propose recommendations of actions that can enhance the resilience to climate change. To answer this question, I combined the assessment of stakeholder agency from the previous publication with a Stakeholder Network Analysis (SNA). A SNA is useful here, because it facilitates the identification and characterisation of the relationships between different stakeholders involved in coastal governance and improves the understanding of different stakeholder roles regarding to their agency within the networks.

Based on Chapter III, a sub-sample of 36 organisations, which are locally active in the Nelson Mandela Metropolitan Area, or hold specific mandates for the management of the coast and ocean, was selected. An online questionnaire was designed to assess i) collaborations for coastal governance (collaboration network), and ii) the exchange of information and knowledge about climate change adaptation within coastal governance (knowledge network). A list of organisations was provided, and survey participants were asked to evaluate their collaboration and knowledge exchange with these organisations. Survey participants were also allowed to add other organisations to the list. The online questionnaire was answered by 20 organisations from the local, provincial, national, and international level. The resulting networks consisted of 41 and 38 organisations for the collaboration and knowledge network, respectively. Based on the questionnaire, four different centrality measures were calculated for each organisation, including strength, betweenness, closeness, and eigenvector (both networks) as well as in- and out-degree for the knowledge network. The analysis of centrality measures of different nodes within a system is rooted in network theory (e.g., Freeman 1979, Cumming 2011, Prell 2011). The results of this study are discussed considering different roles of organisations in the networks concerning the agency of different organisations and organisational archetypes. Further implications for improving knowledge exchange for enhancing the resilience of coastal SES to climate change are derived.

Chapter V: Leveraging Governance Performance to Enhance Climate Resilience

SRQ2.2 seeks to contribute to a better understanding of how system-level interactions between governance processes and their performance can be assessed and contribute to identifying leverage points for enhancing the resilience of coastal SES to climate change. To answer SRQ2.2, I present and test an approach that combines a Capitals Approach Framework (CAF) with Fuzzy Cognitive Mapping (FCM) and a subsequent leverage points analysis. *Capitals* are understood as the assets, capabilities, properties or other components of governance systems, which collectively represent its ability to function well (Carmona et al. 2017, Celliers et al. 2020). The benefit of applying a CAF is that it provides a framework for assessing the adaptive capacity of a governance systems by including both environmental and social components of the SES (Carmona et al. 2017, Celliers et al. 2020, Williams et al. 2020). The application of the FCM, furthermore, enables capturing people's perceptions of causal relationships and facilitates a systems perspective, which is prerequisite for identifying leverage points (Berbés-Blázquez et al. 2017, Giordano et al. 2017).

I applied the presented approach in the case study area to identify leverage points for enhancing climate resilience in the SES of Algoa Bay. In total, 45 governance processes contributing to coastal and ocean governance and climate change adaptation were identified using the CAF. Subsequently, these processes were assessed for their performance by 39 relevant organisations within the Algoa Bay SES. A system-level average rating for the performance of each governance process was calculated and rated as 'low', 'medium', or 'high' performing. In a second step, the interrelations between individual governance processes for environmental management, e.g., the effectiveness and recognition of policies, strategies and actions that enable climate change adaptation and coastal governance, were mapped using FCM. The relationships and their weighting among governance processes were evaluated by five researchers familiar with the Algoa Bay SES.

Similar to Chapter III, an expert-led approach was employed due to the restricted ability to co-develop the FCM with stakeholders from the case study because of the COVID-19 pandemic. Finally, the two centrality measures strength and betweenness were calculated for each governance process, whereas strength centrality was further informed by the in-degree and out-degree. Nodes with a high centrality, but low/medium performance were identified as leverage points (e.g., Williams et al. 2020), because small improvements in these processes can enhance the overall system performance. Governance processes were ranked by both strength and betweenness centrality and the highest-ranking quartiles with medium or low performance were selected as leverage points.

Chapter VI: Disentangling Obstacles to Knowledge Co-Production for Early-Career Researchers in the Marine Sciences

RQ3 seeks to advance the understanding of what obstacles to knowledge co-production exist for ECRs and how they can be overcome. To address this question, Chapter VI provides a perspective on the obstacles that especially ECRs face, and actions that are needed to create the conditions under which knowledge co-production processes can be successful. To achieve this objective, I employed a multi-method approach combining an online survey and a workshop. Both were targeted at ECRs in the field of coastal and marine science, who engage in knowledge co-production with non-academic stakeholders in their research. The survey aimed to identify common and most apparent obstacles to knowledge co-production for ECRs in coastal and marine research.

For formulating the questions of the survey, I conducted a literature review on common barriers in transdisciplinary research and knowledge co-production processes. Based on the review, obstacles were classified into personal, engagement, and institutional obstacles and rated on a Likert-Scale between 1 (not at all challenging) and 5 (very much challenging). The survey was hosted on the LimeSurvey platform and distributed through social media and mailing lists relevant to the topic. In total, 22 ECRs responded to the survey. At a subsequent workshop, preliminary results of the survey were presented and potential actions for mitigating the impacts of obstacles on ECRs future pathways were discussed. Based on the survey and workshop, actions that can be taken at various organisational levels (institutional, community, supervisor, and individual) to leverage change towards a more inclusive environment for ECRs engaging in knowledge co-production were discussed in this publication.

2.3 Case study area: Algoa Bay, South Africa

Algoa Bay, located in the Eastern Cape of South Africa, was chosen as the case study area for advancing methodological and empirical research in Chapters III, IV & V of this dissertation. Algoa Bay is home to the Nelson Mandela Bay Municipality (NMBM), including the cities of Gqeberha (formerly Port Elizabeth), Despatch and Kariega (Fig. 1). It is an integrated SES stretching from land to the ocean including important socio-economic and ecological features, e.g., two economically important industrial ports, strong urban and peri-urban development along the coast, and diverse and pristine ecosystems with high species diversity (Dorrington et al. 2018). The Port of Gqeberha serves local industries such as agricultural products, manganese ore, and petroleum products as well as the prominent automotive industry, which is a primary economic driver for the Bay. The newer Port of Ngqura was established in 2012 and is a deep-water transhipment hub offering port services for containers in transit to global markets as well as within the Sub-Saharan Africa region.

Given its prime ecological and socio-economic importance, Algoa Bay has also been described as one of the most vulnerable coastal areas in South Africa to climate change. Its location between two up-welling systems, the warm Agulhas current and the cool Benguela current (see Fig. 1), results in a particularly high climate variability (van Huyssteen et al. 2013). The area is already experiencing climate-induced changes, including hotter days, more frequent and longer droughts, more intense floods, greater wind speeds, a change in the prevailing wind directions, rising sea levels, and increased (extreme) storm surges (NMBM 2015, Bornman et al. 2016). These impacts are likely to increase in magnitude and frequency over time. In addition, ongoing droughts have resulted in water shortages in the city. Rising sea level is of particular concern, as it is predicted that popular swimming beaches, public infrastructure, and development, including national roads and houses, could eventually be reclaimed by the ocean (CMR 2020).

Coastal management in South Africa is still largely sector-based and top-down, governed by different administrative levels of government and area-based management tools and approaches (Sowman and Malan 2018, Taljaard et al. 2019). 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 Act No. 24 or 2008; Marine Spatial Planning 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 MPAs, 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 organisations, civil society organisations, 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. While some organisations already respond to the impacts of climate change, collective governance action across the land-ocean continuum in Algoa Bay is still conceptually abstract.

Algoa Bay has the longest-standing biophysical monitoring along the country's shoreline as well as a diversity of socio-economic marine and coastal activities (Dorrington et al. 2018). Given the amount of research that has already been conducted, as well as climate and other sustainability-related challenges Algoa Bay is already facing, it presents a suitable case study area for a place-based research approach (see Fischer et al. 2014). Furthermore, it is representative of a typical coastal SES and thus the methods applied in this dissertation can be transferred to other coastal SES.

Figure 1. Map of Algoa Bay located in the Eastern Cape of South Africa. Arrows indicate the warm Agulhas current on the east coast and the cool Benguela current on the west coast of South Africa.

3 Key Findings

This section provides an overview of the key findings of each chapter in response to the RQs as described in section 2.2. Table 2 summarizes the methods and approaches that were applied, key results, as well as theoretical, methodological, and/or empirical contributions of the chapters.

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

For developing a better understanding of the concept of resilience for application in coastal governance, I first discuss the implications of social-ecological resilience for achieving desirable system states. Because the definition of social-ecological resilience refers to the capacities of a system to persist, adapt and transform, I argue that human intervention such as coastal governance is a choice between stabilisation of the current system and the transformation to a more desirable system state.

Secondly, I highlight that for navigating towards a desirable system state, a discussion about the implications of, and tensions between, stabilisation and transformation is required. These tensions include the potential of 'lock-ins' through stabilisation, which can limit the potential for transformative change towards a more desirable future. Furthermore, it is often unclear to what state a system is to be transformed, e.g., what a desirable system state looks like, and what system components are desirable and feasible to be stabilised or transformed. As these are highly normative questions, questions of knowledge co-production and stakeholder engagement are highly important.

Thirdly, I establish the relationship between social-ecological resilience and coastal governance by discussing different components of coastal SES, such as the diversity of actors and management approaches considering the previous themes. I conclude that local coastal governance may be the most appropriate scale for addressing resilience in coastal SES. In the second part of this article, I present a stepwise approach to enabling social-ecological resilience through coastal governance.

The approach highlights the need for collaborative research approaches including knowledge co-production with relevant actors from policy and society. I suggest using the 'three types of knowledge' typology (system, target, transformative) as a more actionable approach to the concept of resilience in coastal governance. The stepwise approach includes i) considering the scale and system boundaries, ii) identifying key SES functions and (un)desirable system characteristics (system knowledge) , iii) developing a common normative vision of a resilient coast (target knowledge), iv) assessing the adaptive capacity and agency of actors within the SES, and v) co-develop information services for informed decision-making (transformative knowledge).

I also highlight that iterative learning cycles of the stepwise approach are necessary for constant reflection and re-evaluation of system characteristics and target setting. Finally, I suggest that research needs to place a greater focus on transformative knowledge, especially with regard to transformative system changes, for operationalizing the concept of resilience in coastal SES facing climate change. Thus, Chapter II contributes to a more actionable application of the concept of resilience for coastal governance.

Chapter III: Stratification of stakeholders for participation in the governance of coastal social-ecological systems

I identified five organisational archetypes that differ from each other by their scoring for scale, power, and resources. The archetype with the highest scoring for agency was called *get-it-done*, and represented organisations with a high measure of available resources and operational scale, and a high measure of power. The second grouping represented mainly government institutions with substantial power, but not present in the Bay and was called *plans-and-planning.* Organisations of this archetype are well-resourced in terms of human capacity and access to data and information. Another group of organisations with low power, but a relatively high level of resources and local presence, which makes them relevant for local decision-making is called *little-by-little*. The archetype *on-the-margin* represents a small group of organisations without authority and being physically based or operating in Algoa Bay. Organisations from this archetype can make focussed input to participation processes but may also be omitted due to the challenge of engaging from a distance. Finally, a large group of mainly non-governmental organisations and advocacy groups with a physical presence and collective interest and agency (e.g., high moral suasion) is called *vocal-and-insistent.*

The methodology proposed and tested in this article enables an informed and intentional approach to stratifying and selecting stakeholders for participation in research processes. The approach advances existing methodologies by providing a process to analyse and select stakeholders based on their agency to act in coastal governance processes. The use of an indicator-based framework, such as proposed here, enables the stratification of stakeholders by different characteristics. The approach also facilitates a remote evaluation of agency by an expert team and is easily adaptable to the case study context. We highlight the need to include stakeholders from different organisational archetypes in research processes to balance representation between stakeholders with different levels of agency. However, the results still need to be interpreted carefully and stakeholders need to be selected in relation to a specific research objective. The study contributes to current research by proposing a new approach for analysing stakeholders and their selection for and participation in research processes. It also provides an overview of the organisations for further engagement in Chapters IV & V.

Chapter IV: Assessing collaboration, knowledge networks and stakeholder agency for enhancing the climate resilience of coastal social-ecological systems

Results of Chapter IV indicate that collaboration between organisations involved in coastal governance is more established than the exchange of information and knowledge about climate change adaptation. Results suggest that individual organisations and organisational archetypes with different degrees and characteristics of agency play different roles in the networks. Some organisations show a high interconnectedness and influence. In the collaboration network, these are mainly development organisations from the archetype *get-it-done* with relevant control over policy-implementation processes related to coastal governance. In the knowledge network, mainly directorates from the NMBM as well as research institutes are strongly interconnected. Other organisations act as bridging organisations. In both networks, these are mainly organisations from the archetype *vocal-and-insistent*, which represent environmental and conservation organisations. This is even more pronounced in the knowledge network, with a consultancy agency as the most important bridging organisation. Furthermore, a few organisations act as information providers, mainly representing government institutions from the archetype *plans-and-planning*. Such organisations have the best access to data and information and generally have high agency.

Results also point to a lack of cross-level and cross-sectoral collaboration and knowledge exchange, as well as formal agreements to share climate information. I suggest that different top-down and bottom-up actions are needed to improve knowledge exchange and thus enhance the resilience of the Algoa Bay SES to climate change. These include the establishment of formal agreements to share climate information and knowledge across sectors and administrative levels; stronger integration of climate information into area-based management processes; supporting and encouraging the role of information providers; and increasing the transformative potential of bridging organisations.

The findings of this study shed light on network structures in coastal governance facing climate change and may be transferable to similar coastal case-studies, where climate change is not yet well integrated into coastal governance. The study contributes to a better understanding of current collaboration and knowledge networks in Algoa Bay and what role organisations play. It further shows what actions are necessary for improving knowledge exchange for enhancing the resilience of the Algoa Bay SES to climate change. The study also advances research on applying and combining SA and SNA in climate change adaptation and environmental governance research by linking the agency of stakeholders to collaboration and knowledge networks.

Chapter V: Leveraging Governance Performance to Enhance Climate Resilience

For enhancing the resilience of the Algoa Bay SES to climate change, I identified 14 leverage points based on high centrality and medium to low performance. Most of the leverage points were governance processes associated with political and human capital, whereas only one leverage point was associated with financial capital. Due to the high interconnectedness and dependence of governance processes, I propose a set of several leverage points that are connected and thus may enhance the overall resilience of the Algoa Bay SES. The set, consisting of seven leverage points, included governance processes from each capital and suggests that both top-down (e.g., support from the provincial government) as well as bottom-up actions (e.g., increased public awareness and understanding of climate change) are required to enable transformative change towards climate resilience. They include improving (a) the support from the 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; and (g) public awareness and understanding of climate change.

Additionally, results suggest that missing links between climate change adaptation and different management approaches (e.g., ICZM, MSP and MPA) need to be established and governance processes at the interface must be strengthened. Here, also support from the provincial government plays a major role. I argue that whereas change is required at the identified leverage points, well-performing and central governance processes need to be maintained in their functioning for managing resilience. The presented approach can be transferred to other case studies for identifying places to intervene in complex SES. In this case, I recommend that the CAF and FCM are co-produced with stakeholders of the governance system so that stakeholders can reflect on their role in the system and can take ownership of the results. The approach can also be applied to analyse relations and interactions between capitals and advances methodological and empirical knowledge on how to operationalize transformation towards climate resilience in SES.

Chapter VI: Disentangling Obstacles to Knowledge Co-Production for Early-Career Researchers in the Marine Sciences

We identified several obstacles that ECRs face while planning and implementing knowledge co-production approaches and structured these into personal, engagement and institutional obstacles. For example, obstacles included the determination of a research topic and search for a suitable supervisor (personal), the difficulty in establishing and maintaining meaningful relationships with non-academic actors (engagement), and expectations to meet pre-defined departmental or institutional requirements (institutional). Based on the obstacles we propose actions that need to be taken at various organisational levels (institutional, community, supervisor, and individual). We highlight that both bottom-up (individual to institutions) and top-down (institutions to individual) actions are required and emphasize that institutions carry the responsibility to create conditions in which the needs of ECRs are met.

This perspective article contributes to sustainability research by providing empirical evidence on obstacles to knowledge co-production. While the survey was specifically targeted at ECRs in the coastal and marine sciences, results are also more broadly applicable to different fields within sustainability science. The article critically reflects on the current academic setting for facilitating knowledge co-production and highlights the need for transformative changes to overcome obstacles. The findings thus contribute to the broader frame of this dissertation by suggesting action pathways that can leverage transformative change towards a more inclusive environment and improved career development for ECRs engaging in knowledge co-production at the interface with stakeholders involved in coastal governance.

Table 2. Summary of chapters by their methods and approaches, key results and theoretical, methodological, and/or empirical contributions.

Methods and approaches	Key results	Contributions to research
Chapter II: Resilience and coastal governance: knowledge and navigation between stability and transformation		
Research synthesis bringing together different bodies of knowledge from resilience, climate change adaptation, environmental governance and sustainability literature	- highlights the importance of navigating between stabilisation and transformation for achieving desirable system states in SES - presents a stepwise approach for enhancing social-ecological resilience through coastal governance by proposing the application of three types of knowledge including system, target, and transformative knowledge - suggests that research needs to place a greater focus on transformative knowledge concerning transformative change for enhancing resilience	**Theoretical:** Better understanding of the concept of resilience in relation to coastal SES and climate change and how to enhance resilience through coastal governance
Chapter III: Stratification of stakeholders for participation in the governance of coastal social-ecological systems		
Snowball sampling; **stakeholder analysis** by agency using an indicator framework; **hierarchical cluster analysis** to identify cluster of stakeholders with similar scoring for indicators of agency	- 113 organisations involved in aspects of coastal and ocean governance were identified and scored for different indicators of agency contributing to the dimensions of power, resources, and scale - hierarchical cluster analysis resulted in five distinct groups of organisations, which were interpreted as stakeholder archetypes based on their scoring - highlights the need to include stakeholders from different organisational archetypes in research processes	**Methodological:** Classification and grouping of stakeholders into archetypes according to their agency; **Empirical:** Overview of organisations and their agency to act in coastal and ocean governance processes of the Algoa Bay SES
Chapter IV: Assessing collaboration, knowledge exchange and stakeholder agency for enhancing climate resilience of coastal social-ecological systems		
Online questionnaire to assess collaboration and knowledge networks; **stakeholder network analysis** using four different centrality measures; **stakeholder analysis** for archetypes	- results suggest different top-down and bottom-up actions including the establishment of formal agreements to share climate information and knowledge across sectors and administrative level; stronger integration of climate information into area-based management processes, supporting and encouraging the role of information providers; and increasing the transformative potential of bridging organisations for enhancing climate resilience	**Empirical:** Better understanding of collaboration and knowledge exchange and the role of stakeholders about improving knowledge flow in coastal governance; **Methodological:** Advancing the application of a SA and SNA by combining stakeholder agency and archetypes with stakeholder networks
Chapter V: Leveraging Governance Performance to Enhance Climate Resilience		
Capital Approach Framework to assess governance performance; **Fuzzy Cognitive Mapping** to map relationships between governance processes; **leverage points analysis** based on high centrality and medium to low performance	- political and financial capital performed highest and lowest, respectively - fourteen leverage points were identified and a set of seven interconnected leverage points was suggested that included bottom-up and top-down governance processes for enhancing climate resilience - results also suggest that missing links between climate change adaptation and different management approaches (e.g., ICZM, MSP and MPA) need to be established	**Methodological:** Mapping of relationships between governance processes and identifying leverage points that can facilitate transformative change; **Empirical:** Recommendations how leverage points can enhance transformative change towards climate resilience of the Algoa Bay SES
Chapter VI: Disentangling Obstacles to Knowledge Co-Production for Early-Career Researchers in the Marine Sciences		
Online questionnaire to identify common obstacles to knowledge co-production for ECRs; **stakeholder workshop** to discuss potential solutions	- obstacles that ECRs face while planning and implementing knowledge co-production approaches were identified and structured into personal, engagement and institutional obstacles - proposes actions that can be taken at various organisational levels (institutional, community, supervisor, and individual) to leverage change towards a more inclusive environment and improved career development for ECRs engaging in knowledge co-production	**Empirical:** Identification of obstacles to knowledge co-production for ECRS in coastal and marine research and proposal of actions that can improve the capacity of ECRs to co-produce knowledge with non-academic stakeholders involved in coastal governance

4 Synthesis

This dissertation contributes to research on generating actionable knowledge for coastal governance to enhance the resilience of coastal SES to climate change. In this synthesis, I illuminate the overall coherence of this dissertation in a unifying concept and provide answers to the RQs in an integrated way. I also highlight the implications of this dissertation and provide an outlook on future research.

4.1 Unifying concept illuminating the overall coherence of this dissertation

Three types of knowledge for a more actionable approach to resilience for coastal governance

Chapter II sheds light on the different characteristics of the concept of social-ecological resilience for application in coastal governance. The concept recognizes the need for adaptation and stabilisation of the current system state while keeping the potential to shift to a different, but more desirable system state through transformation. Resilience, thus, offers an appropriate lens through which to understand and address complex SES and the role of human intervention and agency. The notion of transformation is also closely associated with sustainability research, recognizing the need to transform to higher degrees of sustainability. In response to RQ1, I propose an approach using the three types of knowledge typology (ProClim 1997), describing boundaries, characteristics and processes of the current state of the system (system knowledge), defining what constitutes a desirable alternative system state (target knowledge), and suggesting solution-oriented processes and actions to move towards this desired system state (transformative knowledge). The steps and methods proposed in the approach built the basis for the subsequent application in coastal governance of the Algoa Bay SES in Chapters III-V.

In the following, I demonstrate how the application and combination of different methods and approaches have contributed to generating system and transformative knowledge and to achieving the broader target of enhancing the resilience of coastal SES to climate change (responding to RQ2). I further reveal how this dissertation conceptualises the contribution of different types of knowledge to building the capacities necessary for action, and how knowledge co-production processes can be better facilitated in the academic system (responding to RQ3) (Fig. 2).

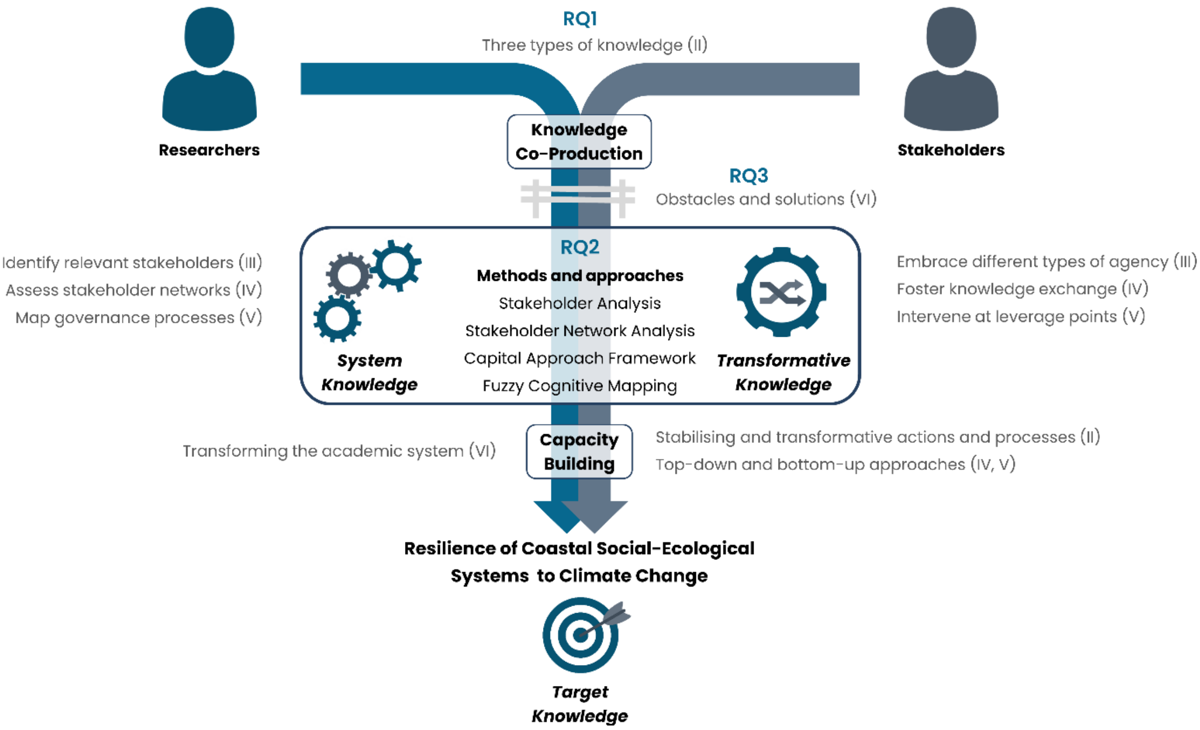

Figure 2. Graphical illustration of the unifying concept of this dissertation. Roman numerals refer to the individual chapters and RQ1-3 to the research questions of this dissertation.

Generating system knowledge

System knowledge is of key importance in understanding the boundaries, components and characteristics of a system. This is largely recognized in the SES and resilience literature, which are based on complex adaptive systems theory (e.g., Levin 1998, Berkes et al. 2004, Preiser et al. 2018). While systems knowledge of coastal SES has previously been described in the literature (e.g., reviewed by Refulio-Coronado et al. 2021), the ability of the governance system to manage towards climate resilience remains less defined. In this dissertation, a methodological contribution for generating system knowledge emerges by suggesting and applying a framework for stakeholder analysis based on agency (SA, Chapter III) and a capital approach framework (CAF, Chapter V). The two methods allowed for the systematic identification of system components and boundaries as proposed in Chapter II. More specifically, the SA identified and classified relevant stakeholders within the SES of Algoa Bay. Subsequent to this analysis, the CAF identified and evaluated specific governance processes relating to social, environmental, political, financial and human capital (Chapter V). In combination these methods illuminated different elements of coastal governance and climate change adaptation management across the SES of Algoa Bay. Furthermore, the stakeholder network analysis (SNA, Chapter IV) facilitated the assessment of current collaboration and knowledge networks as key elements for effective governance. Similarly, the use of fuzzy cognitive mapping (FCM, Chapter V) assessed the connectedness and interdependence of different governance processes within the system. Thus, the place-based research applied in Algoa Bay contributed to a system understanding at the individual, network and process levels of the coastal governance system.

Generating transformative knowledge

Transformative knowledge is necessary to implement actions and processes of change in a system. While research has typically more concentrated on generating system knowledge, the importance of transformative knowledge for achieving resilience and sustainability goals has also been highlighted in recent literature (Rosenzweig and Solecki 2018, Fazey et al. 2020, Reed and Fazey 2021). The results of this dissertation suggest that levers for such transformative change can occur across scales and processes of the system, such as social interactions, management systems, or policy processes, which are key elements of governance. In this dissertation, I identified such levers or intervention points by using network theory to analyse the centrality of different system components (Chapters IV & V). The identification of intervention and leverage points (based on different centrality measures) has implications for improving knowledge exchange and governance performance, which may result in more effective governance, and thus enhanced climate resilience across the Algoa Bay SES. Additionally, the scoring and classification of stakeholders according to their agency (Chapter III) identified five stakeholder archetypes with different functions within coastal governance. For example, Chapter IV shows that stakeholders from the archetype *vocal-and-insistent* (including organisations advocating for environmental protection) play an important role as bridging organisations for both collaboration and knowledge exchange in coastal governance of the Algoa Bay SES.

Knowledge co-production

Knowledge co-production includes principles and strategies for building resilience such as fostering complex systems thinking, encouraging learning, broadening participation, and enhancing polycentric governance (see Biggs et al. 2015). Thus, knowledge co-production between researchers and non-academic stakeholders presents a suitable process for generating system and transformative knowledge. However, especially in coastal systems, a multitude of different stakeholders exist, including stakeholders from governmental and non-government organisations, university, research institutes, business and industry with different interests ranging from tourism to nature conservation, sport and recreation, development, and private businesses. Therefore, a classification for evaluating the stakeholder landscape and classification of stakeholders for participation in knowledge co-production processes presents a useful tool for sustainability research (Chapter III). Results from this chapter also suggest that stakeholders have different types of agency and that this variety has to be considered when inviting stakeholders to be part of knowledge co-production processes.

Additionally, Chapter VI contributes to an improved understanding of obstacles to knowledge co-production between researchers and stakeholders involved in coastal governance (in response to RQ3). ECRs face many obstacles when including knowledge co-production in their research process, and the findings of the chapter suggest that such obstacles are best addressed at different organisational scales. While these results represent common obstacles to knowledge co-production, the main obstacle during the course of this dissertation was to personally engage with stakeholders. This was caused by the travel restrictions as a result of COVID-19, as well as 'stakeholder fatigue' created through an overwhelming amount of projects engaging with stakeholders under the umbrella of a wider *Algoa Bay Project* during the same time period. Such stakeholder fatigue is common to knowledge co-production and other research processes relying on the participation of non-academic stakeholders (Reed 2008). Thus, a clear formulation of goals and benefits for stakeholders is desirable (Suhari et al. 2022), and could have been improved in this study.

Capacity building - from knowledge to action

Co-produced system and transformative knowledge form the basis for translating (scientific) knowledge into action. In the context of this dissertation, I propose transformative solutions for coastal governance to enhance the resilience of coastal SES to climate change. To achieve this desired state, I propose that a navigation between stabilisation and transformation is needed (Chapter II). Transformation in this context means changes in actions and processes towards a governance system that is better capacitated to manage for climate change challenges. As suggested in Chapters IV and V, this can include increasing the transformative potential of bridging organisations, such as through collective climate change projects, as well as through improved support from the provincial government. At the same time, well-functioning processes must be stabilised to manage for resilience. Furthermore, results from the place-based research show that different top-down and bottom-up approaches as well as cross-sectoral actions are needed to build capacities for enhancing the resilience of coastal SES to climate change (see section 4.2.1). Bottom-up initiatives for enhancing climate resilience in the Algoa Bay case study can include individual action from different stakeholders. For example, 'local champions' have been highlighted as an important driver of change within other coastal municipalities in South Africa (Roberts 2010, Carmin et al. 2012, Pasquini et al. 2015). Local champions, in this context, are individuals that push forward climate action within their roles, even though they are not mandated or formally directed. It should be noted, however, that knowledge does not always translate into action, e.g., because municipalities are understaffed, or a lack of financial support jeopardizes participation in action plans (as evidenced by personal insights).

From an academic systems perspective, facilitating a process for translating knowledge into action also requires different measures of success and impact. This is highlighted in Chapter VI and by other researchers suggesting a transformation of the academic system itself is required to create the conditions under which knowledge co-production can be successful (e.g., Fazey et al. 2020, Caniglia et al. 2021, Strand et al. 2022). Such measures include the use of knowledge in decision-making and social learning, and are more reflective of societal impact and applicability of science (Kraemer-Mbula et al. 2020, Cvitanovic et al. 2021, Karcher et al. 2021). Picking up the ball-in-a-cup heuristic presented in Chapter II, such a transformation may result in an alternative, more desirable system state for ECRs (and more advanced researchers) engaging in knowledge co-production processes, and a stable basis for their career development and for bouncing back from failures.

4.2 Implications

4.2.1 Implications for stakeholders and decision-making in Algoa Bay

The Nelson Mandela Bay Municipality (NMBM) most directly benefits from the results from Chapters IV & V. As shown in the case study description, the NMBM in its current form is unable to respond to climate change and other sustainability challenges. Thus, the recommendations posed in this dissertation may help to build the capacity to overcome this limitation. More specifically, results suggest that there is a need to implement formal commitments to share climate information across levels and sectors, establish the role of information providers in the municipality, and reinforce human capital within the municipality. To communicate these findings, a report was sent to relevant representatives of the NMBM. Additionally, a workshop on the 'development and use of climate change information and climate services to support coastal municipalities in South Africa' was held in March 2022. It brought together stakeholders from three coastal municipalities, including the Nelson Mandela Bay Municipality in Algoa Bay, as well as scientists involved in the development of climate services to further discuss associated challenges of the uptake and use of climate information in policy and planning in the coastal municipalities. At the workshop, steps for the improvements of the provision of climate information and uptake by municipalities were discussed.

Furthermore, findings from Chapter V have implications for provincial and national government institutions in South Africa. Results suggest that more support from the provincial government, as well as the priority given to climate change in the 'Integrated Development Plan' can leverage change towards improved governance performance for climate change adaptation. Actions from governmental institutions may include addressing funding issues, offering training focusing on stakeholders with lower agency and capacities, and improving the overall availability and accessibility of climate information. While these suggestions have also been included in the recently adopted Climate Change Bill (Government of South Africa 2022), monitoring of the actual implementation may be necessary. Findings also suggest the need for a more integrated approach to climate change adaptation in coastal planning and management frameworks, such as ICZM and MSP. Especially the recently started process for marine spatial planning in South Africa and the wider Western Indian Ocean region offers an opportunity for the national government to integrate climate change more centrally into coastal planning. To push this notion, results from this dissertation were integrated into a policy brief for the *Western Indian Ocean Science to Policy Platform Series* (see Celliers et al. 2022b).

Finally, the conservation of environmental assets within the Algoa Bay SES presents an important bottleneck for resilience management and needs to be further prioritised within decision-making. This argument is supported by a high betweenness of environmental capital and environmental conservation organisations within the assessed systems. For example, while the recognition of the importance of ecosystems for the economy and the protection against climate change performs high, the actual enforcement of environmental legislation and protection of natural ecosystems performs low in the Algoa Bay SES (Chapter V). Similarly, organisations from the archetype *vocal-and-insistent* (e.g., local presence and high moral suasion) play an important role in advocating for environmental protection and act as bridging organisations that connect stakeholders from policy and practice (Chapter IV). The importance of conserving environmental assets as a mean for resilience management is in line with recent research reviewing relational values in coastal SES and highlighting the need for pro-environmental behaviour at the local level for sustainability transformations (Riechers et al. 2022). It also reemphasises the importance of nature-based solutions for climate change adaptation in (coastal) SES (e.g., Smith et al. 2017, Seddon et al. 2020, Gómez Martín et al. 2020).

4.2.2 Implications for research and academia

The findings of this dissertation have the following (non-exhaustive) implications for research on environmental governance, climate change adaptation, and broader sustainability challenges:

Firstly, the methods applied here are valid and applicable beyond the context of this dissertation. For example, the stakeholder analysis enables a selection of stakeholders relevant to the specific research objective and is nearly universally applicable in other geographic settings. Such an informed and systematic approach to stakeholder selection can be applied in any research project that aims to engage stakeholders in participatory processes. Similarly, the novel approach of combining an assessment of stakeholder agency with a network analysis may have broader application for mapping stakeholders and the relations between them in the field of climate change adaptation and other sustainability challenges. It enables a systems perspective on the connections between stakeholders with different degrees of agency and has the potential to identify WHO are the critical actors to achieve a desirable system state, especially in face of change (e.g., Otto et al. 2020). This may be of particular importance, if research objectives deal with conflicts and strong power imbalances in governance systems, such as agriculture-biodiversity conflicts or fisheries management (e.g., Gorris 2019, Lécuyer et al. 2021, Strand et al. 2022).

Secondly, the findings of this dissertation present a more actionable concept for approaching resilience in (coastal) governance systems. They highlight the importance of system and transformative knowledge for achieving a desirable system state for people and nature. This is not only applicable in the context of climate resilience, but also broader sustainability targets such as the Sustainable Development Goals, or biodiversity targets within the new Global Biodiversity Framework. Thus, the concept contributes to *transformative research*, which can be described as research that "*contributes to solving societal problems*" with the "*aim to catalyse processes of change by actively involving stakeholders in the research process*" (Wuppertal Institute 2022). In the context of coastal research, especially the term *transformative coastal/ocean governance* has gained importance in recent literature and refers to transformative solutions and changes that are targeted at generating innovative and sustainable ideas for coastal and ocean governance (e.g., Rudolph et al. 2020, Satterthwaite et al. 2022, Strand et al. 2022). This dissertation, thus, can provide a frame for transformative coastal governance, for example, by applying the concept in the context of equity and justice for local communities concerning the Blue Economy (e.g., Bennett et al. 2021, Cisneros-Montemayor et al. 2021).

Thirdly, this dissertation has implications for a more critical reflection on i) how transformative research (such as through knowledge co-production processes) is conducted, and ii) what academic foundation is needed so that it can fulfil its societal goal. This is of particular importance in light of the recently proclaimed United Nations 'Decade of Ocean Science for Sustainable Development' (2021-2030), which highlights the need for improving the translation of scientific knowledge into tangible action for more evidence-informed and effective management of coastal and marine SES (Ryabinin et al. 2019). On the one hand, such a critical reflection on how knowledge co-production processes are conducted may include more inclusive visions of what constitutes a sustainable coast, by representing a diversity of perspectives. This can be achieved by including a broad range of stakeholders (including researchers) from different ages, genders, and cultural and academic backgrounds (e.g., Schmidt and Neuburger 2017, Pereira et al. 2018, Rölfer et al. 2022c). On the other hand, facilitating knowledge co-production processes also requires changes in the academic system to create the conditions under which it can be successful.

4.3 Future research

While there are many possible applications of methods and approaches presented in this dissertation, the following suggestions provide possibilities for gaining deeper insights into the Algoa Bay case study, as well as applying them to other case studies and maximising their implications.

Firstly, there is potential for the application and combination of different methodologies in the Algoa Bay case study. Future applications of the SA and SNA in Algoa Bay may assess financial flows between organisations, which are of high relevance when actions for climate change adaptation need to be operationalised. Using an assessment of agency and networks, stakeholders with a lack of financial resources and missing links to more resourced governmental agencies can be identified. Additionally, linking the leverage points analysis with the analysis of stakeholder agency can help to analyse, which stakeholders are key for enhancing the performance of individual governance processes and thus the performance of different capitals.

Secondly, this dissertation only applied a quantitative stakeholder analysis. The application of a qualitative network analysis could assess what type of information and knowledge stakeholders can offer and exchange. This would further increase the empirical insights and societal relevance for local stakeholders. Similarly, results from the case study suggest that the provision of climate information and knowledge could be improved for different stakeholders in Algoa Bay. Further research is needed on the provision of climate information and knowledge, as well as decision-support tools for implementing climate change adaptations and integrating them into management approaches.

Thirdly, whereas this dissertation only applied the approach in one case study, it may be transferred to other coastal SES by applying the presented approach in real-world laboratories, co-producing knowledge for transformation towards climate resilience or broader sustainability goals (e.g., Schäpke et al. 2018, Pereira et al. 2020). Advances of real-world laboratories include the co-production of qualitative knowledge in contrast to quantitative analysis, and self-assessment of stakeholders (e.g., agency). Thus, an application in real-world laboratories could facilitate a truly transdisciplinary implication of the approach and produce actionable knowledge by building capacities and facilitating learning as an important driver for transformation (Caniglia et al. 2021).

5 Conclusion

This dissertation advances research on generating actionable knowledge for coastal governance to enhance the resilience of coastal SES to climate change by providing theoretical, methodological, and empirical insights. Key findings suggests that system and transformative knowledge are particularly important when applying the concept of resilience in coastal governance to generate actionable knowledge. This dissertation also proposes and tests the application of different methods and approaches for generating system and transformative knowledge in a case study in Algoa Bay, South Africa. The place-based research identified actions and processes that can enhance the adaptive capacities of coastal governance for more effective management, which is urgently needed in the Algoa Bay SES that is already facing climate change impacts. Additionally, the findings of this dissertation put forward actions that are needed at different organisational levels of the academic system to facilitate knowledge co-production at the interface with stakeholders involved in coastal governance. Thus, this dissertation provides insights and implications for pressing SES problems and contributes to advancing the field of transformative research for more societally relevant outcomes in the face of climate change and broader sustainability challenges.

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Appendix

The appendix includes the author contribution statements and the publication status as required by the dissertation guidelines. Appendices of the individual publications contributing to this thesis are attached to each publication in the according chapters II–VI.

A1. Author contribution statements

Authors' contributions to the articles and articles publication status (according to §16 of the guideline).

Chapter No.	Journal, Impact Factor* and publication status	Specific contributions	Author status and weighting factor**	Presentation at conference
II	Ecology & Society (**JIF=4.653**); *published*	***Lena Rölfer:*** *conceptualisation, visualisation, writing (original draft);* **Louis Celliers:** conceptualisation, funding acquisition, supervision, writing (original draft; review & editing); **David J. Abson:** conceptualisation, supervision, writing (original draft; review & editing)	Co-author with predominant contribution (1.0)	
III	Ambio (**JIF=6.943**); *accepted with minor revisions*	**Louis Celliers:** conceptualisation, data curation, methodology, funding acquisition, supervision, writing (original draft); ***Lena Rölfer:*** *conceptualisation, formal analysis, methodology, visualisation, writing (original draft; review & editing);* **Nina Rivers:** conceptualisation, data curation, writing (original draft; review & editing); **Sergio Rosendo**: conceptualisation, writing (original draft; review & editing); **Meredith Fernandes**; data curation; writing (original draft; review & editing); **María Máñez Costa:** conceptualisation, writing (review & editing); **Bernadette Snow:** writing (review & editing)	Co-author with equal contribution (1.0)	
IV	REC(**JIF=4.704**); *under review*	***Lena Rölfer:*** *conceptualisation, data curation, formal analysis, methodology, visualisation, writing (original draft);* **Louis Celliers:** funding acquisition, supervision, writing (review & editing); **Meredith Fernandes:** methodology; writing (review & editing); Nina Rivers: writing (review & editing); Bernadette Snow: writing (review & editing); **David J. Abson:** conceptualisation, supervision	Co-author with predominant contribution (1.0)	Western Indian Ocean Marine Science Association Symposium, 10th–15th October 2022, Gqeberha, South Africa (online poster presentation)
V	Earth's Future (**JIF=8.852**), *published*	***Lena Rölfer:*** *conceptualisation, data curation, formal analysis, methodology, visualisation, writing (original draft);* **David J. Abson:** conceptualisation, supervision, writing (original draft; review & editing); **María Máñez Costa:** conceptualisation, data curation, methodology, writing (review & editing); **Sergio Rosendo:** data curation, methodology, writing (review & editing); **Timothy F. Smith:** writing (original draft; review & editing); **Louis Celliers:** conceptualisation, data curation, funding acquisition, methodology, supervision, writing (review & editing)	Co-author with predominant contribution (1.0)	Sustainability Science Days Conference, 18th–19th May 2022, Helsinki, Finland (online oral presentation)

Chapter No.	Journal, Impact Factor* and publication status	Specific contributions	Author status and weighting factor**	Presentation at conference
VI	Frontiers in Marine Science (**JIF=5.247**); *published*	***Lena Rölfer:*** *conceptualisation, data curation, formal analysis, methodology, visualisation, writing (original draft), supervision;* **Xochitl E. Elias Ilosvay:** conceptualisation, visualisation, writing (original draft; review & editing); **Sebastian C.A. Ferse:** conceptualisation, writing (review & editing); **Julia Jung:** conceptualisation, writing (original draft; review & editing); **Denis B. Karcher:** conceptualisation, writing (original draft; review & editing); **Michael Kriegl:** conceptualisation, methodology, writing (original draft; review & editing); **TWGF Mafziya Nijamdeen:** conceptualisation, writing (original draft; review & editing), **Maraja Riechers:** conceptualisation, writing (review & editing); **Elizabeth Zoe Walker**: conceptualisation, visualisation, writing (original draft; review & editing)	Co-author with predominant contribution (1.0)	International Conference for Young Marine Researchers, 13th – 16th September 2022, Bremerhaven, Germany (oral presentation)
		Overall contribution by weighting factor	**5.0**	

Explanation

* *2021 Journal Impact Factor* (JIF) based on data indexed in the Web of Science Core Collection; source: https://jcr.clarivate.com/jcr/browse-journals

***Author status and weighting factor* according to §12b and §14 of the guideline:

Author status	Weighting factor
Single author [Allein-Autorenschaft] = Own contribution amounts to 100%.	1.0
Co-author with predominant contribution [Überwiegender Anteil] = Own contribution is greater than the individual share of all other co-authors and is at least 35%.	1.0
Co-author with equal contribution [Gleicher Anteil] = (1) own contribution is as high as the share of other co-authors, (2) no other co-author has a contribution higher than the own contribution, and (3) the own contribution is at least 25%.	1.0
Co-author with important contribution [Wichtiger Anteil] = own contribution is at least 25%, but is insufficient to qualify as single authorship, predominant or equal contribution.	0.5
Co-author with small contribution [Geringer Anteil] = own contribution is less than 20%.	0

Ich versichere, dass alle in diesem Anhang gemachten Angaben jeweils einzeln und insgesamt vollständig der Wahrheit entsprechen.

A2. List of additional publications and stakeholder outputs

The following list includes (co-)authored publications and stakeholder outputs that were created within the timeframe of my PhD. For each publication/output, I briefly summarize links and additions to this dissertation.

Earth observation and coastal climate services for small islands
Rölfer, L., G. Winter, M. Máñez Costa, and L. Celliers (2020). *Climate Services* 18(April):100168. https://doi.org/10.1016/j.cliser.2020.100168

This short communication summarizes results from a workshop on Earth Observation and Coastal Climate Services for Small Islands, held in Guadeloupe in November 2019. The results contribute to this dissertation by providing insight on i) the common challenges and data needs of coastal social-ecological systems (here small islands) in relation to risk reduction and climate change adaptation; ii) development needs for additional data services; and iii) identify useful methods for the dissemination of such services.

Integrated Research for Integrated Ocean Management
Rölfer, L., Liconti, A., Prinz, N., & Klöcker, C. A. (2021). *Frontiers in Marine Science*, *8*(693373). https://doi.org/10.3389/fmars.2021.693373

This article draws on examples and best-practices from inter- and transdisciplinary research projects that aim at bridging the gap between science, society and policy and proposes key considerations for integrated research approaches in support of the UN Decade of Ocean Science for Sustainable Development. It can be viewed as a broader introduction to the challenges and opportunities of inter- and transdisciplinary research in coastal social-ecological systems.

Sans frontières - Ocean and Coastal Sustainability of the Western Indian Ocean
Celliers, L., Rosendo, S., **Rölfer, L.,** Manez Costa, M., Snow, B., & Rivers, N. (2022). pp.119 in J.M. Maina (Ed): *WIO Science to Policy Platform Series Vol 1 Issue 1.* WIOMSA and Nairobi Convention

This policy brief highlights the need for awareness, understanding, and institutional mechanisms for integrating coastal sustainability in the Western Indian Ocean in four dimensions, including: 1) ocean to land, 2) shore-to-shore (across sub-national and national boundaries), 3) administrative (integration of management interventions between different levels of national to sub-national government), and 4) temporal (integration of different timescales for management, from political time frames to climate time scales). The policy brief is closely linked to results from Chapter II.

Cities & Climate Change in the Coastal Western Indian Ocean (CICLICO) - Interim Report on recent findings from the CICLICO project: Jan 2020-August 2021
Rosendo, S., **Rölfer, L.,** Celliers, L., Manez Costa, M., Snow, B., & Rivers, N.

This report presents interim findings of the CICLICO project to the Nelson Mandela Bay Municipality. Findings include results from the Capital Approach Framework describing the status quo of governance performance for coastal management and climate change adaptation in the social-ecological system of Algoa Bay.

Development and use of climate change information and climate services to support coastal municipalities in South Africa - Workshop Summary
Celliers, L., **Rölfer, L.,** Rosendo, S., Manez Costa, M., Snow, B., & Fernandez, M.

This report summarizes the results of a workshop that was held online in March 2022. It focused specifically on the use of climate change information and associated climate services relevant to coastal and marine management, in support of the sustainability challenges faced by coastal cities in South Africa.

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

Lena Rölfer, Louis Celliers, David J. Abson

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Rölfer, L., L. Celliers, and D. J. Abson. 2022. Resilience and coastal governance: knowledge and navigation between stability and transformation. Ecology and Society 27(2):40. https://doi.org/10.5751/ES-13244-270240

Synthesis

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

Lena Rölfer [1,2], *Louis Celliers* [1,2] and *David J. Abson* [2]

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

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

INTRODUCTION

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

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

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

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

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

UNDERSTANDING RESILIENCE AS A CONCEPT FOR COASTAL GOVERNANCE

Social-ecological resilience and desirable system states

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

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

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

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

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

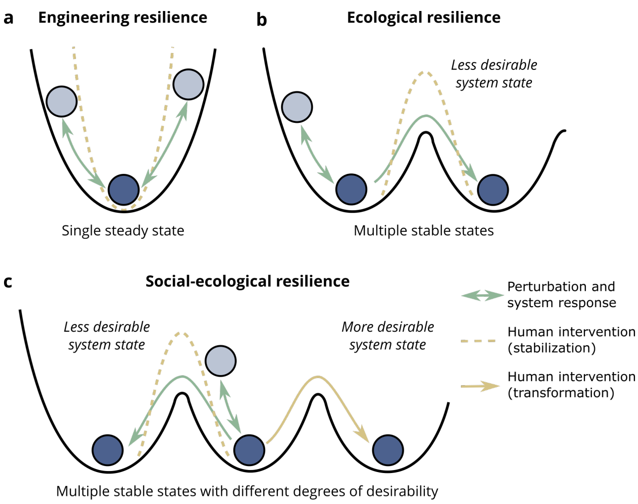


Table 1. Desirable and undesirable characteristics in coastal social-ecological systems with regard to stabilization and transformation, and examples (Oppenheimer and Glavovic 2017, Mcleod et al. 2019, Masselink and Lazarus 2019, Bonnett and Birchall 2020, Dornelles et al. 2020, Thonicke et al. 2020).

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

Tensions between stabilization and transformation

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

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

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

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

The relationship between social-ecological resilience and coastal governance

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

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

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

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

ENABLING SOCIAL-ECOLOGICAL RESILIENCE THROUGH COASTAL GOVERNANCE

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

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

Systems knowledge

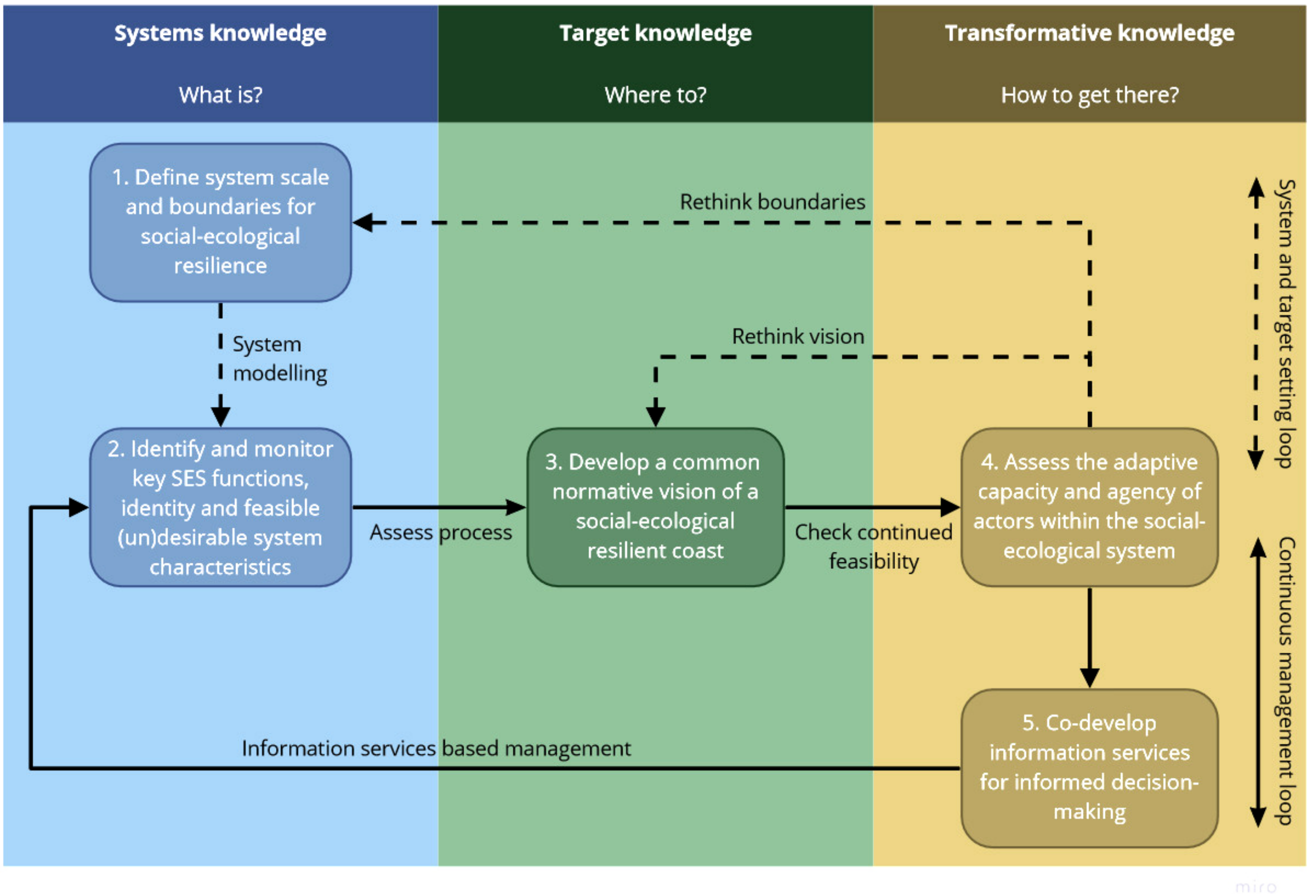
Step 1: Define system scales and boundaries for SER in coastal systems

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

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

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

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

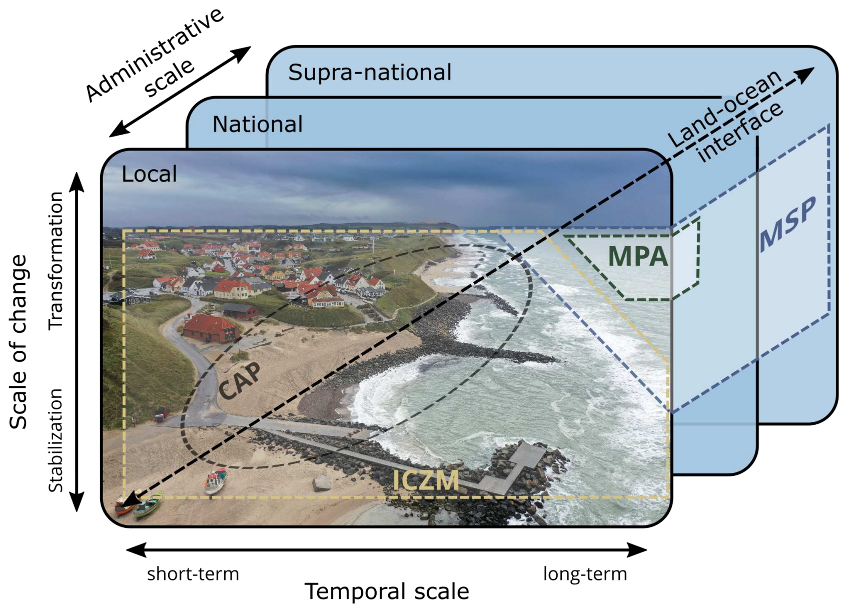


Local coastal governance is defined as place-based political and institutional processes of coastal management and the implementations of related decisions. It creates the conditions for ordered rules and collective action and encompasses actors from government, the private sector, and civil society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

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

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

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



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Iterative learning cycles

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

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

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

CONCLUSION

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

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

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

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

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

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Chapter III: Stratification of stakeholders for participation in the governance of coastal social-ecological systems

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Stratification of stakeholders for participation in the governance of coastal social-ecological systems

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Abstract Knowledge co-production has become part of an evolution of participatory and transdisciplinary research approaches that are increasingly important for achieving sustainability. To effectively involve the most appropriate stakeholders there is a need for engagement and increasing prominence of stakeholders in environmental management and governance processes. The paper aims at developing and testing a methodology for stratifying stakeholders by (i) classifying organisations involved in coastal and ocean governance by their agency, and (ii) grouping them into organisational archetypes for representation and selection in research processes. Agency was measured by the three dimensions of scale, resources, and power. Each dimension was further elaborated as a set of indicators. The methodology is applied in the context of a research project set in Algoa Bay, South Africa. The stratification of organisations enabled the research team to gain a better understanding of the stakeholder landscape of organisational agency, and thus identify the most relevant stakeholder with which to engage. The use of a hierarchical cluster analysis identified five organisational archetypes in relation to ocean and coastal governance in Algoa Bay. The methodology used in this study proposes an informed and intentional approach to create the conditions under which the co-production of and participation in research processes can take place.

Keywords Environmental management · Ocean and coastal governance · Social-ecological systems · Stakeholder agency · Stakeholder analysis

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INTRODUCTION

The sophistication of engagement with stakeholders as a fundamental part of environmental management and governance processes is an increasingly important topic of research (e.g., Burdon et al. 2019; McKinley et al. 2021). Stakeholders are those who have something to win or lose in the governing process (Jentoft 2007), or by the urgency of their concerns, the legitimacy of their interests, and the power they hold (Buanes et al. 2005). Stakeholders are also defined relative to a particular issue which is time- and site-specific (Glicken 2000).

Stakeholders are active participants in knowledge co-production and are often described as "owners" or initiators of the process for which research outputs are intended to create societal impact (Turnhout et al. 2020; Vollstedt et al. 2021; Strand et al. 2022). Knowledge co-production has become part of an evolution of participatory and transdisciplinary research approaches that are increasingly important for achieving sustainability (Mach et al. 2020; Norström et al. 2020). Knowledge co-production processes are interactive and engage both scientific actors and non-academic stakeholders (Scott et al. 2021; Rölfer et al. 2021; Rivers et al. 2022). Actors from outside the academic spheres are recognised for contributing legitimate and often unconventional forms of knowledge and expertise that are increasingly seen as indispensable for solving societal problems (Polk 2015). Some authors describe co-production as one of the most important ideas in the theory and practice of knowledge and governance for global sustainability (Miller and Wyborn 2020).

Legitimate stakeholders are often poorly stipulated or specified in many research projects (Lavery 2018). For example, in the context of climate change adaptation, marginalized stakeholder groups tend to be more

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vulnerable to climate change, but at the same time are less represented in participatory processes (Thomas et al. 2019). In the absence of a process for a careful selection based on the objectives of the effort, there is a danger of only engaging the "usual suspects". These are often small but vocal groups of stakeholders who are already widely engaged not only in research but also in policy and practice. While often convenient for research projects, the continued engagement with willing and available stakeholders may also reinforce the marginalization and exclusion of groups whose voices are rarely heard, thus limiting social learning with potential ethical questions (Stringer et al. 2006).

The rationale for the selection of stakeholders to engage in knowledge co-production in research processes is therefore increasingly important. Who are the right stakeholders involved at the right time and in the right way?—so-called "proper and pertinent stakeholders" (Ahmadi et al. 2019). Stakeholders, as active participants, must be able to act in some meaningful way. For stakeholders to be able to act (i.e., become actors) they need to have *agency*. Generally, agency can be defined as the capacity of individuals and collective actors to change the course of events or the outcome of processes (Pattberg & Stripple 2008; Otto et al. 2020). Some of the key elements that may enable agency include: access to resources, discourses and networks of actors (Duygan et al. 2019, 2021); power (Morrison et al. 2019); and, system roles, power and influence, alignment to the problem, and transformational potential (Lyon et al. 2020). Agency is therefore an important characteristic of the ability of stakeholders to be active participants in knowledge co-production and resulting governance processes.

Research projects that employ transdisciplinary knowledge co-production should therefore be cognisant to include stakeholders that can act to contribute to governance objectives. While stakeholders are often classified by administrative level (local to national), organisational type (e.g., governmental, non-governmental), or sector, such classification pays insufficient attention to their actual agency to act in governance processes. Instead, characteristics that constitute agency are more diverse and create a mosaic of stakeholders that is dynamic relative to the issues and objectives of co-production and governance. This is complex in all contexts, and particularly so in coastal social-ecological systems (SES) because of the numerous stakeholders with diverse interests, the dynamic nature of the environment, and the often overlapping and even conflicting legislation and policy (Pasquier et al. 2020).

This paper builds on previous work by Celliers et al. (2007) and other methodologies with which to analyse and select stakeholders (Mitchell et al. 1997; Reed et al. 2009; Lyon et al. 2020). The paper aims at developing and testing a methodology for stratifying stakeholders by (i) classifying organisations involved in coastal and ocean governance by their agency, and (ii) grouping them into organisational archetypes for representation and selection in research processes. The proposed methodology is applied in the context of a co-production process (climate services for coastal adaptation) in Algoa Bay, South Africa. This methodology was tested during the COVID-19 pandemic and adapted for limited direct engagement with stakeholders while still resulting in a transparent selection of stakeholders in engagement processes relative to a research objective.

METHODOLOGY

Study area

Algoa Bay is locally governed by the Nelson Mandela Bay Municipality (NMBM) consisting of the city of Gqeberha as well as the major towns of Kariega and Despatch in the Eastern Cape province of South Africa. Algoa Bay is an important social and economic hub driven by several automotive supplier companies, two ports and also the only international airport in the Eastern Cape. Algoa Bay is a popular tourist destination, especially for water sports and the nearby Greater Addo Elephant National Park and its recently promulgated Marine Protected Area (MPA; May 2019).

Since the demise of Apartheid, South Africa promulgated new or updated legislation to align with its post-Apartheid constitution. This suite of legislation includes National Environmental Management Act which also includes legislation for Integrated Coastal Management (ICM), Marine Spatial Planning (MSP) and Marine Protected Areas (MPA). The ICM Act, for example, creates a nested system of coastal management from national to local government (Celliers et al. 2013). This interplay of a diversity of ecological features and resources, legislation, management approaches, and social-economic aspects make Algoa Bay a representative case study of a complex coastal SES, and for testing the methodology. It also creates a multi-layered stakeholder landscape that is diverse and dynamic, making engagement challenging.

The proposed stakeholder stratification methodology was developed as part of the Cities and Climate Change in Coastal Western Indian Ocean (CICLICO) research programme. The project adopted a knowledge co-production approach and research activities included an assessment of governance performance for climate change adaptation in Algoa Bay, a social network analysis, and co-production of climate services. The stratification of stakeholders was critically important due to the numerous and diverse stakeholder composition in Algoa Bay relative to the research objectives. At the outset of the project, there was a prevalence of "stakeholder fatigue" that influenced the overall engagement strategy of the project, and the subsequent demand for a much more focused engagement with key stakeholders in the co-production of climate services (i.e., municipal officials).

Identifying stakeholders

The stakeholders in coastal and ocean governance of Algoa Bay were initially classified by organisational type to understand the complexity of representation with regards to their role and interest in ocean and coastal governance in the Bay. Three primary organisational types were identified, namely government, parastatal (semi-state) organisations, and civil society organisations (Fig. 1). A second classification provided more elaboration on the organisational sub-types.

An initial selection of stakeholders included any organisation that had an apparent interest in coastal and ocean governance. Stakeholders were identified from a review of the literature and online resources, Environmental Impact Assessments, provincial, and local coastal working groups. Organisations included were from local, provincial, and national government authorities, community organisations, environmental organisations, development groups, special interest groups, trade unions, landowners, sport and recreational bodies, tourism organisations, and business associations. This initial list of stakeholders was subsequently augmented through chain referrals from known stakeholders (Leventon et al. 2016).

Dimensions of agency

The dimensions of agency used in the stratification of stakeholders were *scale*, *power*, and *resources* as previously proposed by (Celliers et al. 2007), and redefined for the specific context of this study (Fig. 2). Each dimension of agency was further elaborated as a set of indicators for the different dimensions. This was based on the work of Celliers et al. (2007), and previous experience within coastal governance and knowledge of the contributing elements for effective governance.

Dimension 1: Scale

The scale or level at which a stakeholder operates is an aggregate of spatial and functional parameters, and is critically important in this context (e.g., Ernoul and Wardell-Johnson 2013; Pereira et al. 2020). Scale normally refers to geographic or spatial extent, while level refers to different administrative units often linked to spatial scale,

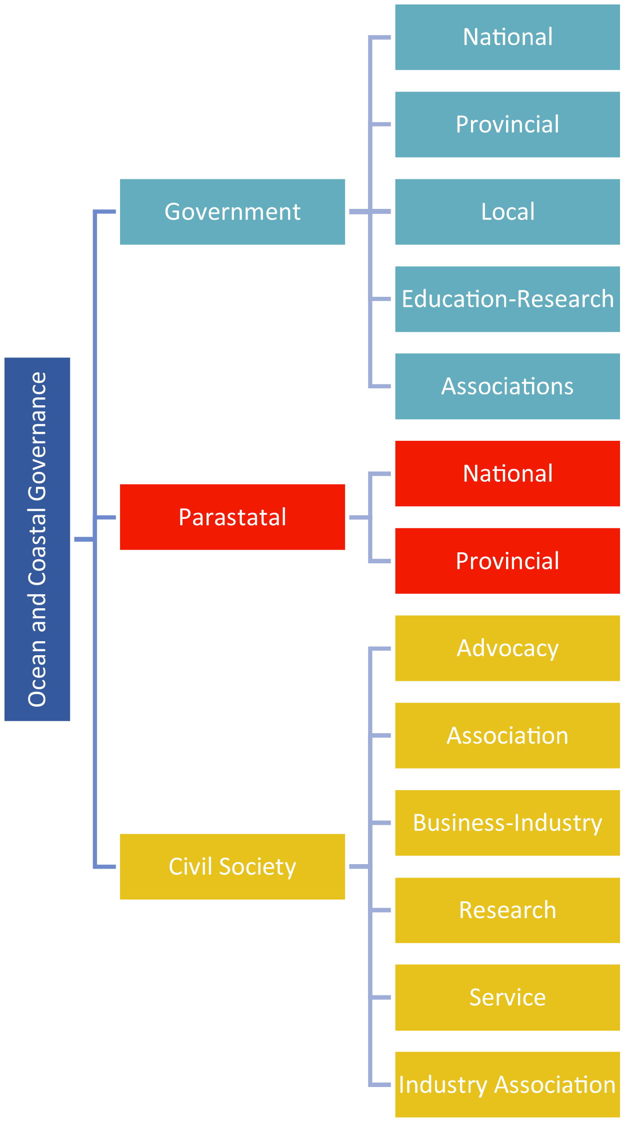

Fig. 1 Organisational type and sub-type of organisations that have a role or interest in ocean and coastal governance in Algoa Bay, South Africa

i.e., municipalities or local government. Each stakeholder operates in a defined *operational (often spatial) scale*; some stakeholders are locally based, some are provincial (regional), and some function at a national scale. The scale of a stakeholder's operation will have a direct bearing on their frame of reference and the perspective they bring to the network.

The function of an actor within the network is determined by a concept of their "charter" or *mandate,* which can be bestowed as legislative, political, or operational objectives. The charter restricts interaction with neighbouring stakeholders and the legitimacy with which a stakeholder engages with issues raised within the Algoa Bay system. Another interesting aspect of scale is the influence of the *representativeness* of the organisation; this

Fig. 2 Dimensions of agency redefined for the specific context of this study

means that representativeness refers to the *constituency* represented by the stakeholder. In other words, an organisation may present or demonstrate interest at a large spatial scale but by a small constituency. Conversely, for example, a professional society could have a limitation in operational scale but represent many persons directly affected by the policy issues under consideration, e.g., an organized group of many different stakeholders.

Dimension 2: Power

The role and influence of power on relationships between organisations is a key dimension of the agency of organisations. Power is also unavoidable and should be discussed openly (Turnhout et al. 2020). It has also been highlighted as an important feature for transforming to higher degrees of resilience and sustainability (Olsson et al. 2014; Barnes et al. 2020). For the purposes of the present analysis, we have chosen to consider power as a function of political relevance, legislative power, executive power, moral power or suasion and the power to enforce decisions or regulations.

Political relevance is the extent to which the institution has a specific political role to play in the policy issues being dealt with (e.g., Nightingale 2017). Some institutions are part of the public sector and have specific political roles to fulfil; some individuals might be elected officials with political scripts to follow, while some may have an ostensibly 'politically neutral' position, such as professional bodies or academic and research institutions.

Legislative power, is the ability to create, modify and repeal laws that govern society including the power to make rules and regulations, both formal and informal (e.g., Martino et al. 2019). Legislative power will also differ between organisations. Some organisations, such as organs of civil society, may have no legislative power, while organs of state (local, provincial, and national) may have considerable power in their sphere.

Executive power refers to the capacity and mandate to make decisions (e.g., the distribution of executive power between levels; Celliers et al. 2015). Some organizations will have been delegated power by the government (national, provincial, or local) to make decisions that affect all citizens within their area of jurisdiction e.g., in the Algoa Bay case national government delegating decisions to the conservation agency SanParks. Other organizations may only be able to make decisions that are binding on their members.

Some organizations will have *moral power* or *moral suasion* which may or may not be in proportion to their scale. This power is the power to speak with authority on a topic and to bring to the discussion opinions and examples that may persuade others to follow the stakeholder's lead. It is expected that if the issue being discussed is of a scientific nature a research organization with a reputation for excellence will exert a large degree of influence simply because of the weight of its moral authority. Moral power is the ability to persuade, i.e., where people or groups that may hold little practical power manage to influence situations in a positive or negative direction through persuasiveness (Bos et al. 2020; Lyon et al. 2020).

Some organizations are also likely to have some degree of *enforcement power*, i.e., the power to compel either other members of the organization, or members of the public, to comply with decisions made by the stakeholder (e.g., Tosun 2012). This may be a constitutionally created power such as that enjoyed by the police force, or it may be a power assented to by virtue of membership in a group, e.g., a fishing club must enforce its constitution and conditions of membership.

Dimension 3: Resources

Each of the organizations that make up the stakeholder constellation will also be endowed with varying amounts of capital: financial capital, human capital, and infrastructure in the form of equipment and other physical assets. The *financial capital* of an institution is an important factor in determining the extent of the human, infrastructural and other resources available to the institution. Financial resources are often a limiting factor in determining priorities among the different policy issues with which an organization must deal. For example, resource limitations from central government are often a barrier to long-term climate adaptation (Porter et al. 2015) and a lack of resources also influences engagement with society (Baker et al. 2012).

The *human capital* that an organization has at its disposal is a function of the number of people it can deploy on a policy issue and the extent of the knowledge-base that those people possess. Sufficient in-house human or technical capacity or access to external relevant expertise makes the use of scientific information for management more likely (Lemos et al. 2012), and mainstreaming climate change adaptation is expected to be challenging because of existing strains on resources and capacity in many developing countries (Pasquini et al. 2013).

Finally, *infrastructure* (e.g., communication, mobility) is a further component of the resource dimension and includes such things as vehicles, boats/ships, telephones, offices, and equipment as well as special hardware and other physical assets. The extent of the infrastructure available to an organization, both in terms of quantity and quality, affects the extent to which an organization can quickly and easily communicate, respond to issues, engage in research, and access other members of the network or other resources.

Evaluation of agency

Dimensions of agency were elaborated in an evaluation framework that consisted of indicators, evaluation criteria, description, and a scoring system (see Supplementary Table S1–S3). Critical design principles of the evaluation framework included the ability to: (a) apply the framework remotely due to the inability to meet in person during the COVID-19 pandemic; and (b) simplicity of indicators and scoring categories to allow for a fast and accurate assessment by experts or expert panels using publicly available sources of information such as organisational websites or annual reports.

The first step of applying the evaluation framework was an assessment of the organisation by three experts working independently from one another. The second step was a consensus process where the expert panel debated scores, fact-checked assumptions, and agreed on final scores. The three expert evaluators were knowledgeable about the social, ecological, and economic context relative to the coastal and ocean area of Algoa Bay. Scoring (and scoring validation) of organisations were originally intended for a broader stakeholder panel including the expert evaluators, but under COVID-19 lockdowns, continuous and convenient access to such a stakeholder panel was not possible.

Data analysis

The scores for the different dimensions of agency were calculated as a normalized aggregate of the indicators for each organisation. An overall score for each organisation was defined as ‘agency’, which was calculated as a normalized aggregate across all indicators. The normalized scorings range from 0 to 1 with 1 indicating the highest score. An agency of 1 would be an organisation that has a physical presence in Algoa Bay with a high institutional mandate and constituency, which is highly resourced and has the highest power e.g., Nelson Mandela Bay Municipality.

A hierarchical cluster analysis (HCA) was performed using the statistical software R (R-Core-Team 2021) to identify clusters of organisations with similar scorings for the indicators within clusters, but distinct from other clusters. An agglomerative bottom-up approach applying the ‘complete-linkage clustering’ method was used, which forms clusters of organisations based on the maximum Euclidian distance (dissimilarity) between different clusters. The dissimilarity clustering approach was chosen to identify archetypes that are distinct from each other. Using this approach, the agglomerative coefficient was 0.86, meaning that 86% of the variance are explained by the clustering. The optimal number of expected clusters (k) was identified by the Sum of Squares of the dataset and set to $k = 5$ at a distance (similarity) of 5.8. A dendrogram was plotted showing all 113 institutions assigned to groups 1–5 accordingly (see Supplementary Fig. S1).

RESULTS

The methodology for stratifying stakeholders resulted in classifying organisations involved in coastal and ocean governance by their agency to act in governance processes and grouping them into organisational archetypes for representation and selection in research processes.

Classification by agency and organisational type and sub-type

From the initial desktop analysis, 113 organisations were identified: 18 from government, 19 parastatal and 76 civil society organisations (Fig. 3).

The indicators of agency show that some of the organisational groups inherently have greater agency, e.g., national government and parastatals. The organisational agency is generally lower in civil society (< 0.3) but there are more organisations ($n = 76$; Table 1). Civil society organisation indicators for power score generally low, as opposed to that of government. Government sub-groups show higher agency for local government (municipality), followed by provincial and then national. This is primarily driven by a similar trend in resources. It is worth noting that the type of resources for these sub-groups are probably

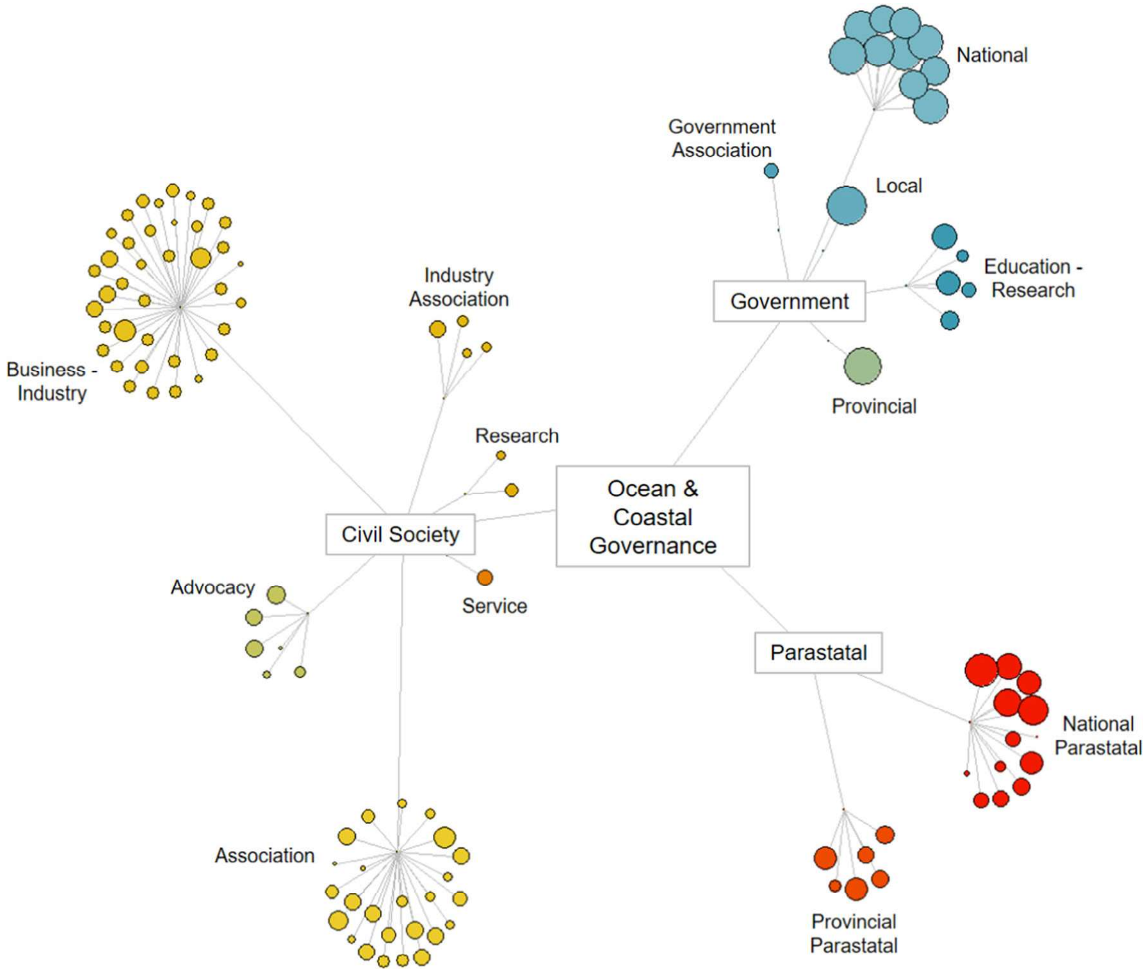

Fig. 3 The network of 113 organisations involved in aspects of ocean and coastal governance in Algoa Bay classified by their organisation type and sub-type. Each coloured circle represents an organisation, and the circle size shows its degree of agency in the governance system (e.g., organisations with larger circles have higher agency)

very different, i.e., strategic, and high-level planning resources at the national level (i.e., data and information), as opposed to tactical and operational support for local government (i.e., bulldozers and local knowledge).

Organisational archetypes

The use of the hierarchical cluster analysis enabled the identification of organisational archetypes in relation to their agency to act in ocean and coastal governance in Algoa Bay. The analysis (see dendrogram, Supplementary Fig. S1) resulted in the definition of five groupings of organisations that shared common characteristics of the individual dimensions and indicators of agency.

The hierarchical clustering of organisations by agency was further interpreted through the analysis of the statistical summaries for each of the grouping (Fig. 4). These summaries were combined with the known organisational mandate of the members of the groupings, which resulted in stakeholder archetypes stratified by similarities of three indicators of agency (Table 2). For example, organisations in group 1 are characterized by comparably high scores for power and resources and are represented at different scales (see outliers; Fig. 4). By looking at the organisational types in this group (mainly governmental) the archetype "plans and planning" was proposed.

For providing a better overview of the stakeholder landscape in the case-study area of Algoa Bay, the contribution of the different organisational types and sub-types to the resulting organisational archetypes based on their scoring for different indicators of agency is visualized in Fig. 5.

DISCUSSION

With the increasing importance of knowledge co-production between researchers and non-academic actors, an

Table 1 Arithmetic mean scores across indicators of the dimensions of scale, resources, and power, and aggregated as agency, of organisational types and sub-types involved in aspects of ocean and coastal governance of Algoa Bay, South Africa

Organisational (Sub-)type	*n*	Scale	Power	Resources	Agency (mean) ± SD
Civil society	76	0.48	0.10	0.36	0.27 ± 0.08
Advocacy	6	0.35	0.13	0.43	0..27 ± 0.13
Association	25	0.44	0.16	0.36	0.29 ± 0.09
Business-Industry	38	0.56	0.04	0.35	0.27 ± 0.07
Industry Association	4	0.31	0.21	0.28	0.26 ± 0.06
Research	2	0.17	0.18	0.47	0.25 ± 0.07
Service	1	0.67	0.15	0.33	0.34
Government	18	0.69	0.56	0.65	0.62 ± 0.19
Association	1	0.44	0.25	0.28	0.31
Education-Research	5	0.53	0.18	0.67	0.41 ± 0.12
Local	1	0.89	0.75	1.00	0.86
National	10	0.75	0.74	0.62	0.71 ± 0.07
Provincial	1	0.83	0.75	0.89	0.81
Parastatal	19	0.49	0.30	0.52	0.41 ± 0.17
National	13	0.45	0.33	0.52	0.41 ± 0.20
Provincial	6	0.56	0.23	0.54	0.40 ± 0.09
Grand total	113	0.52	0.21	0.43	0.35 ± 0.17

SD Standard Deviation of scoring between organisations belonging to the same organisational sub-group

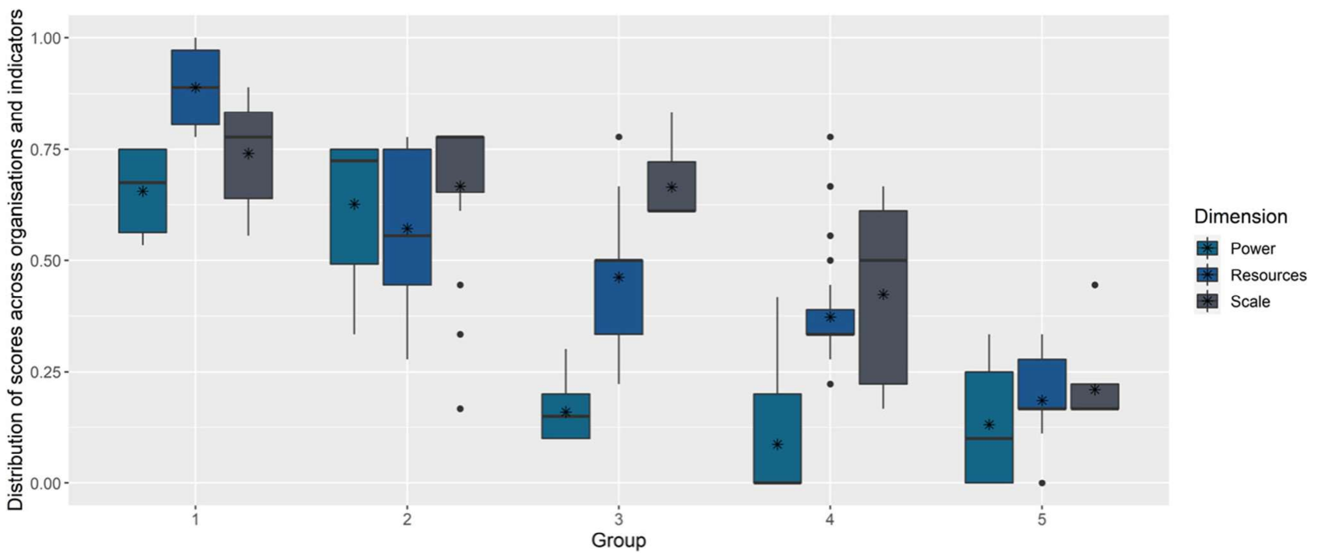

Fig. 4 Distribution of scores for power, resources and scale across organisations and indicators for five organisational archetypes involved in aspects of ocean and coastal governance in Algoa Bay, South Africa. Boxes show 75th percentiles of distribution; stars indicate the arithmetic mean score per dimension and organisational archetype; dots visualize outliers

informed approach to stakeholder and public engagement in research processes can improve the outcomes of co-production. Especially in complex coastal SES, where effective governance is an important driver for achieving sustainability objectives, the participation of the 'right' stakeholders is essential. The approach used in this study proposes such an informed and intentional approach to create the conditions under which co-production of and participation in research processes can take place. Here we will discuss the advantages of the proposed approach over other stakeholder analysis approaches, identify its strengths and weaknesses, provide an interpretation of the archetypes and show how the stratification can be applied in research processes.

Table 2 Description of organisational archetypes (resulting from HCA groupings) of organisations involved in aspects of ocean and coastal governance in Algoa Bay, South Africa

Group no	Archetype	Description
1 (*n* = 6)	"Get it done"	This is a small group of organisations with high agency. They have high measures of available resources and operational scale, and high measure of power. These organisations can act locally, and to implement decisions on local issues, in a relatively short period of time. Management actions are directly related to ocean and coastal governance, and the impact of such actions will be experienced by many stakeholders in the system. These organisations have direct authority over implementation and a significant control of policy-implementation processes. These organisations must be included in most science-society engagements related to developing the knowledge-base for local decision-making, e.g., climate change adaptation, biodiversity protection. The Nelson Mandela Bay Municipality (NMBM) is a good example of a representative organisation
2 (*n* = 14)	"Plans and planning"	This relatively large and diverse group of mainly government institutions are mostly thematically or sectorial focussed, i.e., transport, minerals and energy, environment. These organisations have substantial power but mostly brings this to bear through national policy and legislation. There are no locally based organisations in this archetype group but their role is clear with regards to medium- to long-term strategic planning in the ocean and coastal governance domain. This group is well-resourced in terms of human capacity and access to data and information. While they are scoring high for agency overall, it can be argued that they have substantially less agency compared to Group 4. Selection of participation from this group is largely dependent on their sectoral interest and the objective of the governance/stakeholder processes under consideration. The national Department of Environment, Forestry and Fisheries (DEFF) is a good representative organisation of this archetype
3 (*n* = 29)	"Little by little"	This is a large group of organisations who are low in power, but present and active in Algoa Bay. They are relatively well-resourced and operate at the Bay-scale. There are overlaps with other groups (Group 2 in particular), but this group is very relevant to focussed activities in the ocean and coastal space of Algoa Bay. With their relative high level of resources and their local presence and agency, they are important and relevant actors for local decision-making. The South African Environmental Observation Network (SAEON) and the Nelson Mandela University (NMU) are good representative organisations of this archetype
4 (*n* = 9)	"On the margin"	This small group of organisations contribute mostly data and information without authority and without being physically based or operating specifically in Algoa Bay. Low power and physically distant, this archetype can make focussed input to participation processes but may also be omitted due to the challenge of engaging from a distance. Internally, members of this archetype are also very diverse. The Oceanographic Research Institute (ORI), or the Water Research Commission (WRC) are good representative members of this archetype
5 (*n* = 55)	"Vocal and insistent"	This is a large, internally diverse group of organisations that typically score low on all measures of agency. Their physical presence in Algoa Bay makes them relevant stakeholders and their collective interest and agency makes their contribution in participatory processes important and bordering on critical. Even though their operational scales may be small, i.e., conservancy of an area within the larger Algoa Bay area, they are important for latent/dormant power, and the vulnerability of their members. A number of these organisations, given enough motivation and concern, can bring to bear power in the form of moral suasion e.g., fishing companies, community-based organisations. This is also the most difficult archetype to involve in participation processes due to their diversity of interests, motivation, capacity, vulnerability etc. This archetype can easily be to split in smaller sub-groupings. Identifying a typical organisation from this group is difficult due to the high degree of diversity of members but an example could be local NGOs, civil society advocacy groups etc

Advantages over other approaches

Previous approaches for determining 'the right' stakeholders include an analysis along a matrix of power and interest, power and influence, or power, legitimacy, and urgency (Buanes et al. 2004). The selection of the dimensions of such a matrix (e.g., power, interest, influence, or urgency) depends on the purpose of the analysis, what type of information is most relevant to the objective of the project, and for the uptake and implementation of stakeholders (European Commission et al. 2018). However, some of these dimensions are difficult to evaluate, e.g., how to evaluate the interest or urgency of an organisation in relation to other organisations. In this paper, the use of an indicator-based framework evaluated the overall relevance of stakeholders in the SES relative to climate change and adaptation governance objectives. In this way, we not only identify the 'loud voices', e.g., the ones with high power, influence, and interest, but also these organisations that are highly vulnerable to climate change, but with a low agency.

Furthermore, the organisation archetypes identified in this paper are conceptually equivalent to the different stakeholder roles within a complex system that has been previously and differently proposed (Goodman et al. 2017; Lyon et al. 2020). Goodman et al. (2017) proposed stakeholder activities and roles such as Stimulator, Initiator, Broker, Legitimator etc., while Lyon et al. (2020) defined

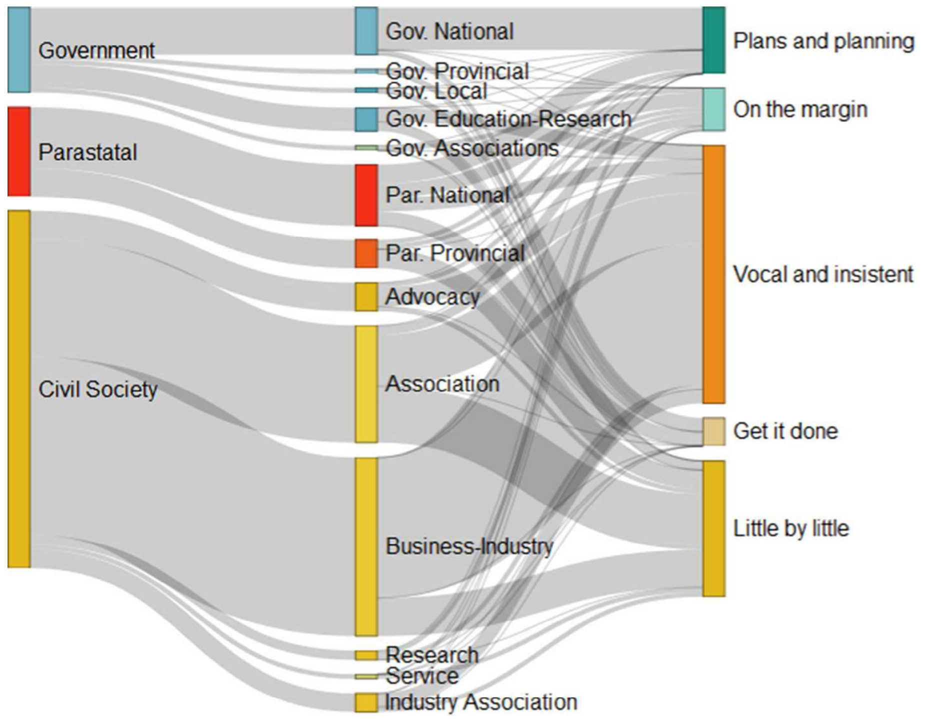

Fig. 5 Sankey diagram visualizing the proportion of organisational types and sub-types to organisational archetypes

stakeholder roles within a complex system and included roles such as Regulator, Decision-maker, Guardian, Owner etc. However, both these approaches require a much greater effort and access (compared to the stratification approach) to stakeholders to examine aspects such as interest, motivation, moral orientation, and transformational readiness that cannot be assessed quickly, and as part of a research project which is not solely focussed on stakeholders.

Strengths and weaknesses of the approach

COVID-19 pandemic conditions created the need for greater involvement of expert evaluators but ideally, evaluation, or validation by a science-society expert group is preferable. The pandemic exponentially also increased the need for online engagement with stakeholders in various research activities. As such, the key strengths of this method were its simplicity and low resource needs (fast and efficient), with the possibility to remotely evaluate organisational agency. The indicator framework was flexible, and the research team adjusted the description of the indicators to fit the research objectives and the reason for which stakeholders would be engaged. The stratification method focussed the engagement process on key stakeholders and reduced project resources. This also reduced further engagement fatigue.

The weakness of the stratification includes a possible over-reliance on expert evaluation of the indicators. However, this can also be scaled according to time and resource availability to include more stakeholder input when the process allows, and less when engagement is challenging, such as during the COVID-19 pandemic, or when stakeholders become "fatigued" from engagement processes. The organisational complexity of some of the stakeholders may make the assessment of a single set of indicators problematic due to the inability (cost, time constraints) to assess individual units within an organisation. This is particularly relevant for large and multifunctional organisations such as local governments, and especially city governments (da Cruz et al. 2018). There is simply no single set of indicators with which to assess the system role of such large and complex organisations. It would be more appropriate to then assess individual functional units or line departments, as well as the overall administrative and political conditions that enable agency, i.e., the role of bureaucracy (Colenbrander and Bavinck 2017), or information flow within public authorities (Celliers et al. 2021a, b).

Interpretation of archetypes and application in research processes

The five archetypes identified in this paper are relatable and easy to communicate the significance of the measures of agency in these statistical but also intuitive groups. It also identified the substantial differences in agency between these categories, and the imbalance between public entities such as local, provincial, and national government, and citizens, and civil society (business, industry, etc.) in general. The archetypes are broadly transferable to similar research settings.

The interpretation of the archetypes remained nuanced and did not simply represent boxes from which enough stakeholders should be drawn to participate. A high measure of agency meant that these stakeholders already make decisions and can change the system through policy or management or even physical means. However, a low measure of agency may have dual meanings. Low agency (and limited operation scale in the area of interest) may correspond to low interest or need to act in that place in time. As such, the engagement with these stakeholders in participatory processes is optional and their absence is not a loss of critical voices or opinion.

Low agency at the local scale may also mean greater vulnerability to change, e.g., extreme weather events. This may be particularly true for membership organisations, or associations where members themselves are vulnerable or limited in agency, such as local, subsistence fishers. The interpretation of low agency still requires a contextual understanding of organisations and their functions and operations within the area of interest, and relative to the research objectives. This will always require interpretation by the research team and the societal stakeholders themselves.

The stratification of stakeholders by agency proved useful in the further identification of the 'right' stakeholders for research on the SES in Algoa Bay. For example, a sub-sample of stakeholders was chosen for a network analysis of collaboration and knowledge exchange for climate change adaptation, only including those stakeholders that are locally based in Algoa Bay or have a specific mandate for local coastal governance (Rölfer et al., under review). Thus, the organisational archetype "on the margin" was excluded from this objective. Another example was the assessment of governance performance for climate change adaptation (Rölfer et al. 2022). In this case, representation from all archetypes was desired to integrate the perceptions of stakeholders from different levels of agency for scoring governance performance.

CONCLUSION

In this paper, we developed and tested a methodology with which to stratify stakeholders and to understand their strategic and functional roles in a coastal social-ecological system. The organisational assessment and the statistical identification of archetypes were chosen for its flexibility (in terms of redefining indicators, selection of expert or stakeholder evaluators, remotely executed) but also for the convenience and relative speed with which the research team could develop a more nuanced understanding of the stakeholder and organisational landscape of a coastal SES such as Algoa Bay. This is particularly important for climate adaptation planning. In the approach described in this paper, we recommend including further examination of not only the assessment of agency in relation to an external (research) objective, but also an examination of the connectedness of organisations in a highly networked SES such as a coastal city. Further research, therefore, may include linking the organisational archetypes to a Social Network Analysis to disentangle the role of stakeholder groups with high agency in empowering and supporting stakeholder groups with lower agency, in the context of climate change adaptation.

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Declarations

Conflict of interest None of the authors are declaring conflict of interest.

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Chapter IV: Assessing collaboration, knowledge networks and stakeholder agency for enhancing the climate resilience of coastal social-ecological systems

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Assessing collaboration, knowledge exchange and stakeholder agency for enhancing the climate resilience of coastal social-ecological systems

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Abstract

Coastal governance plays a central role in building the capacities for adaptation and transformation towards climate resilience in coastal social-ecological systems (SES). However, enhancing climate resilience requires effective coordination between organisations involved in coastal governance. Therefore, more information about the role and agency of organisations and the relationships between them is needed. This paper aims to improve the understanding of collaboration, knowledge exchange, and stakeholder agency for enhancing climate resilience, using a SES lens in a case study in Algoa Bay, South Africa. We apply and combine a stakeholder analysis and stakeholder network analysis, which is currently underrepresented in climate change adaptation research. Results suggest that different top-down and bottom-up processes are needed for improving knowledge exchange and enhancing climate resilience in coastal governance of the Algoa Bay SES. These include: establishing formal agreements for exchanging climate information and knowledge across sectors and administrative levels; stronger integration of climate information into area-based management approaches; fostering the role of information providers and increasing the transformative potential of bridging organisations. These suggestions may also be more broadly applicable and transferable to similar coastal SES. Ultimately, the results of this study shed light on network structures in coastal governance facing climate change and advance research on applying and combining stakeholder and network analyses in climate change adaptation and environmental governance research.

Keywords: coastal governance, climate resilience, network analysis, knowledge exchange, transformation

1 Introduction

Recent studies have highlighted the need for transformations in social-ecological systems (SES) to move towards sustainability and resilience (Glaser et al. 2018; Steffen et al. 2018; Grafton et al. 2019; Folke et al. 2021). This is particularly important due to the uncertainty of climate change impacts and the fact that incremental adaptation is often no longer sufficient (Rosenzweig and Solecki 2018; Cinner and Barnes 2019; Barnes et al. 2020). Coastal regions present complex SES often under pressure from various aspects of climate change, including ocean acidification, sea-level rise, changed precipitation, and variations in wind and wave conditions (Pörtner et al. 2019). This has severe impacts on the environment and human activities (e.g., Halpern et al. 2015; Nash et al. 2017; IPCC 2019). Adapting to climate change impacts and transforming to more desirable SES states is of high priority to maintain ecosystem functioning and livelihoods of coastal communities (Thonicke et al. 2020).

Coastal governance, defined as the place-based political and institutional processes of coastal management and the implementations of related decisions (Adger et al. 2003; Shah and Shah 2006; Ojwang et al. 2017), plays a central role in building the capacities for adaptation and transformation towards climate resilience (Celliers et al. 2020; Jozaei et al. 2022; Rölfer et al. 2022). Climate resilience, in this context, can be understood as actions and processes (adaptive and transformative in nature) that enable organisations involved in coastal governance to maintain a functioning and sustainable SES in face of climate change. Governance systems can be seen as a network of stakeholders from different administrative levels, sectors and organisational types, e.g., government agencies, non-governmental organisations, and associations from local to international level (Armitage et al. 2009; Weiss et al. 2012; Schlüter et al. 2020). In such governance networks, collaboration and knowledge exchange are central to successful and effective management and decision-making, especially with regard to climate change (Berkes 2009; Fazey et al. 2013; O'Mahony et al. 2020).

While area-based management approaches, such as Integrated Coastal Zone Management (ICZM), can facilitate capacity building, collaboration and knowledge exchange for the implementation of coastal and climate policies (O'Mahony et al. 2020), an understanding of the degree of knowledge exchange on climate related issues in coastal governance is still poor (Mabudafhasi 2002; Cárcamo et al. 2014; Thorne et al. 2017). It also raises questions relating to the role and *agency* of different stakeholders to act in coastal governance processes (Charli-Joseph et al. 2018; Sayles et al. 2019; Partelow et al. 2020). Agency can be defined as "the capacity of individual and collective actors to change the course of events or the outcome of processes" (based on Pattberg and Stripple 2008; Otto et al. 2020b). Assessing and understanding collaboration, knowledge networks and stakeholder agency, thus, can help to reduce vulnerability of SES and enhance the resilience to climate change (Bodin and Crona 2009; Prell 2011; Weiss et al. 2012).

Within SES and environmental governance research, the use of stakeholder analysis combined with stakeholder network analysis have gained importance for describing and analysing stakeholders and their relationships to one another (Cumming et al. 2017; de Vos et al. 2019; Horcea-Milcu et al. 2020). A Stakeholder Analysis (SA) includes a variety of approaches, such as assessments of power, interest, vulnerability, resources, problem alignment or system roles of different stakeholders (Reed et al. 2009, 2018; European Commission 2018; Lyon et al. 2020). The concept of agency, as an approach to frame and analyse stakeholders, has gained particular attention over the last years, as it has been described as an important lever for transformation to coastal sustainability (e.g., Charli-Joseph et al. 2018; Haas et al. 2021) and for climate change adaptation more specifically (e.g., O'Brien and Sygna 2013; Otto et al. 2020a). The agency to act in coastal governance processes includes a combination of stakeholder properties, such as political power, or the availability of resources and access to information and knowledge. Different types of agency in turn can influence bottom-up initiatives or top-down decision-making as a response (Schlüter et al. 2019; Lam et al. 2020).

A Stakeholder Network Analysis (SNA) facilitates the analysis and understanding of different stakeholder relationships and the identification of central actors, who can enhance collaboration and support the implementation of a strategy, roadmap or action plan (Reed et al. 2009; European Commission 2018). With regard to climate change, the exchange of *climate information and knowledge* within governance networks are of particular importance (Rosenzweig and Solecki 2018). Climate information and knowledge, in this context, is referred to as any kind of data, information and knowledge that can support climate change adaptation in coastal SES, such as climate change projections, or flood lines, reports on climate impacts, and adaptation options. While the authors are aware that 'information' is not the same as 'knowledge' (see Celliers et al. 2021), the term 'knowledge network' is chosen for simplicity. Even though studies applying SA and SNA already exist, e.g. with regard to natural resource management, climate adaptation, and sustainability transformations (e.g., Lienert et al. 2013; Ahmadi et al. 2019; Lam et al. 2020), quantitative approaches for network analysis in environmental governance research are still recent and scarce; and the combination of SA and SNA is currently underrepresented in climate adaptation research (Cárcamo et al. 2014; Ziervogel et al. 2017).

This paper aims to improve the understanding of collaboration and knowledge networks, and stakeholder agency to act in coastal governance processes facing climate change. The paper examines the complexity of these issues through a case study in Algoa Bay, South Africa. A combination of SA and SNA are applied to: i) assess collaborations and the flow of climate information and knowledge between organisations involved in coastal governance; ii) identify the role of organisations (individual and organisational archetypes) in collaboration and knowledge networks through measures of centrality and agency; and iii) propose recommendations for improving knowledge exchange in coastal governance to enhance climate resilience in coastal SES. The paper, therefore, advances research on applying and combining SA using measures of agency and SNA in climate change adaptation and environmental governance research.

2 Material and Methods

2.1 Case study context

Algoa Bay, in the Eastern Cape of South Africa, is home to the Nelson Mandela Bay Municipality (NMBM), including the cities of Gqeberha (formerly Port Elizabeth), Despatch and Kariega (Fig. 1). It is an integrated SES stretching from land to the ocean including important social-economic and ecological features, e.g., two economically important industrial ports, strong urban and peri-urban development along the coast, and diverse and pristine ecosystems with high species diversity (Dorrington et al. 2018). The Port of Gqeberha serves local industries such as agricultural products, manganese ore, petroleum products as well as the prominent automotive industry, which is a primary economic driver for the Bay. The newer Port of Ngqura was established in 2012, is a deep-water transhipment hub offering port services for containers on transit to global markets as well as within the Sub-Saharan Africa region. Both ports are linked to rail and road networks, which connect to the rest of South Africa. Furthermore, Algoa Bay was selected as a case study for the first Marine Spatial Plan in South Africa, as it has the longest standing biophysical monitoring along the country’s shoreline as well as a diversity of socio-economic marine and coastal activities (Dorrington et al. 2018).

Given its prime ecological and socio-economic importance, Algoa Bay has also been described as one of the most vulnerable coastal areas in South Africa to climate change. Its location between two up-welling systems, the warm Agulhas current and the cool Benguela current, results in a particularly high climate variability (van Huyssteen et al. 2013). The area is already experiencing climate-induced changes, including hotter days, more frequent and longer droughts, more intense floods, greater wind speeds, a change in the prevailing wind directions, rising sea levels, and increased (extreme) storm surges (NMBM 2015; Bornman et al. 2016). These impacts are likely to increase in magnitude and frequency over time. In addition, ongoing droughts have resulted in water shortages in the city. Rising sea level is of particular concern, as it is predicted that popular swimming beaches, public infrastructure, and development, including national roads and houses, could eventually be reclaimed by the ocean (CMR 2020a).

Figure 1. Map of Algoa Bay located in the Eastern Cape of South Africa. Arrows indicate the warm Agulhas current on the east coast and the cool Benguela current on the west coast of South Africa.

Coastal management in South Africa is still largely sector-based and top-down, governed by different administrative levels of government and area-based management (ABM) tools and approaches (Sowman and Malan 2018; Taljaard et al. 2019). Different institutional arrangements for such ABM tools include Integrated Coastal Management (ICM), Marine Spatial Planning (MSP), and nature protection areas, including Marine Protected Areas (MPAs). Government institutions are mandated to operationalise such management tools. For example, the national Department for Forestry, Fisheries and the Environment (DFFE) is responsible for leading the MSP process, and for enforcing rules and regulations governing MPAs. Such enforcement is assisted by other national government agencies including the South African National Parks (SANParks) and the South African National Biodiversity Institute (SANBI) and provincial entities like the Eastern Cape Parks and Tourism Agency (ECPTA).

On a local level, the NMBM Directorate 'Public Health' is responsible for environmental management in Algoa Bay. Specifically, the Sub-Directorate 'Environmental Management' (Coastal Zone Management section) is responsible for implementing the provisions of the *National Environmental Management: Integrated Coastal Management Act, 2008 (Act 24 of 2008)* in the municipal area, including the coast up to 500 m from the shoreline into the Bay. Other municipal departments (i.e., 'Sports, Recreation, Arts and Culture', 'Infrastructure and Engineering' and 'Human Settlements') have operational responsibilities within the coastal zone. In August 2015, the NMBM published its first 'Climate Change and Green Economy Action Plan'. However - and despite the above-mentioned climate induced changes - no specific directorate in the NMBM addresses climate change adaptation issues for the Bay (CMR 2020b). In addition, management objectives on land are still separated from the ocean. This means that the NMBM - in its current state - faces considerable challenges to achieving sustainability and climate change adaptation objectives. Algoa Bay therefore presents a suitable case study for the identification of key stakeholders that can facilitate improved collaboration and knowledge exchange for sustainable coastal management in the context of climate change adaptation.

2.2 Stakeholder identification and questionnaire design

An initial stakeholder identification within the framework of the CICLICO (Cities and Climate Change in the Coastal Western Indian Ocean) project identified 113 organisations relevant to coastal and ocean governance of the Algoa Bay SES. Organisations were identified from a review of literature and online resources, Environmental Impact Assessments, and provincial and local coastal working groups, as well as by means of snowball sampling (Leventon et al. 2016). The list included organisations from government, parastatal (semi-state) and civil society, e.g., national to local stakeholders from government, education and research institutes, (industry) associations, businesses/industry, and advocacies. For the purpose of this paper, a sub-sample of organisations was selected, including organisations, which are locally active in the Nelson Mandela Metropolitan Area, or hold specific mandates for the management of the coast and ocean. In total, 36 organisations active in decision-making, tourism, nature conservation, development, research, and service provision were identified and asked to participate in a questionnaire. Due to COVID-related travel restrictions, the questionnaire was conducted online using LimeSurvey (LimeSurvey Project Team / Carsten Schmitz 2012).

The questionnaire was divided into three parts: i) stakeholder information, and ii) assessment of collaborations for coastal governance (collaboration network), and ii) assessment of the exchange of information and knowledge with regard to climate change adaptation within coastal governance (knowledge network). Participants were asked to represent their organisation (as opposed to personal representation), in order to assess collaborations and knowledge exchange from an organisational level. For a common understanding among participants, the terms coastal governance, collaboration, and climate information and knowledge were explained. *Coastal governance* was defined as actions that contribute to maintaining a healthy and productive coastal environment, and which can relate to tourism and recreation, or the continued provision of ecosystem services to people in the form of livelihoods and local economic development. *Collaboration* was defined as the exchange of resources, information and knowledge, or working towards common objectives. Lastly, *climate information and knowledge* were defined as any kind of data, information and knowledge that can support climate change adaptation, such as climate change projections, or flood lines, reports on climate impacts, and adaptation options.

In the first part of the questionnaire, basic stakeholder information was requested, including the name of the organisation, and administrative level of operation, e.g., international, national, provincial (Eastern Cape), or local (NMBM). In the second and third part of the questionnaire, participants were asked to assess their collaboration with other organisations in respect to coastal governance in Algoa Bay. They were also asked to define the nature of the exchange of scientific information and knowledge for the purpose of climate change adaptation with other organisations. For the collaboration network, participants were asked to identify organisations they collaborate with and assess the frequency of collaboration (weekly, monthly, or yearly). For assessing knowledge exchange, participants were asked to indicate the direction of information flow (receive, provide, exchange) and the frequency of exchange (weekly, monthly, or yearly). Even though the frequency of collaborations does not necessarily translate into stronger/better relationships between organisations, it was used to simplify the comparison with the knowledge network, as well as to simplify the online assessment for survey participants. For an easier assessment of collaborations and knowledge exchange, a list of the 36 organisations relevant to coastal governance of Algoa Bay was provided with the option to add other organisations or stakeholders they frequently interact with. Participants were also asked if there are any formal agreements to share climate information and knowledge with other organisations, and what type of information or knowledge is exchanged, using open-ended questions.

2.3 Stakeholder Analysis: Organisational archetypes based on agency

In a previous assessment (see Celliers et al., in print) organisations were categorized and grouped into organisational archetypes according to their agency to act in coastal governance processes. Agency, in this context, was measured by dimensions of scale, power, and resources (based on Celliers et al. 2012). Scale is described as the level at which an organisation operates, including spatial and functional parameters, e.g., operational scale and organisational mandate to achieve management objectives in Algoa Bay. Power is considered as a function of executive and legislative power, political relevance, enforcement role and moral suasion to influence policy issues. Resources, in this context, is composed of varying amounts of capital, including financial and human capital, as well as infrastructure in the form of equipment and other physical assets (Celliers et al., in print). The three dimensions cover a broad range of organisational characteristics that are important for achieving management objectives of coastal governance at the intersection with climate change adaptation in Algoa Bay.

A total of 113 organisations were scored for eleven indicators by three experts knowledgeable within the coastal domain in Algoa Bay (see Table A1 for a full list of indicators). The normalized scores (between 0 and 1) for each indicator were then aggregated per dimension, and the arithmetic mean across all indicators was referred to as the agency of the organisation. An agency of 1 would be an institution that has physical presence in Algoa Bay with a high institutional mandate and constituency, which is highly resourced and has the highest power (Celliers et al., in print).

Subsequently, a hierarchical cluster analysis (HCA) was performed using 'complete-linkage clustering' to identify clusters of organisations that have a similar scoring for indicators internally, but are distinct from other clusters externally, using the maximum Euclidian distance (dissimilarity). We chose to use a dissimilarity clustering approach because we were seeking to identify distinct archetypes. The HCA resulted in 5 distinct groupings of organisations with similar characteristics (agglomerative coefficient of 0.893). Each group was then evaluated by their organisational types, scoring for the three dimensions and categorized into organisational archetypes. More details on the methodology can be found in Celliers et al. (in print). The descriptions of the organisational archetypes based on their medium scores for scale, power and resources are presented in Table 1. The remaining archetype 'on the margin' presented a small group of organisations without authority and without being physically based or operating in Algoa Bay. As none of the stakeholders in this study belong to this archetype, it is not presented here.

Table 1. Description of organisational archetypes of organisations involved in coastal governance in the Algoa Bay SES, described by the three dimensions of agency, namely scale, resources and power (adapted from Celliers et al., 2022).

Organisational Archetype	Description
Get-it-done	This archetype represents organisations with the highest agency, based on the highest scoring for available resources, operational scale, and power. Organisations have the ability to act locally, and to implement decisions on local issues in a relatively short period of time. Management actions are directly related to ocean and coastal governance, and the impact of such actions will be experienced by many stakeholders in the system. These organisations have direct authority over implementation and a significant control of policy-implementation processes. Organisations from this archetype must be included in participatory processes related to developing the knowledge-base for local decision-making such as climate change adaptation, or biodiversity conservation.
Vocal-and-insistent	This is an internally diverse archetype of organisations including local NGOs, civil society advocacy groups which typically score low on all measures of agency. Their physical presence in Algoa Bay makes them relevant stakeholders and their collective interest and agency makes their contribution in participatory processes important and bordering on critical. Even though their operational scales may be small, i.e., conservancy of an area within the larger Algoa Bay area, they are important for latent/dormant power, and the vulnerability of their members. Even though organisations score low on power, enough motivation and concern can have high influence in the form of moral suasion e.g., fishing companies, community-based organisations. This archetype can easily be split into smaller sub-groupings.
Plans-and-planning	This archetype presents a relatively diverse group of mainly government institutions, which are mostly thematically or sectorial focussed, i.e., transport, minerals and energy, and environment. Organisations of this archetype have substantial power, which is mostly enacted through national policy and legislation. Their role is clear with regards to medium- to long-term strategic planning in the ocean and coastal governance domain and there are no locally-based organisations in this archetype. Organisations are well-resourced in terms of human capacity and access to data and information. While they are scoring relatively high for agency overall, they have substantially less agency compared to the archetype "get-it-done".
Little-by-little	This archetype includes organisations from research and education, which are low in power, but present and active in Algoa Bay. They are relatively well-resourced and operate at the Bay-scale. There are overlaps with other groups ("vocal-and-insistent" in particular) but this group is very relevant to focussed activities in the ocean and coastal space of Algoa Bay. With their relative high level of resources and their local presence and agency, they are important and relevant actors for local decision-making.

2.4 Stakeholder Network Analysis

In preparation for the network analysis, two adjacency matrices were created from the questionnaire for the collaboration and knowledge network, respectively. The frequency of interactions (collaboration, knowledge exchange) was translated into a numerical value between 1-3, with 1 indicating lower frequency (yearly), and 3 indicating higher frequency (weekly). If two individual stakeholders assessed the common frequency of interaction between their organisations differently, the higher value was chosen. Even though we acknowledge a potential over-interpretation, this approach was chosen, as an average would display false relations (Lam et al. 2020). The adjacency matrices were then imported to the statistical computing environment RStudio (R Core Team 2021) and analysed using the *igraph* package. Network-level cohesion measures were calculated for both networks, including the number of nodes and edges, network density, average path length, diameter, degree, betweenness and eigenvector (see Table 2 for descriptions).

For analysing the centrality of organisations within the network, four different centrality measures were calculated at the node-level, including *strength, betweenness, closeness* and *eigenvector* using the statistical computing environment RStudio (R Core Team 2021). *Strength*, in this context, is the number of connections of an organisations multiplied by the weight of connections (here a numerical value for frequency) (Freeman 1979). It indicates the interconnectedness of an organisation in the network. *Betweenness* indicates the number of times an organisation in the network lies on a shortest path between other organisations that are otherwise disconnected (Freeman 1979; Cumming 2011). Organisations with high betweenness centrality can be referred to as 'bridging organisations' (Freeman 1979). They are organisations that can help to connect otherwise disconnected stakeholders, e.g. by customizing information from one stakeholder and providing it to a third party. They are sometimes also referred to as 'boundary organisations' working at the interface between different sectors, such as at the science-society/implementation interface (Dale et al. 2019), or between different administrative levels (Cárcamo et al. 2014). *Closeness* indicates the independence of an organisation to all other organisations in the network. It is highest for organisations that have shortest paths to other organisations in the network (Freeman 1979; Cumming 2011; Prell 2011). *Eigenvector* indicates the influence of an organisation based on influence of an adjacent organisation in a network. It considers the number of connections of the adjacent organisation and can be interpreted as the future influence of an organisation (Freeman 1979; Prell 2011). For the knowledge network, the in- and out-degree of organisations were additionally calculated, to indicate the degree to which organisations receive (in-degree) or provide (out-degree) information.

Subsequently, mean centrality values were calculated for the organisational archetypes. As there was a significant difference whether organisations participated in the survey or not (two-tailed t-test, p-value < 0.005), mean centrality values were only calculated for organisations that participated in the survey. Even though survey participants by default have more links to other organisations and therefore are more central in networks, they are also those stakeholders with a higher interest in the topic. We therefore argue that the results would not have been significantly changed, if more (less engaged) organisations would have participated in the survey. Pairwise t-tests were carried out to analyse different centrality values between archetypes and 'p-adjusted' was calculated using the 'Bonferroni' adjustment method to correct for multiple comparisons. For the knowledge network, information flows were additionally calculated for all organisations (n=38) as an aggregate across organisational archetypes using the *assortnet* package, and visualized as a chord diagram using the *circlize* package.

Both networks initially included all organisations from the list that was provided to survey respondents (n=36). However, in the knowledge network, one organisation (Minerva Bunkering) was not connected to any other organisation and therefore excluded. Additional organisations were added from survey respondents for the collaboration (n=5) and knowledge network (n=3), resulting in a slightly greater collaboration network.

3 Results

The online questionnaire was answered by 20 organisations at local (n=7), provincial (n=2), national (n=10), and international (n=1) level. Different sectors, e.g., government, education/research, businesses, (industry) association, and advocacy, were represented. The resulting networks consisted of 41 and 38 organisations for the collaboration and knowledge network, respectively. For brevity, the participating organisations are referred to via acronyms (see Table A3 and A4 for details). According to the stakeholder analysis, organisations were categorized and described by four different organisational archetypes (see Table 1). The archetype *plans-and-planning* represented mainly national organisations, *vocal-and-insistent* includes national and international organisations, and *get-it-done* and *little-by-little* represent mainly local and some national (mainly national scientific) organisations. The number of organisations by organisational archetype is displayed in Table A2.

Different network-level cohesion measures describing the stakeholder networks are displayed in Table 2. The collaboration network showed more connections between organisations and hence had a higher network density compared to the knowledge network. Accordingly, the average path length between any two organisations was shorter for the collaboration network, whereas the longest number of steps was equal with six steps in both networks. Network degree, describing the extent to which one actor is holding all links in the network, was similarly low for both networks. Finally, network betweenness and network eigenvector were slightly higher for the knowledge network. That means that in the knowledge network more organisations lie on a shortest path between two other organisations; and the influence of organisations based on the influence of adjacent organisations is higher compared to the collaboration network.

Table 2. Network cohesion measures to describe and compare the collaboration and knowledge network (Freeman 1979; Vance-Borland and Holley 2011; Prell 2011; descriptions based on Cárcamo et al. 2014).

Cohesion measures	Description	Collaboration network	Knowledge network
Number of nodes	Number of organisations in the network	41	38
Number of edges	Number of connections in the network	302	259
Network density	Number of actual connections divided by the possible number of connections	0.37	0.18
Average path length	Average number of steps between any two actors	1.69	1.97
Network diameter	Longest number of steps between any two actors	6	6
Network degree	Extend to which one actor is holding all the links in the network	0.46	0.45
Network betweenness	Variation in the number of times that actors in the network lie on path between other actors	0.15	0.22
Network eigenvector	Measure of the influence of a node in a network based on influence of adjacent nodes	0.51	0.65

3.1 Collaboration network for coastal governance

In the collaboration network, the interactions between organisations were assessed with regard to coastal governance (e.g., the exchange of resources, information and knowledge, or working towards common objectives). Figure 2 shows the collaboration network consisting of 41 organisations displayed as nodes and the existence and frequency of collaboration indicated by finer (yearly) or thicker (weekly) edges. Whereas organisations in the centre of the network hold many connections to other organisations - and therefore are more central - organisations further away from the centre have fewer connections. The values calculated for strength, betweenness, closeness and eigenvector can be seen in Table A3 and are visualized in Fig. 2a-d. Even though strength and eigenvector were strongly correlated (r = 0.984, Fig. A1, left), both measures were included in the analysis based on their different interpretations.

Results for the centrality measure strength (Fig. 2a) show a broad distribution of the interconnectedness of organisations within the collaboration network. Whereas some organisations are connected to the network by a single collaboration and low frequency of interaction (e.g., outer circle of Fig. 2a), other organisations are highly interconnected. The Eastern Cape Development Corporation (ECDC) scored highest for strength, followed by the NMBM Directorate 'Human Settlements' (NMBM4), Nelson Mandela University (NMU), Coega Development Corporation (Coega), and NMBM Directorate 'Economic Development, Tourism and Agriculture' (NMBM1) in decreasing order. Eigenvector centrality (Fig. 2c) showed a similar distribution of highest scoring organisations, except for the last two, as NMBM1 scored slightly higher than Coega, and therefore has a slightly higher influence on the network. In terms of betweenness (Fig. 2b), only a few of organisations showed a high scoring, and therefore can be interpreted as bridges between other organisations. Organisations with highest betweenness were Coega, followed by the Wildlife and Environment Society of South Africa (WESSA), Anchor Environmental Consultants (AnEC), the South African Foundation for the Conservation of Birds (SANCCOB), and the Eastern Cape Department of Economic Development, Environmental Affairs and Tourism (DEDEAT). Finally, closeness, indicating the independence of organisations to other organisations in the network, showed the most homogenous distribution among centrality measures (Fig. 2d). The organisations with slightly higher closeness scores compared to other organisations were in decreasing order: AnEC, Coega, the South African Environmental Observation Network (SAEON), NMBM1 and SANCOBB.

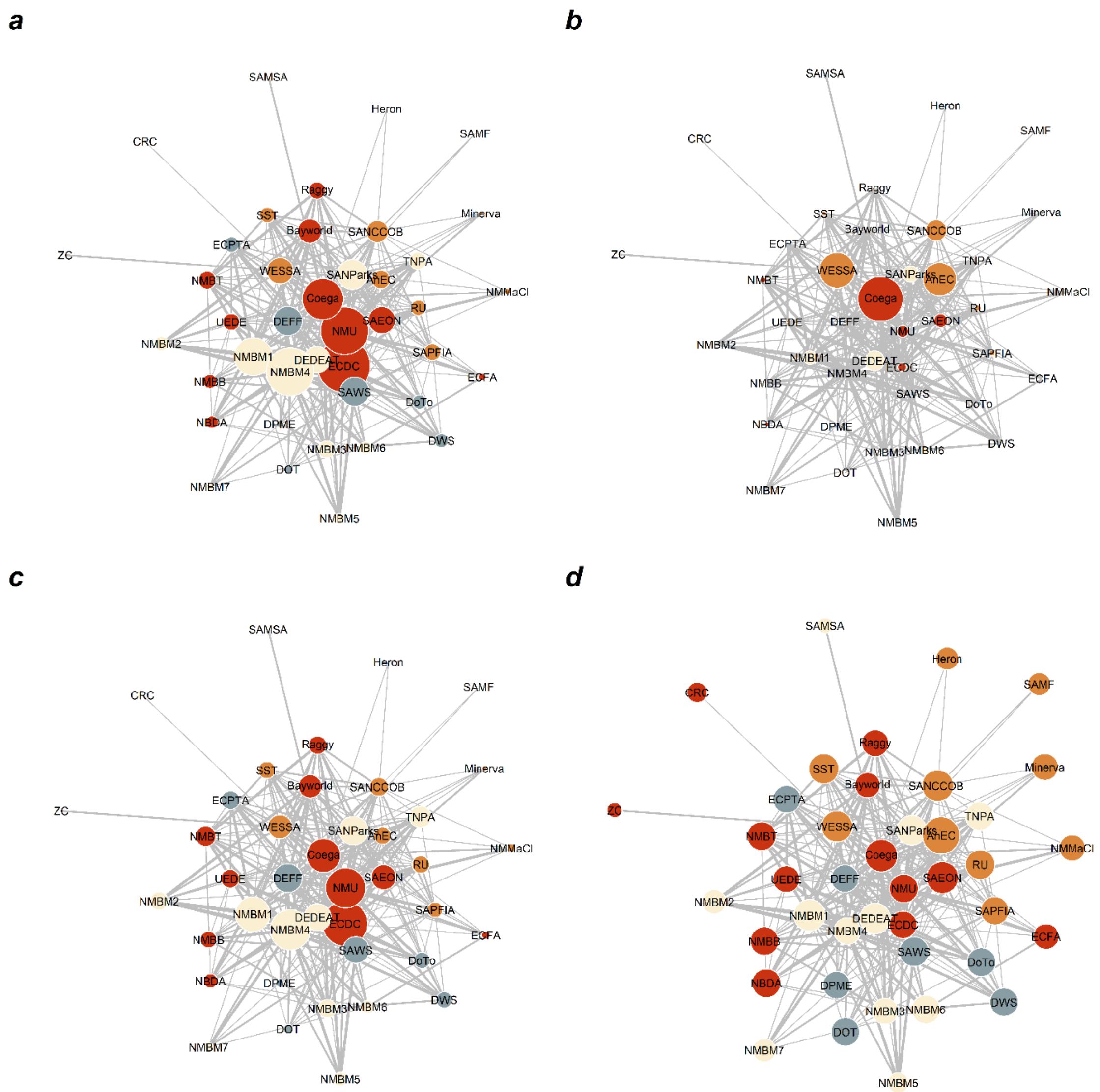

Figure 2. Collaboration networks with node size indicating the centrality of organisations for a) strength, b) betweenness, c) eigenvector, and d) closeness. Colours indicate organisational archetypes: beige = get-it-done; red = little-by-little, grey = plans-and-planning; orange = vocal-and-insistent. Labels are acronyms of organisations and a full list of organisations can be found in Table A3.

Additionally, mean values for the four centrality measures were calculated by organisational archetype. Even though there was no significant difference between archetypes (pairwise t-test, p-adjusted > 0.2, Table A5), results show some distinct trends (Fig. 3). Organisations with high strength and eigenvector centrality are mainly characterized by the archetypes *little-by-little* and *get-it-done*, and represent mostly organisations involved in the sector of development from local level (NMBM1/4, Coega), and provincial level (Eastern Cape Development Corporation, ECDC). The Nelson Mandela University (NMU), which is also under the five most central organisations in terms of strength and eigenvector, is involved in research and education. Even though *plans-and-planning* scored fairly high for strength and eigenvector, none of the organisations from this archetype were under the most central organisations. For betweenness and closeness centrality, mainly organisations from the archetype *vocal-and-insistent* and *little-by-little,* that are active in environmental and conservation management scored high, such as SANCOBB, SAEON, AnEC, and WESSA. However, also here, development organisation such as Coega (*little-by-little)* and NMBM1 and DEDEAT from the archetype *get-it-done* played a significant role.

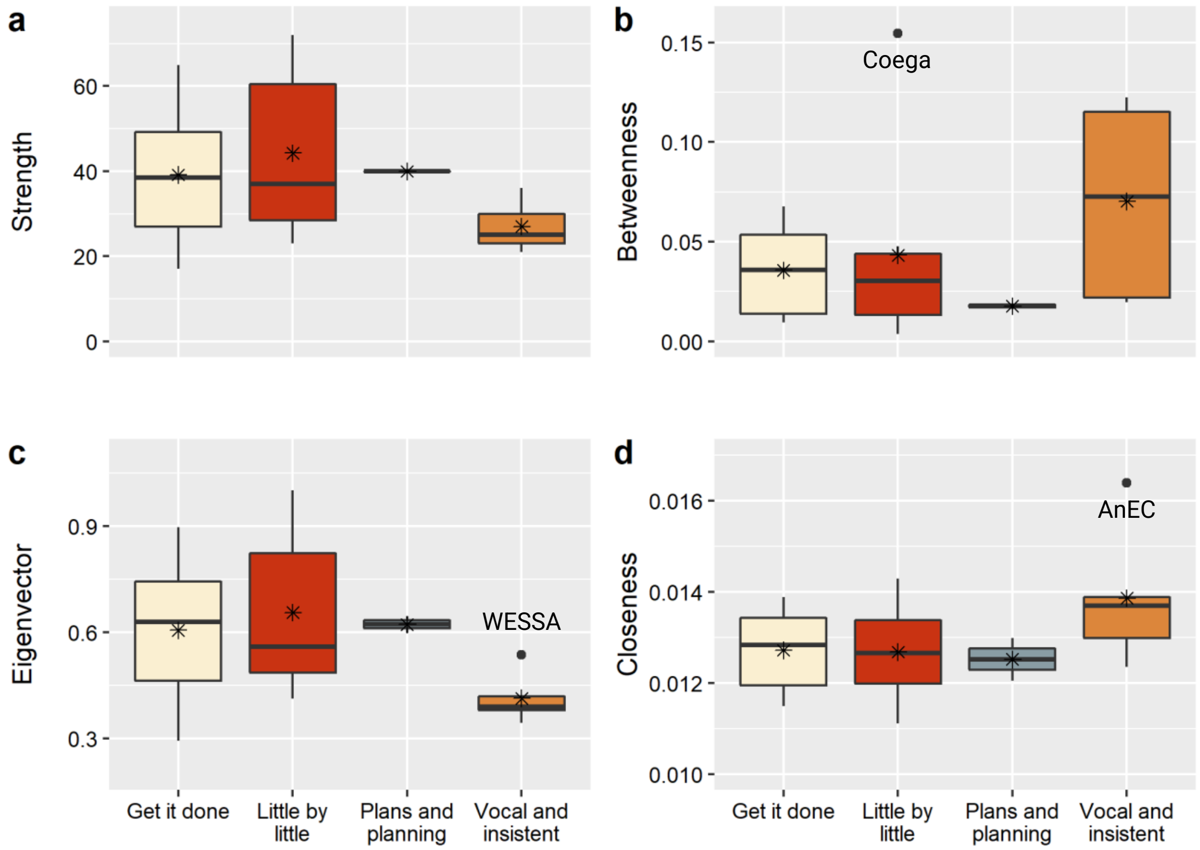

Figure 3. Boxplots for centrality measures of the collaboration network by organisational archetypes for a) strength, b) betweenness, c) eigenvector, and d) closeness (n = 6 ,7, 2, 5 from left to right). Boxes show the 75th percentiles of distribution, with horizontal lines indicating the median. Mean values are symbolized by stars and outliers are shown as dots outside of the boxes, including the acronym of the outlier organisation.

3.2 Knowledge network for climate change adaptation within coastal governance

In the knowledge network, the exchange of information and knowledge related to climate change adaptation within coastal governance was assessed. Results from the open-ended questions show that several formal agreements to share climate information and knowledge (and other environmental data) exist, e.g. Memorandum of Understanding (MoU), research permits and data sharing agreements. However, such agreements almost exclusively exist between organisations at the national level, e.g. scientific and research institutions (Nelson Mandela University, South African Environmental Observation Network, South African Weather Service), nature conservation organisations (South African National Parks, South African Institute for Aquatic Biodiversity, South African Foundation for the Conservation of Birds), and national government (Department of Forestry, Fisheries and the Environment). Only the Nelson Mandela University mentioned a MoU with the local level NMBM. The type of climate information ranged from environmental data (e.g., sea-surface temperature, currents, nutrient levels, water quality, biodiversity data), sea-level rise and flood lines, to sector related climate change adaptation information, seasonal forecasts, and climate projections.

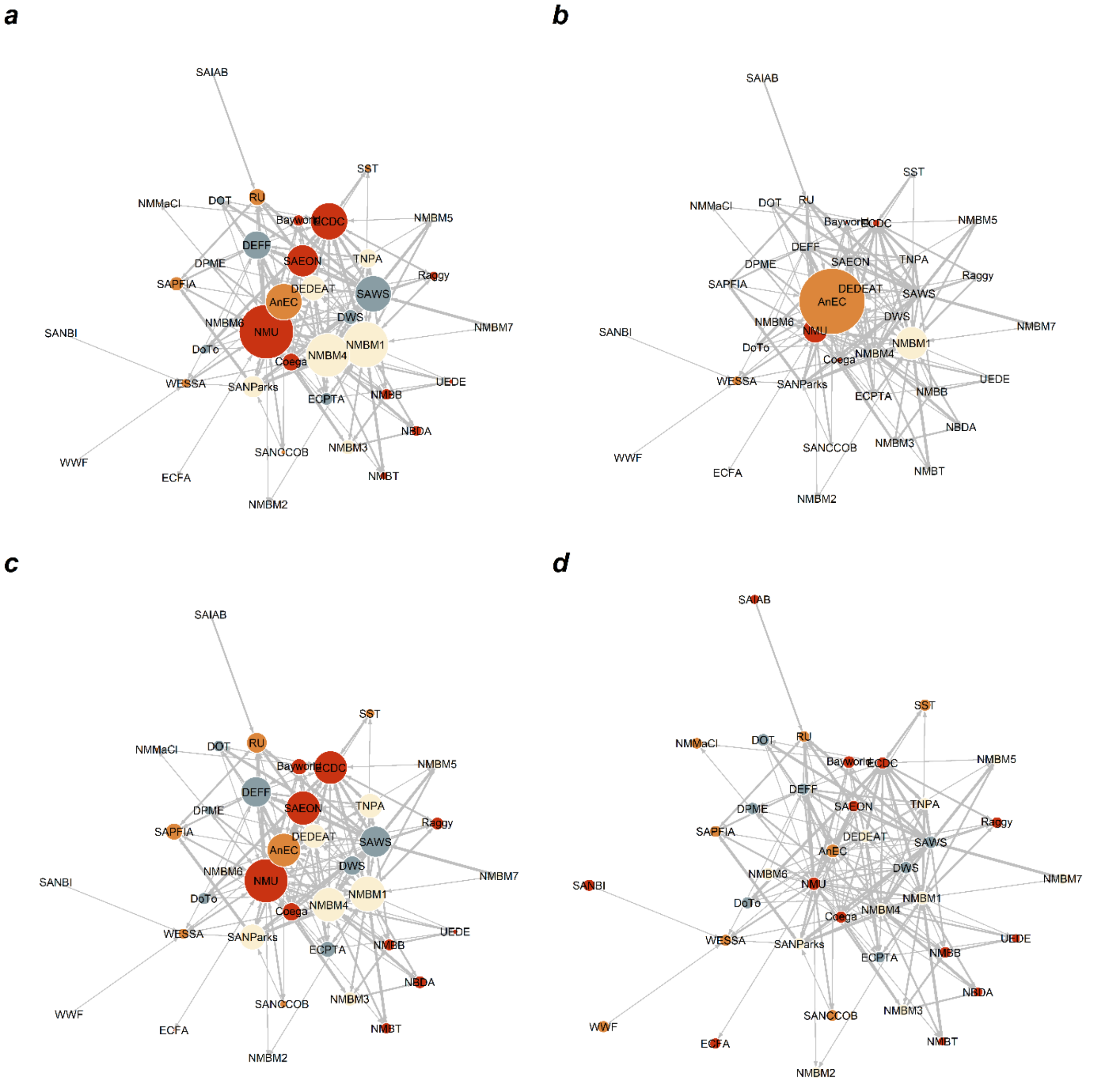

Figure 4. Knowledge networks with node size indicating the centrality of organisations for a) strength, b) betweenness, c) eigenvector, and d) closeness. Colours indicate organisational archetypes: beige = get-it-done; red = little-by-little, grey = plans-and-planning; orange = vocal-and-insistent. Labels are acronyms of organisations and a full list of organisations can be found in Table A4.

Figure 4 shows the knowledge network consisting of 38 organisations displayed as nodes and the existence and frequency of exchange, as well as the direction of information flow (receive, provide, exchange) indicated by finer (yearly) or thicker (weekly) edges and the direction of arrows, respectively. The values calculated for strength, betweenness, closeness and eigenvector can be seen in Table A4 and are visualized in Fig. 4a-d.

Results show that approximately one third of organisations in the knowledge network are well interconnected, as visualized by strength centrality (Fig. 4a). The NMU scored highest for strength, followed in decreasing order by NMBM1, NMBM4, ECDC, the South African Weather Service (SAWS) and AnEC, of which the last two had the same score. The high scoring for strength was based on a high in- and out-degree for most of these organisations. However, for SAWS the high value was mainly explained by the high out-degree and therefore provision of information, and for ECDC by the high in-degree and hence receipt of information (see Table A3). Eigenvector centrality in the knowledge network was similar to strength. However, instead of SAWS and ECDC, SAEON ranked under the top five for eigenvector centrality (Fig. 4c), and therefore show a higher influence on the network. For betweenness centrality, only three organisations showed a noticeable scoring (Fig. 4b), namely AnEC, NMBM1 and the NMU. Additionally, DEDEAT and NMBM4 and WESSA showed a slightly higher betweenness centrality compared to other organisations in the network. Interestingly, the highest betweenness score in the knowledge network (AnEC) was more than double as high compared to the collaboration network (0.3947 compared to 0.1546). Finally, closeness (Fig 4d) was equally homogenous in the knowledge network, but significantly lower compared to the collaboration network. The highest scoring organisations for closeness were in decreasing order: AnEC, NMU, NMBM1, DEDEAT, the NMBM Directorate 'Public Health' (NMBM6), and SAWS. Overall, SANCOBB and Coega belong to the most central organisations in the collaboration network, but not in the knowledge network. Oppositely, NMBM6 (Public Health) and SAWS are central in the knowledge network, but not in the collaboration network.

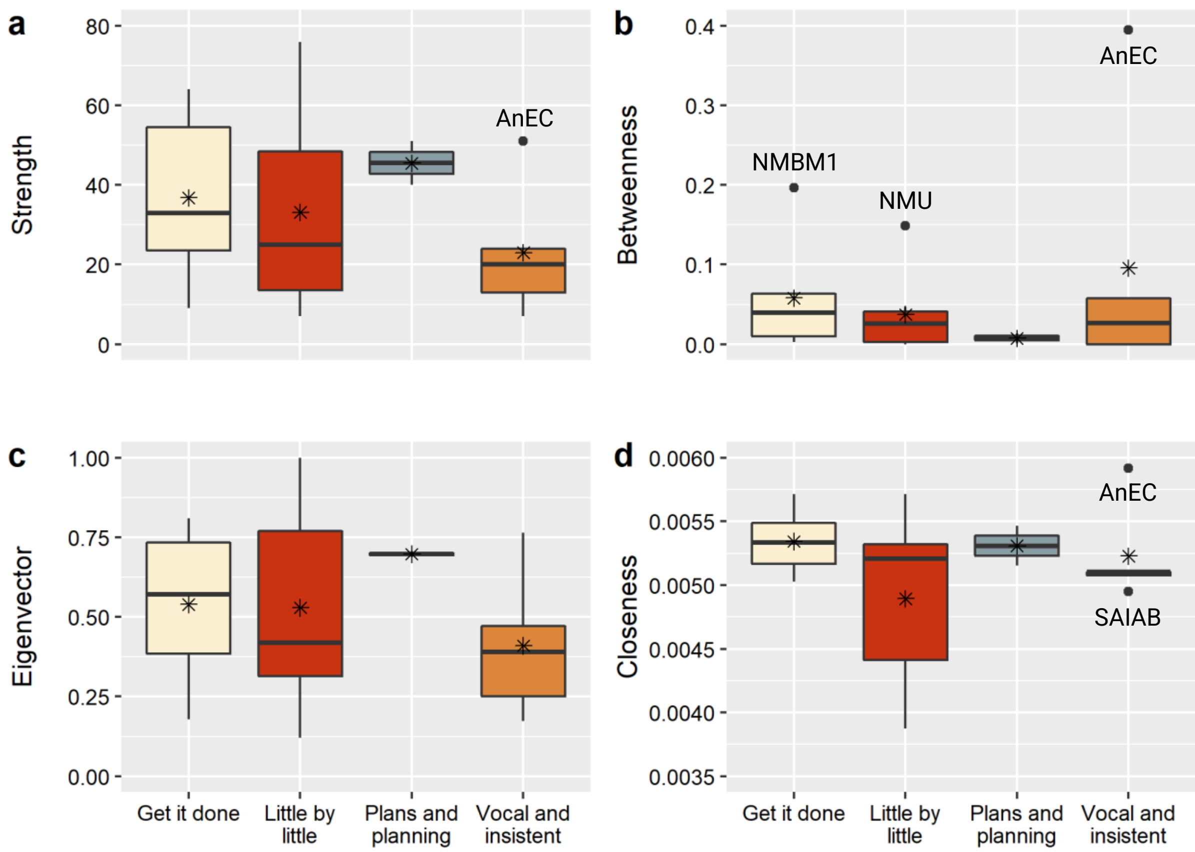

Figure 5. Boxplots for centrality measures of the knowledge network by organisational archetypes for a) strength, b) betweenness, c) eigenvector, and d) closeness (n = 6 ,7, 2, 5 from left to right). Boxes show the 75th percentiles of distribution, with horizontal lines indicating the median. Mean values are symbolized by stars and outliers are shown as dots outside of the boxes, including the acronym of the outlier organisation.

Similar to the collaboration network, mean values for the four centrality measures were not significantly different between archetypes (pairwise t-test, p-adjusted > 0.4, Table A6) and trends were similar to the collaboration network (see Fig. 5). However, there was a significant difference for closeness between the collaboration and knowledge network (two-tailed t-test, $p<0.001$). The closeness of organisations was generally lower in the knowledge network, and the three archetypes *plans-and-planning, get-it-done* and *vocal-and-insistent* showed similar values, whereas in the collaboration network *vocal-and-insistent* scored higher for closeness than the other archetypes.

Furthermore, the high value for strength for *plans-and-planning* is mainly explained by its high out-degree, whereas *vocal-and-insistent* show a slightly higher in-degree than out-degree (Fig. A2). Whereas organisations with high strength and eigenvector in the collaboration network were mainly involved in the sector of development, in the knowledge network, organisations from research and education (NMU, SAEON) and service provision (SAWS) were more central. For three of the four centrality measures, AnEC clearly exceeded the scoring of other organisations for the archetype *vocal-and-insistent* and most other archetypes (Fig. 5a,b,d), highlighting its overall importance within the knowledge network.

For further investigating the knowledge network, flows of climate information were analysed by organisational archetype and visualized in Figure 6. Based on the width of out-going arcs, the archetype *plans-and-planning* proportionally provides more information to other archetypes. The archetypes *little-by-little* and *vocal-and-insistent* receive proportionally more information (width of in-coming arcs). The archetype *vocal-and-insistent* both receives and provides information with the archetype *little-by-little*. *Plans-and-planning* mainly provide to the archetypes *little-by-little* and *get-it-done*, which themselves show the highest exchange of information between the two (thick red and beige arcs).

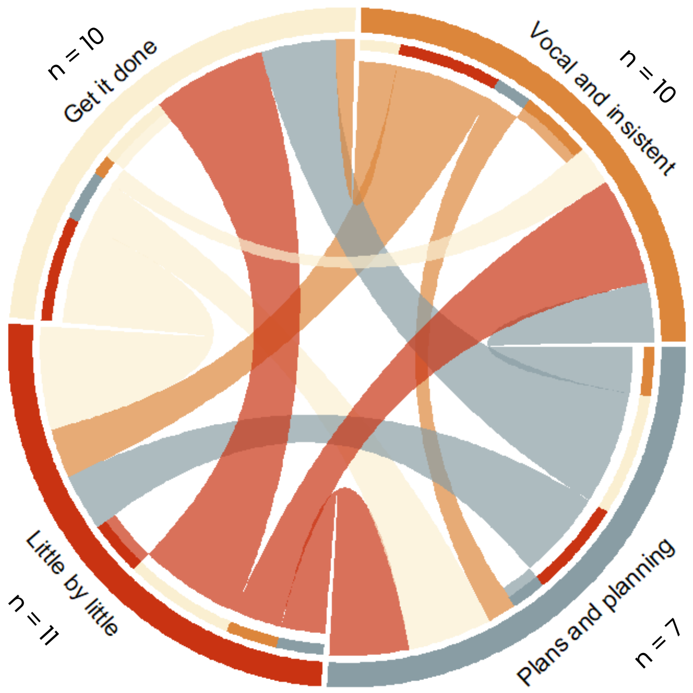

Figure 6. Chord diagram visualizing the proportional flow of climate information and knowledge between organisational archetypes, scaled to the number of organisations per archetype (number of organisations (n) per archetype is indicated on outer ring). The flow direction is indicated by colours of the arc, e.g., red arcs showing the flow of information from *little-by-little* to respective other archetypes. Empty spaces indicate the proportion of information flows between organisations of the same archetype.

4 Discussion

The network assessments provide an overview of the current status of collaboration and knowledge exchange in the Algoa Bay SES. It thus presents a snapshot of the present status, while such networks, in fact, are dynamic over time. The question of what differentiates the two networks, which role organisations play, and how knowledge exchange in coastal governance can be improved to enhance climate resilience in the coastal SES of Algoa Bay, will be further explored in the following sections.

4.1 Collaboration is more established than knowledge exchange

In this paper, the interactions between organisations with regard to collaboration for coastal governance (collaboration network), and the exchange of climate change information and knowledge for climate change adaptation within coastal governance (knowledge network) were assessed. Results indicate that there is a higher number of total connections, higher frequency of interaction and higher interconnectedness of organisations (measured by strength centrality) in the collaboration network compared to the knowledge network. This is also supported by a higher network density (Table 2) and a significantly higher closeness between organisations in the collaboration network. Consequently, general collaboration between organisations involved in coastal governance of the Algoa Bay SES is more established than the exchange of information and knowledge with regard to climate change adaptation.

The limited knowledge exchange compared to more general collaboration is not surprising given the absence of climate change legislation. However, the recently adopted Climate Change Bill (Government of South Africa 2022) may create the top-down conditions that will result in much stronger networks and collaboration between organisations. The Climate Change Bill aims at enabling "*the development of an effective climate change response and a long-term, just transition to a low-carbon and climate-resilient economy and society for South Africa in the context of sustainable development*". Furthermore, there are good examples of bottom-up climate change information exchange from other metropolitan cities in South Africa, which have prioritized climate change through local champions (Roberts 2010; Carmin et al. 2012; Pasquini et al. 2015). Whereas the City of Cape Town and the eThekwini municipality in Durban have dedicated climate change directorates, the NMBM is lacking such bundled and coordinated activities in their municipality. Consequently, there may be a lack of experience within organisations in the NMBM in dealing with climate-related impacts compared to coastal management, which has been implemented by the ICM Act more than a decade ago and specifically calls for establishing multi-level collaborations as part of the Act (Celliers et al. 2013). The Climate Change Bill, once enacted, may have the same affect, to enhance information flow and collaboration with regard to climate change adaptation in coastal governance.

4.2 Organisations and organisational archetypes play different roles in networks

The centrality measures reveal different roles of organisations within networks. While some organisations are highly connected to many other organisations, and therefore often show a higher influence, other organisations act as information providers, or bridging organisations.

4.2.1 Organisations with high interconnectedness and influence

Collaboration between organisations in coastal governance is mostly driven by a high interconnectedness and influence of development organisations. These organisations are mainly associated with the archetypes *little-by-little* and *get-it-done* (Fig. 3a, c), and include organisations such as Eastern Cape Development Corporation (ECDC), Coega Development Corporation and the NMBM directorates 'Human Settlements' and 'Economic Development, Tourism and Agriculture' (Fig. 2a, c). Such organisations and archetypes show the highest rating for operational scale, e.g., physical presence, representation, and organisational mandate to achieve management objectives in Algoa Bay (Table A1). As mentioned in the archetype descriptions (Table 1), the archetype *get-it-done* also shows a high availability of resources and power, and the archetype *little-by-little* is well-resourced and operates at the local scale, but is low in power. Activities related to coastal management in the Bay, therefore, are mainly driven by local economic development, as the archetype *get-it-done* has more authority over the implementation and significant control of policy-implementation processes directly related to coastal governance.

In the knowledge network, the archetypes *little-by-little* and *get-it-done* also score as the top five for influence and interconnectedness. Also the NMBM directorates 'Human Settlements' and 'Economic Development, Tourism and Agriculture' (*get-it-done*) play a significant role for knowledge exchange (Table A4). However, the NMU (*little-by-little*) shows a much greater role in terms of interconnectedness and influence compared to the collaboration network, and SAEON (*little-by-little)* ranks higher for eigenvector centrality compared to the collaboration network, indicating their potential for playing a more central role for knowledge exchange in the future. NMU and SAEON are the main research entities in the Bay. The significant interconnectedness of NMU may be explained by its leading role in the recently established Algoa Bay MSP Project (Reed and Lombard 2017; e.g., Dorrington et al. 2018), which connects various stakeholders with an interest in coastal development and planning. The NMU and especially the Institute for Coastal Marine Research has a longstanding MoU with the NMBM for applied and transdisciplinary research that requires close interaction with local stakeholders from the municipality and civil society.

4.2.2 Bridging organisations

In the collaboration network, environmental and conservation organisations from the archetype *vocal-and-insistent* such as WESSA, SANCOBB, and AnEC, were identified as bridging organisations (Fig. 2b). WESSA and SANOCBB are involved in environmental education and have recently established a group called 'Algoa Bay Ocean Stewardship', including members from sea-based enterprises, environmental NGOs, parastatal organisations, and community researchers advocating for environmental protection and ocean activism in the Bay. All of these are linked to the archetype *vocal-and-insistent* representing NGOs, or civil society advocacy groups, which score low on all measures of agency, but physical presence and high moral suasion. WESSA also scored high for eigenvector centrality, which indicates their potential future influence in the network.

In the knowledge network, the importance of bridging organisations was even more pronounced. Results reveal that knowledge exchange is based on fewer organisations, but significant influence and bridging character. Here, different organisations and organisational archetypes play a significant role. The archetypes *vocal-and-insistent* and *get-it-done* score under the top five for betweenness and therefore show the greatest importance for bridging between other organisations. In particular, one consulting company takes a central position, both in terms of a bridging between organisations, as well as exchanging information independently in the network (Fig. 4b, d). The central role of environmental consultants in both networks is not surprising given the reliance on consulting companies for environmental planning, risk and environmental impact assessments in South Africa. Even though, some of the consulting companies are not actually present in the Bay and only work on a contract-basis.

4.2.3 Organisations acting as information providers

Based on the out-degree of organisations, only a few of organisations act as information and knowledge providers (Table A4). These include SAWS, NMU and NMBM1 (Directorate 'Economic Development, Tourism and Agriculture'), which are all governmental agencies. Whereas different archetypes show a high interconnectedness in the knowledge network, the archetype *plans-and-planning* play a significant role in terms of knowledge provision, based on out-degree (Fig. A1), and their significant influence (Fig. 5c). This is also supported by the chord diagram visualizing the proportional flow of information from this archetype to other archetypes (Fig. 6). Organisations included in this archetype are mainly government institutions with substantial power, enacted through national policy and legislation, as well as strategic planning and access to data and information. In contrast to collaboration, knowledge exchange for climate change adaptation seems to be more dependent on organisations from the archetype *plans-and-planning*.

4.3 Lack of cross-level and cross-sectoral collaboration and knowledge exchange

While the network displays which stakeholders are connected to each other, it also indicates missing links. Results show that some organisations with a strategic or operational mandate were rather remote within the collaboration network. For example, organisations mandated to support or undertake coastal management, including DFFE (*plans-and-planning*) and SANParks at the national level, and the NMBM directorate 'Public Health' (both *get-it-done*) at the local level, did not show a high centrality. While DFFE has no major presence in the Bay, SANParks is very active on an operational scale, e.g., with regard to coastal monitoring and security. This reflects a disconnect between strategic planning and operational realities of coastal managers and a lack of local-level control over policy-implementation processes for coastal governance, which is often highlighted in coastal management literature (e.g., Celliers et al. 2015; Colenbrander et al. 2015; Elrick-Barr and Smith 2021).

Similarly, results from the knowledge network suggest that information and knowledge flow for climate change adaptation is rather reliant on top-down processes, but does not reach the local level sufficiently. Supporting this, we found that formal agreements to share climate information only exist either within specific sectors at the national level, or with regard to a specific objective, e.g., between organisations working in the marine sector, or between environmental conservation organisations. In contrast, there was no formal agreement to share information across organisations from the marine and terrestrial sector, nor between national and local organisations, e.g., *plans-and-planning* and *get-it-done*.

Comparable results were found in the context of the Swiss adaptation strategy, investigating the role of stakeholders to bridge between multi-level climate change adaptation governance (Braunschweiger 2022). The study finds that both cross-level and cross-sectoral collaboration for climate change adaptation was fragmented. While in our study NGOs were most important in terms of bridging between different stakeholders, results from Braunschweiger (2022) suggest that federal governmental actors exhibit a significant bridging role for cross-sectoral collaboration. Yet, they conclude that cross-level collaboration, e.g., between national and municipal level, needs action from higher level actors and by adaptation funding programs (Braunschweiger 2022), which may be transferable to the Algoa Bay case study.

4.4 Improving knowledge exchange to enhance climate resilience of coastal social-ecological systems

The aim of this paper was to gain an improved understanding of collaboration, knowledge networks and stakeholder agency for enhancing climate resilience of the coastal SES in Algoa Bay, South Africa.

We found that the present collaboration networks in Algoa Bay reflect the implementation of multi-stakeholder collaboration through the ICM Act. In contrast, coastal governance significantly lacked an exchange of information and knowledge with regard to climate change adaptation. Results suggest that different top-down and bottom-up actions and processes are required for improving knowledge exchange and climate resilience in coastal governance of the Algoa Bay SES:

Firstly, this includes the establishment of formal agreements for sharing climate information and knowledge across sectors and administrative levels, e.g., between SAEON and the NMBM. The relevance of bringing together actors across multiple scales has long been recognised in resilience literature (Olsson et al. 2004; Folke et al. 2010), and especially with regard to transformative agency in SES (e.g., Westley et al. 2013). Improved knowledge flow between different scales may also include a stronger integration of climate information into ABM processes. Other studies have shown, that existing coastal governance networks, such as established through coastal committees and ABM approaches and frameworks (e.g., ICM, MSP and MPA mechanisms), can support the exchange of climate information and knowledge and enhance collaborative governance across diverse stakeholders and their interests (Tobey et al. 2010; Frazão Santos et al. 2020).

Secondly, supporting and encouraging the role of information providers and increasing the transformative potential of bridging organisations can contribute to enhancing climate resilience. The importance of bridging organisations, to connect different stakeholder groups and leverage change, has been highlighted as an important feature for knowledge dissemination and adaptive governance in SES (Folke et al. 2005; Berkes 2009). Cinner and Barnes (2019) highlight that stakeholders who can bridge between or link different stakeholders in a network, may be relevant for supporting transformative action for enhancing climate resilience. For example, WESSA – one of the important bridging organisations in the collaboration network with potential future influence – disseminates knowledge between scientific actors and the public and stated that they plan on increasing their climate related activities in Algoa Bay. It is also likely that there are organisations, which are currently not included in the analysis, but may be of future relevance in providing relevant climate information and knowledge. These can include boundary organisations, such as climate service providers that can tailor climate information and knowledge to the local context, e.g., in the form of customized products for coastal municipalities (Swart et al. 2021).

Thirdly, such top-down processes will include political will and leadership for an improved support of climate actions and transfer of knowledge to lesser resourced local municipalities by provincial and district governments (Reddy et al. 2021). Bottom-up processes include local level champions that push forward climate change related topics, even though they are not specifically mandated. Similar recommendations as proposed here have been included in the Climate Change Bill, but monitoring of the actual implementation may be necessary to achieve the same effect of enactment as through the ICM Act. While the suggestions are based on the Algoa Bay case study, they may also be applicable and transferable to similar coastal SES.

Finally, further qualitative network approaches, assessing the nature of collaboration and the type and form of information and knowledge that organisations require, may be needed for building the capacities for climate change adaptation. This will help to identify organisations, which can play an important future role in the knowledge network, by bridging between information providers (e.g., SAWS and SAEON) and information 'seekers' on the local Bay level. Future applications combining a SA and SNA may also assess financial flows between organisations, which are of high relevance, when actions for climate adaptation need to be operationalised.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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Supplementary Material

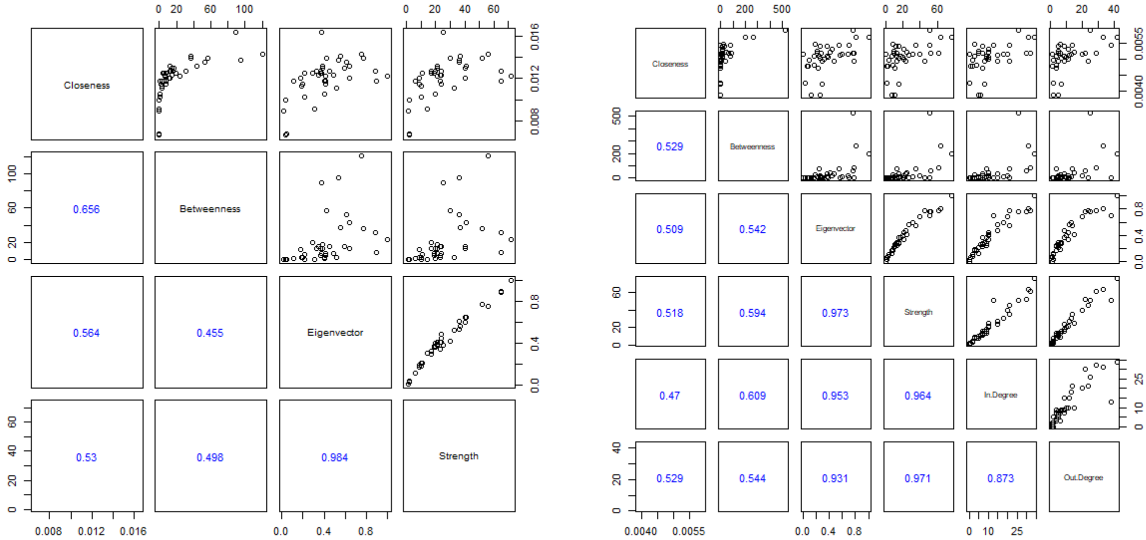

Figure A1. Correlations for centrality measures for the collaboration network (left) and the knowledge network (right).

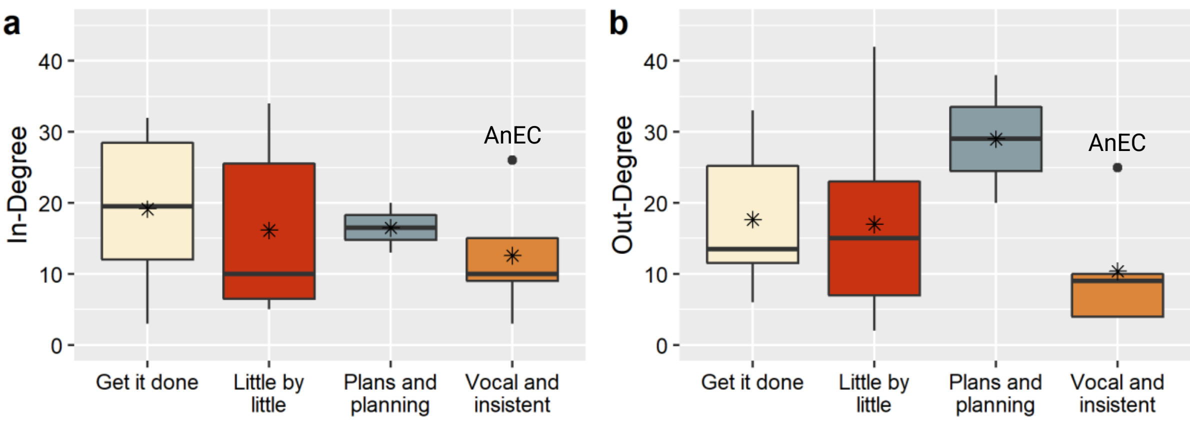

Figure A2. Boxplots for centrality measures of the knowledge network by organisational archetypes for a) in-degree, and b) out-degree (n = 6 ,7, 2, 5 from left to right). Boxes show the 75th percentiles of distribution, with horizontal lines indicating the median. Mean values are symbolized by the star and outliers are shown as dots outside of the boxes.

Table A1. Dimensions of agency (scale, power, resources) described by their respective indicators for the Algoa Bay system.

Dimensions	Indicators
Scale	*Spatial framework* – operational scale and physical presence of organisation in Algoa Bay
	Organisational mandate – organisational mandate to achieve management objectives in Algoa Bay
	Representation or constituency - membership or headcount of organisations
Power	*Executive power* – promulgate and case to enforce legislation
	Legislative power – draft and set in motion the promulgation of legislation
	Political relevance – the extent to which an organisation has a political role or political influence to play in policy issues of Algoa Bay
	Moral power/suasion – the extent to which an organisation can exercise its moral authority and status to harness public opinion and influence decision making
	Enforcement role - level at which an organisation can affect the compliance with legal and management instruments
Resources	*Human capacity* - Staff numbers, skill and knowledge to affect objectives or initiatives in Algoa Bay
	Financial capacity - Funding dedicated to achieving management objectives or initiatives linked to ABMs
	Infrastructure and material goods - the extent of the infrastructure available to an organisation, e.g., vehicles, boats, equipment as well as specialist hardware and other physical assets

Table A2. Number of organisations by organisational archetype for survey participants and resulting collaboration and knowledge networks.

Organisational archetype	Survey Participants	Collaboration Network	Knowledge Network
Plans-and-planning	2	7	7
Vocal-and-insistent	5	10	10
Get-it-done	6	11	10
Little-by-little	7	13	11
Total number	**20**	**41**	**38**

Table A3. Centrality measures, archetype and administrative level for organisations in the collaboration network. Bold numbers indicate the five highest values for each centrality measure.

Acronym	Organisation	Archetypes	Admin Level	Strength	Betweenness	Closeness	Eigenvector
NMBM1	NMBM: Economic Development, Tourism and Agriculture	Get-it-done	Local	**52**	0.0465	**0.0139**	**0.7754**
NMBM2	NMBM: Sports, Recreation, Arts and Culture	Get-it-done	Local	20	0.0009	0.0105	0.4052
NMBM3	NMBM: Electricity and Energy	Get-it-done	Local	24	0.0095	0.0115	0.4125
NMBM4	NMBM: Human Settlements	Get-it-done	Local	**65**	0.0097	0.0118	**0.8969**
NMBM5	NMBM: Infrastructure and Engineering	Get-it-done	Local	14	0	0.0091	0.309
NMBM6	NMBM: Public Health	Get-it-done	Local	17	0.0254	0.0125	0.2944
NMBM7	NMBM: Safety and Security	Get-it-done	Local	10	0.0006	0.0102	0.2114
SANParks	South African National Parks	Get-it-done	National	41	0.0556	0.0132	0.6438
TNPA	Transnet National Ports Authority	Get-it-done	National	24	0.0086	0.0123	0.4875
SAMSA	South African Maritime Safety Authority	Get-it-done	National	2	0	0.0068	0.0428
DEDEAT	Department of Economic Development, Environmental Affairs and Tourism	Get-it-done	Provincial	36	**0.0677**	0.0135	0.6133
NBDA	Nelson Mandela Development Agency	Little-by-little	Local	17	0.0167	0.0127	0.3246
NMBT	Nelson Mandela Bay Tourism Board	Little-by-little	Local	24	0.0197	0.0127	0.4526
Bayworld	Bayworld	Little-by-little	Local	33	0.0037	0.0111	0.5207
Raggy	Raggy Charters	Little-by-little	Local	23	0.0037	0.0118	0.4072
NMBB	Nelson Mandela Bay Business Chamber	Little-by-little	Local	19	0.0095	0.0125	0.3717
Coega	Coega Development Corporation	Little-by-little	Local	**56**	**0.1546**	**0.0143**	**0.7559**
ZC	Zwartkops Conservancy	Little-by-little	Local	2	0	0.0066	0.0303
CRC	Cape Receife Conservancy	Little-by-little	Local	1	0	0.0089	0.0152
SAEON	South African Environmental Observation Network	Little-by-little	National	37	0.0476	**0.0141**	0.5597
NMU	Nelson Mandela University	Little-by-little	National	**65**	0.0405	0.0127	**0.8902**
UEDE	Urban Econ Development Economists	Little-by-little	National	23	0.0066	0.0118	0.4133
ECDC	Eastern Cape Development Corporation	Little-by-little	Provincial	**72**	0.0302	0.0122	**1**
ECFA	Eastern Cape Black Fishers Association	Little-by-little	Provincial	10	0.0034	0.0112	0.1826
SAWS	South African Weather Service	Plans-and-planning	International	40	0.019	0.013	0.5992
DEFF	Department of Environment, Forestry and Fisheries	Plans-and-planning	National	40	0.0162	0.012	0.6456
DWS	Department of Water and Sanitation	Plans-and-planning	National	19	0.0062	0.0125	0.3654

Acronym	Organisation	Archetypes	Admin Level	Strength	Betweenness	Closeness	Eigenvector
DPME	Department of Planning, Monitoring and Evaluation	Plans-and-planning	National	9	0.0148	0.012	0.1765
DOT	Department of Transport	Plans-and-planning	National	11	0.0069	0.0125	0.2155
DoTo	Department of Tourism	Plans-and-planning	National	20	0.0164	0.0127	0.3644
ECPTA	Eastern Cape Parks and Tourism Agency	Plans-and-planning	Provincial	21	0.0084	0.0122	0.4111
Minerva	Minerva Bunkering	Vocal-and-insistent	International	6	0.0014	0.0118	0.1126
Heron	Heron Marine Bunkering	Vocal-and-insistent	International	2	0	0.01	0.0333
NMMaCl	Nelson Mandela Bay Maritime Cluster	Vocal-and-insistent	Local	9	0.0023	0.0115	0.1926
RU	Rhodes University	Vocal-and-insistent	National	21	0.0218	0.013	0.3896
WESSA	Wildlife and Environment Society of South Africa	Vocal-and-insistent	National	36	**0.1223**	0.0137	0.5358
SANCCOB	Southern African Foundation for the Conservation of Coastal Birds	Vocal-and-insistent	National	30	**0.0725**	**0.0139**	0.4198
SAPFIA	South African Pelagic Fishing Industry Association	Vocal-and-insistent	National	23	0.0196	0.0123	0.3447
AnEC	Anchor Environmental Consulting	Vocal-and-insistent	National	25	**0.115**	**0.0164**	0.3808
SST	Sustainable Seas Trust	Vocal-and-insistent	National	21	0.0159	0.0132	0.3831
SAMF	South African Marine Fuels	Vocal-and-insistent	National	2	0	0.01	0.0333

Table A4. Centrality measures for organisations in the knowledge network. Bold numbers indicate the five highest values for each centrality measure.

Acronym	Organisation	Archetypes	Admin Level	Strength	Out-degree	In-degree	Betweenness	Closeness	Eigenvector
NMBM1	NMBM: Economic Development, Tourism and Agriculture	Get-it-done	Local	**64**	**33**	**31**	**0.1964**	**0.0057**	**0.8099**
NMBM2	NMBM: Sports, Recreation, Arts and Culture	Get-it-done	Local	3	1	2	0.001	0.0048	0.0744
NMBM3	NMBM: Electricity and Energy	Get-it-done	Local	21	11	10	0.0024	0.005	0.3281
NMBM4	NMBM: Human Settlements	Get-it-done	Local	**61**	**29**	**32**	**0.0645**	0.0052	**0.7813**
NMBM5	NMBM: Infrastructure and Engineering	Get-it-done	Local	11	4	7	0.0011	0.0047	0.2271
NMBM6	NMBM: Public Health	Get-it-done	Local	9	6	3	0.0186	**0.0055**	0.1784
NMBM7	NMBM: Safety and Security	Get-it-done	Local	8	4	4	0	0.0048	0.1665
SANParks	South African National Parks	Get-it-done	National	31	13	18	0.0066	0.0052	0.589
TNPA	Transnet National Ports Authority	Get-it-done	National	27	12	15	0.005	0.0051	0.5611
DEDEAT	Department of Economic Development, Environmental Affairs and Tourism	Get-it-done	Provincial	35	14	21	**0.0601**	**0.0055**	0.5526
Bayworld	Bayworld	Little-by-little	Local	16	9	7	0.0258	0.0054	0.3724
Coega	Coega Development Corporation	Little-by-little	Local	25	15	10	0.0346	0.0052	0.4184
NBDA	Nelson Mandela Development Agency	Little-by-little	Local	15	7	8	0	0.0042	0.291
NMBB	Nelson Mandela Bay Business Chamber	Little-by-little	Local	16	7	9	0.0078	0.0051	0.268
NMBT	Nelson Mandela Bay Tourism Board	Little-by-little	Local	11	5	6	0	0.0039	0.2553
Raggy	Raggy Charters	Little-by-little	Local	13	5	8	0.0007	0.005	0.291
NMU	Nelson Mandela University	Little-by-little	National	**76**	**42**	**34**	**0.149**	**0.0057**	**1**
SAEON	South African Environmental Observation Network	Little-by-little	National	45	24	21	0.0053	0.005	**0.7761**
UEDE	Urban Econ Development Economists	Little-by-little	National	7	2	5	0	0.0039	0.1214
ECDC	Eastern Cape Development Corporation	Little-by-little	Provincial	**52**	22	**30**	0.0471	0.0052	0.7646
ECFA	Eastern Cape Black Fishers Association	Little-by-little	Provincial	2	1	1	0	0.0048	0.0568
SAWS	South African Weather Service	Plans-and-planning	International	**51**	**38**	13	0.0015	**0.0055**	0.7065
DEFF	Department of Environment, Forestry and Fisheries	Plans-and-planning	National	40	20	20	0.0136	0.0052	0.6893
DOT	Department of Transport	Plans-and-planning	National	12	5	7	0.012	0.0054	0.2644

Acronym	Organisation	Archetypes	Admin Level	Strength	Out-degree	In-degree	Betweenness	Closeness	Eigenvector
DoTo	Department of Tourism	Plans-and-planning	National	13	6	7	0.0016	0.0052	0.2797
DPME	Department of Planning, Monitoring and Evaluation	Plans-and-planning	National	10	5	5	0.0091	0.0053	0.2162
DWS	Department of Water and Sanitation	Plans-and-planning	National	21	11	10	0.0123	0.0053	0.4444
ECPTA	Eastern Cape Parks and Tourism Agency	Plans-and-planning	Provincial	18	9	9	0.0112	0.0051	0.3628
SANBI	South African National Biodiversity Institute	Vocal-and-insistent	International	1	1	0	0	0.0052	0.0071
WWF	WWF	Vocal-and-insistent	International	1	1	0	0	0.0052	0.0071
NMMaCl	Nelson Mandela Bay Maritime Cluster	Vocal-and-insistent	Local	4	2	2	0.0032	0.005	0.1003
AnEC	Anchor Environmental Consulting	Vocal-and-insistent	National	**51**	**25**	**26**	**0.3947**	**0.0059**	**0.7648**
RU	Rhodes University	Vocal-and-insistent	National	24	9	15	0.0268	0.005	0.4719
SAIAB	South African Institute for Aquatic Biodiversity	Vocal-and-insistent	National	2	2	0	0	0.0043	0.0268
SANCCOB	Southern African Foundation for the Conservation of Coastal Birds	Vocal-and-insistent	National	7	4	3	0	0.0051	0.1739
SAPFIA	South African Pelagic Fishing Industry Association	Vocal-and-insistent	National	20	10	10	0	0.0051	0.3895
SST	Sustainable Seas Trust	Vocal-and-insistent	National	10	5	5	0.009	0.0052	0.2205
WESSA	Wildlife and Environment Society of South Africa	Vocal-and-insistent	National	13	4	9	0.0577	0.0051	0.2501

Table A5. Results from pairwise t-tests for four centrality measures and different organisational archetypes for the collaboration network. To correct for multiple comparisons 'p-adjusted' was calculated using the 'Bonferroni' adjustment method.

Centrality Measure	Archetype 1	Archetype 2	n1	n2	p-value	p-adjusted
Strength	Get-it-done	Little-by-little	6	7	0.573	1
	Get-it-done	Plans-and-planning	6	2	0.950	1
	Little-by-little	Plans-and-planning	7	2	0.743	1
	Get-it-done	Vocal-and-insistent	6	5	0.227	1
	Little-by-little	Vocal-and-insistent	7	5	0.0835	0.501
	Plans-and-planning	Vocal-and-insistent	2	5	0.346	1
Betweenness	Get-it-done	Little-by-little	6	7	0.754	1
	Get-it-done	Plans-and-planning	6	2	0.607	1
	Little-by-little	Plans-and-planning	7	2	0.461	1
	Get-it-done	Vocal-and-insistent	6	5	0.198	1
	Little-by-little	Vocal-and-insistent	7	5	0.293	1
	Plans-and-planning	Vocal-and-insistent	2	5	0.157	0.942
Closeness	Get-it-done	Little-by-little	6	7	0.952	1
	Get-it-done	Plans-and-planning	6	2	0.838	1
	Little-by-little	Plans-and-planning	7	2	0.867	1
	Get-it-done	Vocal-and-insistent	6	5	0.132	0.795
	Little-by-little	Vocal-and-insistent	7	5	0.109	0.654
	Plans-and-planning	Vocal-and-insistent	2	5	0.196	1
Eigenvector	Get-it-done	Little-by-little	6	7	0.644	1
	Get-it-done	Plans-and-planning	6	2	0.918	1
	Little-by-little	Plans-and-planning	7	2	0.829	1
	Get-it-done	Vocal-and-insistent	6	5	0.116	0.698
	Little-by-little	Vocal-and-insistent	7	5	**0.0459**	0.275
	Plans-and-planning	Vocal-and-insistent	2	5	0.211	1

Table A6. Results from pairwise t-tests for four centrality measures and different organisational archetypes for the knowledge network. To correct for multiple comparisons 'p-adjusted' was calculated using the 'Bonferroni' adjustment method.

Centrality Measure	Archetype 1	Archetype 2	n1	n2	p-value	p-adjusted
Strength	Get-it-done	Little-by-little	6	7	0.763	1
	Get-it-done	Plans-and-planning	6	2	0.630	1
	Little-by-little	Plans-and-planning	7	2	0.486	1
	Get-it-done	Vocal-and-insistent	6	5	0.306	1
	Little-by-little	Vocal-and-insistent	7	5	0.434	1
	Plans-and-planning	Vocal-and-insistent	2	5	0.231	1
Betweenness	Get-it-done	Little-by-little	6	7	0.712	1
	Get-it-done	Plans-and-planning	6	2	0.541	1
	Little-by-little	Plans-and-planning	7	2	0.712	1
	Get-it-done	Vocal-and-insistent	6	5	0.538	1
	Little-by-little	Vocal-and-insistent	7	5	0.329	1
	Plans-and-planning	Vocal-and-insistent	2	5	0.303	1
Closeness	Get-it-done	Little-by-little	6	7	0.136	0.814
	Get-it-done	Plans-and-planning	6	2	0.936	1
	Little-by-little	Plans-and-planning	7	2	0.329	1
	Get-it-done	Vocal-and-insistent	6	5	0.718	1
	Little-by-little	Vocal-and-insistent	7	5	0.282	1
	Plans-and-planning	Vocal-and-insistent	2	5	0.855	1
Eigenvector	Get-it-done	Little-by-little	6	7	0.946	1
	Get-it-done	Plans-and-planning	6	2	0.478	1
	Little-by-little	Plans-and-planning	7	2	0.443	1
	Get-it-done	Vocal-and-insistent	6	5	0.433	1
	Little-by-little	Vocal-and-insistent	7	5	0.454	1
	Plans-and-planning	Vocal-and-insistent	2	5	0.215	1
In-degree	Get-it-done	Little-by-little	6	7	0.621	1
	Get-it-done	Plans-and-planning	6	2	0.766	1
	Little-by-little	Plans-and-planning	7	2	0.968	1
	Get-it-done	Vocal-and-insistent	6	5	0.329	1
	Little-by-little	Vocal-and-insistent	7	5	0.582	1
	Plans-and-planning	Vocal-and-insistent	2	5	0.671	1
Out-degree	Get-it-done	Little-by-little	6	7	0.919	1
	Get-it-done	Plans-and-planning	6	2	0.251	1
	Little-by-little	Plans-and-planning	7	2	0.217	1
	Get-it-done	Vocal-and-insistent	6	5	0.319	1
	Little-by-little	Vocal-and-insistent	7	5	0.348	1
	Plans-and-planning	Vocal-and-insistent	2	5	0.0746	0.448

Chapter V: Leveraging governance performance to enhance climate resilience

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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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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).

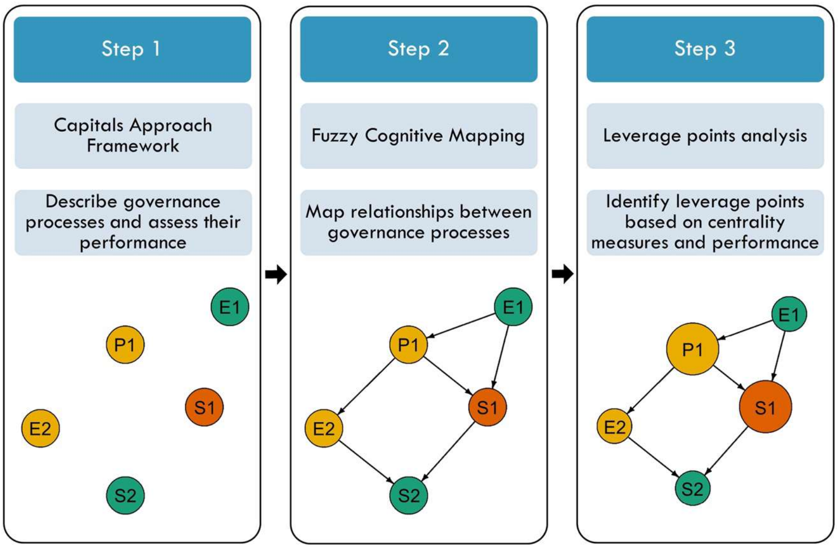


Figure 1. Illustration of the step-wise approach and its implementation. Letters in the nodes indicate the type of capital (E = environmental, S = social, P = political) to which different governance processes contribute. Numbers denote different processes. Colors indicate the performance of governance 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).

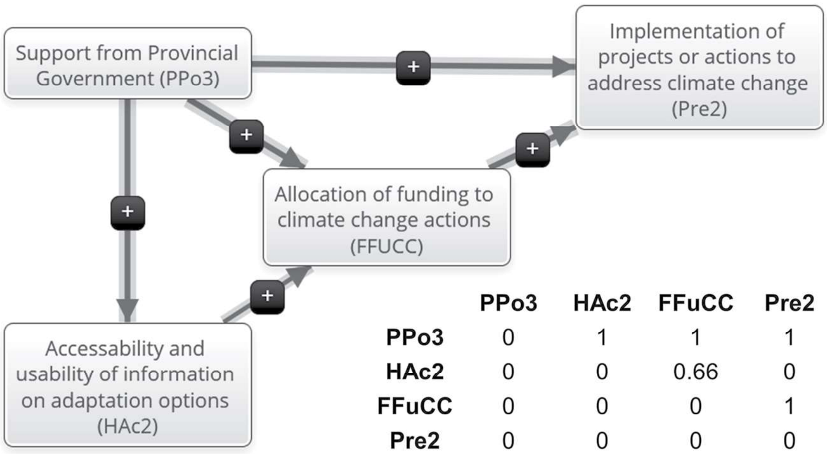
To assess the performance of the 45 governance processes, an online survey and online interviews of 39 relevant organizations within the Algoa Bay SES were carried out. Organizations were identified from a review of the literature and online resources, environmental impact assessments, and provincial 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.

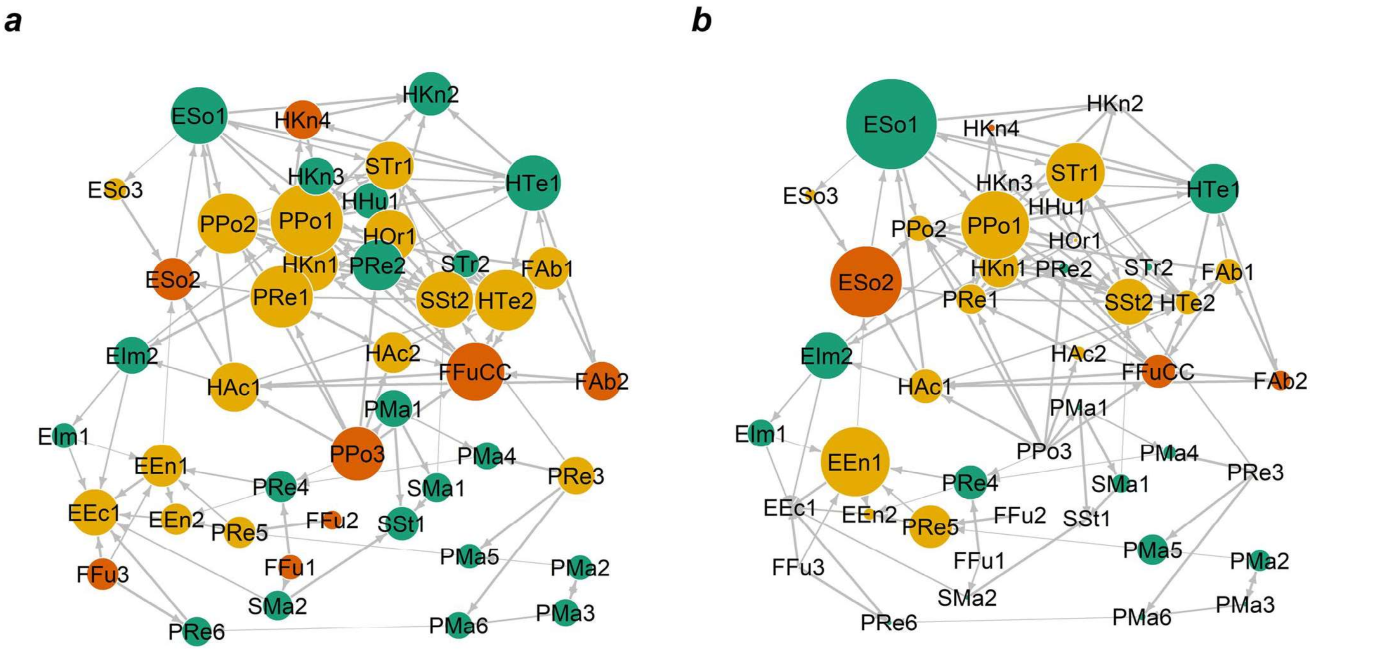


Figure 3. System with nodes representing governance processes and edges representing relationships between governance processes. Arrows indicate the direction, and the width of arrows indicates the weight of relationships. Nodes are sized to the centrality measures (a) strength and (b) betweenness as 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

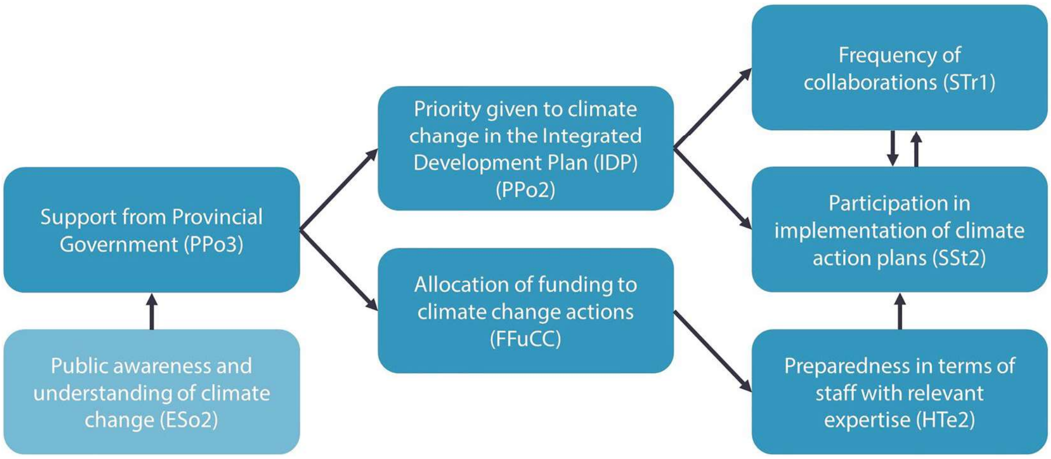


Figure 4. Suggested set of leverage points (policy interventions) that can enhance climate resilience across the social-ecological system of Algoa Bay. Arrows indicate systemic interdependencies between leverage points.

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).

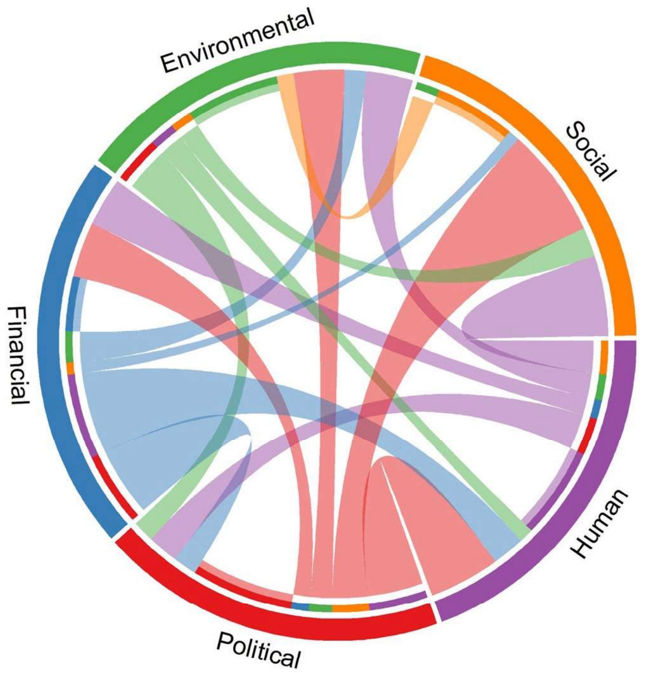


Figure 5. Chord diagram visualizing flows between capitals as sum of weighted relationships between governance processes contributing to different forms of capital (scaled to the sum of total flows within capitals). The direction of flow is indicated by its color, for example, all red strings originate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

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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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Erratum

The following error was discovered after publication of this paper: References are missing from the list of References From the Supporting Information. The missing references have been added, and this may be considered the authoritative version of record.

Chapter VI: Disentangling obstacles to knowledge co-production for early-career researchers in the marine sciences

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Disentangling Obstacles to Knowledge Co-Production for Early-Career Researchers in the Marine Sciences

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Knowledge co-production involving researchers and non-academic actors is becoming increasingly important for tackling sustainability issues. Coastal and marine social-ecological systems are one example where knowledge co-production is important, yet also particularly challenging due to their unique characteristics. Early-Career Researchers (ECRs) often face specific obstacles when engaging in the process of knowledge co-production. In this perspective paper, we shed light on the particular characteristics of knowledge co-production in marine social-ecological systems and the obstacles ECRs in the marine sciences face. Based on these obstacles, we discuss actions that can be taken at various organizational levels (institutional, community, supervisor, and individual) in order to leverage change towards a more inclusive environment for ECRs engaging in knowledge co-production. We conclude that both bottom-up (individual to institutions) and top-down (institutions to individual) actions are required. However, we emphasize the responsibilities of institutions to create conditions in which the needs of ECRs are met. This will be necessary to adequately support ECRs engaging in knowledge co-production and thus contribute to tackling sustainability challenges in coastal and marine social-ecological systems.

Keywords: transdisciplinary research, stakeholder engagement, actionable science, career development, co-design, co-development

INTRODUCTION

Coastal and marine social-ecological systems (SES) increasingly face challenges that threaten their sustainable use and development. Such challenges include resource overuse, coastal development, pollution, and social injustice that stands in stark contrast with soaring actors' and public demand for participation (Nash et al., 2017; IPCC, 2019; Dahdouh-Guebas et al., 2020). In order to foster sustainable use of coasts and the ocean, the United Nations has proclaimed the 'Decade of Ocean Science for Sustainable Development' (2021-2030). The 'Ocean Decade' accentuates the need for improving the translation of scientific knowledge into tangible action for more evidence-informed and effective management of coastal and marine systems (Ryabinin et al., 2019).

One such way of advancing evidence-informed decision-making is through the co-production of knowledge, and research processes that include non-academic actors[1] (e.g., Tengö et al., 2014; Miller and Wyborn, 2018; Partelow et al., 2020; Caniglia et al., 2021; Schneider et al., 2021). Knowledge co-production can be defined as "iterative and collaborative processes involving diverse types of expertise, knowledge and actors to produce context-specific knowledge" (Norström et al., 2020, p. 183). Such processes hold different temporal phases that aim to ensure early and continuous collaboration between actors, for example through building partnerships across different knowledge systems and understanding project design as a collaborative process (Steger et al., 2021). While variations of knowledge co-production have been applied for many decades in different disciplines, its diverse modes of operation are just starting to be understood (Chambers et al., 2021).

Participatory research and especially knowledge co-production pose a range of challenges (Berkes, 2011; Cvitanovic et al., 2015; Oliver et al., 2019; Walsh et al., 2019). These include structural issues of academic systems, practice orientation vs. scientific excellence, high workload and time pressure, as well as limited access to (knowledge) networks for turning research into action (Deininger et al., 2021; Rogga and Zscheischler, 2021). These challenges are amplified for Early Career Researchers (ECRs) due to common limitations in terms of funding, time, experience, and networks (e.g., Felt et al., 2013; Haider et al., 2018; Fam et al., 2020; Schrot et al., 2020). Thus, identifying and addressing obstacles to knowledge co-production, especially from the perspective of ECRs, may help to better support the generation of co-produced knowledge and ultimately the utility of science for society. Both, the challenges and benefits of knowledge co-production are enhanced in complex systems with a large diversity of local, industrial, academic, and cultural actors such as in marine[2] SES.

The aim of this perspective paper is to better understand the obstacles that ECRs face when engaging in knowledge co-production processes in the context of marine sciences, and to provide guidance for how ECRs can be better supported and enabled to overcome these obstacles. We explore and discuss 1) characteristics of knowledge co-production in marine SES, 2) common obstacles faced by ECRs during these processes, and 3) possible action pathways for mitigating these obstacles. ECRs, in this context, are defined as students and scholars who are at the undergraduate, graduate, or post-graduate level up to 5 years post-PhD.

This perspective paper is based on a survey addressing ECRs in marine research (n=46, including both closed- and open-ended questions) and two workshops that were hosted as part of the International Conference for Young Marine Researchers (ICYMARE) in January and October 2021, complemented by the personal experiences of the authors who are mainly ECRs. More details on the methods can be found in the **Supplementary Material**.

[1] In this paper, we refer to 'actors' rather than 'stakeholders', reflecting the importance of the active engagement of non-academic individuals and organizations in knowledge co-production approaches.

[2] In this paper, we define the coastal and marine SES as a continuum spanning from the coast to the open ocean, including Areas Beyond National Jurisdiction (ABNJ). As we particularly discuss the 'wet part' of such SES, we will further refer to 'marine SES' and 'marine research' for simplicity.

KNOWLEDGE CO-PRODUCTION IN MARINE SOCIAL-ECOLOGICAL SYSTEMS

Marine SES have unique characteristics that make the co-production of knowledge specifically relevant, but at the same time particularly challenging. Through a collaborative mapping exercise, we identified nine overarching themes across environmental, social, and knowledge subsystems that we considered distinctive to marine SES: system boundaries, environmental complexity, accessibility, timescales, governance and administration, actor diversity and objectives, justice and equity, local and Indigenous knowledge, and data and monitoring. Even though the themes may also apply for other SES, the descriptions (**Table 1**) show that especially in the social subsystems of marine SES, strong collaboration and synthesis between diverse actors and management aspects are required.

Our survey showed that the fields of application are diverse, including fisheries, ocean and coastal governance, ecosystem restoration, natural resource management, adaptive capacity for climate change adaptation, Blue Carbon, recreational spaces (beaches, offshore), gender equality, and intersectionality. ECRs mentioned nature conservation (72%) as the main goal of designing a project involving non-academic actors, followed by filling an academic knowledge gap (70%), serving a societal need (57%), and achieving policy impact (57%). Community adaptation (35%), business opportunities (11%) and industrial adaptation (11%) were mentioned less frequently.

OBSTACLES TO KNOWLEDGE CO-PRODUCTION FACED BY ECRS IN THE MARINE SCIENCES

Through the survey and workshop, we identified a variety of obstacles ECRs in the marine sciences face in the planning and implementation of knowledge co-production approaches. The obstacles are structured into personal, engagement, and institutional obstacles; however, many are interlinked, as discussed in the subsequent section of this paper. Phrases in

TABLE 1 | Particular characteristics of marine SES that create challenges for the co-production of knowledge, yet enhance its utility.

Sub-systems	Themes	Descriptions
Environmental	**System boundaries**	Many features of marine SES transgress administrative boundaries (see governance and administration)
		Seascape features are less obvious in contrast to landscapes, which is why the ocean is regularly treated a "big blue space" in intergovernmental management agendas
		Difficulty to set clear boundaries due to the high interconnectedness of the ocean (e.g., migrating fishes, distribution of pollutants) and lack of stationary boundaries
	Environmental Complexity	Particularly diverse ecosystems, which are increasingly exploited by industry and stressed by climate change
		Larger delineation of ocean spaces with stronger compared to terrestrial systems (e.g., physical – depth, temperature)
	Accessibility	Most areas are inaccessible without significant effort (including higher costs for research and management)
		Disconnect between where resources are extracted (ocean) and location of actors (land), which complicates issues of accessibility rights and accountability
	Timescales	Rapid human-made changes (climate change, habitat destruction, pollution) and therefore urgent need for action
		More dynamic change and more rapid turnover of actors and resources compared to terrestrial systems
		Long lasting changes and slow-onset processes, such as uptake of CO_2 in the ocean and subsequent ocean acidification
Social	**Governance and administration**	Overlapping administrative boundaries created by different frameworks (e.g. Exclusive Economic Zone, Large Marine Ecosystems, Regional Seas) and management tools (e.g. Integrated Coastal Zone Management, Marine Spatial Planning, Marine Protected Areas)
		Comparably abstract definition of the ownership of resources (unresolved marine tenures, tragedy of the commons)
		Very challenging to enforce rules and have accountability, especially outside economic zones in Areas Beyond National Jurisdiction
		Different and sometimes overlapping levels of government governing the marine space, as well as lack of regional governance frameworks as opposed to terrestrial systems, where regional agreements are common
	Stakeholder diversity and objectives	Many actors with divergent views, values, and backgrounds
		Spatial overlap of different user groups at the interface of marine and terrestrial systems, including different interests such as tourism, fishing, aquaculture, conservation, renewable energy, seabed mining, extractive industries, shipping
		Contradicting objectives and political administration due to unclear boundaries (e.g., in mangrove SES)
	Justice and ethics	Historic exclusion and discrimination of many local and Indigenous communities
		Sudden exclusion of actors and severe punishments for communities who have relied on marine ecosystem services for centuries (e.g., "no entry" rules imposed in conservation areas)
Knowledge	**Local and Indigenous knowledge**	Local and Indigenous knowledge and cultural perceptions are often overlooked but particularly important to incorporate
		Relational values of the marine system are harder to grasp, as our relationship with some commonly inaccessible ecosystems is not as close as with land-based ecosystems (e.g. value of deep-sea ecosystems compared to tropical forests)
		Challenges in transmitting local and Indigenous knowledge to future generations due to changing SES boundaries, lifestyles, and environmental conditions
	Data and monitoring	Marine systems are more difficult to monitor because of their three-dimensional extent and have limited vantage points for good visibility (e.g. satellite observation can only detect changes in higher ocean layers), difficulty to access because of challenging environmental conditions and remoteness, and relative paucity of dedicated resources
		Lack of social data and knowledge related to social-ecological interactions
		Relatively higher amount of uncertainty in environmental and biological knowledge as a result of limited/scarce data and information

quotation marks are citations from the survey and a full list of obstacles including ratings by the survey participants can be found in the **Supplementary Material (Table S1)**.

Personal Obstacles

Even though personal obstacles are highly diverse and context specific, several overarching themes emerged clearly from the survey and workshop. The first commonly mentioned obstacle emerges at the very beginning of the research process with the determination of a research topic and search for a suitable supervisor. Marine SES, being particularly complex systems, often require integration of knowledge from different scientific fields. Study programs, however, are still often bound to specific scientific disciplines, which one participant described as "*lack of institutional support to engage in 'non-traditional' research methods*", which is also recognized by other studies (e.g. Pannell et al., 2019; Andrews et al., 2020). Similarly, the ability to self-advocate in the face of institutional barriers or conflict situations was mentioned by 42% of respondents as a major obstacle. Some participants (27%) reported discrimination based on their age and/or gender, e.g. in the context of politicians, who were "*skeptical or disrespectful of the work of ECRs*". Similarly, a respondent shared that "*as a 'young' looking female*", her work would often be "*overlooked or co-opted by male team members*". This also highlights the intersectionality of these challenges in terms of age, gender, race, or academic background (e.g. Schmidt and Neuburger, 2017). In combination with stress due to short-term contracts and career uncertainty (71%) as well as difficulties to manage a healthy work-life balance (45%) (see also Susi et al., 2019; Andrews et al., 2020), the mental load for ECRs induced by these personal obstacles can drastically decrease the individual's confidence. This may impede the career development of ECRs who engage in knowledge co-production, and exclude those without strong support systems or with additional responsibilities, such as caring obligations. While we included those challenges under personal obstacles, we acknowledge their systemic causes further discussed in the section "Action pathways for mitigating obstacles".

Engagement Obstacles

Marine SES are often highly contested systems subject to widely diverging interests, requiring the engagement of diverse actors in

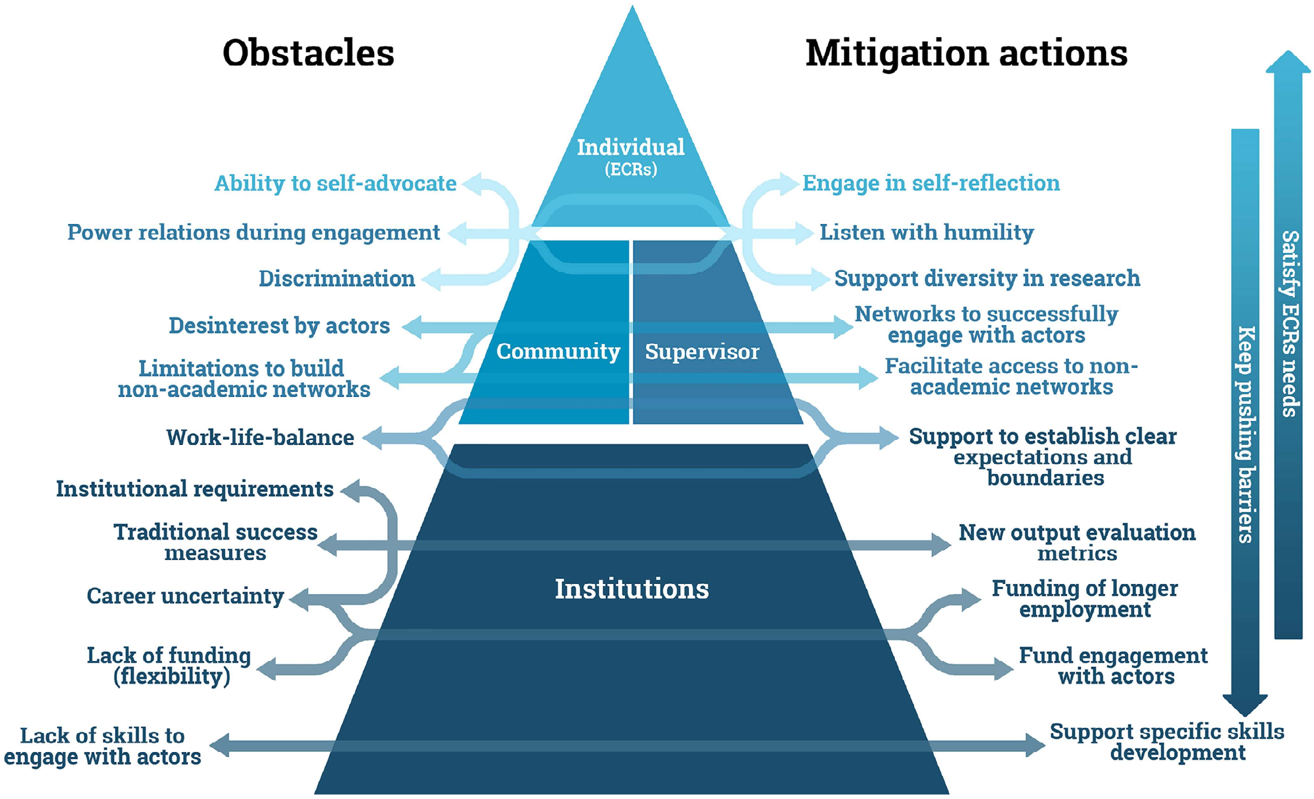

FIGURE 1 | Summary of obstacles (left) to be tackled at different organizational levels (pyramid) with corresponding mitigating actions (right) and action pathways (horizontal arrows). The pyramid represents the hierarchy of needs with *institutions* (bottom) that are to be met before the needs at the *individual* level (top) can be resolved. The *community* (peer and broad scientific community) and *supervisory* level (middle) were considered as support systems to overcome obstacles and improve the engagement with local actors. Vertical arrows on the right side represent top-down and bottom-up actions that are needed to leverage change towards a more inclusive environment for ECRs engaging in knowledge co-production.

the social and political arena. Results from our survey and workshop found various barriers for ECRs to engage with diverse non-academic actors. ECRs often have had limited time or opportunity to build strong networks and personal relations with relevant actors beforehand due to their career stage. Consequently, identifying and being able to effectively engage with diverse actors represents a significant obstacle (41%). During the engagement phase, another major obstacle that emerged was disinterest by actors as a result of previous negative interactions with researchers (67%), and/or due to a lack of perceived value-added to the local context (52%). This disinterest requires critical self-reflection of the researchers, both early-career and advanced, in conducting participatory approaches (Beck et al., 2021). However, power relations created during the engagement are particularly amplified for ECRs due to the commonly prevalent age differences between ECRs and non-academic actors, such as decision-makers (Evans and Cvitanovic, 2018; Fritz and Binder, 2020). Establishing and maintaining meaningful relationships with non-academic actors, hence, represents a major obstacle for ECRs engaging in participatory approaches. The COVID-19 pandemic has increased the degree of uncertainty among ECRS and drastically impacted place-based research (e.g., *via* inability to travel to field study sites), further limiting opportunities for engagement (Vandebroek et al., 2020; Köpsel et al., 2021).

Institutional Obstacles

Most of the obstacles broached by survey participants are academic or institutional in nature. Apart from finding a suitable supervisor (see section "Personal obstacles"), survey participants cited academic expectations affecting the methodological approach (50%). The iterative, inherently messy and nonlinear nature of knowledge co-production processes and the contested nature of many marine SES can make it difficult or unsuitable to adhere to rigid thesis deadlines (e.g., timing, format) (Fisher and Phelps, 2006). In addition, pre-defined departmental/institutional requirements often fail to accommodate the added complexity of working with non-academic actors, and expectations to meet such requirements was mentioned as a major obstacle by 33% of survey respondents.

The scientific culture expecting high output in short timeframes often leaves insufficient room for actor engagement, especially for the process of building relationships, which forms the basis of responsible engagement. These requirements are often connected to expectations of funding agencies and elucidate the obstacles caused by a lack of research flexibility due to funding requirements (32%) as well as a general lack of funding (32%) for sufficient in-depth engagement. Long-term data availability is particularly challenging for marine SES (**Table 1**), and can often only be addressed by long-term programs or investment in partnerships that enable access to historical data (Lundquist et al., 2016). Frequently, such long-term partnerships involve senior collaborators rather than the ECRs themselves, reinforcing the dependence on others for important networks. Even though the lack of funding also applies to more advanced researchers, it is particularly challenging for ECRs. For example, 5 survey participants (3 master, 2 PhD) reported that their work was self-funded, and 20 survey participants (10 master, 5 PhD, 5 PostDoc) reported that they are funded through scholarships, which often reduces the overall research performance both during the degree and throughout the researchers' careers (Horta et al., 2018). Overall, shortcomings in funding of ECRs limit the capacity to produce adequate research results, while also generating tangible, salient outputs that are tailored to context and decision-makers.

ECRs engaging in knowledge co-production are additionally challenged by the need to prove academic ability within a system that relies on traditional measures of success, which are not appropriate for knowledge co-production processes. ECRs must balance traditional academic expectations with more practical engagement, which is often under-valued, ultimately resulting in insufficiently robust assessment of ECR performance (Newig et al., 2019). Similarly, the "soft skills" relevant for engagement (interpersonal skills, facilitation, networking) are often not recognized or taught in academia (Bednarek et al., 2018) - as was mentioned by 50% of survey respondents as a major obstacle. This obstacle may be exacerbated for ECRs with a background in environmental sciences (the majority of survey respondents) who have less guidance developing 'soft skills' in comparison to those with a social science or systems backgrounds, for example. Although such obstacles are relevant at all career stages, they are especially important for ECRs who are more reliant on personal research outputs to prove their academic potential and to gain access to more secure jobs and funding.

ACTION PATHWAYS FOR MITIGATING OBSTACLES

Obstacles for ECRs engaging in knowledge co-production approaches are manifold. Yet, the agency of ECRs to identify and overcome persistent obstacles is limited and often depends on the academic environment (e.g. support by senior researchers, availability of courses), or institutional structure (e.g. funding, measures of success). Hence, the mitigation of obstacles is required at several organizational levels.

In the following, we discuss possible actions at the institutional, community, supervisor, and individual, personal level that can support ECRs to engage in knowledge co-production and in their future career development in this field (**Figure 1**). With this, we seek to find an equilibrium between addressing and acknowledging systemic drivers, while also highlighting the actions ECRs can take to better succeed in navigating such challenges.

Institutional Level

Firstly, funding mechanisms should allocate more resources for longer and full-time employment, flexibility, and coverage of travel costs because engagement must be formally budgeted for. This is particularly important to reduce the stress due to career uncertainty and managing a work-life balance for ECRs. We recommend funding bodies, such as the US National Oceanic and Atmospheric Administration, European Research Executive Agency (Horizon Europe), Western Indian Ocean Science Association, and funding bodies at national levels, should help navigate the local context and potential conflicts, maintain regular communication with grantees, and require engagement and holistic research impact planning in funding agreements (Arnott et al., 2020; Cvitanovic et al., 2021c; Landrum et al., 2022).

Secondly, traditional measures of success need reconsidering for projects that aim at knowledge co-production. This includes a different evaluation of output, which is not measured in research publications, but rather in products that benefit non-academic actors (e.g. reports, tools, infographics, community oriented newsletters, media appearances, public lectures and workshops). It also has to be considered that positive outcomes are much more diverse than *products*, and often rather relate to *processes*. Such 'alternative' metrics include the use of knowledge in decision-making, as well as impacts on individuals, group interactions, organizations, and political processes - which may be intangible (relationships, trust, changes in attitude, mutual learning) (Cooke et al., 2020; Cvitanovic et al., 2021a; Karcher et al., 2021). This calls for a diversification of 'excellence' criteria (i.e., going beyond 'traditional' metrics such as impact factors, funding acquired, number of publications and citations) when considering hiring/promotion, and considering alternative metrics reflective of societal impact, actor engagement, or applicability (e.g. Mitchell and Willetts, 2009; Daedlow et al., 2016; Klein and Falk-Krzesinski, 2017; Kraemer-Mbula et al., 2020).

Lastly, the entrance to participatory approaches needs to be facilitated by universities. ECRs often have a disciplinary background and therefore require a different set of courses to learn the relevant soft-skill for engaging with non-academic actors. This could include more courses on strategies on how to engage with diverse actors (e.g. decision-makers and politicians), to stimulate collaboration (Oliver et al., 2019), and to approach issues from the perspectives of other actors. More recognition and acceptance of 'non-traditional' inter- or transdisciplinary science and scientists may increase opportunities for future ECRs to contribute to the field.

Community Level

This paper refers to two types of 'community level': communities of peer-support and the broader scientific community. Finding people that work on similar topics and establishing a community of support can be extremely beneficial for ECRs. Communicating about difficulties that arise within the knowledge co-production process can help ECRs develop pathways to overcome obstacles by creating networks that help with finding the right methodology, courses and literature[3], and can also provide support at a personal level (e.g. dealing with feelings of isolation, imposter syndrome, mental health). The ICYMARE network, from which this perspective paper emerged, is an excellent example of a bottom-up collaborative initiative that supports ECRs in building a community and working towards a common goal.

However, certain actions to overcome persistent obstacles to knowledge co-production are also the responsibility of the broader scientific community. A major obstacle mentioned in the survey was a disinterest in engagement by non-academic actors resulting from previous negative interactions with researchers, such as *parachute science*, which is still widespread in marine science. *Parachute science* refers to neo-colonial practices characterized by scientists from the Global North conducting research in the Global South without responsibly or authentically engaging with the local context and simply extracting data for publication (Stefanoudis et al., 2021). This particular obstacle highlights the need to address these issues on a systemic and community level to mitigate distrust that may jeopardize the engagement of ECRs and future researchers with non-academic actors (Schmidt and Pröpper, 2017).

Supervisor Level

At the supervisory level, mitigating actions should include more responsive leadership, which focuses on the career progression and security of ECRs (Susi et al., 2019). This may include support to self-advocate in response to institutional barriers and better capacity planning to maintain a healthy work-life balance. Mental health – which is particularly challenging for ECRs and researchers engaging in knowledge co-production (Cosentino and Souviron-Priego, 2021; Sellberg et al., 2021) – should be an open topic between supervisors and ECRs. Establishing a clear set of expectations and boundaries is crucial. While facilitating access to networks of academic peers in their field is an important role for any academic supervisor, in the context of knowledge co-production and engagement of non-academic actors, the relevance of this role is further enhanced given the importance of trust and long-term collaborations in establishing impactful and reliable relationships beyond academia (e.g., Cvitanovic et al., 2021b). Supervisory support should include creating entry points within their existing networks for ECRs and being open to transdisciplinary collaboration. Finding additional suitable mentors may also create space to discuss problems from another angle. More diverse representation of backgrounds, ages, and genders is also needed to not only make knowledge co-production approaches more inclusive but also to overcome biases in traditional (western) science (Swartz et al., 2019).

Individual Level

On a personal, individual level, we identified two main ways to mitigate obstacles: engaging in self-reflection, and focusing on the process. A constant attention to self-reflection can help ECRs regularly check their learning process (Naveed et al., 2017) by prioritizing self-growth and building confidence in their academic work. Tracking and discussing successes and goals with supervisors and community members may further enhance confidence while also enhancing the ability to openly communicate capacity limits or difficulties with administration and colleagues. The process of self-reflection also includes listening with humility when engaging with non-academic actors which in turn creates a space where those actors can see the value created by the engagement (Brugger et al., 2016; Breckwoldt et al., 2021). Additionally, focusing on the process is crucial to avoid being side-tracked by other interests and activities. Finding a balance between ambition and practicality is extremely important to manage a healthy work-life balance while accomplishing high quality research (Andrews et al., 2020).

[3] Literature resources to be used as a starting point for ECRs engaging in knowledge co-production can be found in the **Supplementary Material**.

CONCLUDING THOUGHTS

Knowledge co-production with non-academic actors in research is a complex but rewarding process. While it has gained significant attention over the last years, it is not easy to conduct, especially for ECRs. Knowledge co-production can be described as both a research process and a process of personal development for the researcher who conducts it. ECRs should acknowledge the non-linear and messy nature of the processes, which can lead towards meaningful engagement and relationship building. When designed carefully, knowledge co-production approaches can produce highly desirable outcomes for both actors and researchers, as well as the sustainable management of marine SES.

In this paper, we shed light on the obstacles that ECRs in the marine sciences face when engaging in knowledge co-production. Mitigating these obstacles requires action at several levels. Hence, both bottom-up and top-down actions are required to leverage change towards a more inclusive environment for ECRs engaging in knowledge co-production. Bottom-up actions for ECRs include pushing academic boundaries by looking for and supporting 'non-traditional' metrics of success and impact, and working towards the establishment of interdisciplinary boards. Substantial top-down actions from institutions are required to create conditions that meet the needs of ECRs to enable and support them to engage in knowledge co-production. With this, we want to emphasize the responsibilities of institutions to address deep-rooted systemic problems, including funding limitations, ultimately creating improved career prospects for ECRs engaging in knowledge co-production.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**. Further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

Ethical clearance for the survey was reviewed and provided by an independent ethics board at the Leibniz Centre for Tropical Marine Research following the principle of prior informed consent. All participants were informed about the background and aim of the survey, consent was necessary before proceeding to fill the survey, and participation in the survey was voluntary. Participants were informed about the use, storage and processing of the data in accordance with art. 12 GDPR. The collected information was treated confidentially, and data are made available only in anonymized form.

AUTHOR CONTRIBUTIONS

LR initiated and led the work that built the basis for this perspective paper. XE and MK initiated and conducted an initial "Open Forum" in January 2021, from which further work was inspired. LR and MK led the survey design and implementation. All authors contributed to the survey design as well as planning and implementation of the workshop in October 2021. LR led the writing and wrote the paper with input from all authors. XE, LR, and EW designed **Figure 1**. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.893489/full#supplementary-material

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