Socio-Ecological Resilience in Small Island Developing States through a Socio-Ecological Islandscape Framework and Resilience Capacity Index

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DECLARATION

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ABSTRACT

It can be argued that Small Island Developing States (SIDS) have unique characteristics, i.e. “islandness” that influence the social and environmental aspects of a socio-ecological system. Considering “islandness” as a fundamental element that substantially influences socio-ecological systems on islands, socio-ecological systems, therefore, materialise as socio-ecological islandscapes. The proposed socio-ecological islandscape approach considers these “islandness” factors and argues that these are required for an augmented assessment of socio-ecological systems on SIDS, allowing for more in-depth analysis of sustainability from a landscape outlook. An island-focused outlook acknowledges that islands are distinctive and are not just microcosms for a global perspective. The study makes use of Bayesian Belief Networks to provide empirical evidence of the influence of “islandness” on the socio-ecological systems of SIDS, highlighting the effects of island size as well as the influence of SIDS being an archipelago. The empirical evidence from the BBNs supports the development of the socio-ecological islandscape framework, while the development of a Socio-Ecological Islandscape Resilience Capacity Index (SEIRCI) operationalises the framework to illustrate the benefits of taking a socio-ecological islandscape perspective. The study highlights the need for a robust index development process, through analysing a variety of theoretical frameworks and weighting methodologies (PCA, entropy and equal weighting). The results of the SEIRCI further illustrate the effects of “islandness”, provide further justification of the special designation status of SIDS and identify the trends within the socio-ecological islandscape-resilience nexus.

Keywords:

Socio-ecological systems, Small Island Developing States, socio-ecological islandscapes, resilience, spatial resilience, Socio-ecological islandscape resilience capacity index, Bayesian Belief Network.

PREFACE

In prefacing this thesis, it is important to note that several internationally published works by the author (R. Nel) have been derived from research on moving "Socio-Ecological Resilience in Small Island Developing States through a Socio-Ecological Islandscape Framework and Resilience Capacity Index". The research articles are listed below, and their respective front covers are given in the appendices.

[2]Nel, R., K. F. Mearns, M. Jordaan & P. Goethals (2021). Towards understanding the role of islandness in shaping socio-ecological systems on SIDS: the socio-ecological islandscape concept. *Ecological Informatics*. 62, 1-17. https://doi.org/10.1016/j.ecoinf.2021.101264

Nel, R., K. F. Mearns, M. Jordaan & P. Goethals (2022). The role of modelling in resource management within the livelihood-conservation nexus: A socio-ecological systems approach to Sand Forest harvesting, Northern KwaZulu-Natal. *Ecological Informatics*. 69, 1-13. https://doi.org/10.1016/j.ecoinf.2022.101600

[2] This article was published directly from chapter 3 of this thesis, while the thesis continued to be completed. Therefore, significant overlap can be observed.

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Finally, to my wife Nadia Nel, who has continued to be a source of encouragement and a reason to keep persevering. Thank you for all the sacrifices that you have made and for being my biggest supporter.

DEDICATIONS

This thesis is dedicated to my wife Nadia Nel, who has always been my greatest source of motivation; to my daughter Emily Iris Nel, who is my greatest source of joy and whose smile helped me persevere; and to my late mother Margaret Nel, who may be gone from this world, but will never be forgotten.

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LIST OF ABBREVIATIONS AND ACRONYMS

BBN – Bayesian Belief Network

CPT – Conditional Probability Tables

EPI – Environmental Performance Index

GDP – Gross Domestic Product

HDI – Human Development Index

IUCN – International Union for Conservation of Nature

KBA – Key Biodiversity Areas

LSCI – Linear Shipping Connectivity Index

NFA – National Footprint Accounts

PC – Principal Component

PCA – Principal Component Analysis

RLI – Red List Index

SEI – Socio-ecological Islandscape

SEIRCI – Socio-Ecological Islandscape Resilience Capacity Index

SES – Socio-ecological Systems

SIDS – Small Island Developing States

UN – United Nations

UNDP – United Nations Development Programme

WGI-GE – World Governance Indicators: Government Effectiveness

CHAPTER 1. INTRODUCTION

1.1 Anthropocene, islands and socio-ecological systems

Currently, one of the most significant problems of global concern is environmental degradation, which has far-reaching consequences for both human health and environmental quality, as well as the global economy (Rahman, 2020). A new era dubbed the “Anthropocene” has been used to describe the augmented rate of global environmental change, fortified by climate change and biodiversity loss, which is the direct consequence of human activities (Berkes, 2017). Islands are currently being confronted with growing threats stemming from this global change as well as unsustainable local practices, which are exacerbated by an inherent vulnerability to social, economic, and ecological changes (Bunce et al., 2009; Hay, 2013; Jupiter et al., 2014; Plieninger et al., 2018). In June 1992, this inherent vulnerability was acknowledged through the United Nations Conference on Environment and Development (UNCED), where it was recognised that Small Island Developing States (SIDS) are: “*a special case for both environment and development. They are ecologically fragile and vulnerable. Their small size, limited resources, geographic dispersion and isolation from markets, place them at a disadvantage economically and prevent economies of scale*” (UNCED, 1992: 193). Small Island Developing States are therefore considered to be a specific group of States and Associate Members of the United Nations regional commission that are affected by these distinctive vulnerabilities (UN-OHRLLS, n.d.).

Such SIDS face numerous issues related to the Anthropocene, such as climate change, overexploitation, invasive species, habitat alteration and disease, which are often more prominent on islands given their unique insular nature (Graham et al., 2017). From just a biodiversity standpoint, islands have been subject to significant losses, with the majority of worldwide extinctions occurring on islands (i.e., 95% birds, 90% reptiles, 69% mammals and 68% flora), while an estimated 70% of countries and territories considered most vulnerable to coral reef degradation and loss are also SIDS (UN-OHRLLS, 2017). Economies on islands are often extensively affected by environmental degradation, as the economy tends to rely on the quality of their natural capital, through subsistence farming, fishing and/or tourism (Graham et al., 2017). Reflecting the challenges being confronted in SIDS, the UN unveiled the Samoa Pathway (UN, 2014: 4), which states that SIDS: "*recognize that poverty eradication, changing unsustainable and promoting sustainable patterns of consumption and production and protecting and managing the natural resource base of economic and social development are the overarching objectives of and essential requirements for sustainable development*".

Recognising the growing global crisis brought about by the Anthropocene, the United Nations General Assembly established a collection of 17 global goals – the Sustainable Development Goals (SDGs), in 2015, with the ambition to ensure global sustainable development for both developing and developed nations, thereby improving human well-being and conserving the environment on a global scale (Geijzendorffer et al., 2017). Human well-being is intrinsically linked to the services provided by the environment in which they are embedded, as these natural resources are core pillars of socio-economic systems and influence not only human well-being, but also the environment and economy (Merino-Saum et al., 2018).

An approach that was employed to critically investigate the relationship between ecosystem services and human well-being used a socio-ecological systems perspective (Berkes, 2017), which considers social and ecological subsystems as coupled and interdependent, and can be defined as a linked system where people are dependent on the environment and the environment is affected by the actions of people (Cumming et al., 2012; Berkes, 2017). This approach, as described by Berrouet et al. (2018), examined the relationships between the social and ecological subsystems with three different viewpoints. Firstly, how the provision of services associated with ecosystems fulfils human need; secondly, the effect on the integrity of the ecological subsystem resulting from the dynamics of the social subsystem demand; and lastly, the response of the social and ecological subsystems to external and internal drivers of change. This in-depth cross-examination of the varying relationships between society and the environment can plausibly provide noteworthy discernment regarding a society's ability to achieve the SDGs. Such a nexus between SDGs and socio-ecological systems is provided by Cumming et al. (2017), which showed that a fundamental component of a socio-ecological system, i.e. the ecological subsystem, contributes substantially to achieving SDGs such as No Poverty, Zero Hunger, Life Below Water, Life on Land, etc. The understanding that socio-ecological systems underpin, to an extent, SDGs is used here to show the implications of maintaining functioning socio-ecological systems and the use of a socio-ecological systems perspective in possibly achieving various SDGs, thereby reducing, and in some instances reversing, the effects brought on by the Anthropocene. The socio-ecological systems approach has shown effectiveness in understanding aspects such as vulnerability, resilience and pressure, environmental governance, environmental management, as well as livelihoods (Berkes, 2017; Berrouet et al., 2018; Estoque & Murayama, 2017; Virapongse et al., 2016; Yanez et al., 2014), including socio-ecological systems studies that have been undertaken on SIDS (Yanez et al., 2014; Banos-González et al., 2017; Ciftcioglu, 2017; Estoque & Murayama, 2017; Schmitz et al., 2017).

According to Hay et al. (2013), communities on SIDS can be regarded as a socio-ecological system. From a geographical standpoint, socio-ecological systems emerge as socio-ecological landscapes (Petrosillo et al., 2010) and viewing socio-ecological systems from a spatially explicit landscape perspective provides a more realistic basis for integrating social and ecological subsystems in a geographical context (Zurlini et al., 2012). Therefore, from a real-world geographic perspective, an island and its communities form an integrated socio-ecological landscape. However, not only is there a significant absence of studies focused on small island dynamics that consider socio-ecological systems (Christensen & Mertz, 2010), but socio-ecological systems studies undertaken on islands seldom consider the uniqueness of islands (Yanez et al., 2014; Banos-González et al., 2015b; Ciftcioglu, 2017; Schmitz et al., 2017). Islands have unique characteristics that continue to shape their socio-ecological systems. These characteristics are often described as “islandness” and include characteristics such as size (small area), isolation (connectivity and distance from mainland), limited resources (land boundedness) (Foley, 2018), as well as intrinsic (structure and ecological complexity) and extrinsic (local human impact) variability (Harter et al., 2015). Intrinsic characteristics refer to aspects such as whether the island is part of an archipelago, and also the number of inhabited islands in the archipelago. Local human impact differs from that of continental countries due to issues such as a lack of economies of scale. “Islandness” defines those variables that have distinct effects on the socio-ecological systems of islands; however, not all the characteristics will be associated with every island.

Aspects of “islandness” have resulted in a historical heavy reliance on local ecosystem services from both land and sea that persists for several SIDS, as well as resultant dependencies on factors such as trade and influence by mainland economies and policies (Plieninger et al., 2018). It can be argued that “islandness” contributes immensely to understanding the socio-ecological systems of an island. For example, island size and isolation may affect biological diversity, which will impact the livelihood strategies of local communities. In turn, the same aspects also influence trade and tourism, which further contribute to the livelihood of communities. “Islandness” has an influential bearing on the three previously discussed channels, which Berrouet et al. (2018) argued that a socio-ecological systems perspective investigates. In the simplistic example of isolation as an “islandness” characteristic, isolation would affect biological diversity based on the island biogeography theory, thereby affecting the abundance of ecosystem services. The physical isolation of an island will also affect the demand dynamics, as fulfilling the shortfall in an island context would require either importing or a greater demand on a limited resource pool. This relationship is heavily influenced by external factors such as fluctuations in oil costs, which increase shipping costs and are directly proportional to the degree of isolation of the island. Likewise, archipelagos often create significantly complex relationships within socio-ecological systems and are an example of the effect of “islandness”, as shown in the relationship between the main island of the Republic of Mauritius and its marginal “sister” island of Rodriquez. Migration to the main island of Mauritius, in this case, has caused a collapse of social resilience on Rodriquez (Bunce et al., 2009).

Considering “islandness” as a fundamental element that significantly influences socio-ecological systems on islands, socio-ecological systems, therefore, materialise as socio-ecological islandscapes. ‘*Socio-ecological islandscape’* is a more encompassing term of socio-ecological systems that occur in an island context, as islandscapes include the island land- and seascape, the nearest mainland, surrounding islands, as well as the dominant sea (Vogiatzakis et al., 2017) and therefore integrates the unique “islandness” characteristics that play an important role in the evolution of socio-ecological systems on SIDS. Consequently, the notion of a socio-ecological islandscape was proposed.

1.2 The socio-ecological islandscape concept

The socio-ecological islandscape concept is based on the socio-ecological systems framework, in which the principal premise is that the framework is an: "*integrated perspective of humans-in-nature*" (Berkes, 2017: 3). The socio-ecological islandscape viewpoint contains the same idea; however, it argues that in an island-landscape nexus, it is a requisite of the socio-ecological systems framework to take into account "islandness" and the concept of islandscapes as a significantly influential feature. The socio-ecological systems framework shown in Figure 1-1 illustrates the theoretical adaptation of how "islandness" would be taken into consideration within all aspects of a system, in order to assess environmental problems from a socio-ecological islandscapes perspective.

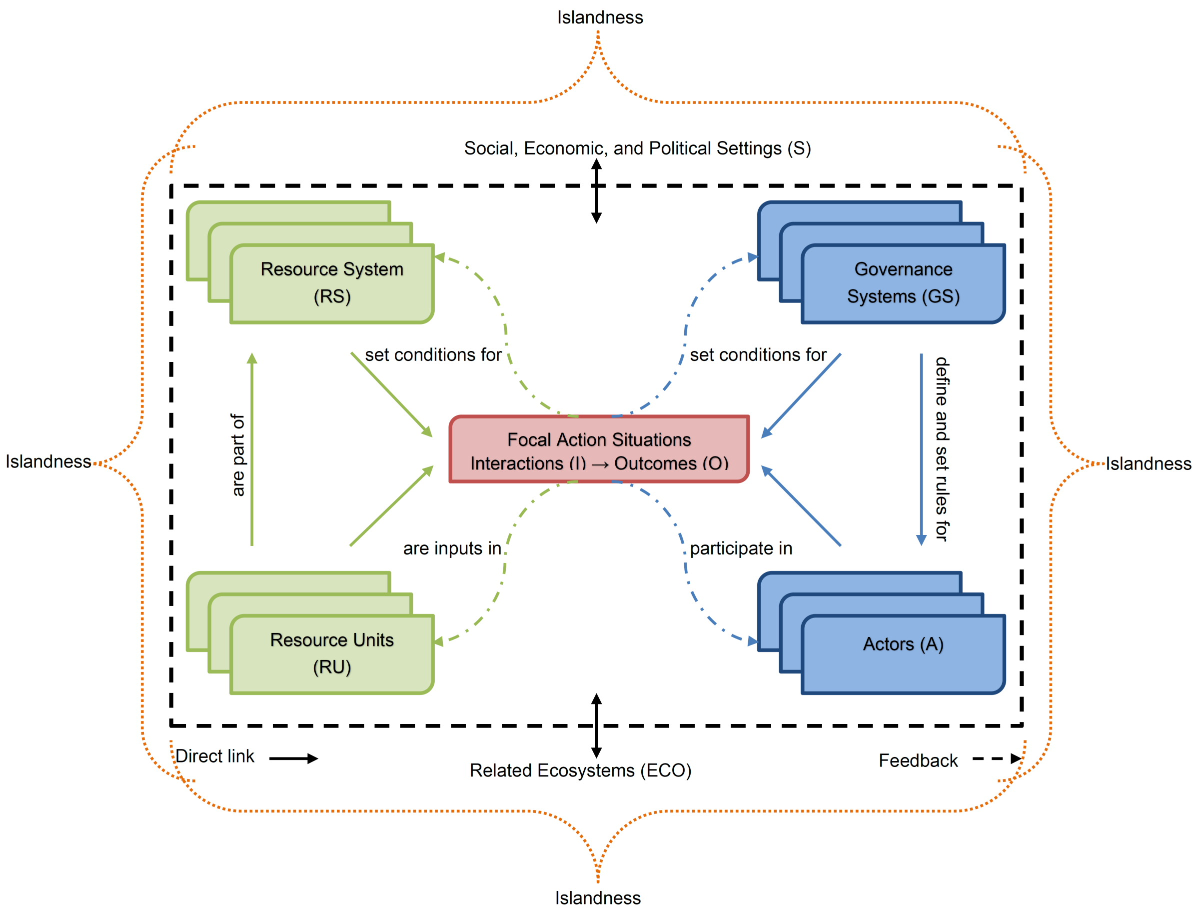


Figure 1-1: The socio-ecological system framework modified to take into consideration the influence of "islandness" on the entire system (Adapted from McGinnis & Ostrom, 2014)

The socio-ecological systems framework allows for analysing the interconnectedness between the social and ecological subsystems (Virapongse et al., 2016) present within a landscape (Petrosillo et al., 2010), which, from an island perspective, constitutes an islandscape (Vogiatzakis et al., 2017). A socio-ecological systems approach is vital in identifying how components in a system interact, thereby gaining an understanding of the activities that result in either an enhancement or depreciation in the sustainability of a system (Ostrom, 2009). It provides a framework for developing a diagnostic tool to understand causality in the sustainability of complex socio-ecological systems (McGinnis & Ostrom, 2014).

It can be argued that islands have unique characteristics, i.e. “islandness”, that influence the social and environmental aspects of a socio-ecological system. The contribution of “islandness” to the economic disadvantages and ecological fragility of SIDS, as opposed to islands that are overseas territories, has been acknowledged (UNCED, 1992). Overseas territories often have access to resources and support structures from national governments (Forster et al., 2011), which SIDS do not. The proposed socio-ecological islandscape (Figure 1-2) approach considers these different factors and argues that these are required for an augmented assessment of socio-ecological systems on SIDS, allowing for more in-depth analysis of sustainability from a landscape outlook. An island-focused outlook acknowledges that islands are distinctive and are not just microcosms for a global perspective (Chandler & Pugh, 2018). Furthermore, considering the current global position, merging the “islandness” and Anthropocene ideas is beneficial to island studies (Larjosto, 2018).

As mentioned, not only do socio-ecological system studies on islands omit the influence of “islandness” (Yanez et al., 2014; Banos-González et al., 2015b; Ciftcioglu, 2017; Schmitz et al., 2017), these studies tend to limit the operationalisation of said “islandness” variables within models and analysis, thereby shifting away from an island-focused perspective. An example of this can be drawn from index development, where many indices include large mainland countries that don’t have issues of scale or isolation, yet are compared to SIDS (Assa & Meddeb, 2021). The proposed framework will also provide a platform for the operationalisation of the socio-ecological islandscape concept, allowing studies to be more island-focused.

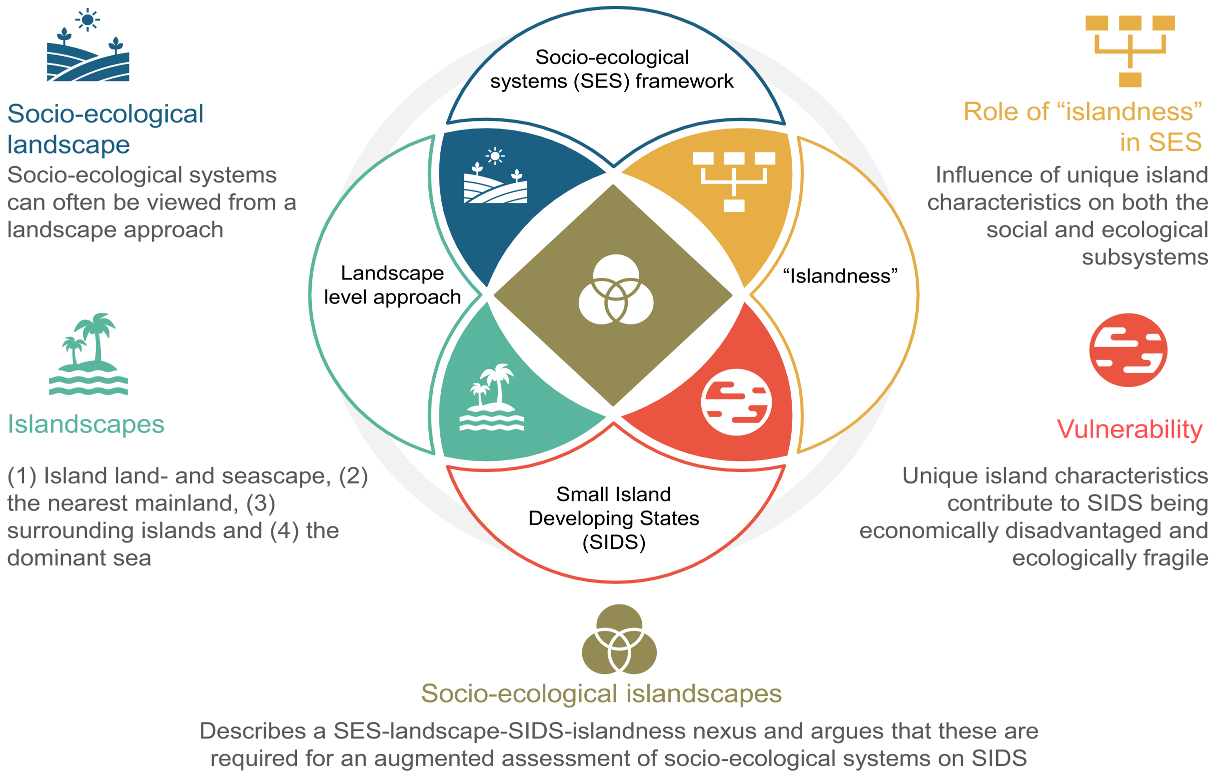


Figure 1-2: The proposed Socio-Ecological Islandscape framework

Ultimately, and as illustrated in the socio-ecological islandscape framework, the amalgamation of factors describes a SES-landscape-SIDS-islandness nexus. The consolidation of the major aspects of the framework was developed considering:

- A landscape-level approach is necessary as SIDS communities often exist as a socio-ecological system (Hay et al., 2013), while socio-ecological systems emerge geographically as socio-ecological landscapes (Petrosillo et al., 2010); however, landscapes in an island context expand into an islandscape (Vogiatzakis et al., 2017). This understanding allowed for a scale to be identified for socio-ecological islandscape studies, as well as the landscape elements that should be included;
- The crux of the framework is the idea that, because of the influence "islandness" has on SIDS (Scandurra et al., 2018), this influence should be considered when using the socio-ecological systems framework for research on SIDS;

- The framework is developed around the concept of a nexus, which is the connecting point among all aspects of the framework (i.e., SIDS, socio-ecological systems, islandness, and landscapes). This approach ensures that no link is viewed in isolation of the others (e.g. only the link between SIDS and socio-ecological systems, dismissing "islandness", which is currently a prevailing approach) and instead a holistic socio-ecological islandscape approach is taken; and
- The framework allows a new set of "islandness" variables to be incorporated into an existing socio-ecological system analysis, while remaining flexible in how these interactions are interpreted. Depending on the socio-ecological system being analysed, "islandness" variables can be incorporated, for instance, as having interactions with actors and/or resource units.

1.3 The socio-ecological islandscape-resilience nexus

As previously mentioned, islands have an inherent vulnerability to social, economic, and ecological modifications (Bunce et al., 2009; Hay, 2013; Jupiter et al., 2014; Plieninger et al., 2018). This inherent vulnerability of islands to perturbations needs further investigation, especially in relation to sustainable development (Bunce et al., 2009). Considering that the central idea of sustainability is the measured consumption of resources to ensure future use remains uncompromised, a vital component of the sustainability of island socio-ecological systems is their resilience to future uncertainties and shocks (Hay et al., 2013), as this would directly affect future resource requirements.

The original definition of resilience advocates that resilience is the magnitude of change that a system can endure before moving into an alternative stable state (Angeler & Allen, 2016). In terms of socio-ecological systems, Berkes (2017: 4) states that: "*a resilient social-ecological system has the ability to respond to perturbations while preserving the functioning and identity of the system. In general, resilient systems have the ability (1) to absorb shocks and stresses, (2) to self-organize, and (3) to learn and adapt.*"

The main goal of any socio-ecological landscape (i.e. islandscape) is the: "*wellbeing of a community, non-human life forms, and their geophysical environment* (Halliday &

Glaser, 2011: 4). These socio-ecological landscapes are constantly evolving, and one aspect that influences this development is their resilience (Ciftcioglu, 2017). Cumming et al. (2012) advocated that landscapes can be viewed as socio-ecological systems and questioned, in terms of the sustainability and resilience of landscapes, whether the system can be altered toward a more resilient delivery of the goal of socio-ecological landscapes, i.e., the well-being of ecosystems and humans. As elements of landscapes (especially islandscapes) interact across various locations and spatial scales, a subset of resilience theory that has been used in understanding the resilience capacity of landscapes (Nyström & Folke, 2001; Li et al., 2014; Lucash et al., 2017; Rescia & Ortega, 2018) is spatial resilience. Angeler and Allen (2016: 618) provide a tractable shorthand definition of spatial resilience: *"the contribution of spatial attributes to the feedbacks that generate resilience in ecosystems and other complex systems and vice versa*". Spatial resilience emphasises several important aspects, including location, connectivity, and context for resilience. The foundation for this theory is that variations in spatial attributes (such as patterns and processes) at different scales both impact and are impacted by the resilience of the system (Cumming, 2011a).

Considering that the island characteristics which make up "islandness" also influence the vulnerability of islands (UN-OHRLLS, 2011; Harter et al., 2015), spatial resilience, from a socio-ecological islandscape perspective, could be the most relevant approach to understanding the inherent resilience capacity of islands. Understanding the resilience capacity of socio-ecological systems in terms of their general ability to withstand perturbations and whether the system can be altered to improve resilience is critical to the sustainability of islands, specifically from a land management and planning perspective (Rescia & Ortega, 2018). Therefore, understanding trends in the socio-ecological islandscape-resilience nexus can provide vital information regarding the sustainability of SIDS.

1.4 Research question and aims

Preliminary literature has provided three assertions: (1) that "islandness" has a degree of importance in the continued evolution of socio-ecological systems on SIDS, (2) the socio-ecological islandscape-resilience nexus can provide fundamental information about the sustainability of SIDS, and (3) there has been very limited socio-ecological systems research on SIDS that has considered "islandness" in their evaluation, or how the different components of "islandness" diverge in their magnitude of impact.

Thus, to utilise the proposed socio-ecological islandscape concept to augment the assessment of socio-ecological systems and subsequent landscape sustainability, an understanding of what impact each of the unique characteristics of "islandness" has on a system, both as individual components and as a collective, is necessary. Furthermore, it is vital to present the benefits of this knowledge in solving environmental issues at a landscape level in SIDS. Providing initial supporting evidence of the advantage of taking the socio-ecological islandscape approach allows for an outline for future use and provides the first steps needed to move towards more robust socio-ecological systems research on SIDS and further improvements on the socio-ecological islandscape concept.

The suggested importance of "islandness", its links to resilience and the potential value of its use in evaluating environmental challenges have prompted the following primary research question and associated secondary research questions:

Primary Research Question

What is the influence of "islandness" in shaping socio-ecological resilience within a Small Island Developing State context?

Secondary Research Questions

1) *To what extent do "islandness" variables influence a simulated socio-ecological system on a Small Island Developing State?*
2) *To what extent does operationalising the socio-ecological islandscape concept provide information on the socio-ecological resilience of Small Island Developing States?*

The proposition of the socio-ecological islandscape concept would further socio-ecological systems studies on islands and prompt consideration of important and unique island characteristics in a more focused approach. Studying challenges on islands with a socio-ecological islandscape perspective may provide substantial value in terms of a viewpoint that perceives the island(s) as a single system with unique influences. Such an outlook, for example, would be beneficial to the complex socio-ecological systems that encompass both Mauritius and Rodriguez (Bunce et al., 2009).

To justify the proposed notion of a socio-ecological islandscape, this study aims to (1) investigate the role of "islandness" in influencing socio-ecological systems on SIDS, (2) analyse trends in the socio-ecological islandscape-resilience nexus through developing a socio-ecological islandscape resilience capacity index, and (3) demonstrate the benefits of taking a socio-ecological islandscape perspective. The approaches used to address these aims are discussed in the following sections.

1.4.1 Aim 1: Investigate the role of "islandness" in influencing socio-ecological systems on SIDS

Evidence that the influences of unique island characteristics, which form the basis of the socio-ecological islandscape framework, are significant enough to shape the evolution of socio-ecological systems is required to substantiate the proposed notion. Furthermore, the differing degrees of impact each characteristic has on the systems, as individual components and as a collective, provide the comprehensive knowledge needed to further expand the socio-ecological islandscape framework. Seeing the high intricacy of socio-ecological systems (Berkes, 2017) and the complexity of analysing the complete system (Nel et al., 2022), computational modelling may prove to be a valuable tool in understanding the interdependencies within a system (Schmitz et al., 2017). A particularly suitable modelling method for socio-ecological systems is Bayesian Belief Networks (BBNs) (McCann et al., 2006; Chen & Pollino, 2012; Kelly et al., 2013; Nel et al*.,* 2022), owing to the ability of BBNs to manage intricacy and uncertainty (Aguilera et al., 2011). BBNs are able to 1) incorporate issues from multiple dynamics (i.e. social, ecological, and economic), 2) utilise data from multiple sources, 3) handle missing data, and 4) the simple causal graphical structure of the BBN means that it can easily be interpreted and utilised by policy and decision-makers (Chen & Pollino, 2012). Most importantly, BBNs allow for a degree of uncertainty to be incorporated and explicitly represented, which is particularly valuable given that this study is investigating a novel framework. To provide evidence for the proposed socio-ecological islandscape concept, the study will construct a set of BBNs imitating how socio-ecological islandscapes and the respective "islandness" influence may appear in the real-world context.

Several objectives will need to be accomplished in order to achieve the overarching aim. These objectives are as follows:

- ❖ To establish a relevant set of socio-ecological islandscape variables;
- ❖ To construct a set of BBNs to model the relationships within the socio-ecological systems present on islands, taking "islandness" into consideration; and
- ❖ To evaluate the results of the BBNs to determine the influence of "islandness" on socio-ecological systems within a SIDS context.

1.4.2 Aim 2: Determine the trends in the socio-ecological islandscape-resilience nexus using the Socio-ecological Islandscape Resilience Capacity Index (SEIRCI)

An index can be described as either a quantitative or qualitative measure resulting from observations that, when frequently examined, can provide useful trends and highlight specific issues (Nardo et al., 2008). Gao et al. (2023) stated that using a composite index is a common approach to measuring sustainability.

The development of the socio-ecological islandscape resilience capacity index (SEIRCI) is intended to provide a baseline measure of the inherent capacity of the socio-ecological islandscape of an island to be resilient to perturbations and to evaluate how change can either positively or negatively affect this intrinsic resilience, from which insights into both the cascading effects of such changes and possible areas for action can be provided.

The development of the socio-ecological islandscape resilience capacity index (SEIRCI) will also provide an initial roadmap for operationalising the socio-ecological islandscape concept, which is an important step in pivoting studies towards a more island-centric focus.

Several objectives will need to be accomplished in order to achieve the overarching aim. These objectives are as follows:

- ❖ To establish a relevant set of variables;
- ❖ To determine the relative weighting for each variable;

- ❖ To conceptualise a socio-ecological islandscape resilience capacity index (SEIRCI) for measuring resilience capacity; and
- ❖ To undertake a time-series analysis of the general resilience capacity of a set of SIDS using the socio-ecological islandscape resilience capacity index.

Undertaking a time-series analysis, along with analysing other regional patterns from the results of the SEIRCI, will provide information on trends observed at the intersection of socio-ecological islandscapes and resilience.

1.4.3 Aim 3: Demonstrate the benefits of taking a socio-ecological islandscape perspective.

To demonstrate the value of the socio-ecological islandscape concept, the unique resilience factors related to SIDS are examined from a socio-ecological islandscape perspective. This will provide evidence of the benefits of a socio-ecological islandscape perspective and a point of departure for future research. To provide this evidence, the resilience capacity of socio-ecological systems on SIDS, using spatial resilience theory from a socio-ecological islandscape perspective (i.e., the socio-ecological islandscape-resilience nexus), is measured to provide a general resilience capacity for SIDS and subsequent actionable information on their sustainability.

Two high-level objectives will need to be accomplished in order to achieve the overarching aim. These objectives are as follows:

- ❖ Exploring the links between socio-ecological islandscapes and spatial resilience; and
- ❖ Identifying how both the BBNs and SEIRCI developed can be used as informative tools in decision-making on SIDS, highlighting the respective benefits of integrating the ecological islandscape concept within each.

1.5 Research design and methodological outline

1.5.1 Multi-stage exploratory mixed-method design

After reviewing the core mixed-method research approaches, it was determined that these would not be adequate for the purposes of this research. Therefore, as discussed in Creswell and Creswell (2018), more complex research needs to incorporate core designs into a "process" of research. To this end, a multi-stage exploratory sequential mixed-method research design was undertaken for this study. Typically, an exploratory sequential mixed-method approach utilises both quantitative and qualitative analysis in the research design, where the qualitative analysis is undertaken in the initial phase, a feature (BBN and Index) is constructed within the second phase and is tested within a third quantitative phase (Creswell & Creswell, 2018). These types of research methods take on a three-phase structure; however, as the socio-ecological islandscape (SEI) BBN guides the development of the SEIRCI, a multi-stage exploratory mixed-method approach with five stages was proposed. Each stage of the research process moves towards achieving one of the three aims set out for this study (Figure 1-3). A qualitative analysis was undertaken in phase one of the study, through the analysis of literature to understand both the SES-landscape-SIDS-islandness nexus and the subsequent socio-ecological islandscape-resilience nexus. This analysis led to the development of a set of SEI BBNs, which was subsequently tested within a quantitative phase, which derived critical information needed to inform the development of the SEIRCI, augmented by the analysis of literature in phase 1. Consequently, the SEIRCI was tested within a second quantitative phase.

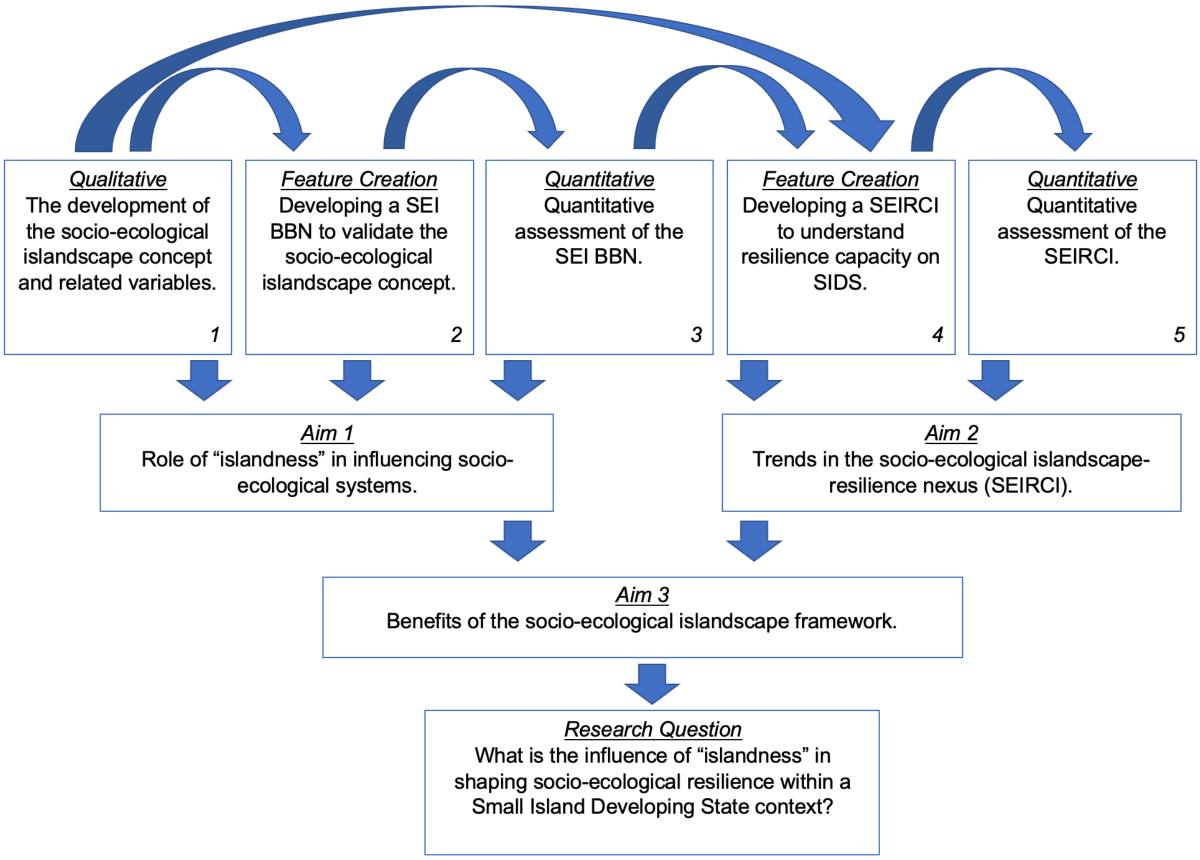


Figure 1-3: Multi-stage exploratory mixed-method design.

As presented in Figure 1-3 there are 5 main stages of the multi-stage exploratory mixed-method process envisaged for the study, which cumulate to achieve the aims of the study. The details of each stage of the research are given below:

- ❖ Stage 1: Within stage 1 of the research process, a qualitative analysis of literature was undertaken to (1) conceptualise the proposed socio-ecological islandscape framework (Figure 1-2) and (2) understand driving forces related to SIDS resilience and sustainability to ascertain suitable variables for various aspects of the study (i.e. for the BBN development and the SEIRCI development).
- ❖ Stage 2: This entailed the first "feature creation" stage of the research process. This is where the socio-ecological islandscape BBN models were developed. These models drew on the qualitative analysis of the previous stage to

determine (1) the socio-ecological systems structure of the BBNs and (2) to guide the variable selection.

- Stage 3: This stage will provide empirical support for the socio-ecological islandscape concept through empirical evidence of the influence of "islandness" on socio-ecological systems of SIDS.
- Stage 4: The SEIRCI will draw on qualitative information provided by Stage 1 and information provided in Stage 3 in determining (1) the variables used in the development of SEIRCI and (2) to guide the theoretical frameworks used.
- Stage 5: Lastly, a quantitative analysis of the SEIRCI will be undertaken to provide information on the trends observed within the socio-ecological islandscape-resilience nexus.

1.5.2 Methodological outline

The methodology for the study is divided into two main aims and a corresponding two-phase design structure, as shown in the schematic representation of the methodological outline (Figure 1-4). The third aim was realised after achieving aims 1 and 2. The following sections offer a brief description of the key elements of the methodology applied in the research.

1.5.2.1 Develop a socio-ecological islandscape concept

The socio-ecological islandscape concept is the crux of the study and forms part of each phase of the study. The socio-ecological islandscape concept was introduced and defined in this introductory chapter and continues to be examined in all stages of the study.

1.5.2.2 Construct socio-ecological islandscape BBNs (SEI BBNs)

To successfully develop a set of SEI BBNs, a collection of environmental, social and economic variables needs to be identified, and the respective data for analysis assembled. The variables need to be relevant for developing a set of SEI BBNs. Once the variables are identified, a set of SEI BBNs can be developed to imitate how "islandness" influences socio-ecological systems within a SIDS context, after which the results from these models can be analysed. The results of these SEI BBNs provide evidence of the role that "islandness" has in influencing socio-ecological systems as well as in supporting the notion of a socio-ecological islandscape concept, thereby achieving aim 1 and contributing to aim 3 of the study.

1.5.2.3 Assess the resilience capacity of the socio-ecological islandscape

Several steps are required in this stage of the study. The results of quantitative analysis (i.e. SEI BBNs), along with an analysis of how spatial resilience indicators link to SIDS, were used in the development of a socio-ecological islandscape resilience capacity index (SEIRCI) that can be used to assess the resilience capacity of a socio-ecological islandscape. The proposition of developing a composite index is that it is neither biased nor specific to any island and, therefore, can be replicated in most circumstances with the least possible modification. This SEIRCI aims to utilise existing indicators that are regularly updated to create an index that can be used to examine trends within the socio-ecological islandscape-resilience nexus (aim 2).

1.5.2.4 Analysis and review of the results of the test cases

Once the index is developed, it needs to be tested against real-world cases. The study includes using test cases of numerous SIDS to (1) measure the resilience capacity of each test case, (2) assess how the resilience capacity of the SIDS has changed over time, and (3) provide a measure to evaluate underlying causes that can affect the sustainability of the island. The use of test cases allows for the examination of the importance of the information provided by the SEIRCI in understanding the general resilience capacity of an island and what it means for both the society and the environment upon which it depends. The information generated from the SEIRCI provides insights into the possible cascading effects of changes to the socio-ecological islandscape and ultimately establishes the overall value of the socio-ecological islandscape concept, thereby contributing to aim 3 of the study.

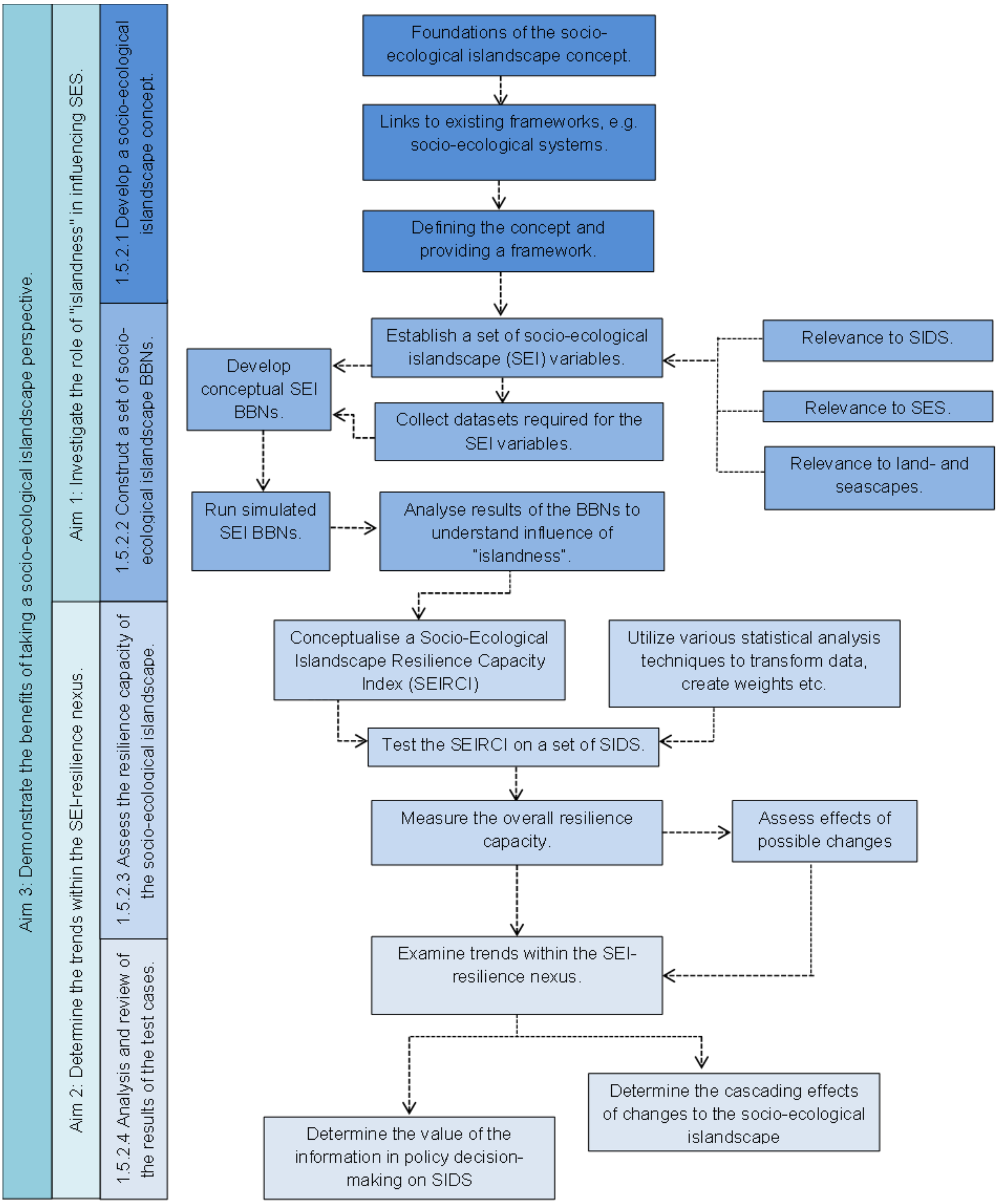


Figure 1-4: Schematic outline of study methodology

1.6 Organisation of chapters

The chapter outline used in this research thesis is as follows:

Chapter 1 (Introduction): The introductory chapter provides an initial outline of the socio-ecological islandscape concept and delves into the basis of the notion through examination of socio-ecological systems, landscapes, “islandness”, and the threats currently facing SIDS within the Anthropocene. Further to these insights, this chapter introduces the relationship between socio-ecological islandscapes and resilience theory, explaining the connection through spatial resilience. The chapter draws on these various elements to present the research question, aims and objectives of the study, which ultimately culminate in the development of the socio-ecological islandscape concept. An outline of the approach for achieving the aims is also given, namely, providing evidence to justify the socio-ecological islandscape concept using BBNs and a Socio-Ecological Islandscape Resilience Capacity Index, which aims to assess the resilience capacity of islandscapes and indicate the value of using a socio-ecological islandscape perspective.

Chapter 2 (Literature study): The literature study covers several themes. Firstly, the literature study further investigates a few elements highlighted in the introduction chapter, namely the significance of socio-ecological systems, spatial resilience theory, and a greater understanding of SIDS. The investigation of some of these aspects covers their evolution, current theoretical debates, and their application in the scientific literature. These major themes encompass numerous sub-themes (e.g., emerging issues and future perspectives of SIDS), theories (e.g., the socio-ecological systems framework and the driver-pressure-state-impact-response framework), and debates that are also covered during the literature study.

Chapter 3 (The role of “islandness”): The premise behind the Socio-Ecological Islandscape Bayesian Belief Networks (SEI BBNs) is to provide detailed information on the interconnected relationships within the socio-ecological islandscapes to (1) substantiate the use of the concept, (2) ascertain the varying effects of the “islandness” components, and (3) provide critical analysis needed to develop robust criteria for assessing the resilience capacity of SIDS. This chapter delves into how the BBNs were created, as well as the findings of the models.

Chapter 4 (The Socio-Ecological Islandscape Resilience Capacity Index): The Socio-Ecological Islandscape Resilience Capacity Index (SEIRCI) is a vital component of the study. This chapter details the development of the SEIRCI, from providing the indicators selected for the index and the methods used to determine the weighting of each indicator within the index, to the structure of the index based on the results of the SEI BBNs.

Chapter 5 (SEIRCI results and discussions): The results of the SEIRCI are discussed in Chapter 5. Comparisons between the weighting methodologies and the theoretical frameworks are discussed in detail, culminating in the selection of the final approach to the SEIRCI. The resilience capacities of different islands are illustrated and discussed. Overall trends in the resilience capacity of SIDS are scrutinised to ascertain the trends in the socio-ecological islandscape-resilience nexus and to demonstrate the value of using a socio-ecological islandscape perspective for environmental challenges.

Chapter 6 (Synthesis, recommendations and conclusion): The concluding chapter states the findings of the research and the identified problems, along with recommendations for possible solutions to the identified problems. Furthermore, any gaps in research, as well as recommendations regarding possible further research, are also set out in this chapter.

1.7 Summary

The socio-ecological islandscape framework was created to provide researchers with a foundation for progressive research into socio-ecological systems on SIDS by prompting consideration of “islandness” in how these socio-ecological systems have evolved and continue to evolve. The socio-ecological islandscape framework essentially urges researchers to ask questions about “whether any aspect of “islandness” influences what is being researched and “how the research being undertaken could benefit from taking a socio-ecological islandscape perspective”.

However, to (1) substantiate the notion of the socio-ecological islandscape concept, (2) provide an initial investigation into the role that “islandness” has on socio-ecological systems on SIDS, (3) understand the trends within the socio-ecological islandscape-resilience nexus, and (4) illustrate the benefits of using the socio-ecological islandscape framework in assessing environmental problems on SIDS, this study uses a multi-stage exploratory mixed-method research design.

Through this design, the study has contributed to the body of knowledge by introducing a novel concept and associated framework: the socio-ecological islandscape concept and framework. The study also offers methodological contributions, presenting a roadmap to operationalising "islandness" variables through both a BBN and index development. Lastly, the application of the Socio-Ecological Islandscape Resilience Capacity Index introduces an initial rapid evaluation tool that can be used to gain insights into resilience capacity across numerous SIDS.

The methodology includes the use of several frameworks, theories and techniques; therefore, a comprehensive literature study has been done in Chapter 2 to gain the in-depth knowledge needed to utilise these various components. Further to this, the literature study also covers the four critical factors that contribute to the socio-ecological islandscape framework, i.e. landscape sustainability, SIDS, the socio-ecological systems framework and "islandness".

CHAPTER 2. LITERATURE STUDY

2.1 Introduction

To begin unravelling the relationships between the various elements of the socio-ecological islandscape-resilience nexus, it is important to understand each element of the nexus separately and present what literature has already examined regarding the relationships each element has with the others, allowing for initial inferences to be made. As previously discussed, the empirical examination of the nexus has been undertaken in two separate parts: first, by examining the SES-landscape-SIDS-islandness nexus, where a socio-ecological islandscapes notion was proposed; after which, the socio-ecological islandscape-resilience nexus is further explored. This coupling of aspects of the initial SES-landscape-SIDS-islandness nexus provides a more focused attempt at examining these interrelationships, and, as shown within the literature review, there is a logical flow to analysing the socio-ecological islandscape-resilience nexus through this separate assessment of coupled components (Figure **2-1**). This logical flow includes examining five major themes (and associated subthemes): SIDS, "Islandness" characteristics, socio-ecological systems, landscape sustainability and resilience. The literature review then synthesises these perspectives as coupled components to explore how they interact and inform one another, thereby exploring their nexus point. The literature review, therefore, aims to achieve the following objectives:

1) To provide a review of the four major aspects of the SES-landscape-SIDS-islandness nexus that ultimately forms the socio-ecological islandscape notion;
2) To discuss spatial resilience to provide a clear understanding of concepts and definitions;
3) To provide preliminary inferences, based on published literature, regarding the relationships between the different components; and
4) To assess what conclusions have been drawn from the literature regarding the nexus.

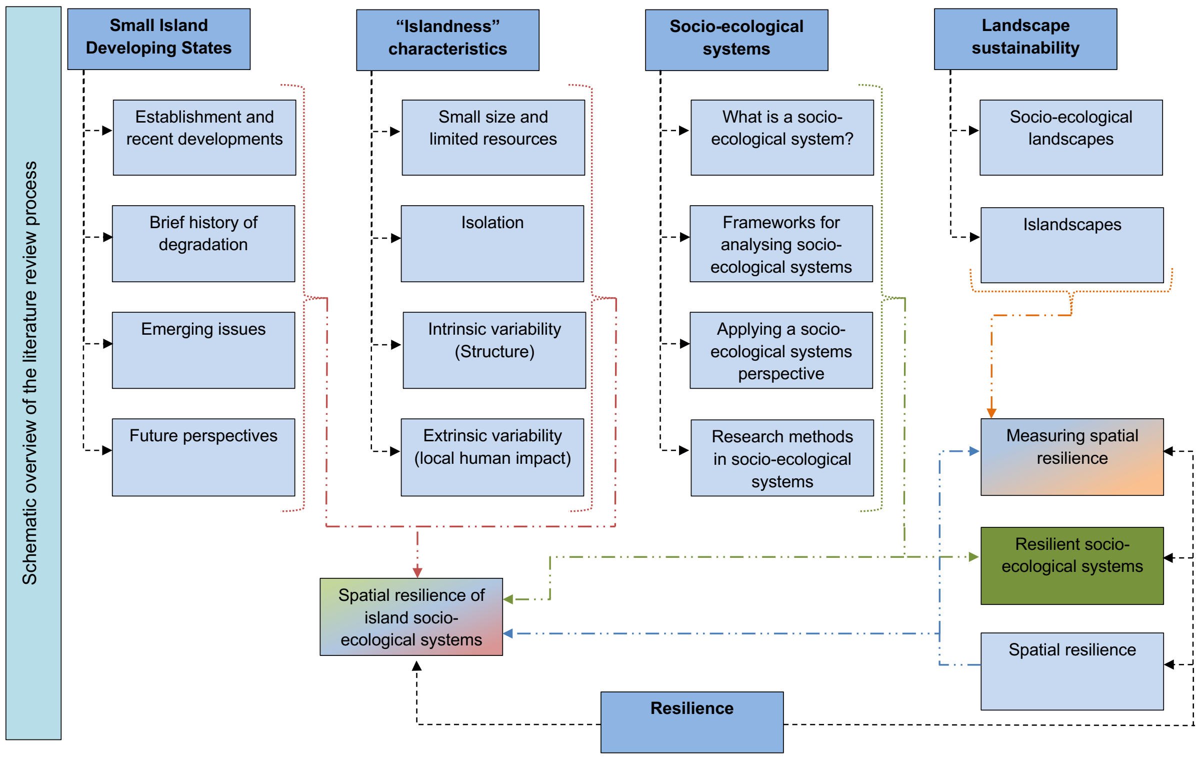


Figure 2-1: Schematic overview of the literature review process.

Bold squares represent chapter sections with the subsections for each linked with black arrows. The coloured arrows illustrate the logical flows for the literature review process, showing how preceding sections informed the development of subsequent sections.

Critically, the literature review describes key concepts that are needed to underpin the socio-ecological islandscape framework, namely SIDS, "Islandness" characteristics, socio-ecological systems and landscape sustainability. These sections provide important links between the concepts and the study, allowing for the foreshadowing of certain methodological decisions regarding variable selection for the study, foundational socio-ecological system frameworks for the BBN structure and modelling method selection. Similarly, for the operationalisation of the socio-ecological islandscape concept, the fundamentals of resilience and, more importantly, spatial resilience have been described. This, however, leads into a crucial aspect of the study, as the nexus between socio-ecological islandscapes and spatial resilience is explored and synthesised, thereby informing aspects of the operationalisation of the socio-ecological islandscape concept (i.e., the SEIRCI development).

2.2 Small Island Developing States (SIDS): History, emerging issues and future perspectives

2.2.1 Establishment and recent developments

Small Island Developing States (SIDS) were first recognised as being inherently vulnerable by 197 nations at the United Nations Conference on Environment and Development in June 1992, where they were recognised as a distinct group of countries that are: "*a special case for both environment and development. They are ecologically fragile and vulnerable. Their small size, limited resources, geographic dispersion and isolation from markets, place them at a disadvantage economically and prevent economies of scale*" (UNCED, 1992: 193).

The importance of SIDS remained on the global agenda, with the UN Global Conference on the Sustainable Development of Small Island Developing States in April 1994 adopting the Barbados Programme of Action aimed at: "*addressing the special challenges and constraints facing small island developing states"* (UN, 1994: 9). The Barbados Programme of Action provided specific actions and measures for areas such as climate change and sea-level rise, natural and environmental disasters, energy resources, tourism, biodiversity, marine resources, transport and communication, and science and technology, that needed to be addressed at a national, regional, and international level (UN, 1994). However, in September 1999 a United Nations General Assembly for the review and appraisal of the implementation of the Programme of Action for the Sustainable Development of Small Island Developing States recognised that advancement had been unbalanced and that: "*the pace of globalization and trade liberalization has affected the economies of small island developing States by presenting new problems and opportunities for them and increasing the need for focused implementation of the Programme of Action"* (UNGA, 1999: 6). The general assembly reiterated the vulnerability of SIDS, highlighting issues of increasing globalization, broadening disparities in income and a continuous decline of the global environment (UNGA, 1999), and recognised that the rate of global change is persistently shaping SIDS.

Thus, SIDS have remained at the forefront of the world stage, with the special case of SIDS being reaffirmed at the World Summit on Sustainable Development in 2002 and the Mauritius Strategy and Mauritius Declaration in 2005 (UN, 2014). The latest significant policy declaration was at the Third UN Small Island Developing States (SIDS) Summit held in September 2014, in which the Samoa Pathway provided for a representation of the commitments of the 115 SIDS leaders. Importantly, in the Samoa Pathway, leaders of SIDS: "*recognize that poverty eradication, changing unsustainable and promoting sustainable patterns of consumption and production and protecting and managing the natural resource base of economic and social development are the overarching objectives of and essential requirements for sustainable development"* (UN, 2014: 4).

2.2.2 Brief history of environmental degradation

Socio-ecological islandscapes have an extensive history of being impacted by human societies, with observed early extinctions, deforestation, and modification of habitats at a local level due to both settlement and subsistence requirements (Braje et al., 2017; Larjosto, 2018), with an extreme instance of human impact being societal collapse on Rapa Nui (Lima et al., 2020). An example of a significant impact of prehistoric humans on islands was the introduction of invasive species, such as the Pacific Rat (*R. exulans*), which were observed globally on islands across all climatic regions. The Pacific Rat has caused both extinction and considerable loss of indigenous island species as well as severing connections within island ecosystems (Harper & Bunbury, 2015). Another example of these effects from early human societies on islands is on Rapa, French Polynesia, where, due to prehistoric population growth and the associated environmental degradation within a resource-limited area, competition for resources and land occurred (Kennett et al., 2006). As illustrated, "islandness" characteristics and the subsequent vulnerability that they cause are not a modern source of influence on island socio-ecological systems. Although Hay (2013) stated that islands and associated societies were not inherently vulnerable, rather their resilience was affected by colonialism, development, and globalisation. However, historical human-environment interactions on islands are shown to have always been complex and shaped by "islandness" characteristics, such as size, isolation, and variability of the local human impact (Braje et al., 2017), which affected their vulnerability to change. The study by Braje et al. (2017) took not only a socio-ecological systems perspective on the historical relationships between man and nature, but arguably also a socio-ecological islandscape approach. These archaeological perspectives on human-environment interactions further the need for the socio-ecological islandscapes concept, as both current and historical studies should consider the effect of “islandness” in their assessments of the human-environment interactions on islands.

Proceeding the already impacted landscapes by indigenous societies, European colonialism significantly influenced and eventually altered socio-ecological islandscapes on colonized islands (Lewis, 2009), such as massive deforestation undertaken for the establishment of plantations for commercial sugar production on the Caribbean islands that substantially altered the local landscape and associated habitat, with sugar cane having a high nutrient requirement that ultimately resulted in soil collapse and erosion (Lightfoot et al., 2013). The magnitude of anthropogenic change during the colonial period, which included the introduction of: “*agrarian systems, plantations, fur trade outposts, and commercial fishing and whaling ventures”* (Lightfoot et al., 2013: 101), completely outstripped the impact that indigenous societies had on islands over centuries, resulting in environments transitioning to completely different states (Braje et al., 2017).

More recently, development and globalisation have further reduced islands' resilience and increased their exposure to global change, consequently increasing their vulnerability. Globalisation and its demand for export products, for instance, have seen large quantities of arable land on Pacific Islands given to commodity production, decreasing food system resilience (Campbell, 2014). Largely, islands have a history of being moulded by changes in international economic and political affairs and the proliferation of technology (Hay et al., 2013), and these challenges remain persistent, especially for SIDS that are intrinsically vulnerable. This innate vulnerability is highly influenced by “islandness”, which has affected the human-environment interactions on islands for centuries (Braje et al., 2017) and will continue to influence these relationships for generations to come.

2.2.3 Emerging issues

In contemporary society, some of the major emerging pressures on island biodiversity remain overexploitation, agriculture, invasive species, and development (Russell &

Kueffer, 2019). These threats not only affect biodiversity but also island communities, which are also under stress from issues such as energy security, population dynamics, a decline in island social structures (Hay, 2013) and pollution (SPREP, 2016).

Overexploitation on islands has led to a loss of biodiversity (Pelling & Uitto, 2001; Graham et al., 2017), a reduction in food security (Hanich et al., 2018) and an increase in invasive species (Russell et al., 2017). Queen conch (*Lobatus giga*), for example, has high cultural, economic and food security significance in the Bahamas and has been subjected to continued overfishing, which has considerably reduced its population and will potentially result in the future collapse of the queen conch fishing industry (Stoner et al., 2018), having serious ramifications for livelihoods and biodiversity.

Increasing agricultural production often leads to habitat removal (Russell et al., 2017) and agricultural runoff (Smith et al., 2021) that pollutes marine ecosystems and puts significant pressure on island water resources, as in the case of increased squash production in Tongatapu (van der Velde et al., 2007). Pollution from waste, industry and agriculture is considered one of the major issues affecting socio-ecological systems on Pacific islands due to insufficient management of these pollution sources, which: *"degrade natural ecosystems and reduce their resilience to climate change impacts"* (SPREP, 2016: 7). To illustrate this, significantly high concentrations of hydrocarbons and pesticides were measured by Smith et al. (2021) around the capital of the Solomon Islands (Honiara) and Vanuatu (Port Vila), which were observed to have toxic impacts on the respective ecosystems.

"Islandness" contributes to the high vulnerability of islands to invasive species, which not only impacts biodiversity and ecosystem functioning but also the livelihoods of communities and the overall economy (Russell et al., 2017). Human societies have corroded natural biogeographical barriers, especially on islands, by facilitating species dispersal beyond their natural frontiers into new regions where they can establish, resulting in significant ecological damage (Graham et al., 2017). In addition, microbial pathogens that infect vulnerable native species can result in rapid extinction events, which are often accompanied by the introduction of non-native species (including humans) to islands (Graham et al., 2017).

Urban development has significant ramifications for biodiversity on islands, often due to limited resources and small land area. The importance of biodiversity to SIDS cannot be overstated; it supports the livelihoods of most SIDS communities through economic benefits (e.g., tourism and fisheries), cultural importance, and important ecosystem services (e.g., food supply, water supply, and coastal protection) (UN-OHRLLS, 2017). The implications of "islandness" for urban development are evident in the Maldives, where sizable expansion of islands through land reclamation and engineered structures is taking place, degrading the reef ecosystem and consequently affecting future food security (Duvat, 2020). Mauritian wetlands, which were historically affected by agriculture, are being fragmented and transformed by intensive land-use requirements, with urbanisation currently the most significant (Laurance et al., 2012). Biodiversity loss from land-use change is not the only cause of environmental degradation from urbanisation, as consumption patterns of urban populations (Saito et al., 2020) and the lower perceived benefits that urban populations place on ecosystem services (Lapointe et al., 2020) increase demand on the environments in which they are embedded. From an economic and social perspective, rural-urban migration associated with urbanisation is linked to improved economic status (rural-urban migration) and rural development (remittances); however, negative implications were also observed, such as reduced food productivity and changing social dynamics (increasing workloads for an increasing female population) (FAO et al., 2018). The complexity regarding rural-urban migration increases in some SIDS, considering their isolated and sometimes fragmented (i.e. archipelago) nature.

In addition, SIDS remain highly dependent on fossil fuel imports as their major source of energy (Surroop et al., 2018; Curto et al., 2019) and continue to be a substantial challenge for their energy security, especially when external forces such as price volatility and supply disruption could threaten that security (Genave et al., 2020). According to Raghoo et al. (2018), imported fossil fuels (mainly oil) is 70% of the electricity mix in Africa, the Caribbean, and Pacific islands, which indicates the need for more diverse energy sources (Surroop et al., 2018).

Tourism is a complex and significant issue for most SIDS, where economies are often highly dependent on tourism (Pratt, 2015; Pathak et al., 2021), and its development has the potential to improve the quality of life for many SIDS communities (Puig-

Cabrera & Foronda-Robles, 2019). However, tourism on SIDS is particularly vulnerable to external forces, such as price volatility (Pratt, 2015) and climate change (Pathak et al., 2021). Unsustainable tourism can also place the natural capital of SIDS under sizeable strain from increased consumption by tourists (Hall, 2010), such as the over 1 000 000 visitors Aruba experienced in 2017 compared with a local population of only 105 000 (Hampton & Jeyacheya, 2020). However, biodiversity preservation and conservation on SIDS is often justified by tourists' attraction to the pristine nature of these "destinations" (Hall, 2010), further adding to the complexity of tourism on SIDS.

Current pressures from climate change being exerted on SIDS include rising sea levels, ocean acidification and increased climate variability and weather extremes (Hay, 2013; Larjosto, 2018). Although sea level rise is predicted to cause significant future impacts on SIDS (Albert et al., 2016), sea levels have so far risen approximately 1.3 and 1.7 mm yr^{-1} through most of the 20th century and rose between 2.8 and 3.6 mm yr^{-1} since 1993 (Nurse et al., 2014) – rates which have already created challenges for SIDS. Rising sea levels observed from 1947 – 2014 along low-lying reef islands in the Solomon Islands caused the complete loss of five vegetated reef islands and severe shoreline recession on six islands, of which two resulted in the devastation of villages and the subsequent relocation of communities (Albert et al., 2016). Sea-level rise has also been noted to increase tidal flooding, which can significantly affect the freshwater supply for low-lying islands and atolls by increasing the salinity in coastal aquifers, which is often the only source of water (Oberle et al., 2017). Sea-level rise is also a contributing factor to the increase in extreme weather events, such as the flooding experienced in the Maldives in May 2007, which caused the entire island of Fares to flood – a phenomenon that also affected almost a third of Maathoda (Wadey et al., 2017). The intensity of these extreme weather events is also expected to increase, as observed with Hurricane Dean in 2007, which devastated 40% of the mangroves in the Portland Bight area of Jamaica (Stephenson & Jones, 2017). Increasing threats from climate change, coupled with "islandness" and the high permeability of aquifers near coastal waters, create higher water security exposure on SIDS (UNEP, 2014). Compounding the above-mentioned issues is the continued degradation of reefs. Ocean reefs provide numerous ecosystem services to SIDS (including coastal protection), while their degradation occurs through large-scale coral bleaching resulting from ocean acidification and rising ocean temperatures (Thomas et al., 2020). An illustration of the effects of large-scale bleaching was provided by Alling et al. (2007), where surveys conducted in 2002-2003 in the remote Phoenix Islands (Kiribati) recorded a nearly 100% coral mortality rate in the lagoon and a 62% coral mortality rate on the outer leeward slopes of the Kanton Atoll reefs.

2.2.4 Future perspectives

On the current trajectory, future perspectives for socio-ecological islandscapes suggest noteworthy problems. Island biodiversity is set to continue to decline in the future, with agriculture, development and invasive species remaining persistent threats (Russell & Kueffer, 2019), however, as global surface temperatures are forecasted to potentially increase by 1.5°C by the end of the 21st century (IPCC, 2014), climate change will soon become the most significant threat to island biodiversity and those societies whose livelihoods are dependent on these natural resources (Russell & Kueffer, 2019). For instance, on New Providence and Paradise Islands in the Bahamas, climate change impacts (e.g. erosion and coral bleaching) are expected to significantly impact the natural resources on which the tourism sector is highly dependent (Pathak et al., 2021), which would have a cumulative impact on the economy and livelihoods of communities, not to mention the direct consequences that climate change impacts will have on food security. Lenderking et al. (2021: 242) described climate change interrupting food supply through: *“rising air and sea surface temperatures, variability in precipitation patterns, increases in storm intensity, and impacts on water availability”* and reiterated the high vulnerability of food security to climate change, particularly on islands, where there are generally low agricultural diversity and high dependency on imports.

Once again, sea-level rise is forecasted to be one of the greatest climate change impacts affecting SIDS, with projected increases of between 0.35 m and 0.70 m expected to significantly exacerbate tidal flooding, coastal erosion, and the threat posed to food and water security (Nurse et al., 2014; UNEP, 2014). Sea-level rise, along with other climate change impacts, will also have severe effects on island population dynamics, due to the high density of coastal populations, driving communities to relocate into more centralised areas and causing inter-island and continental migration (Bunce et al., 2009; Harter et al., 2015; Betancort et al., 2019). Additionally, the issues that islands have around their isolated nature may be further exacerbated by the effects of rising sea levels and associated coastal flooding, particularly as considerable amounts of transport infrastructure and linked operations are situated in high-risk coastal areas (i.e. low-lying coastal airports and seaports) (Monioudi et al., 2018).

Similarly, ocean acidification and rising temperatures will continue to cause coral bleaching and reef degradation, with current modelling predicting that, under a scenario of continued high fossil fuel usage, annual severe bleaching will consistently occur by 2034 and the entire world’s coral reef system will be bleached by the end of the century (UNEP, 2020). For example, a 2°C temperature increase scenario would push countless coral reef species along Pacific Islands beyond their tolerance, reducing overall ecosystem functioning (source of coastal protection, food security and tourism) and resilience of not only the coral reef but also the reliant communities (Wier & Orcherton, 2013; Nurse et al., 2014).

Climate change will also have significant indirect impacts on socio-ecological islandscapes. Invasive species and climate change are generally directly proportional (Bellard et al., 2013) due to their adaptability and greater range of tolerance to habitat modification (Russell et al., 2017). Invasive species, which are currently the most significant driver of biodiversity loss on islands, are only set to worsen with increasing temperatures (Russell et al., 2017), having a cascading effect on island community livelihoods and health (Nurse et al., 2014).

2.2.5 Synthesis of a SIDS perspective

SIDS are characterised by a socio-ecological system that is historically fragile, which continues to persist, and is set to become increasingly vulnerable to perturbations with the onset of global threats (e.g., climate change). These potential disturbances risk fundamentally altering the socio-ecological balance on SIDS, which has played a substantial role in underscoring a socio-ecological islandscape framework that considers SIDS at its core, rather than a socio-ecological system framework that does not explicitly account for “islandness” characteristics.

A central feature of socio-ecological systems on SIDS, as derived from historical and emerging issues, is the societal pressures exerted on limited resources, whether through intensive agriculture, overexploitation, or overtourism. This dimension of consumption and the concept of resource scarcity are fundamental in operationalising the socio-ecological islandscape concept. As mentioned, climate change is at the forefront of future risks for SIDS and should be a key component in modelling and operationalising the socio-ecological islandscape concept.

2.3 "Islandness" characteristics

"Islandness" characteristics that contribute to SIDS being some of the most vulnerable countries to change (Mycoo et al., 2017) are discussed in the following section. Related interactive features are examined together.

2.3.1 Small size and limited resources

The small size of SIDS is often characterised by a shortage of both land and resources (Larjosto, 2018) that are frequently associated with high endemism (Kueffer & Kinney, 2017) and areas vulnerable to disasters (Pratt, 2015). This scarcity, in turn, limits the suitability for human uses, which further influences the land-use patterns on islands (Fernandes & Pinho, 2017). This constrained relationship results in a highly interconnected system where the limitations shaping biodiversity have a compounding effect on the restrictions affecting society.

Island size plays a major role in species survival, particularly given the global changes brought about during the Anthropocene. Generally, to ensure effective dispersal, species require accessibility to appropriate habitats that are not restricted by anthropogenic activities, and, considering the spatial constraints of a majority of SIDS, such dispersal is noticeably limited (Harter et al., 2015). This results in these species being considered more vulnerable to decreases in the extent of their habitat (Graham et al., 2017). Whilst being cognizant of the biodiversity requirements, consider that the limited land available for development, coupled with the physical boundary presented by the surrounding sea, has promoted densification. The inability of SIDS to expand beyond their boundary has subsequently created cities that, by a total land mass to city area ratio, can be considered comparatively large (Larjosto, 2018). This has often resulted in SIDS expanding their spatial extents through land reclamation or artificially developed islands (Duvat, 2020). Increased urbanisation, as well as land reclamation for increased development, was attributed to significant loss of biodiversity on SIDS (Russell & Kueffer, 2019; Duvat, 2020) which had a cascading effect on the communities' livelihoods that are derived (e.g. subsistence agriculture and wild harvest for food and income) from, and heavily dependent on, this natural capital (UNEP, 2014; Kueffer & Kinney, 2017). Often, natural resources that are the foundations of community livelihoods have the potential to prevent an increase in poverty; however, sustained loss of these resources will most likely intensify poverty (Shackleton et al., 2007). Moreover, poverty is a significant driver of resource demand and often leads to further resource exploitation and habitat alteration (Graham et al., 2017). However, ensuring environmental protection, economic development and maintaining community livelihoods, considering the limited size and resources of SIDS, may prove challenging (Fernandes & Pinho, 2017). This further emphasises the interconnected nature of SIDS and the influence that factors such as island size have on a socio-ecological system, and the need for a socio-ecological islandscape perspective.

Poverty is directly correlated to the health of a country's economy, which is also significantly influenced by island size (Vítová et al., 2019). The concept of "economies of scale" relates to the savings gained through higher production outputs (Cho et al., 2017), which, owing to their size, SIDS are unable to achieve (Pratt, 2015; Connell, 2016). Thus, SIDS are further hindered as infrastructure that is a prerequisite for business often remains underdeveloped (Hay, 2013), including infrastructure needed to ensure energy security (Genave et al., 2020) and transportation facilities that are under threat from climate change (Monioudi et al., 2018). The ability of SIDS to establish a diverse economic base has been hampered by the limited resources present (Hay, 2013), resulting in 9 of the 48 countries on the UN's list of Least Developed Countries being SIDS (Graham et al., 2017), illustrating the high levels of poverty associated with some SIDS. This uniform economy has therefore significantly contributed to SIDS being comparatively more dependent on tourism than other states (Hay, 2013), which increases pressure on the natural capital (Hampton & Jeyacheya, 2020). Tourism, however, is also linked to economic upliftment in SIDS (Pratt, 2015), which is directly proportional to island size, with more populated SIDS attracting more tourists (Vítová et al., 2019). Furthermore, a consequence of a lack of natural resources is the high predisposition to import goods (particularly capital goods) and services, with very few options for import substitutions (Pratt, 2015). Consequently, tourist consumption cannot be adequately met by small local markets; therefore, heavy dependence on export markets exists (Pratt, 2015). Dependence on exports, coupled with some SIDS being characteristically isolated, further exacerbates the effects of smallness and having limited resources. This remoteness and its influence are discussed in the next section.

2.3.2 Isolation

Isolation has substantial effects on island economies, such as high transportation costs (Pratt, 2015), limited openness to international trade (Takahashi, 2019), and disconnection from international policy decision-making (Pelling & Uitto, 2001; Guillotreau et al., 2012; Fernandes & Pinho, 2017).

The accessibility and connectivity of SIDS to the global community and markets, for trade, tourism, and development, are highly contingent on transportation (Monioudi et al., 2018). However, transportation in the context of island remoteness is a problem that leaves SIDS socio-ecological islandscapes highly exposed, based on the significant food and energy imports by SIDS, which face external price and supply volatility (Nurse et al., 2014), affecting food and energy security. Thus, SIDS that are less connected to trade routes and are more isolated have a higher exposure to external forces affecting the transportation of goods. Paired with a high level of openness to trade, the isolation of SIDS together with the necessary primary production required to compete internationally and meet commitments of international trade agreements may result in environmental degradation (van der Velde et al., 2007). Generally, isolated island economies are in an unfavourable position in relation to international trade (Takahashi, 2019), with geographic immediacy to major global markets being linked to higher GDP per capita on SIDS (McElroy & Medek, 2012). The disconnection experienced from institutions that make policy decisions, often with profound impacts on SIDS, exacerbates a number of these challenges (Guillotreau et al., 2012). In addition, remoteness often results in expensive tourism (Connell, 2016), with tourist numbers being inversely correlated to travel costs and accessibility (Vítová et al., 2019). Thus, SIDS are comparatively more dependent on tourism compared to other states (Hay, 2013), and this has a relatively significant effect on an island's resilience. As seen during the COVID-19 pandemic, the tourism industry on SIDS was severely affected, with expected GDP losses ranging from 7.3% to as high as 16% (Seychelles and Maldives) (Gu et al., 2021).

While isolation often results in issues surrounding the economy, another less commonly observed issue relates to information availability. Foley (2018) discussed that the isolated and fragmented nature of islands is often a cause for gaps in environmental data, leading to substandard decision-making. This highlights the need for island-centric measures that can be used in decision-making on SIDS.

2.3.3 Intrinsic variability

Intrinsic variability is used to explain the structural differences between SIDS, namely that islands have different physical structures based on their origin, including whether they form part of an archipelago, as well as their ecological complexity.

The physical structure of islands can present developmental challenges, as physical development is costly on islands that are volcanic or coralline in origin (Mycoo et al., 2017). In addition, island structure also determines the magnitude of the impacts of climate change on an island (Larjosto, 2018), as large continental islands are not as susceptible to sea-level rise as atolls (Nurse et al., 2014). Islands are also composed of a high ratio of coastline to land area (Fernandes & Pinho, 2017), resulting in a concentration of capital assets along the coastal zone of islands, where connections, urbanisation and the effects of climate change most frequently occur (Larjosto, 2018).

The fragmented structure of archipelagos causes and intensifies an array of issues in SIDS. Fragmentation often results in the establishment of a centre-periphery logic (Favole & Giordana, 2018), where development is focused on what is considered the central economic and political hub (e.g. Male in the Maldives). Consequently, there are reduced incentives for the development of regional centres owing to the concentration of labour, political systems, and administrative services in these hubs, which are often the capital cities (UN-Habitat, 2015). The centre-periphery model associated with fragmentation also makes the provision of services on the periphery more challenging

(UN-Habitat, 2015), as basic services, including electrical networks, cannot be shared (Frenandes & Pinho, 2017; Genave et al., 2020) and need to be developed separately.

The effects of the centre-periphery model extend to human development, where inequality is seen to be higher on the periphery compared to in the capital (Betancort et al., 2019). Correspondingly, there are often issues around social cohesion between inhabitants of the capital and peripheral islands, such as polarised migration flows and declining social resilience on peripheral islands (Bunce et al., 2009). Belep (New Caledonia), for example, is regarded as marginalised and backward by both its inhabitants and those in the capital (Favole & Giordana, 2018). Being cognizant of the emerging issues on SIDS, fragmentation creates a more challenging situation in terms of resilience. Inter-island transport is critical for archipelagos (Luis, 2004), which are also subject to the price volatility of imported fuels. Considering the inequality and lack of development often experienced by inhabitants of peripheral islands, the cost burden associated with fuel price increases is likely to affect these vulnerable communities. In examining issues on islands, especially archipelagos, a socio-ecological islandscape perspective is vital. Policy decisions, developments and consumption patterns of capitals may affect peripheral islands. Even from a tourism viewpoint, inter-island competition for tourism could change social dynamics, with inter-island migration taking place towards areas of higher development.

Islands are associated with high levels of endemism and are considered biodiversity hotspots (Graham et al., 2017; Harper & Bunbury, 2017; Kueffer & Kinney, 2017), which is often a driving factor for tourism (Hall, 2010) and a basis for supporting community livelihoods. However, in contrast to mainland ecosystems, the number of species on oceanic islands is comparatively low, having a simplistic closed-system community structure that is more vulnerable to anthropogenic change, meaning the overall ecological integrity of island ecosystems is inherently more fragile (Harter et al., 2015). Biodiversity also differs between islands, and therefore, island vulnerability will also vary. Habitat diversity, for example, is positively correlated with island size and structure (such as an archipelago) and negatively correlated with low-lying islands and those at high and low altitudes (Russell & Kueffer, 2019). Island biogeography theory supports these variances, as it argues that species richness on islands increases with increasing size and decreasing isolation (Chen et al., 2011). This variability in ecological complexity also gives rise to disparity in resource availability on SIDS and the varying contributions that existing natural capital has on community livelihoods. Energy security in Papua New Guinea and Trinidad & Tobago differs from that of other SIDS, as these have fossil fuel deposits and are energy exporters (Raghoo et al., 2018). While large, forested areas on SIDS such as Fiji, Papua New Guinea, Samoa, Solomon Islands, Suriname and Vanuatu allow for wood processing to be a major economic contributor, this contrasts with Bahrain, Marshall Islands and Nauru, where forest cover is less than 1% of total land cover (Wilkie et al., 2002). Differences in ecological complexity, as shown in the examples provided, are largely a factor when considering human needs, whose differences among islands are discussed in the following section.

2.3.4 Extrinsic variability (Local human impact)

The effects of local human impacts observed on SIDS have been described in previous sections; however, a few factors influence the unevenness of impacts caused by different island societies. Some of the major factors that drive the issues previously discussed, such as tourism, resource exploitation, urbanisation, etc., are the history, economic situation, population growth, and policy decisions (politics) on SIDS.

Historical influences play a significant role in how contemporary island societies interact with their environment. Some SIDS noted by early societies developed significant basic infrastructure, market institutions and international tourism and have higher per capita GDP and life expectancy (McElory & Medek, 2012). The presence of tourism infrastructure is a key contributor to tourism flows, as is the language and historical (or political) origin and the degree of economic development (Vítová et al., 2019), again indicating the influence of historical human impacts. However, the economies of SIDS are fragile, as there is a significant dependence on: "*foreign aid, remittances and preferential trade agreements"* (Pratt, 2015: 149), meaning that SIDS often have low GDP growth with high levels of both unemployment and underemployment (Pratt, 2015). Low economic development on islands is related to large-scale direct exploitation of the natural capital (Connell, 2013), which is the foundation of livelihoods in SIDS communities. As the population growth rate increases and the natural capital is heavily utilised, such as through agricultural intensification, mining and forestry, the livelihood foundations are placed under increasing pressure (Hay, 2013). Nonetheless, Auty (2017) argued that size, isolation, and limited resources can be compensated for by means of beneficial policy decision-making. In a comparative study between Mauritius, which is resource-poor, and resource-rich Trinidad and Tobago, it was observed that beneficial policies in Mauritius created economic diversification, which ensured rapid economic and political growth compared to Trinidad and Tobago, whose policies hindered diversification and established a vulnerable economy. Vítová et al. (2019) noted that political stability is another significant factor in determining tourism flows to SIDS. In addition, Matthew and Gaulin (2001) examined the link between resource scarcity and conflict on SIDS using resource-poor Nauru and the resource-rich Solomon Islands as case studies. These authors observed that political stability and policy decisions concerning trade openness ensured the absence of conflict in Nauru, compared to the conflicts witnessed in the Solomon Islands.

2.4 Socio-ecological systems

2.4.1 What is a socio-ecological system?

Recognition has been given that challenges arising from natural resource and environmental management occur at the nexus between complex ecological and social subsystems (Berkes et al., 2003). One of the foremost acknowledgements of this interaction was by Berkes and Folke (1998), who employed a socio-ecological systems viewpoint of how humans interacted within nature, with a specific focus on the then-emergent resilience theory. Berkes and Folke (1998: 4) stated that, within the socio-ecological systems standpoint: "*the delineation between social and natural systems is artificial and arbitrary*." The fundamental concept is that societies, in their entirety, are intrinsically entrenched within their environment, ultimately forming part of it and thereby shaping it at both a local and global scale (Anderies et al., 2004; Folke et al., 2016). Equally, humans significantly depend on and co-evolve with nature (Berkes, 2017), thereby being affected by changes taking place within the environment in which they are embedded. Simply put, the social and ecological subsystems are coupled and interdependent, and can be defined as a linked system in which people depend on the environment and the environment is affected by people's actions

(Cumming et al., 2012; Berkes, 2017). Both the social and ecological subsystems, however, may comprise a multitude of levels (Berkes, 2017). For example, a specific tree species may form part of a particular vegetation type, which in turn forms part of a larger biome. Comparably, when considering nested social aspects within the social subsystem, an individual may form part of a community that exists within a set of communities that may share a common pool of resources or form part of the same jurisdiction.

Essential to understanding the reasoning behind socio-ecological system collapse versus those that remain resilient is: "*the identification and analysis of the relationships among multiple levels of these complex systems at different spatial and temporal scales"* (Ostrom, 2009: 420). Central to analysing socio-ecological systems is the use of a framework.

2.4.2 Frameworks for analysing socio-ecological systems

2.4.2.1 Socio-ecological systems frameworks

Three of the more consistently utilised frameworks include the original Berkes and Folke (1998) **socio-ecological framework**, the Anderies et al. (2004) **robustness framework** and the continually developing Ostrom (2007) multitier **socio-ecological systems framework** (Colding & Barthel, 2019). A study by these latter authors explored the socio-ecological discourse 20 years after it was initially envisioned, thereby indicating the popularity of utilising these different frameworks. It revealed that recent studies were inspired by either the original Berkes and Folke (1998), Anderies et al. (2004), or Ostrom (2007) frameworks, indicating a preference for using a framework that was best suited to the scenario rather than the most recently published.

The initial iteration of the socio-ecological systems framework (Figure 2-2) was conceived by Berkes and Folke (1998) to understand what provides institutional resilience and whether it is equally beneficial for institutional and ecological resilience to be coupled (Colding & Barthel, 2019). The original framework was designed as an investigative tool for assessing local resource management systems that were not subject to conventional resource management but rather those with a continuous practice for resilience building at a local level (Colding & Barthel, 2019).

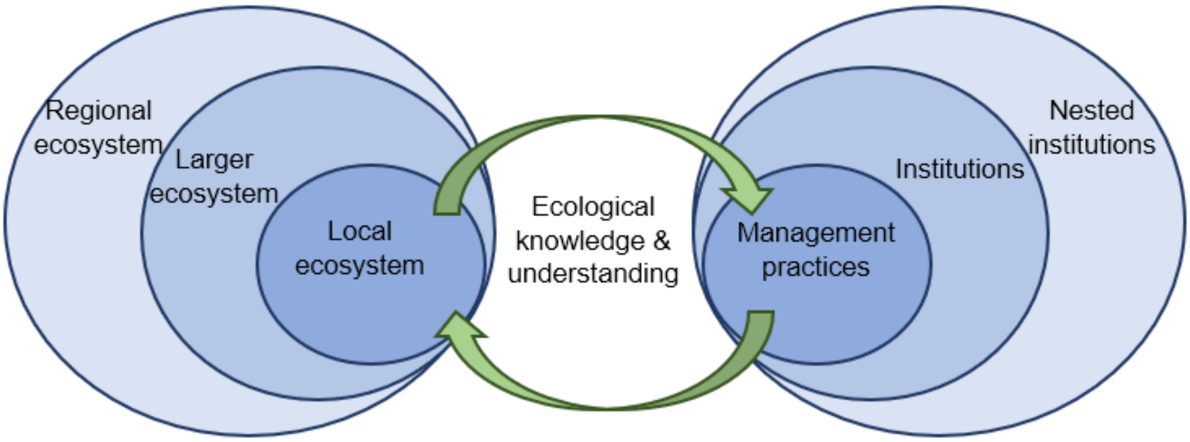


Figure 2-2: Modified conceptual framework based on Berkes and Folke (1998) for the analysis of linked social-ecological systems (Colding & Barthel, 2019 (CC BY-NC 4.0))

Berkes et al. (2003) later employed the same framework to try to understand the adaptability of socio-ecological systems to remain sustainable in the face of change and shocks, while considering the dynamic nature of ecosystems. More recently, a study by Heslinga et al. (2017) was informed by the framework to better understand the interactions between tourism and landscapes in coastal areas in the Dutch Wadden, including tourism's potential to build resilience within the socio-ecological system.

Anderies et al. (2004) argued that, in intentionally planned systems, applying resilience theory is problematic and therefore developed a model to assess the robustness of socio-ecological systems, allowing for the identification of possible vulnerabilities of systems to disturbances. The key feature of the model developed by Anderies et al. (2004) is that it can: "*recognize both the designed and self-organizing components of a SES and to study how they interact*". The model (Figure **2-3**) describes four different entities, namely, resources, which are utilised by resource users as well as public infrastructure providers, and public infrastructure, which refers to both physical and social capital (Colding & Barthel, 2019). The model also allows for exploring the effects of external disturbances on resources, social actors and infrastructure, as well as providing the necessary links that determine the relevant interactions between each of the entities.

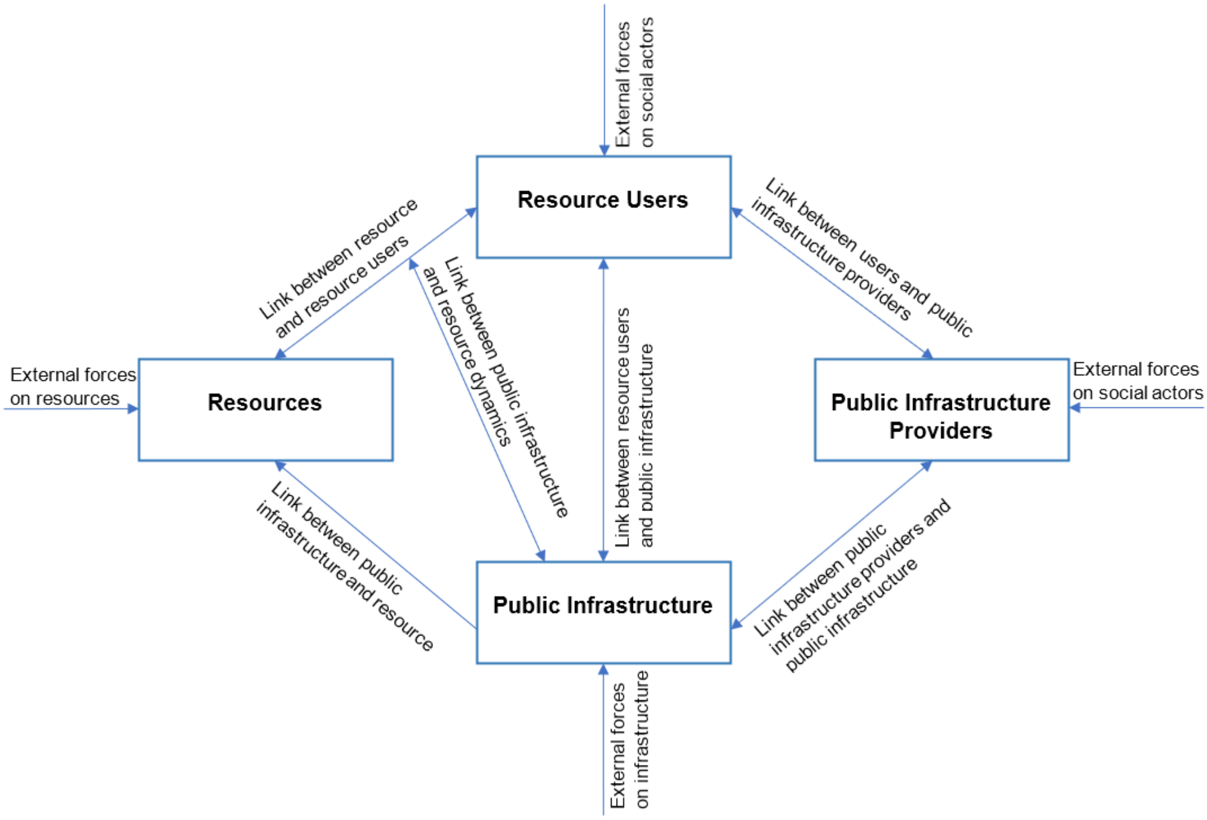


Figure 2-3: Robustness framework for analysing socio-ecological systems (Adopted from Anderies et al., 2004, cited in Colding & Barthel, 2019 (CC BY-NC 4.0))

Recent examples of the use of the robustness framework are provided in Naylor et al. (2019) and Rubiños and Anderies (2020). The first case utilised the robustness framework to assess local scale responses to dealing with the effects of intense storms on Cornwall, allowing for improved local climate change adaptation planning (Naylor et al., 2019) In the second instance, the resilience of the Piura Basin to floods perpetrated by El Niño was investigated, using the framework, wherein the high vulnerability of the basin was determined (Rubiños & Anderies, 2020). According to Colding and Barthel (2019), the robustness framework developed by Anderies et al. (2004) provided the inspiration for the multitier socio-ecological systems framework developed by Ostrom (2007).

Ostrom (2007) developed a socio-ecological systems framework as a diagnostic tool for structuring and organising a multitude of variables identified as affecting interactions and outcomes within socio-ecological studies (Colding & Barthel, 2019). A key process of the diagnostic tool is organising the identified variables in a nested, multitier framework (Ostrom, 2007). This multitiered framework facilitates the organisation of second-tier variables in a nested manner, enhancing understanding of how each variable may be affected by and affect the greater ecological, socio-economic, and political state in which it is embedded (Colding & Barthel, 2019). In the first iteration of the framework by Ostrom (2007), scholars could organise and then examine how attributes of (1) a resource system, (2) the resource units produced within that resource system, (3) the users of that resource system and (4) the governance system that both affects and is indirectly affected by interactions and the subsequent outcomes. An example of this organisation is provided by Nel et al. (2022), which organised variables within the multitier socio-ecological systems framework to more closely examine informal Sand Forest harvesting (Figure 2-4).

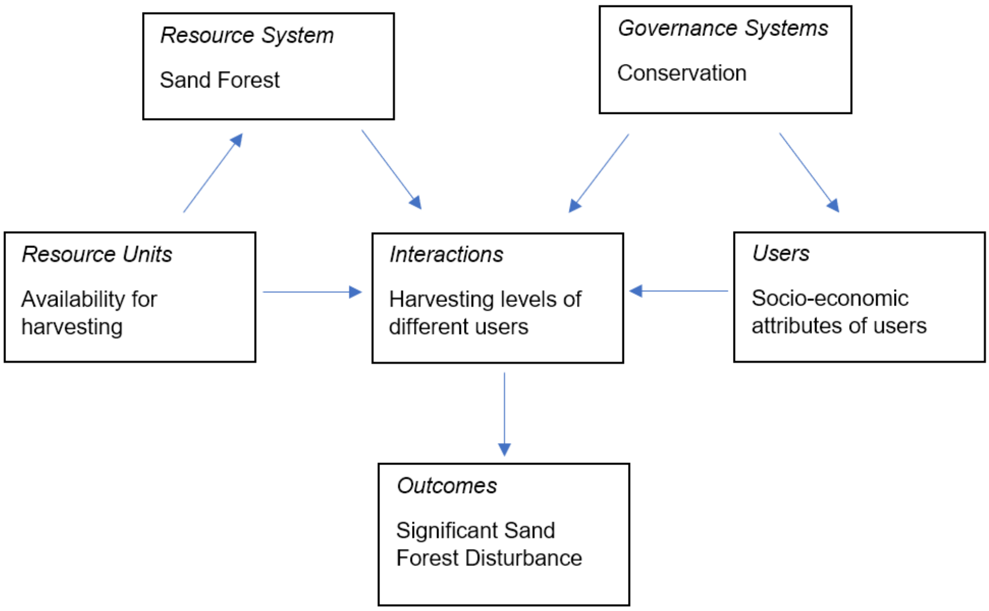


Figure 2-4: Conceptual SES framework for analysing informal Sand Forest harvesting, based on the Ostrom (2007) multitier framework (Adapted from Nel et al., 2022)

The initial multitier socio-ecological systems framework devised by Ostrom (2007) aimed to be applied to defined management circumstances within a sphere of shared resources, where users extract resource units from a resource system and also provide for the preservation of said resource system in accordance with regulations stipulated by the governance system. These all occur within the context of the overarching ecological, social, political, and economic setting (McGinnis & Ostrom, 2014). Ultimately, within the initial framework derived by Ostrom (2007), the utilisation and the preservation of the resource system were regarded as among the most significant types of interactions and outcomes (McGinnis & Ostrom, 2014). However, attention within socio-ecological system studies moved towards a much wider set of social and ecological variables that are considered important in such a system. Therefore, the multitier socio-ecological systems framework (Figure 2-5) was revised in such a way that it made it more applicable to a wider array of empirical settings whilst ensuring that the generalizability of the framework made it more applicable (McGinnis & Ostrom, 2014).

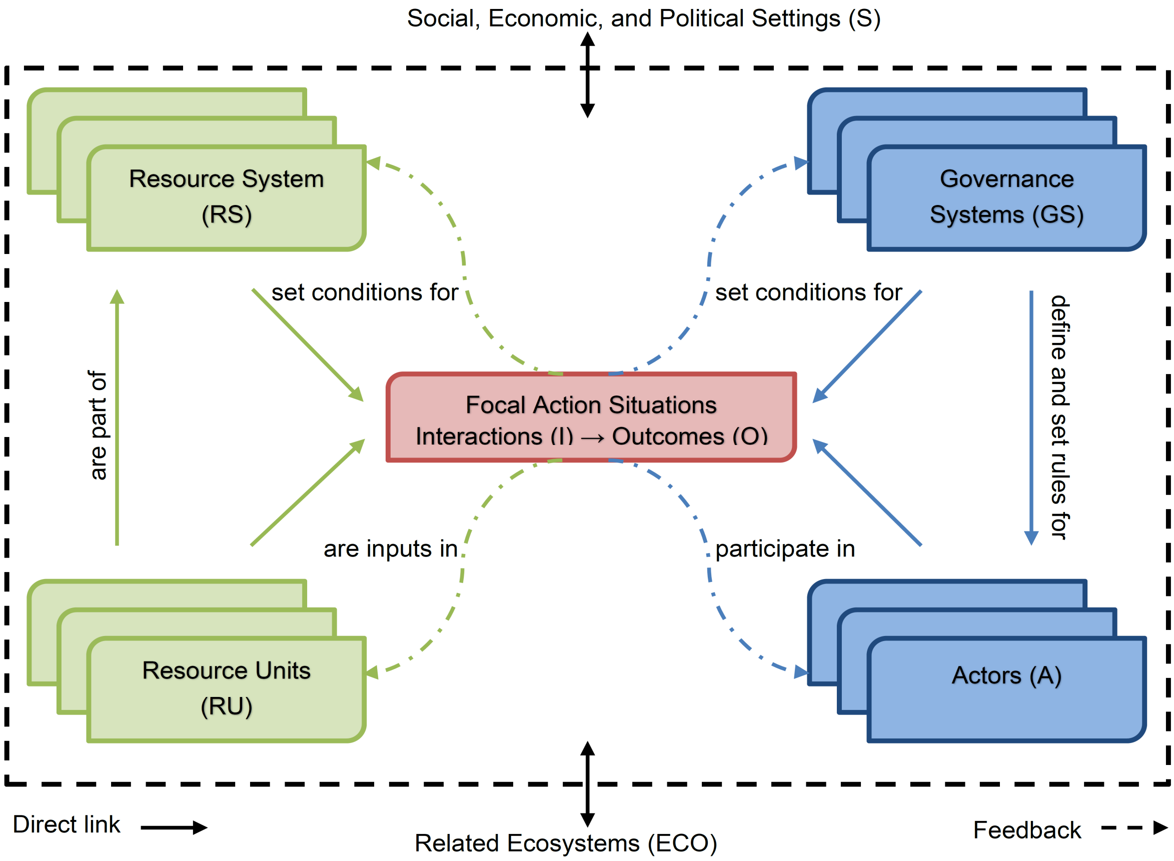


Figure 2-5: Multitier framework for analysing socio-ecological systems (McGinnis & Ostrom, 2014; Colding & Barthel, 2019 (CC BY-NC 4.0))

The revisions to the framework were made to increase its generalisability by expanding its applicability to more complex socio-ecological systems where: "*multiple sets of actors consume diverse resource units extracted from multiple interacting resource systems in the context of overlapping governance systems*" (McGinnis & Ostrom, 2014). Several significant revisions to the initial framework include, but are not limited to, the following:

- Recognising action situations: within the original framework (Ostrom, 2007), action situations were integrated into the actions and outcomes aspect of the framework. However, the revised framework was amended to include the broader term action situations, which describes how actors, in situations, make decisions between different options based on information pertaining to the possible actions of other actors and the cost-benefit of potential outcomes (McGinnis & Ostrom, 2014). Simply put, the action situations are: "*where all the action takes place as inputs are transformed by the actions of multiple actors into outcomes"* (McGinnis & Ostrom, 2014).

- Generalising users to actors: The applicability of the framework was significantly expanded by changing users to actors. This enabled the assessment of scenarios where the actors directly involved in the extraction of resources differ from the actors consuming the product derived from the extraction process. Ultimately, it allows for the classification of groups of actors based on the assortment of activities in which they are involved (McGinnis & Ostrom, 2014). An example of a socio-ecological system necessitating the term actors is given in a study by Mohammed et al. (2017), which examined the role of external actors for sustainable forests. Within the study, there is a differentiation between actors that (1) directly benefit from forest goods and services and (2) the government's forestry department, which plays a role as an external actor.
- Multiple versions of top-tier components: The preliminary socio-ecological framework was often interpreted as a single set of users that were reliant on a specific resource unit that was extracted from a single resource system, embedded in a single key governance system that interacted in a single central action situation. The allowability of including multiple governance settings or ecosystems was included in the outlying Social, Economic, and Political Settings and Related Ecosystems categories, though the first iterations of the framework were often interpreted as though the framework allowed only for a single case of each first-tier component (McGinnis & Ostrom, 2014). Realistically, socio-ecological systems studies often include more than a single resource system or unit, as well as multiple actors. Therefore, the framework now illustrates the ability to include multiple instances of each of the top-tier components, where applicable (McGinnis & Ostrom, 2014). This is illustrated in a study by Naranjo-Madrigal et al. (2015), where an understanding of socio-

ecological drivers was needed to ensure effective management of artisanal fisheries in Costa Rica. This socio-ecological system included multiple dive sites as well as multiple target species that needed to form part of the analysis.

The multitier socio-ecological systems framework was utilised to analyse several different socio-ecological systems across various scales. An adaptation of the framework was used to understand how the roles of actors (policy, private and community) within socio-ecological systems across Europe could be both complementary and synergistic in furthering socially beneficial outcomes, strengthening ecosystem services and overall system sustainability (Dwyer et al., 2020).

There are also instances where more than one framework can be used in conjunction for a more comprehensive analysis of a socio-ecological system. To draw attention to how forestry institutions affect forest ecosystems, forest functions, and social arrangements in the Quatre-Montagnes forest (south-east of France), Houballah et al. (2020) employed both the multitier and the robustness framework. The multitier socio-ecological systems framework was utilised to explain the significance of infrastructure-related variables in influencing interactions between components of the socio-ecological system, after which the robustness framework was applied to analyse ecosystem functions for infrastructure governance. Through the combined use of the frameworks, the study provided insights into designing effective forest management with substantial infrastructure dependencies.

The socio-ecological framework developed by Ostrom (2007) continues to develop as a diagnostic instrument used to understand the factors of sustainability in complex socio-ecological systems (McGinnis & Ostrom, 2014). The most recent expansion of the framework was published by Schlüter et al. (2019) and is referred to as the social-ecological action situations (SE-AS) framework (Figure 2-6). The framework aims to assist in the development of theories about the configurations of action situations that would describe an emergent social-ecological phenomenon, which include regime shifts, transformations and traps that result from: "*interactions among and between human and nonhuman entities within and across scales"* (Schlüter et al., 2019: abstract)

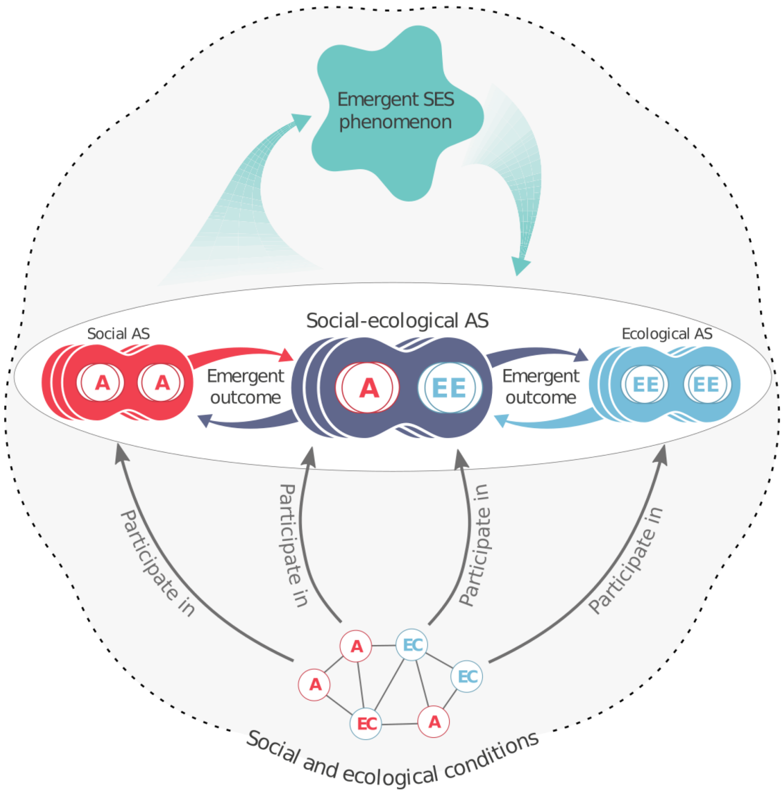


Figure 2-6: The generic social-ecological action situations (SE-AS) framework (Schlüter et al., 2019) (CC BY-NC 4.0))

Within the SE-AS framework, the ellipse at the centre represents imagined configurations of action situations that create emergent socio-ecological phenomena. An envisaged configuration is established through recognising social-ecological, social, and ecological action situations from the multitude of interactions within the socio-ecological system (bottom network) that are deemed pertinent from either an empirical or theoretical viewpoint. Emergent phenomena are caused by a continuous process of local interactions that influence emergent outcomes to which they then adapt, as shown by the green arrows (top interaction).

From the three main socio-ecological systems frameworks that could be identified as prominent features in future aspects of the study, the revised multitier framework by McGinnis and Ostrom (2014) was selected. The revised multitier framework has clear components, explicit connection points between components of the socio-ecological system (e.g., between governance systems and actors), and is easily interpretable, making it highly suitable for incorporating "islandness" and for modelling with BBNs. While both the robustness framework and social-ecological action situations (SE-AS) framework also share similar properties, they have notable features that have excluded them from use. The robustness framework differentiates between resources used by resource users and public infrastructure, which would create additional complexities in data gathering. The aim of the social-ecological action situations (SE-

AS) framework differs from the more practical aims of this study and was therefore excluded from consideration.

2.4.2.2 Alternative frameworks used to analyse socio-ecological systems

As socio-ecological systems research advanced, frameworks arose from the necessity for concepts that provide structure and an interdisciplinary approach to complex problems in socio-ecological systems. In addition to the socio-ecological systems framework, an array of other frameworks was developed to analyse socio-ecological systems, differing in the way they approach the conceptualisation of the social and ecological systems and their interactions (Binder et al., 2013). Additional frameworks that were initially considered for the socio-ecological islandscape concept included the Driver-Pressure-State-Impact-Response (DPSIR) framework and the sustainable livelihoods framework (SLA).

The DPSIR framework (Figure 2-7), developed by the Organisation of Economic Cooperation and Development and the European Environment Agency (Gari et al., 2015), is a theoretical framework that examines the cause-and-effect relationships within the socio-ecological system and supports decision-making in response to environmental problems (Spanò et al., 2017). The framework considers driving forces that exert pressure on the environment, resulting in changes in the state of the environment. Subsequently, these changes result in impacts on the socio-ecological system that elicit a societal response.

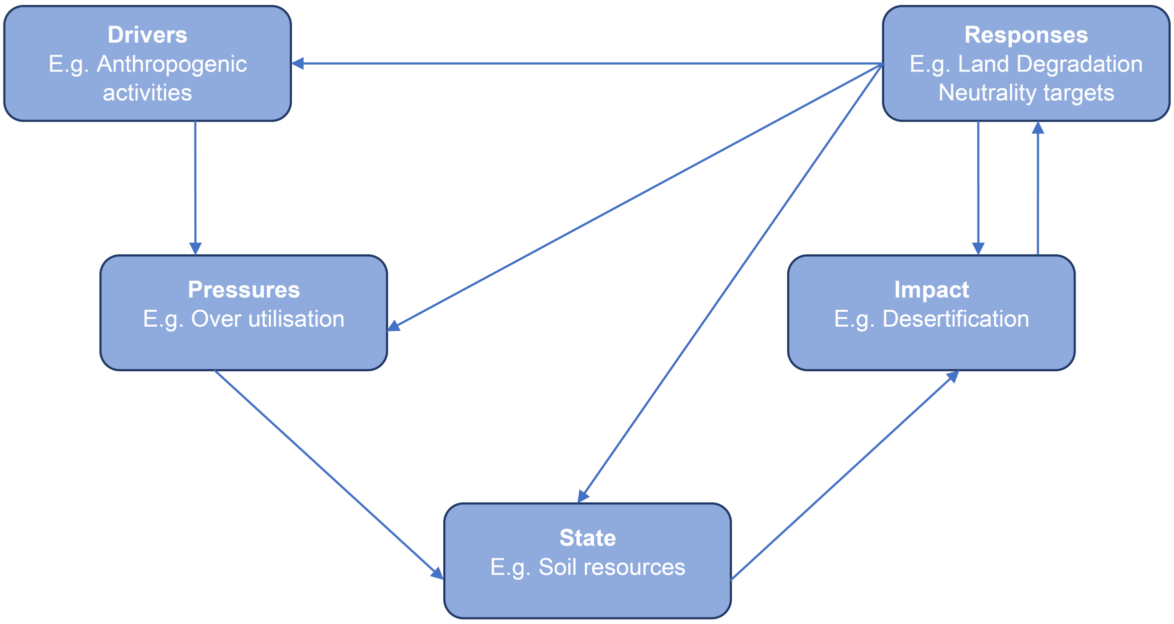


Figure 2-7: The Driver-Pressures-State-Impact-Response framework (European Environment Agency (EEA), 1999. Environmental Indicators: Typology and Overview. Technical report No 25).

A study by Janssens de Bisthoven et al. (2020) illustrates the use of the DPSIR in socio-ecological system studies by providing a socio-ecological assessment of the Lake Manyara Basin (Tanzania) to support future sustainable management in an area threatened by land- and water-use conflicts, decreasing water levels, and erosion. However, there are significant issues related to the use of the DPSIR, such as its hierarchical structure and inability to consider complex interactions between different types of indicators (Balzan et al., 2019), due to the use of linear unidirectional causal chains to represent highly intricate environmental issues (Gari et al., 2015). Considering the complexity of the influence "islandness" poses to socio-ecological systems, the DPSIR framework was not considered viable as a basis for the socio-ecological islandscape concept.

The sustainable livelihood approach framework (SLA) was initially developed by the United Kingdom's Department for International Development (DFID) (Su et al., 2016), with the aim of arranging communities' livelihoods by considering the vulnerabilities they faced and their available assets (Mahama & Maharjan, 2019). This organisation of livelihoods allows the identification of assets (natural capital, physical capital, economic capital, human capital, and socio-cultural capital) that can form the basis of a livelihood, thereby contributing towards understanding the relationship between them and the means for developing an adequate livelihood strategy. The SLA also considers that certain contextual factors will affect the composition of the livelihood resources, while transforming structures and processes affect how these resources form part of the livelihood strategies (Mahama & Maharjan, 2019). The SLA (Figure 2-8) is therefore comprised of five major components, namely contexts, livelihood assets, transforming structures and processes, livelihood strategies, and livelihood outcomes (Su et al., 2016).

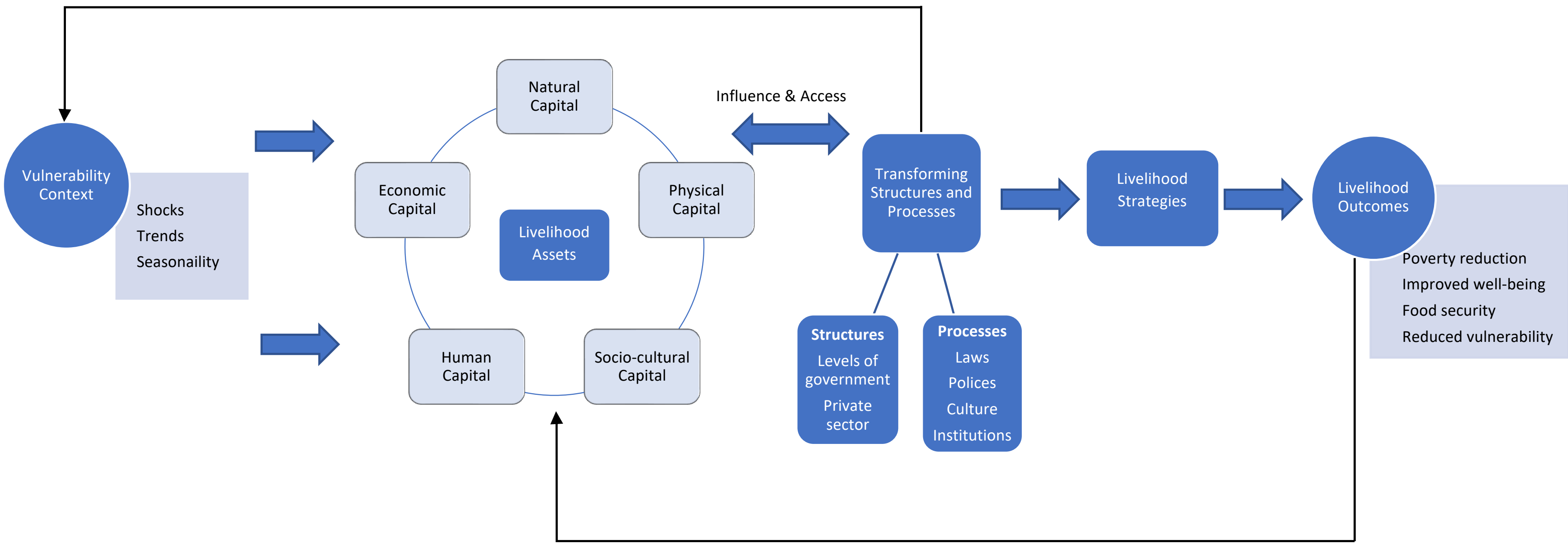


Figure 2-8: The Sustainable Livelihood Approach Framework (Adapted from DFID, 1999)

An example of the application of the SLA was provided by Su et al. (2019), who used the framework to understand the relationship between tea and tourism within Hetu Town, Anhui Province, China, and found a direct correlation between improving diversity and choice and the livelihood sustainability of communities. Although the SLA was seriously considered for the socio-ecological islandscape concept, the outcomes are strongly socially driven rather than equally social and environmental, with a focal point on how external drivers influence resource users and their livelihood strategies. The DPSIR and SLA are heavily focused on pressures on either the social or environmental aspects of a system, with unilateral human-nature interactions (Gopirajan et al., 2021), therefore, these frameworks were not further explored for the development of the socio-ecological islandscape concept.

2.4.3 Applying the socio-ecological systems perspective

The socio-ecological systems approach may be applied to a multitude of environmental and social problems. The fundamental recognition of the complexity of natural systems with a coupled human-environment viewpoint and with an operational method, through the frameworks developed, that provides broad parameters for the inclusion of environmental and social variables, supported the widespread application of the socio-ecological system. This differentiates the socio-ecological systems approach from other practices (Teitelbaum et al., 2019). Insights into the application of the socio-ecological systems approach are provided to give a brief understanding of the flexibility and extent to which it can be used.

Within the environmental management field, the continuously rising stakes of emergent environmental issues have prompted the need for an integrative approach, such as the socio-ecological systems perspective (Virapongse et al., 2016). Understanding how social and ecological subsystems interact is a vital step in answering several pertinent questions regarding a system's sustainability. The socio-ecological system approach allows for the initial mapping and examination of how different elements within a system interact, thereby allowing for further analysis. This is illustrated by Mallick (2019), who analysed livelihood resilience across five rural communities by initially determining the attributes of the socio-ecological systems of these communities. However, the socio-ecological system has the capacity to be used beyond a diagnostic means and as an environmental management tool. This is shown by Sunderland et al. (2017), who used a socio-ecological systems approach to understand the impacts of land use and agrarian change, and how these changes affect conservation, livelihoods, and food security. The results of the study showed that changes in land use from forest to agriculture did not necessarily improve livelihoods.

Furthermore, socio-ecological systems have also been useful in other aspects of environmental management and sustainability, such as understanding how societies transition and the changes that occur within the system (Malhotra et al., 2021), evaluating different management or environmental scenarios (Schmitz et al., 2017), understanding the vulnerability of communities to various pressures (Jara et al., 2020) and of particular importance, the ability to investigate resilience (Mallick, 2019). The inclusiveness of the socio-ecological systems perspective and its continued successful application were paramount in the decision to employ it and the associated frameworks as a fundamental core for establishing a concept aiming to assess human-environment interactions on SIDS.

2.5 Landscape sustainability

There has been a growing recognition that examining issues around sustainability at a landscape scale provides valuable insights for management decisions (Tourinho et al., 2022). This is due to the correlations seen between landscapes and sustainability (Zhou et al., 2024) as described by Wu (2013: 999) in the definition given for landscape sustainability, which is as follows:

"*Landscape sustainability is defined as the capacity of a landscape to consistently provide long-term, landscape-specific ecosystem services essential for maintaining and improving human well-being in a regional context and despite environmental and sociocultural changes*.

Landscapes are considered the quintessential scale to examine human-environment interactions (Hanspach et al., 2014; Liao et al., 2020), as the spatial extent of more localised studies may be unable to incorporate the greater social, economic, or environmental aspects within a system, resulting in certain patterns or processes being excluded (Wu, 2013). A study by Morán-Ordóñez et al. (2013) illustrates this differentiation in scale effectiveness, whereby changing demand at a local scale in the Cantabrian Mountains heathland altered regional actions, creating a mismatch between landscape service demand and delivery and thereby threatening the sustainability of the landscape. An argument could also be made for why landscape-level analyses are more valuable than globalised studies, as information derived at a global level is often less operational in nature and therefore less useful for developing localised policies (Wu, 2013). This is seen in the study by Estoque and Murayama (2017), where a social-ecological status index was used in a global assessment of countries' social-ecological status. The study provided relative information on a country's comparative status and the potential reasons for that status; however, the most valuable aspect of the insights gained is the ability to convey them to the public. The data at the country level are not sufficiently in-depth to develop actionable recommendations. Interactions between society and the environment that take place at a landscape level often reverberate both locally and globally, making the associated composition and arrangement very important and supporting the application of a landscape approach (Wu, 2021). Pickard et al. (2017) illustrated this idea, where research on the spatial configuration of urbanisation across a landscape showed the effects that different urban configuration scenarios would have on ecosystem services. Though all scenarios showed degradation of ecosystem services, these existed on a gradient depending on the arrangement, revealing a trade-off. Ultimately, the landscape-level information has consequences for local policy development and, considering the effect urbanisation has on biodiversity, global concerns. Thus, landscapes can be seen as the geographical realisation of socio-ecological systems (Petrosillo et al., 2010; Wu, 2021). The following section will further discuss the rationale for using landscapes to operationalise socio-ecological systems in the form of a socio-ecological landscape.

2.5.1 Socio-ecological landscapes

Examining socio-ecological systems at a landscape scale offers a more practical foundation for understanding the nuances associated with human-environment interaction within a spatial context (Zurlini et al., 2012) and whose effectiveness has been shown to be evident (Hanspach et al., 2014). This may result from socio-ecological landscapes that often contain a multitude of ecosystems (inclusive of a number of interacting ecosystem services), economic activities as well as social systems (such a varying levels of governance issuing policy recommendations within the same landscape), resulting in this scale of assessment being highly effective at addressing the interdisciplinary nature of socio-ecological systems, allowing analyses to consider these nestled challenges as a single entity (Cummin, 2011a). A landscape approach to socio-ecological systems has been successfully used in many studies. These include using landscape structure to inform the identification of socio-ecological networks and bundled ecosystem services (Arnaiz-Schmitz et al., 2018; Lorilla et al., 2020), examining land use change to understand the status of ecosystems within a landscape, thereby providing insights for land use planning and policy development (Sahle & Yeshitela, 2018) and understanding how historical societies and their associated human-environment interactions evolved in relation to how these changes caused the landscape in which they were embedded to evolve (Ullah et al., 2019).

2.5.2 Islandscapes

As a result of the development of islands at the intersection between land and sea, islands encompass both landscapes and seascapes. In addition, islands have generally been subjected to anthropogenic changes that have resulted in the emergence of a myriad of anthromes. The summation of these factors (i.e. landscapes, seascapes, and societal influences) creates a distinctive environment that has been dubbed "islandscapes" (Cheer et al., 2017; Vogiatzakis et al., 2017). Considering that the focal point of landscape sustainability is generally at a regional scale, and decisions made within the landscape may be consequential to surrounding landscapes (Meyfroidt et al., 2013), it is vital to take an islandscape perspective, thereby allowing incorporation of surrounding islands. For example, Rodrigues Island is economically dependent on Mauritius in terms of its agricultural export, while the food supply in Mauritius is affected by this relationship. Consequently, if a shock occurs on Rodrigues (e.g., drought) that affects the annual output of certain crops (e.g., onions), this will affect the economy and food security on both Rodrigues and Mauritius. The broader notion of islandscapes, as opposed to single-island landscapes in an archipelago setting, was deemed more appropriate for developing a concept to assess challenges related to SIDS. Therefore, there is an emergent rationalisation for describing socio-ecological systems present on SIDS as socio-ecological islandscapes.

2.6 Resilience

Holling (1973: 14) stated that resilience: "*is a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables"*, a definition that still holds a considerable amount of weight in current resilience research (Angler & Allen, 2016). Although the resilience concept emerged in ecology, it has gained traction in numerous fields, and is being applied to various approaches assessing complex and coupled systems, such as in engineering (Li & Gao, 2021), environmental management (An et al., 2021), human health (Choi & Kim, In Press), livelihoods (Amadu et al., 2021) and urban planning (Serdar et al., 2022). The resilience concept places considerable importance on aspects such as uncertainty, non-linear dynamics, thresholds, and shocks (Folke, 2006). Thresholds can be considered the tipping point at which a perturbation can cause a system to shift to an alternative state (Angler & Allen, 2016), which could be easy or difficult to reverse, or completely irreversible (Farley & Voinov, 2016). The resilience approach considers that these disturbances to a system can occur gradually and rapidly, and that there exists a relationship between these that interact over differing temporal and spatial scales (Folke, 2006). For example, a rising sea temperature is a gradual change that affects fishing communities on SIDS. Sea temperature influences coral reefs, which, at a certain threshold, results in bleaching. The rapid change in the system resulting from the bleaching has significant effects on the entire system, from biodiversity to the food supply for reliant local communities.

However, as stated by Field and Parrot (2017: 31): "*several properties contribute to system resilience, including adaptive capacity, diversity, redundancy, slow-changing variables, feedbacks, and connectivity"*. Of particular importance is adaptative capacity, which has varying definitions, though it was summed up effectively by Warrick et al. (2017: 1040), who stated that: *"definitions of adaptive capacity often explicitly emphasise the ability to both proactively and reactively respond to perturbations."* Adaptive capacity not only explains how a system prevents change, but also its ability to reorganise structures and process, emerging as a different system without compromising the system’s sustainability (Folke, 2006). Continuing with the example given, the ability of the local community to adapt to a changing food supply would improve the resilience of the entire system, as reduced consumption of seafood-based protein would reduce the resultant pressure on the reef system by changing the trajectory of the community's food system. Variables that influence dynamics within a socio-ecological system can be considered as either slow-changing or fast-changing. Fast-changing variables are those affected by short-term perturbations and are less useful for understanding the long-term state of a system, while slow-changing variables often drive fast-changing variables and are vital for understanding how a system will be able to adapt or respond to change (Ferrara et al., 2016).

Resilience has been studied in both depth and breadth. Therefore, it is important to focus the review on aspects that relate to the objectives of the study. Subsequently, the following section aims to discuss how resilience pertains to the socio-ecological system, provide an overview of spatial resilience and how it materialises on SIDS, as well as approaches to measuring spatial resilience.

2.6.1 Resilient socio-ecological systems

Resilience with respect to a socio-ecological system is the ability of the system to adapt or transform, whilst maintaining the capacity to support human well-being, in response to a change, especially in circumstances where the change is unexpected and results in a shock to the system (Biggs et al., 2015; Folke et al., 2016). The transformation may result in the separate components of the system changing (i.e., adapting) according to the new state, while the overall function of the system is maintained (Ciftcioglu, 2017). A system is not always required to be functioning at 100% capacity for it to be considered as being resilient; instead, it remains functional in the face of internal and external changes (Rubinos & Anderies, 2020). An example of this is alluded to in Jara et al. (2020), where due to El Niño events, changes in species composition and quantity were recorded around two areas (i.e. Vegueta and Huacho) of the Peruvian coast, affecting localised artisanal fishing. Yet, Huacho has entrenched adaptive capacity in the form of a more diverse local economy, which allows the system to remain functioning even when a core element (i.e. quantity of species vital to the system) is under stress.

However, socio-ecological systems are composed of different interacting components (i.e. social, economic and ecological), resulting in the feedbacks and thresholds within such systems being far more intricate. Within the complex interactions that comprise socio-ecological systems are several thresholds, and for a system to be resilient, both the ecological and social thresholds should be considered as being important. Likewise, the feedback loops between the components of the system are more complicated than considering resilience solely in terms of either the ecological or social aspect. Therefore, examining resilient socio-ecological systems requires significant amounts of information and in-depth analysis of the complex human-environment relationships. Consequently, predicting the resilience of socio-ecological systems is more difficult than predicting the resilience of their individual components (Cote & Nightingale, 2012; Li et al., 2020). The resilience concept has shown itself to be successful at examining changes taking place within socio-ecological systems at both temporal and spatial scales (Ciftcioglu, 2017). As shown by Whitfield et al. (2019), the resilience concept was used to understand the effects of El Niño on six diverse socio-ecological systems across the Tropics.

Further adding to the complexity of socio-ecological system resilience is the notion that a disparity may exist between the social and ecological systems, creating a situation where the feedback loops may negatively affect each component, pushing the subsystems past their thresholds and causing the system as a whole to deteriorate into an unsustainable state (Boonstra et al., 2016). This problem-causing mismatch is referred to as a socio-ecological trap (Cumming, 2016), which finds its origins in poverty traps, although they differ as poverty traps are devoid of ecological dynamics (Eriksson et al., 2021). For example, Yang et al. (2019) discussed how the historical transition from agriculture to coal mining in Shanxi Province (China) and the subsequent degradation of land and depletion of resources led to mining closures and the creation of a poverty trap. However, it can be argued that this is an example of a socio-ecological trap, as continued land degradation would further reduce productive capacity, affecting current and future income.

Linking the socio-ecological resilience back to the previous discussion around landscape resilience, there is increasing consensus that environmental management and planning policies should aim at preserving the resilience of socio-ecological systems at a landscape scale (Field & Parrot, 2017), with the resilience perspective ensuring such strategies are underpinned by the notion of managing the ability of a socio-ecological system to adapt to changes rather than trying to control the changes to which the system is subjected (Folke, 2006). A subset of resilience that is considered effective for analysing resilient landscapes is spatial resilience, owing to its focus on patterns and processes (Cumming, 2011b) that correspond with the overarching approach to examining landscape sustainability.

2.6.2 Spatial resilience

Spatial resilience is regarded as the way in which spatial attributes of the variables within a complex system influence feedback (both internally and/or externally) that creates resilience across different temporal and spatial scales (Allen et al., 2016; Rescia & Ortega, 2018). As a subset of resilience theory, the focal point of spatial resilience is on patterns and processes that exist at various locations across a landscape and at varying spatial scales, as these landscapes have intrinsic spatial attributes that influence whether the system is resilient (Cumming, 2011a; Allen et al., 2016). Cumming et al. (2017) considered that, beyond the significance of the spatial arrangement of a system and the interactions that exist between them, there are important factors that influence the spatial resilience of a system, such as temporal dynamics, connectivity, context, as well as spatial feedback and subsidies. In addition, areas that are spatially linked and maintain the system's prior spatial attributes after a disturbance increase the likelihood of the system either returning to the previous state or maintaining functionality. This is regarded as system memory (Chuang et al., 2018). Spatial resilience elements can be separated into elements that are within the system (internal) and those that influence the system externally, both of which interact and may result in either a system being maintained or a transition to a different state, which may or may not be functional (Allen et al., 2016). The internal elements include spatial arrangements, system properties (size, shape and the number and nature of the boundaries), temporal dynamics and location-specific influences, while the external elements consist of context (i.e. the influence of elements surrounding the system), connectivity and spatial feedback and subsidies (Cumming, 2011b). As in resilience theory, a landscape may not necessarily remain in the same state to be considered resilient; however, spatial attributes must be maintained at a level that keeps important patterns and processes critical for continued functioning (Cumming, 2011b).

The goal of investigating spatial resilience, and in particular understanding the baseline spatial resilience of any given system, is to use this information to determine the trajectory of a system's resilience based on scenarios, which can ultimately be significantly influenced by policies and management strategies (Cumming, 2011a). Therefore, from a land planning perspective, understanding a system's general resilience capacity to withstand perturbations is vital, and the insights gained from this understanding could be a useful tool in the spatial planning and management of complex socio-ecological systems (Rescia & Ortega, 2018).

2.6.3 Spatial resilience of island socio-ecological systems

Understanding resilience in the context of spatial configurations or patterns within socio-ecological systems has been growing steadily (Cumming et al., 2017) and is of particular importance in socio-ecological systems under pressure, which may result in a transition to an alternative state (Lucash et al., 2017). The socio-ecological systems that are present on SIDS are an example of such a socio-ecological system. The links between the internal and external spatial resilience elements formulated by Cumming (2011b) and SIDS have been examined in Table 2-1, with the aim of providing a point of departure for modelling these elements in a socio-ecological islandscape context. Robust modelling of spatial resilience accounts for all elements of spatial resilience; therefore, each element should form part of operationalising spatial resilience on SIDS.

Table 2-1: Internal and external spatial resilience elements (Cumming, 2011b) and their links to Small Island Developing States

Spatial Resilience	**Links to Small islands developing states**
Primary internal elements	
Spatial arrangement	The configuration of communities in relation to the archipelago in SIDS will affect both the type of resources relied on by the communities as well as access to resources these communities will have. This spatial arrangement can often be influenced by the

Spatial Resilience	Links to Small islands developing states
	configuration of other elements within the SIDS, such as services, natural capital, and topography.
System properties (e.g., size, shape and the number and nature of the boundaries)	Several system properties effect SIDS, such as the size of the island, which will significantly affect the number of resources available and prevent economies to scale and SIDS, by nature, have a hard boundary that encompasses the entirety of the system (i.e., surrounded by the sea).
Temporal dynamics	An example of temporal factors that influence the functioning of the socio-ecological system on SIDS includes climate vulnerability, which affect both exposure and sensitivity to climate change as well as a measure of adaptive capacity.
Location	Location refers to specific unique properties (i.e., physical, environmental or socio-economic) of the system that can directly contribute to their resilience capacity. Due to the finite resources available to SIDS (both in terms of human and natural resources), this aspect is of particular importance.
Primary external elements	
Context	Context refers to the spatial surroundings, which can include aspects of governance and global economic influences on the local system. Considering political and economic position of SIDS within the global arena, these aspects contribute considerably to their overall resilience capacity.
Connectivity	An important aspect of functionality of a socio-ecological system is the connectivity between people and resources, either social resources (economic opportunities, services) or ecological resources (natural capital). Connectivity within a SIDS can include hard boundaries, due to the dominance of the sea. The most influential aspect of connectivity related to SIDS is their isolation. The distance of the islands from the mainland has significant effects on the economy, biodiversity, and politics of SIDS.
Spatial feedbacks	Taking the example of population dynamics, spatial feedbacks that influences this is migration, either between islands within the same archipelago or to the mainland. Spatial feedbacks from spatial

Spatial Resilience	Links to Small islands developing states
	variations can either positively or negatively affect the system. In the case of migration, the social resilience decreases, however, the pressure of natural capital also decreases.
Spatial subsidies	Subsidies within SIDS are limited as a result of their location in space and their inherent hard boundaries. One significant subsidy that affects a number of SIDS is tourism, which is a major contributor to both the economy and the consumption of resources.

According to Li and Liu (2020), evaluating the state-transitions of service supply in socio-ecological systems is a growing trend in clarifying and quantifying resilience mechanisms. In addition, Field and Parrot (2017) discussed the usefulness of network theory in examining ecosystem services and resilience. These methods can also be useful in understanding regime shifts and the impacts of various landscape network nodes in the context of spatial resilience. Subsequently, the following section will discuss modelling spatial resilience in a socio-ecological islandscape.

2.6.4 Measuring spatial resilience

To have a useful focal point for effectively measuring the various elements of spatial resilience in a socio-ecological islandscape, different approaches can be taken. Allen et al. (2016) advocated for a specific resilience approach, measuring resilience "of what to what", while Rescia and Ortega (2018) proposed the notion of considering the resilience capacity of a system, meaning the general ability of the system to withstand disturbances and not transition into a different state. Paas et al. (2021: 14) stated that: *"General resilience relates to a system's robustness, adaptability, and transformability, regardless the type of challenge or shock"*. This understanding of different spatial resilience capacities in socio-ecological islandscapes is a vital point of departure for explaining the mechanisms responsible for perturbations (Allen et al., 2016). Measuring general resilience in terms of its spatial resilience capacity provides valuable land use planning information for decision-making (Rescia & Ortega, 2018) and can be assessed by evaluating the system elements that provide resilience to that system (Paas et al., 2021).

Composite indicators have been used as measures of multidimensional concepts, such as the nexus between social and environmental performance linked to sustainability (Zhang & Wu, 2022), and for mapping social vulnerability to floods (Ajtai et al., 2023). Kwatra et al. (2020) further elaborate on the usefulness of indicators and indices, highlighting their ability to provide an indication of the status of sustainability as well as directions for policy formulation. However, Kwatra et al. (2020) also identified important considerations for developing a sustainability development index, such as being based on accessible data, being relevant to the underlying issues being measured and being able to show trends over time. The development of indices as a common practice in establishing a measure for complex issues is so widespread that a handbook for constructing composite indicators was published by the European Commission in 2008 (Nardo et al., 2008). This handbook identifies several benefits to developing a composite index, such as its ability to summarise complicated issues into easier-to-interpret measures that can be readily used by decision-makers and the ability to do time-series analysis of the issue, thereby assessing the progress of a country over time (Nardo et al., 2008).

Currently, the key indices which are widely adopted for determining sustainability are the Environmental Performance Index (EPI) and the Human Development Index (HDI) (Philips, 2023). The EPI is a comprehensive index that utilises 58 performance indicators to measure the relative gap between a country and established environmental policy targets (Block et al., 2024). While the HDI provides a summarised measure of the average achievement of a country in important human development dimensions, such as a healthy lifespan, level of education and an acceptable living standard (UNDP, 2025). However, neither of these indices is island-centric in its approach. Assa and Meddeb (2021) argue that, when developing indices for SIDS, consideration should be given to their unique characteristics. This aligns with the socio-ecological islandscape concept and, along with the noted flexibility and usability of an index to measure complex dimensions, such as the socio-ecological islandscape-resilience nexus, has been key in the decision to develop an index for measuring the resilience capacity of SIDS. The development of the Socio-Ecological Islandscape Resilience Capacity Index is detailed in the forthcoming chapters.

2.7 Summary

The current vulnerabilities of SIDS continue to be thoroughly researched, with key pressures identified as overexploitation, agriculture, invasive species, and development, while future perspectives indicate that climate change will soon become the most significant threat (Russell & Kueffer, 2019). Exacerbating these issues are the "islandness" characteristics, such as island size and isolation, thereby contributing to the vulnerability of SIDS (Mycoo et al., 2017). However, while these driving factors have been extensively researched, there is scarce research that looks at how these different factors interact with each other and compound, further increasing the vulnerability of SIDS. This raises questions regarding whether islands that are small but close to the mainland are more vulnerable than large islands that are isolated. Or whether an island that is considered to be large, but its landmass is fragmented into an archipelago, experiences similar development issues as a large, singular island?

In looking for a framework that can answer these questions, the growth of the socio-ecological systems framework emerged. The socio-ecological framework developed by Ostrom in 2007 has continued to develop, with several iterations proposed, the latest of which was proposed by Schlüter et al. (2019). However, the recurring sentiment within the literature is that SIDS are viewed as an epitome for the rest of the world (Chandler & Pugh, 2018); however, as the literature discusses, this is in contrast to the uniqueness of SIDS. The various frameworks available for assessing socio-ecological systems are broadly designed to accommodate any type of study; however, with the growing threat to SIDS, an island-centric framework that ensures the unique characteristics of islands are considered is needed.

While there is a growing body of literature on the concept of resilience and its application to various complex and coupled systems (An et al.,2021; Li & Gao, 2021; Serdar et al., 2022), there is still a limited amount of research being conducted on SIDS. This is also observed in the subset field of spatial resilience, where progress into its operationalisation has been made (Allen et al., 2016), yet this study provides the first attempt to link the internal and external elements of spatial resilience to the socio-ecological islandscapes.

Lastly, research on SIDS resilience is often confined to a local context (i.e. a single country), and very few measures of resilience exist at a global scale. Furthermore, measures that are at a global scale often don't take "islandness" into account (Assa & Meddeb, 2021), leading to issues related to the applicability and usability of the measurement. There is a need for a global island-centric resilience index that can provide SIDS with an easier-to-interpret measure that can be readily used by decision-makers.

The next chapter of the study moves into the first feature creation of the research design, namely, modelling the socio-ecological islandscape. This chapter will detail both the design decision and the results of the socio-ecological islandscape model, which aims to capture the role "islandess" characteristics have in influencing socio-ecological systems.

CHAPTER 3. THE ROLE OF "ISLANDNESS"

3.1 Introduction

The socio-ecological islandscape (SEI) concept is a hypothesised notion aimed at better understanding how socio-ecological systems materialise within a Small Island Developing States (SIDS) context, taking into account the idea of "islandness" and its apparent influence. To create a robust understanding of a potential socio-ecological islandscape, an unbiased account of how its components, by and large, interact is central. This understanding provides the fundamental building blocks for further assessment of these interactions. Proposing a concept that ultimately argues that **when doing any investigation on SIDS, the influence of "islandness" needs to be considered for an improved reflection of the situation** must be grounded in evidence rather than just in theory. Consequently, insights into how interactions occur in a socio-ecological islandscape and whether "islandness" affects these interactions are crucial for validating the socio-ecological islandscape concept.

To attain this essential information, this study employed the use of Bayesian Belief Networks (BBNs) developed to emulate how a socio-ecological islandscape potentially materialises in the real-world context, displaying the role "islandness" plays in shaping the system. Thus, BBNs have been identified as suitable for modelling environmental systems due to their ability to take an integrated approach to multiple problems, connections, and outcomes. This integrated approach is key to creating a model that captures the structure of a socio-ecological system and represents it in a simplified manner for policymakers and decision-makers. Moreover, BBNs are suitable for utilising information and data from dissimilar sources and for handling missing data (Chen & Pollino, 2012). The development and consequential results of the BBNs used to provide evidence of the socio-ecological islandscape concept are detailed in the subsequent chapter.

The development of the socio-ecological islandscape BBNs (SEI BBNs) involved a few steps, principles, and guidelines to ensure that the networks were robust, unbiased, and focused on the problem being researched in this study. A schematic overview (Figure 3-1) of the process undertaken to develop the SEI BBNs is provided below, while the various aspects that were considered in the development method are described in the following sections.

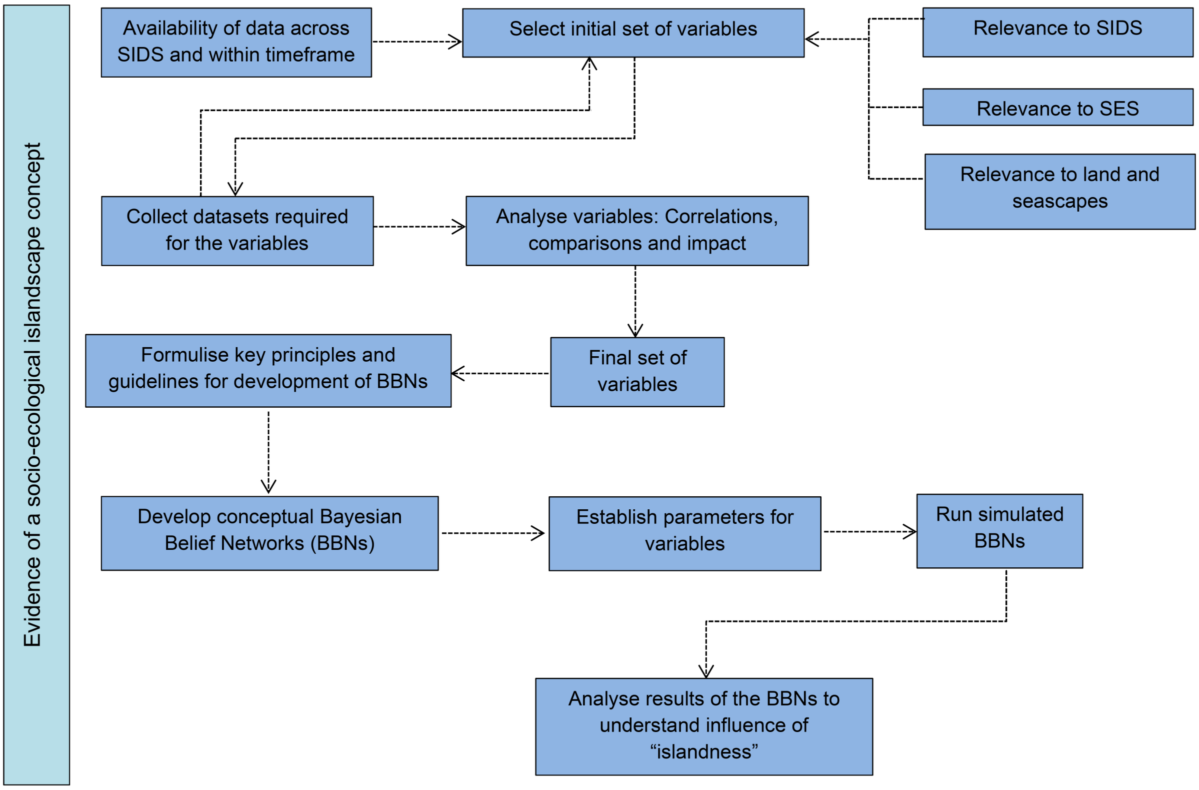


Figure 3-1: Schematic overview of the BBN development process

3.2 Socio-ecological islandscape concept: Variables

3.2.1 Initial variable selection

Although Harter et al. (2015) mentioned island variability, the specific arguments here are ecological complexity and local human impact, which contribute to an island's vulnerability. These aspects of vulnerability can also be described as the ecological and human components of a socio-ecological system. The variability between islands essentially details the differences between these components and the relationships between them, which describe the socio-ecological system of a specific island. However, there are specific elements of an island's socio-ecological system that are common across most SIDS and significant to their sustainability.

A paper titled "*Small Island Developing States – Small islands Big(ger) Stakes"* was published in 2011 by the Office of the High Representative for the Least Developed

Countries, Landlocked Developing Countries and Small Island Developing States (UN-OHRLLS) (UN-OHRLLS, 2011). The paper describes the major challenges currently facing SIDS. The ability of island ecosystems to provide the required services is a fundamental component that can be described within the concept of island ecological complexity. Several massive challenges faced by SIDS are causally linked to the services provided by ecosystems on islands. Such challenges include climate change, freshwater resources, over-harvesting, and biodiversity degradation (UN-OHRLLS, 2011). This paper noted that both fishing and tourism are significant components of SIDS' GDP, while trade and transport have a major influence on the economy (UN-OHRLLS, 2011). These are not only linked to the ecosystem services on the islands but also form part of the local human impact. Local human impact on islands, however, should not be confined to those who reside on the island, but should include all who benefit from the ecosystem services provided. Taking cognisance of the various aspects that make up ecological complexity and the local human impacts, both common and significant to SIDS, as well as the concept of "islandness", several key variables can be derived to understand a socio-ecological islandscape.

The dynamic complex nature of socio-ecological systems has been established; however, Hanspach et al. (2014) argued that numerous of these socio-ecological systems are in essence moulded by a comparatively small number of variables. The relationship between these variables should be identified and examined, thereby lessening the perceived complexity of studies of socio-ecological systems and enabling the production of useful scientific and policy insights (Hanspach et al., 2014). The table below (Table 2-1), therefore, discusses the key variables selected for potential use in developing a set of BBNs to understand a socio-ecological islandscape. The key variables selected were driven by literature and guided by the OECD's principles for indicator selection (i.e., relevance, accuracy, timeliness, accessibility, interpretability, and coherence) (Nardo, 2008). In relation to the above, a few important points considered in selecting the variables are discussed in the forthcoming section on data collection.

Table 3-1: Initial set of variables investigated for the socio-ecological islandscape concept

Variable	Key	SES Category	Rationale	Data Input	Source
Isolation*	Iso	"Islandness"	Isolation from sources of colonization (Weigelt & Kreft, 2013) and from markets (Hay, 2013) result in increased vulnerability of islands. Isolation also has a significant effect on transport, increasing its costs (UN-ORHLLS, 2011).	Isolation Index	Dahl, 2010
Island size*	Size	"Islandness"	Small size places islands at a disadvantage due to a reduction in economies of scale (Hay, 2013; Scandurra et al., 2018), and depending on the size of the island, more vulnerable to human impacts (Vogiatzakis et al., 2017). In addition, the effects of isolation are less evident on larger islands (Weigelt & Kreft, 2013).	km^2	Dahl, 2010**
Inhabited archipelago*	Inh_Arch	"Islandness"	A core-periphery model exists in terms of the spatial development of islands, where the capital island is generally dominated by urban centres that comprise the largest population and resources in contrast to outer islands. This resource availability difference may have serious implication on the sustainability of an archipelago (Fernandes & Pinho, 2017). However, the presence of surrounding land masses (i.e. an archipelago) is associated with colonization and preservation of plant species richness on islands (Weigelt & Kreft, 2013).	<u>Qualitative:</u> Yes / No	Multiple***
Number of inhabited archipelagos*	Inh_Num	"Islandness"		<u>Qualitative:</u> 1 / 2 – 10 >10	Multiple***
Number of islands*	Is_Num	"Islandness"	The influence of both island size and whether the outer islands of an archipelago are inhabited, is likely exaggerated by the number of islands that make up the archipelago. The SIDS that has a large land area that is disaggregated over a significant distance may not have the inherent positive attributes associated with a larger island. Scattered resources may be difficult to consolidate into a	<u>Qualitative:</u> 1 / 2 – 10 >10	Multiple***

Variable	Key	SES Category	Rationale	Data Input	Source
			single economy. Similarly, issues that arise from having outer islands being inhabited would be potentially exacerbated, as this number increases.		
Linear Shipping Connectivity Index	LSCI	"Islandness"	Transport connectivity is an engrained element in the success of a country's access to world markets, with regular shipping services for import and export of manufactured goods being attributed significant importance. The Liner Shipping Connectivity Index (LSCI) was developed by UNCTAD to determine a country's level of integration into global liner shipping networks (UNCTAD, 2018). This provides a proxy for how isolated islands are from global markets, rather than just physical isolation.	LSCI score	UNCTAD, 2019
Government Effectiveness	WGI_GE	Governance	Governance, in terms of the SES approach, is considered as a key component of the system and not a separate entity (Berkes, 2017). Estoque and Murayama (2017) utilised government effectiveness (a worldwide governance indicator) as a measure of the governance integrity in the resilience of SES.	GE score	World Governance Indicators, 2018
Key Biodiversity Area (KBA) covered by protected areas	KBA_Cov	Governance	Protected areas act as refuges and contain high degrees of biodiversity, however, they only allow marginal direct benefits to be derived (Gu & Subramanian, 2014).	% KBA covered by protected areas	UNSTATS, 2019
Tourism Trends	Tour_Trend	Actors	A significant number of SIDS are dependent on the tourism sector as a major (and often dominant) contributor to both	%Δ Tourism arrivals	UNWTO, 2019

Variable	Key	SES Category	Rationale	Data Input	Source
Number of Travellers	Tour_Num	Actors	growth and development (Hay, 2013). However, as discussed by Cheer et al. (2017), tourism not only increases resilience but also increases vulnerability, through the introduction of increased pressures on resources as well as causing way of life changes.	Number of tourists	UNWTO, 2019
Tourism Expenditure	Tour_Exp	Actors		Inbound expenditure	UNWTO, 2019
Population Growth	Pop_G	Actors	Population annual growth rate and density have been utilised in numerous studies as summary indicators of human pressure (Salvati et al., 2013; Banos-González et al., 2015a; Arnaiz-Schmitz et al., 2017; Scandurra et al., 2018).	Population growth	World Bank, 2019
Population Density	Pop_D	Actors		Population density	World Bank, 2019
Economic diversity (excl. tourism)	Econ_Div	Actors	High economic diversity allows for improved adaptive capacity thereby causing communities to be more resilient to disturbances, such as declines in product price (Schippers et al., 2015) as well as the vulnerability caused by dependence on tourism due to unpredictability of tourism revenue growth (Hay, 2013).	Product concentration and diversification indices of exports and imports	UNCTAD, 2019
Endemic	Endemic	Resource Units	Endemism is often used as indicator for determining biodiversity hotspots as well as setting priority areas (Bonn et al., 2002), however, although endemism is relatively high on islands, conservation efforts have remained relatively low (Kier et al., 2009). In addition, endemism provides a proxy of ecological complexity on islands.	Number of endemic species	IUCN, 2019
Red List Index	RLI	Resource Units	The IUCN Red List is regarded as being the global standard for determining extinction risk and is used by a number of the foremost international conventions and agreements (e.g. SDGs) as part of the discourse concerning both conservation and the general biodiversity status (Lacher &	RLI score	IUCN, 2019

Variable	Key	SES Category	Rationale	Data Input	Source
			Hilton-Taylor, 2018). The Red List Index provides a measure for the change in aggregate extinction risks across groups of species (IUCN, 2019) and was used as a measure of the state of biodiversity by McGeoch et al. (2015) in monitoring biological invasions across the broader Antarctica.		
Biocapacity	Biocap	Resource System	*"On the supply side, a city, state or nation's biocapacity represents the productivity of its ecological assets (including cropland, grazing land, forest land, fishing grounds, and built-up land)"* (Ecological Footprint Network, 2019).	Biocapacity score	Global Footprint Network, 2018
Biodiversity (KBAs)	Bio	Resource System	KBAs are places that substantially support the global preservation of biodiversity (Brooks et al., 2015), and would therefore be an important proxy for the size of ecological components in an SES.	km^2	BirdLife International, 2019
Climate Vulnerability	Clim_Vul	Related Ecosystems	In order to realise sustainable development on SIDS, substantial adaptation to both definite and anticipated impacts of climate change are pivotal (Robinson & Dornan, 2017). The Notre Dame-Global Adaptation Index (ND-GAIN) is a measure of both the vulnerability to climate disruptions as well as the readiness of a country to leverage private and public sector investment for climate change adaptation (Chen et al., 2015).	Climate Vulnerability score	ND-GAIN, 2019
Climate Readiness	Clim_Read	Social, Economic and Political Setting		Climate Readiness score	ND-GAIN, 2019
Gross Domestic Product (GDP)	GDP	Social, Economic and Political Setting	A frequently employed measure of income for a whole country is GDP (Mumford, 2016), which essentially provides a crude representation of economic prosperity. Although studies have suggested more accurate measures, such as Genuine Progress Indicator (Kubiszewski et al., 2013),	GDP per capita growth	World Bank, 2019

Variable	Key	SES Category	Rationale	Data Input	Source
			these measures are not suitable for time-series and scaled applications due to lack of data. For the purposes of this study, GDP remains the most valuable measure. Furthermore, GDP per capita has been utilised in socio-ecological patterns of vulnerability (Kok et al., 2016).		
Ecological Footprint	EF	Interactions	"*Ecological Footprint measures the ecological resources that a given population requires to produce the natural resources it consumes (including plant-based food and fiber products, livestock and fish products, timber and other forest products, space for urban infrastructure) and to absorb its waste, especially carbon emission*" (Ecological Footprint Network, 2019).	Ecological Footprint score	Global Footprint Network, 2018
National Footprint Account	NFA	Outcomes	*"If a population's Ecological Footprint exceeds the region's biocapacity, that region runs an ecological deficit. Its demand for the goods and services that its land and seas can provide—fruits and vegetables, meat, fish, wood, cotton for clothing, and carbon dioxide absorption—exceeds what the region's ecosystems can renew. A region in ecological deficit meets demand by importing, liquidating its own ecological assets (such as overfishing), and/or emitting carbon dioxide into the atmosphere. If a region's biocapacity exceeds its Ecological Footprint, it has an ecological reserve"* (Ecological Footprint Network, 2019).	NFA score	Global Footprint Network, 2018
Human Development Index	HDI	Outcomes	A widely used indicator to understand socio-economic development is the human development index (HDI), which establishes the median success of human development in a country based on three basic dimensions: life expectancy (i.e. a long and healthy life), education (i.e. access to	Human Development Index score	UNDP, 2018

Variable	Key	SES Category	Rationale	Data Input	Source
			knowledge), and income (i.e. a decent standard of living) (Estoque & Murayama, 2017).		
*Data for the "islandness" variables are based on a combined best approximation from different sources. In order to minimise the risk of inaccurate data, the inhabited archipelago, number of islands and number of inhabited islands were captured as qualitative data. Additionally, in the BBN, "islandness" data were categorized to further minimize risks (refer to section3.3.3 Parameters). **For island size, Dahl (2010) was used as primary source while World Population Review (2019) was used to confirm placement of observations in the correct category in the BBN. ***CIA (2019), City Population (2019), Dahl (2010), World Population Review (2019)					

3.2.2 Data collection

Extensive data collection was done for this study and included numerous international databases such as, but not limited to, the World Bank, IUCN, Ecological Footprint Network, UNDP, etc. In addition, and where appropriate, local data were sourced (e.g. census data). The intended outcomes of the data collection included obtaining datasets that provided reasonable coverage of both the time frame and SIDS, eliminating variables with insufficient information, and ensuring comparable information across SIDS. The motivation for focusing on international datasets was based on the overarching approach of using multiple SIDS within the modelling, thereby allowing for a comprehensive understanding of interactions that are not biased, for instance, being based on global orientation (i.e. Pacific vs. Indian Ocean). Using international databases allowed a single, uniform variable to be used across all SIDS; however, it is acknowledged that differences may exist between international datasets and data generated on a case-by-case basis (i.e., information determined at the government level). Utilising international databases ensured that information was collected and reported in a consistent format, thereby enabling comparability. The complete dataset included 33 SIDS across all 24 variables over a 10-year period (2004 – 2014), totalling 7920 values. The SIDS included in the analysis are shown in Table 3-2.

Table 3-2: SIDS used in the study (UN-OHRLLS, 2011; UN Sustainable Development Goals Knowledge Platform, 2019)

Small Island Developing States		
Antigua and Barbuda	French Polynesia	São Tomé and Príncipe
Aruba	Grenada	Seychelles
Bahamas	Haiti	Singapore
Bahrain	Jamaica	Solomon Islands
Barbados	Kiribati	St. Kitts and Nevis
Cape Verde	Maldives	St. Lucia
Comoros	Mauritius	St. Vincent and the Grenadines
Cuba	Micronesia	Timor-Leste
Dominica	Palau	Tonga
Dominican Republic	Papua New Guinea	Trinidad and Tobago
Fiji	Samoa	Vanuatu

Additionally, a few factors identified during data collection influenced the initial set of variables for the study. These factors included the following:

1) The SEI BBNs take an integrated approach, analysing relationships across numerous SIDS between economic, social, and environmental subsystems over a 10-year period. SIDS were selected as a focus area of the socio-ecological islandscape concept due to the previously mentioned inherent vulnerability acknowledged through the United Nations Conference on Environment and Development;
2) All islands used in the development of the SEI BBNs were SIDS as per the UN list of Small Island Developing States at the time of analysis (UN-OHRLLS, 2011; UN Sustainable Development Goals Knowledge Platform, 2019);
3) Island type was excluded as international datasets are provided per country and are not subdivided into the islands within SIDS. Countries such as Antigua and Barbuda consist of two different island types, namely volcanic and raised coral (Antigua), as well as raised coral with lagoon (Barbuda). Furthermore, SIDS such as the Federated States of Micronesia and Fiji include volcanic, atoll and raised coral island types (Dahl, 2010);
4) Data used for the SEI BBNs are also taken over a 10-year period (2004 – 2014), ensuring that short-term shocks in the system (e.g. 2008 recession or a momentary drop in tourism) are negated, therefore providing a better understanding of long-term relationships within the socio-ecological islandscape;
5) The database of variables used is based on the most comprehensive datasets available during the timeframe and across the greatest number of SIDS possible. The dataset is incomplete, with some missing values across the database, which motivates employing a BBN. However, it is the most comprehensive database that could have been developed over the 10-year period (2004 – 2014);
6) The timeframe (2004 – 2014) was restricted by the availability of data for several datasets, as a number of datasets had not been updated by the time of the BBN analysis, thereby limiting the degree to which the BBNs can be used;

7) Data collection was finalised by November 2019 for the development of the BBNs. Any additional data released after this date were not considered for the BBNs; and
8) Climatic zones were not included in the SEI BBNs as the networks are aimed at developing a landscape socio-ecological system. Although climate may influence islands, climate has a few sub-variables that may be difficult to model and provide valuable links within a socio-ecological system. The model is not intended to be a climate model.

3.2.3 Variable analysis: Correlations, comparisons and impacts

The initial set of variables identified for possible use in understanding interactions within a socio-ecological islandscape needed to be analysed to ensure they were the most appropriate. Moreover, the degree of modelling complexity in BBNs increases with the number of variables (Marcot, 2017), especially when several variables are essentially proxies for the same issue. Tourism, as an example, was previously mentioned as an important issue within SIDS (Connell, 2016), however, the initial set had three possible variables that could be used as proxies for its influence. A variable analysis phase that provided a preliminary understanding of how the variables correlate and their potential impacts within the system, therefore allowed the study to determine which variables are (a) more suitable, (b) duplicates (i.e. providing the same information on the system) and (c) will have very little impact on the system. The variable analysis phase was undertaken in two stages, namely a Pearson correlation coefficient and a Principal Component Analysis (PCA).

3.2.3.1 Pearson correlation coefficient: Pre-processing and variable correlations

Using data from 33 different SIDS creates marked differences in values and, therefore, numerous outliers within the data. Prior to utilising the dataset for modelling, it needed to be determined whether to keep the outliers (standard dataset) or remove them (outlier-excluded dataset). Outliers are generally removed from a dataset due to the uneven effects these values often have on conclusions related to variable relationships (Aguinis et al*.,* 2013) and can also cause Principal Component Analysis bias resulting from a deviation in factor loadings (Hosseini & Kaneko, 2011), which has importance in proceeding steps. However, removing outliers increases the number of missing values/observations within the dataset. Furthermore, outliers may be categorised as "influential outliers", which are data points that are accurate, lie far from other data points, and also influence the conclusions derived from the variables' relationship (Aguinis et al., 2013). To determine the value of removing outliers from the dataset, a Pearson correlation matrix was computed on the standard dataset and the outlier-excluded dataset[3]. Prior to undertaking a Pearson correlation, qualitative data (i.e., number of islands, inhabited archipelago, and number of inhabited islands) were coded into quantitative data using broad categories (e.g., inhabited archipelago: 1 = Yes, 2 = No).

Pearson correlation coefficient is a measure of the linear correlation between two variables (Zhuge et al., 2020), and the value is represented on a scale between -1 and 1 (where -1 represents a strong negative correlation, 0 represents no correlation, and 1 represents a strong positive correlation) (Hong et al., 2020). As illustrated in Figure 3-2, the correlation between variables showed a marked overall increase across the outlier-excluded coefficient matrix (b) as opposed to the standard data coefficient matrix (a). Although in some instances the correlations between variable pairs decreased (e.g., LSCI and Tour_num), given the value of removing outliers in the modelling process (Aguinis et al., 2013) and the overall improvement in correlations, the outlier-excluded dataset was utilised for further analysis and modelling in the BBNs.

[3] Outliers were removed from the dataset using the 1.5IQR rule.

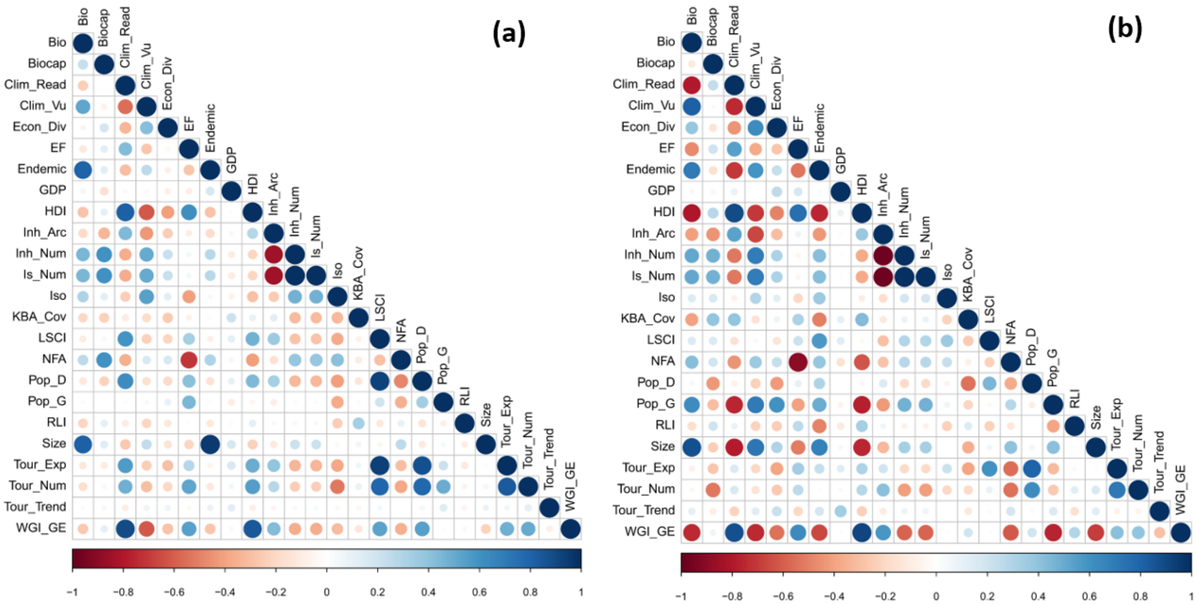


Figure 3-2: Pearson correlation coefficient matrix of initial variable set (a) standard data compared to (b) data with outliers removed

3.2.3.2 Principal Component Analysis (PCA): Variable comparisons and impacts

A PCA is utilised on a dataset comprising many interconnected variables to reduce dimensionality whilst retaining a significant amount of the data's variation. A PCA accomplishes this by transforming a set of variables into a new set of Principal Components (PCs). These PCs are both uncorrelated and ordered to ensure that the first PCs retain the greatest variation from all the initial variables. Ultimately, the PCA reduces the number of variables to a smaller set of PCs that explain a large portion of the variation in the observed variables (Hosseini & Kaneko, 2011). Two important outcomes of a PCA include:

1) <u>Cumulative variance</u>: a measure of the explained variance, calculated from the eigenvalues, which details the magnitude of variance associated with the respective PCs. In a PCA, using cumulative variance to determine which PCs to retain for analysis is an acceptable practice. A general rule, as stated in Hosseini and Kaneko (2011), is that enough PCs need to be retained to explain 90% of the variation in the data; and
2) <u>Factor loadings:</u> a function of the eigenvalues and eigenvectors generated by the PCA and indicate the influence of each variable on the respective PCs (Tripathi & Singal, 2019).

The PCA has been widely used in variable reduction and selection processes by means of enabling the identification of redundancies or highly correlated variables that can be discarded (Tripathi & Singal, 2019). These authors reported a PCA study to select variables required in the development of a novel water quality index. The PCA successfully reduced the initial set of 20 variables to 9 core variables. Similarly, in a study by Recatalá and Sacristán (2014), a PCA was used to develop a minimum indicator set for evaluating resource quality and environmental impacts at a planning level. Using a PCA ensures an objective approach to the selection of variables (Tripathi & Singal, 2019)

In the present study, the PCA[4] was undertaken with the aim of (a) comparing similar variables to determine which would be the most suitable in the SEI BBNs and (b) determining if there are variables whose impact would be insignificant enough to be removed for further analysis, reducing the number of variables and ultimately reducing the complexity of the SEI BBNs.

Firstly, a PCA was performed on the initial 24 socio-ecological islandscape variables (SEI variables), and the respective cumulative variances (Figure 3-3) and factor loadings (Table 3-3) were generated. Consequently, the first PCs (n=8) were retained for analysis based on the cumulative variance of the initial 24 SEI variables, accounting for 91% of the variation. Therefore, the factor loadings for the variables were assessed using these eight PCs. In addition, the factor loadings in the biplots (Figure 3-4a) developed for the PCA show the correlation (acute angle = positive, obtuse angle = negative, and 90° angle = no correlation) between the variables and their impacts (based on length and direction) on PC1 and PC2. The results of the PCA on the initial 24 SEI variables allowed for the following deductions to be made:

1) <u>Tourism</u>: of the three possible tourism variables, the loadings for [Tour_Trend] are insignificant in the first two principal components, while [Tour_Num] and [Tour_Exp] both have significant loadings in PC2. Additionally, there was a strong correlation between [Tour_Num] and [Tour_Exp], both of which provided

[4]Standardisation (or z-scores) by means of subtracting the mean and dividing by the standard deviation was undertaken on the data as part of the PCA. The PCA was undertaken using RStudio (RStudio Team, 2025).

the same information for the tourism proxy. Consequently, [Tour_Exp] was selected as it has a slightly higher loading in PC2.

2) Isolation: comparatively, the factor loadings of [Iso] were slightly higher than those of [LSCI]; however, [LSCI] had a higher factor loading in PC3. Considering that within PC3, variables with high factor loadings include [Inh_Arc], [Is_Num] and [Inh_Num], it indicates that PC3 has a strong association with "islandness", [LSCI] was retained for further investigation.
3) Redundant "islandness" variables: several "islandness" variables, namely [Inh_Arc], [Is_Num] and [Inh_Num], have similar factor loadings in PC3 and are highly positively or negatively correlated. To reduce redundant variables, [Inh_Num] was selected for further use because it effectively combines information from the other variables.
4) Population variables: [Pop_D] has a significantly higher factor loading than [Pop_G] and was therefore retained. In addition, many of the variables with high factor loadings on PC2 were associated with users; therefore, PC2 has a strong association with the social subsystem.
5) Economic diversification: of the variables that represent actors, [Pop_D] and [Tour_Exp] have a stronger association with PC2; therefore, [Econ_Div] was not retained for further modelling.
6) GDP: Although [GDP] has a high factor loading in PC5, [Clim_Read], which also describes the economic, social and political setting within a socio-ecological system, and contains a strong economic component, has a higher factor loading in PC1 that corresponds to variables that also entail economic, social and political aspects, such as [HDI], [Clim_Vul] and [WGI_GE]. Subsequently, [GDP] was not retained for further analysis.

As a result of the variable analysis, the final variable dataset was reduced to 16 SEI variables, from which another PCA was performed (Figure 3-4b). The aim for doing an additional PCA on the reduced number of variables was to determine (1) if fewer components were required to explain a comparable or greater proportion of variance in the PCA, (2) determine in further reduction in variables is required based on a 0.3/-0.3 factor loading threshold for significance (Richman, 1988), and (3) use the PCA as an exploratory tool (Le Clec'h et al., 2016) to understand patterns in the data which allow for discernments into relationships which were used in the development of the

SEI BBNs. The results of the PCA on the 16 SEI variables provided the following insights:

1) Variance: fewer components were required to explain a greater proportion of variance, as only six (n=6) PCs were required to explain 92% of the variation (Figure 3-3);
2) Variable reduction: Factor loadings for each variable were above 0.3/-0.3 significance threshold within the first six (n=6 PCs (Table 3-4);
3) Relationships: Correlations between variables have been used in the development of the SEI BBNs and are described in section 3.3.4.

In addition to the above, and as shown in (Figure 3-4a and Figure 3-4b) there is preliminary evidence, based on the relative correlations between the “islandness” and socio-ecological variables in the initial 24 SEI variables PCA, as well as on the subsequent 16 SEI variables PCA, of the influence of “islandness” variables on a socio-ecological system. However, a PCA cannot handle missing data; therefore, only 85 observations from 12 SIDS were utilised from a possible 330 observations from 33 SIDS in the PCA of the 16 SEI variables. This is as a result of the uneven reporting of environmental, social and economic indicators across numerous SIDS, and therefore does present a degree of unintended selection bias rooted in the concept of established data-gathering infrastructure. The PCA has therefore only been used as a preliminary variable reduction and exploratory technique, rather than as a method for providing evidence of the socio-ecological islandscape concept, to gain practical insights. However, cognisance must be given to the provisional evidence provided by the limited data used, as a preliminary indication of the correlations between “islandness” and socio-ecological systems on SIDS. The ability of BBNs to handle missing data is a key factor in selecting them as the primary method for analysing potential socio-ecological islandscape relationships.

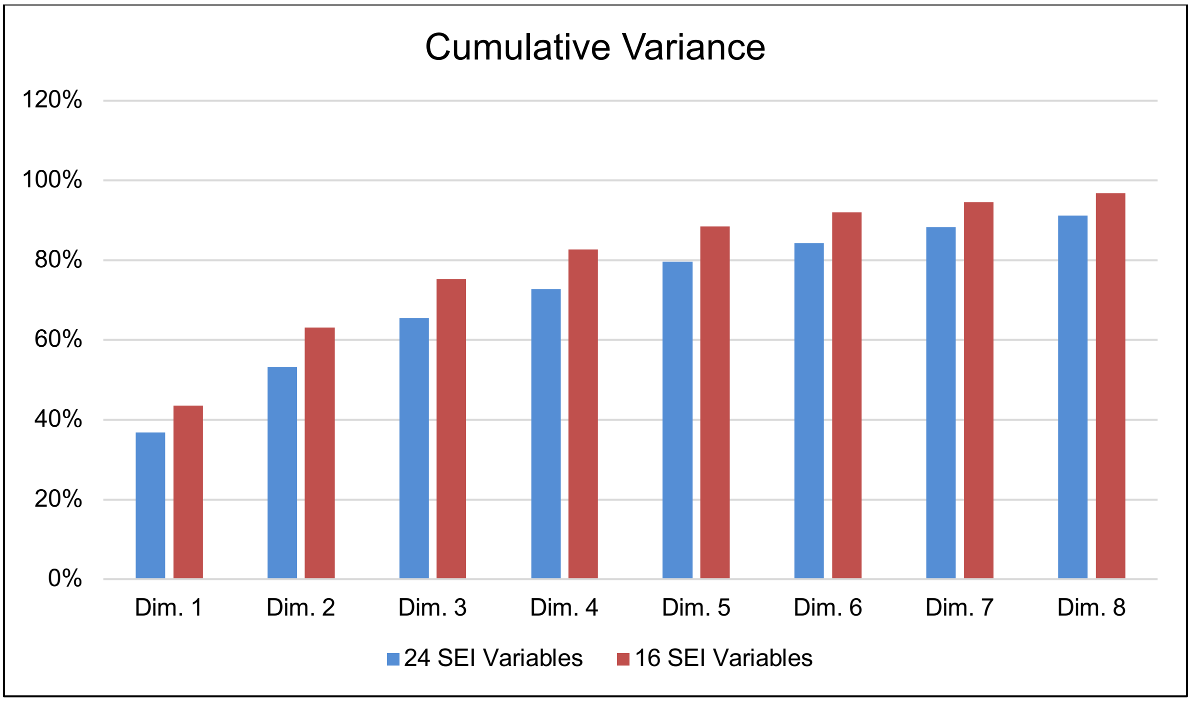


Figure 3-3: Comparison of the cumulative variance between the Principal Component Analysis (PCA) for the 24 SEI variables and the final 16 SEI variables

Table 3-3: Factor loading for the initial 24 SEI variables

Variable	Principal Component							
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Tourism Trends (Tour_Trend)	0.08	0.03	0.06	-0.01	0.40	0.56	-0.16	-0.37
Linear Shipping Connectivity Index (LSCI)	0.04	0.21	-0.42	0.21	0.10	0.01	-0.11	0.12
KBA Coverage (KBA_Cov)	-0.09	-0.36	-0.05	-0.19	0.10	-0.05	0.05	0.42
Ecological Footprint (EF)	-0.21	-0.05	-0.32	-0.32	0.08	-0.13	-0.03	-0.11
Economic Diversification (Econ_Div)	0.19	-0.10	0.11	-0.22	0.37	-0.19	0.26	-0.14
Biocapacity (Biocap)	0.00	-0.34	-0.30	0.22	-0.13	0.21	0.06	0.13
Red List Index (RLI)	-0.10	-0.10	-0.02	-0.25	-0.45	0.37	0.26	-0.41
Gross Domestic Product (GDP)	-0.01	0.00	-0.10	-0.13	0.55	0.39	0.20	0.20
Human Development Index (HDI)	-0.31	-0.10	-0.17	-0.03	0.02	0.00	0.11	-0.03
National Footprint Account (NFA)	0.21	-0.14	0.22	0.37	-0.14	0.23	0.05	0.11
Climate Readiness (Clim_Read)	-0.30	-0.12	-0.03	0.13	0.11	-0.06	0.09	0.16

Variable	Principal Component							
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Climate Vulnerability (Clim_Vu)	0.30	-0.01	-0.07	-0.18	0.01	-0.14	0.31	-0.05
Population Growth (Pop_G)	0.26	0.03	0.08	-0.17	0.13	-0.34	-0.22	-0.22
Population Density (Pop_D)	-0.06	0.42	-0.14	-0.01	-0.10	0.08	-0.28	-0.09
Government Effectiveness (WGI_GE)	-0.32	0.02	-0.09	0.06	-0.01	-0.07	0.19	-0.09
Isolation Index (Iso)	0.08	0.04	-0.17	0.48	0.13	-0.21	0.51	-0.36
Inhabited Archipelago (Inh_Arc)	-0.23	0.16	0.34	0.09	0.06	-0.04	0.12	0.05
Island Size (Size)	0.25	0.18	0.07	-0.17	-0.20	0.20	0.28	0.26
Number of Islands (Is_Num)	0.23	-0.16	-0.35	-0.09	-0.08	0.01	-0.08	-0.05
Biodiversity (Bio)	0.28	0.13	0.00	-0.10	-0.12	0.02	0.22	0.13
Endemic	0.25	0.25	-0.11	0.20	0.05	0.01	-0.04	0.24
Number of Travellers (Tour_Num)	-0.13	0.36	-0.01	-0.30	-0.06	0.03	0.24	0.17
Tourism Expenditure (Tour_Exp)	-0.11	0.39	-0.27	0.03	0.02	0.02	0.13	0.01
Number of Inhabited Islands (Inh_Num)	0.23	-0.16	-0.35	-0.09	-0.08	0.01	-0.08	-0.05

Table 3-4: Factor loading for the final 16 SEI variables

Variable	Principal Component					
	PC1	PC2	PC3	PC4	PC5	PC6
Linear Shipping Connectivity Index (LSCI)	0.02	-0.36	0.42	0.29	-0.16	0.01
KBA Coverage (KBA_Cov)	-0.18	0.32	0.21	0.03	0.32	0.15
Ecological Footprint (EF)	-0.27	-0.11	0.37	-0.15	0.31	-0.16
Biocapacity (Biocap)	-0.08	0.28	0.47	0.17	-0.46	0.14
Red List Index (RLI)	-0.12	0.11	0.11	-0.71	-0.45	-0.22
Human Development Index (HDI)	-0.36	0.00	0.12	-0.05	-0.03	0.20
National Footprint Account (NFA)	0.24	0.27	-0.19	0.18	-0.46	0.17
Climate Readiness (Clim_Read)	-0.35	0.05	-0.05	0.16	-0.04	0.38
Climate Vulnerability (Clim_Vu)	0.31	0.07	0.21	-0.15	0.26	0.19
Population Density (Pop_D)	-0.01	-0.51	-0.08	-0.06	-0.19	-0.25
Government Effectiveness (WGI_GE)	-0.35	-0.08	-0.03	-0.08	-0.13	0.32
Island Size (Size)	0.30	-0.08	0.04	-0.40	0.05	0.44
Biodiversity (Bio)	0.33	-0.06	0.12	-0.21	0.08	0.33
Endemic	0.31	-0.22	0.08	0.24	-0.09	0.08
Tourism Expenditure (Tour_Exp)	-0.10	-0.50	0.11	-0.06	-0.09	0.31
Number of Inhabited Islands (Inh_Num)	0.20	0.11	0.52	0.05	-0.02	-0.26

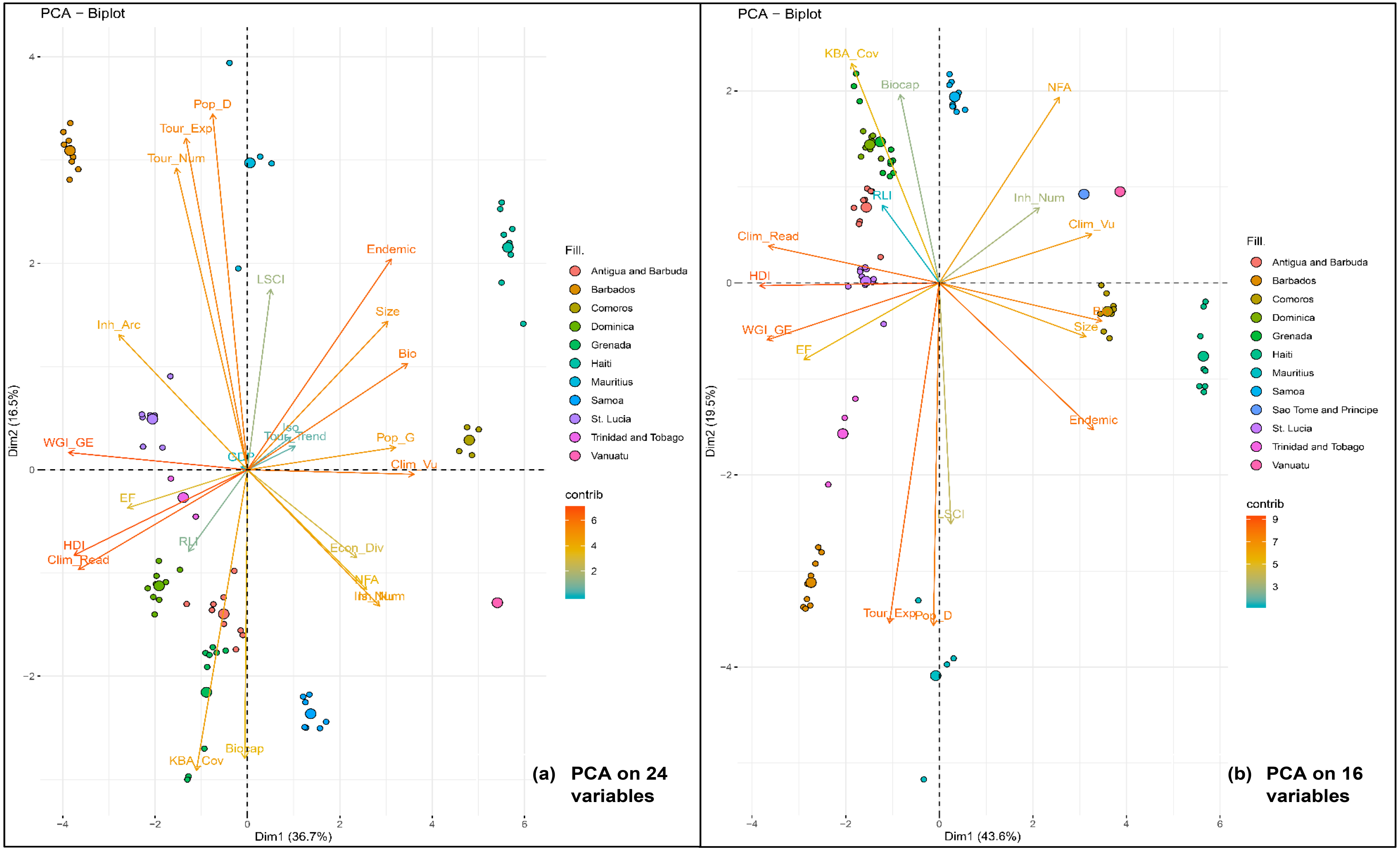


Figure 3-4: Principal Component Analysis (PCA) on (a) initial set of variables compared to (b) final reduced set of 16 variables

3.3 Socio-ecological islandscape concept: Bayesian Belief Networks

3.3.1 Principles, guidelines and best practice

Chen and Pollino (2012) detailed that uncertainties, which are often found in BBNs, originate from issues such as an incomplete understanding of system processes, environmental systems being characteristically stochastic, data inaccuracies, as well as the subjective biases of "expert knowledge" in the elicitation of probabilities. These potential issues in BBNs have led to the adoption of two main principles for model development. Firstly, the socio-ecological islandscape is a new concept; therefore, acquiring expert knowledge may introduce subjective bias based on the expert's focus area within the system. As such, information from the exploratory PCA analysis was used in developing the models. Secondly, an equifinality viewpoint was adopted, in which it is considered that several possible models, sets of variables, and parameters may effectively describe the system. Consequently, several models were simulated and analysed.

There are a number of guidelines and best practises for the development of BBNs that were suggested by numerous authors (Charniak, 1991; Marcot et al., 2006; Chen & Pollino, 2012), including guidelines that are designed specifically for BBNs within the realm of environmental and resource management (Barton et al., 2012) and environmental modelling (Aguilera et al., 2011). A number of key points that were considered from these various literature sources are shown below:

- Where possible, the number of connections from parent nodes to any given node was kept at three or fewer. In addition, the number of states within the nodes was limited to five or fewer;
- As far as possible, nodes within the BBNs were observable and calculable;
- Connections were made between variables that are likely to be correlated. It should be noted that a statistical assumption of BBNs is that prior probabilities are uncorrelated with regard to input nodes that are not connected; and
- To prevent a weakening of the output nodes' sensitivity to the input nodes and reduce uncertainty, a maximum of five layers of nodes was used in the BBNs, where possible.

3.3.2 Framework and conceptual model

Chen and Pollino (2012), discussed the possible approach of assessing an array of models based on different hypotheses of a system. In a similar approach, several frameworks (as described in the forthcoming sections) commonly used to describe systems served as a foundation for the development of the SEI BBNs. These networks were then evaluated to determine the most accurate framework(s) for describing a socio-ecological islandscape. Moreover, Kelly et al. (2013) described using multiple models to mitigate potential structural uncertainty in the framework. Considering the novelty of the socio-ecological island concept, using multiple models to explain the system is a sound approach to the study.

The core ideology ingrained in the contemporary socio-ecological systems approach is that society is not separate from the environment on which it relies. Rather, society is fundamentally embedded within the environment, acting upon it through its decisions (i.e. interactions) and subsequently being affected by those decisions (i.e. outcomes) (Berkes, 2017). Ostrom (2009) highlighted that within a complex socio-ecological system, a number of subsystem components that are separable interact to produce outcomes. Governance, actors, resource systems, and resource units all interact to produce outcomes. These outcomes often reflect the system's ecological and social performance (Ostrom, 2009). Awareness should also be given to the relationships between key aspects, such as the fact that resource units form part of a resource system or that governance often defines rules for actors. These relationships may influence how aspects contribute to the overall relations. As demonstrated in the conceptual model (Figure 3-5), government effectiveness (governance) would influence the prevalence of tourism (actors), which would, in turn influence the magnitude of consumption, represented as the ecological footprint (interactions) within the socio-ecological system. The socio-ecological islandscape concept, however, posits that all these aspects are influenced by “islandness”, which shapes their interactions and relationships.

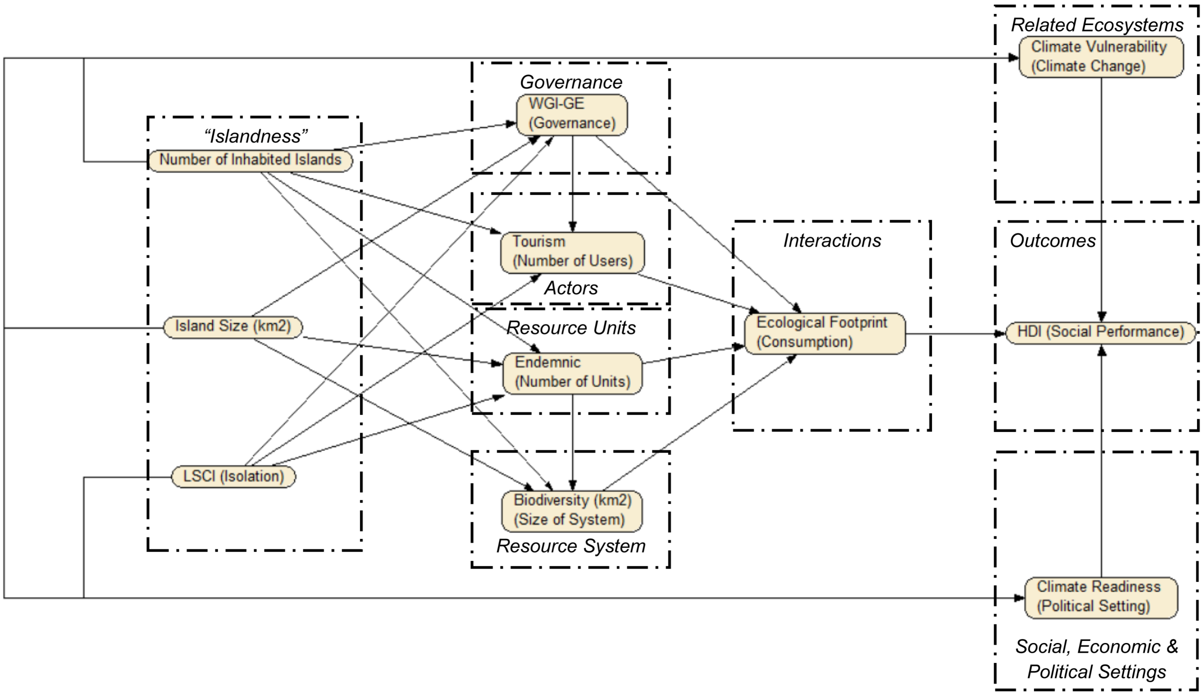


Figure 3-5: Conceptual socio-ecological islandscape Bayesian Belief Network (Adapted from McGinnis & Ostrom, 2014)

3.3.3 Parameterization

The BBNs were originally intended to process only discrete data; however, real-world data is often continuous and therefore requires parameterisation. Where datasets lacked predefined parameters, a supervised discretisation process for continuous variables, using the median as a cut-off value to create two bins (Naranjo-Madrigal et al., 2015), was used. The adjusted mean was used because it is a more relevant measure in the SIDS context, as comparing values between SIDS provides a more realistic picture than comparing them with continental countries that have economies of scale and are not isolated (i.e., taking an island-centric approach). In addition, utilising the adjusted mean allowed for a simpler model that is easily interpreted by policy and decision-makers and ensured that the number of Conditional Probability Tables (CPTs) was kept to a minimum. However, this method assumes the distributions are not heavily skewed (largely addressed by removing outliers) and does not account for context-specific thresholds. Context-specific thresholds may be difficult to ascertain given that data is collected for both mainland and SIDS. The CPTs provide a "*degree of belief (expressed as probabilities)*" of the state of a node given what the state of the parent node is (Chen & Pollino, 2012: 134). The respective parameters used in the SEI BBNs are provided in Table 3-5. The CPTs were calculated at each node, considering the BBN structure and the respective empirical data, using the data-driven expectation-maximisation (Gupta & Chen, 2011) algorithm for parameter learning.

Table 3-5: Variable parameters used in the SEI BBNs

Variable	Parameter	Predefined / user defined
Number of Inhabited Islands	One Between 2 and 10 Above 10	User defined
Island Size (km^2)	Small (1 – 1 000 km^2) Medium (1 000 – 10 000 km^2) Large (>10 000 km^2)	User defined
Linear Shipping Connectivity Index (LSCI)	Adjusted Mean	User defined
Government Effectiveness (WGI-GE)	Low (-2.5 – 0) High (0 – 2.5)	Predefined
KBA Coverage (% coverage)	Adjusted Mean	User defined
Tourism (Inbound expenditure)	Adjusted Mean	User defined
Population Density (per km^2)	Adjusted Mean	User defined
Endemic (Number of species)	Adjusted Mean	User defined
Red List Index (RLI)	Adjusted Mean	User defined
Biodiversity (km^2 of KBAs)	Adjusted Mean	User defined
Biocapacity	Adjusted Mean	User defined
Ecological Footprint	Adjusted Mean	User defined
Climate Vulnerability	Low (0 – 4.3) High (4.3 – 1)	Predefined
Climate Readiness	Low (0 – 3.7) High (3.7– 1)	Predefined
National Footprint Account (NFA)	Deficit (<0) Reserve (>0)	Predefined
Human Development Index (HDI)	Low to medium (0 – 0.699) High to very high (0.699 – 1)	Predefined
*Mean was adjusted based on the removal of outliers.		

3.3.4 Simulated Bayesian Belief Networks

Four SEI BBNs were developed using Netica 6.05 (Norsys Software Corporation, 2020), simulated, and used in the analysis to provide evidence for the socio-ecological islandscape concept and to offer further understanding of the role of "islandness". Descriptions of the SEI BBNs and the respective insights gained from the PCA used to develop their approaches are provided in Figure 3-6. Some of the uniform characteristics in each of the SEI BBNs include:

- The foundation of developing the SEI BBNs was utilising the multitier socio-ecological systems framework developed by McGinnis and Ostrom (2014) (Figure 2-5), based on its distinctive structure, understandable components and easily interpretable connections.
- The multitier socio-ecological systems framework was adapted to include "islandness", thereby conceptualising the socio-ecological islandscape framework. This was used as the building blocks of each of the SEI BBNs (Figure 1-1). Each of the SEI BBNs contains the respective "islandness" variables (i.e. number of inhabited islands, island size and a measure of isolation) that influence the core socio-ecological system components. These socio-ecological system components include governance, actors, resource system, resource units, interactions, outcomes, related ecosystems, and social, economic, and political settings. A single variable has been selected for each component based on the concept and correlations between variables, as per Figure 3-6;
- As climate change is a critical issue in island contexts, these were included in all the SEI BBNs. Climate vulnerability not only considers changing climate patterns but also the vulnerability of SIDS to the changing patterns, whilst climate readiness considers the overall social, economic and political situation of islands;
- The ecological footprint and the Human Development Index (HDI) are known to be correlated (Galli et al., 2015), and the ecological footprint is used to determine a country's National Footprint Account (NFA). Ecological footprint was, therefore, the best representation of interactions at this scale and was consequently used as a proxy in all the networks;
- A BBN cannot be used to solve all aspects in a single model; therefore, the networks were differentiated between considering the effects of "islandness" on either the social or ecological performance, based on differing interrelated variables; and
- The SEI BBNs used time-series data where appropriate, given the overall observation of how SIDS have, on average, fared over the 10-year timeframe (2004 – 2014).

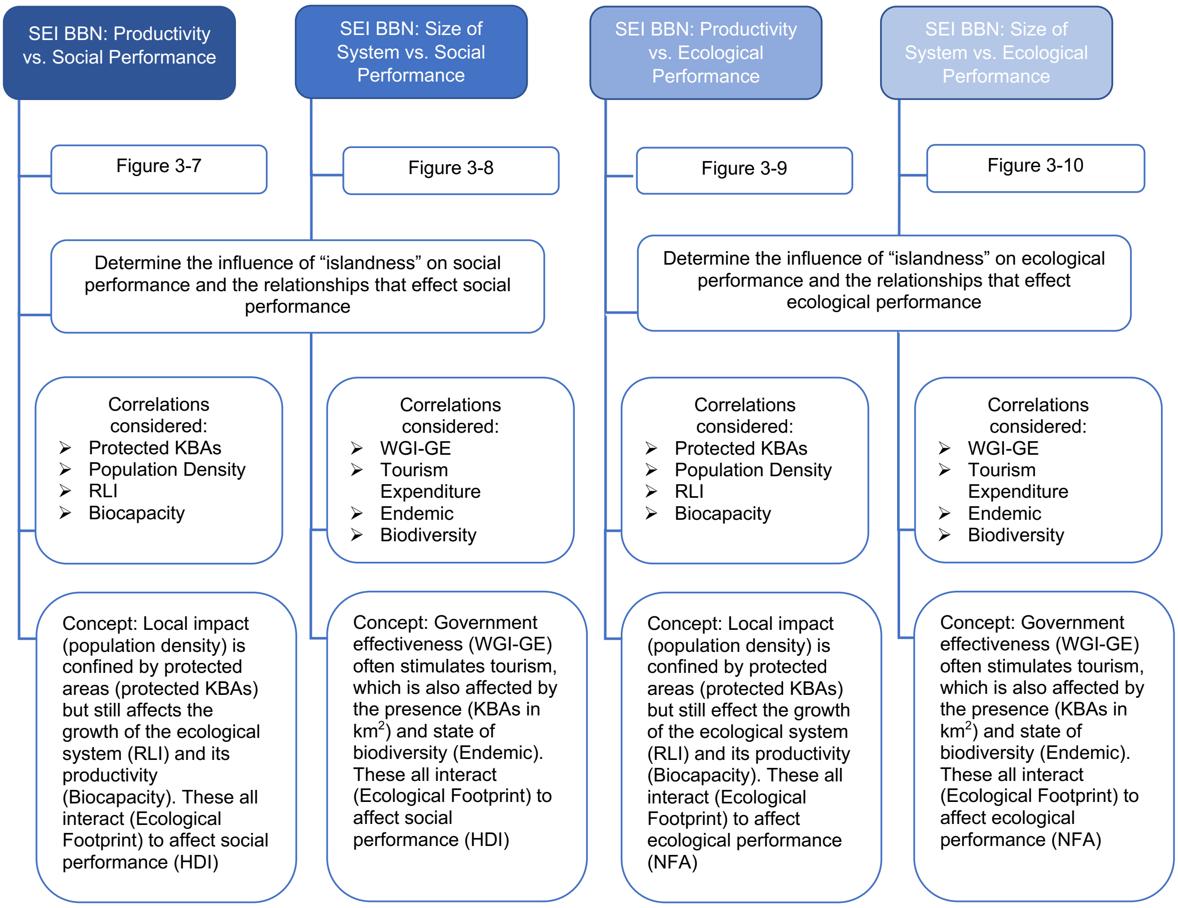


Figure 3-6: Concepts used in the development of the SEI BBNs

The subsequent figures (Figure 3-7 to Figure 3-10) depict the baseline of the probable relationships between various key sub-components of the larger and more complex system, expressed as different versions of the socio-ecological islandscape concept. With the baseline probabilities defined for each state within the network, the probabilities of these states within the parent variables (given a particular outcome within the final output node) can be observed.

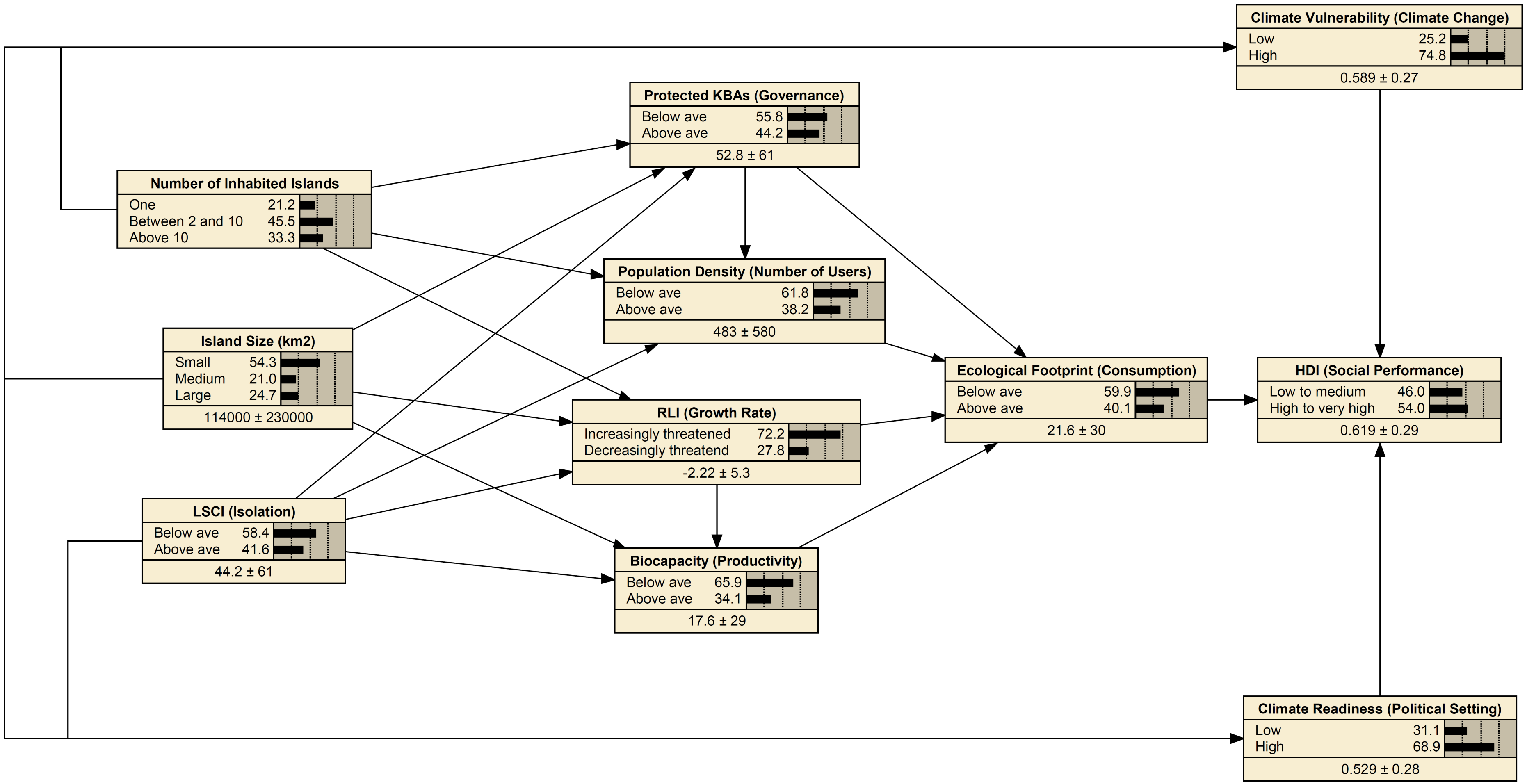


Figure 3-7: SEI BBN: Productivity vs. Social Performance

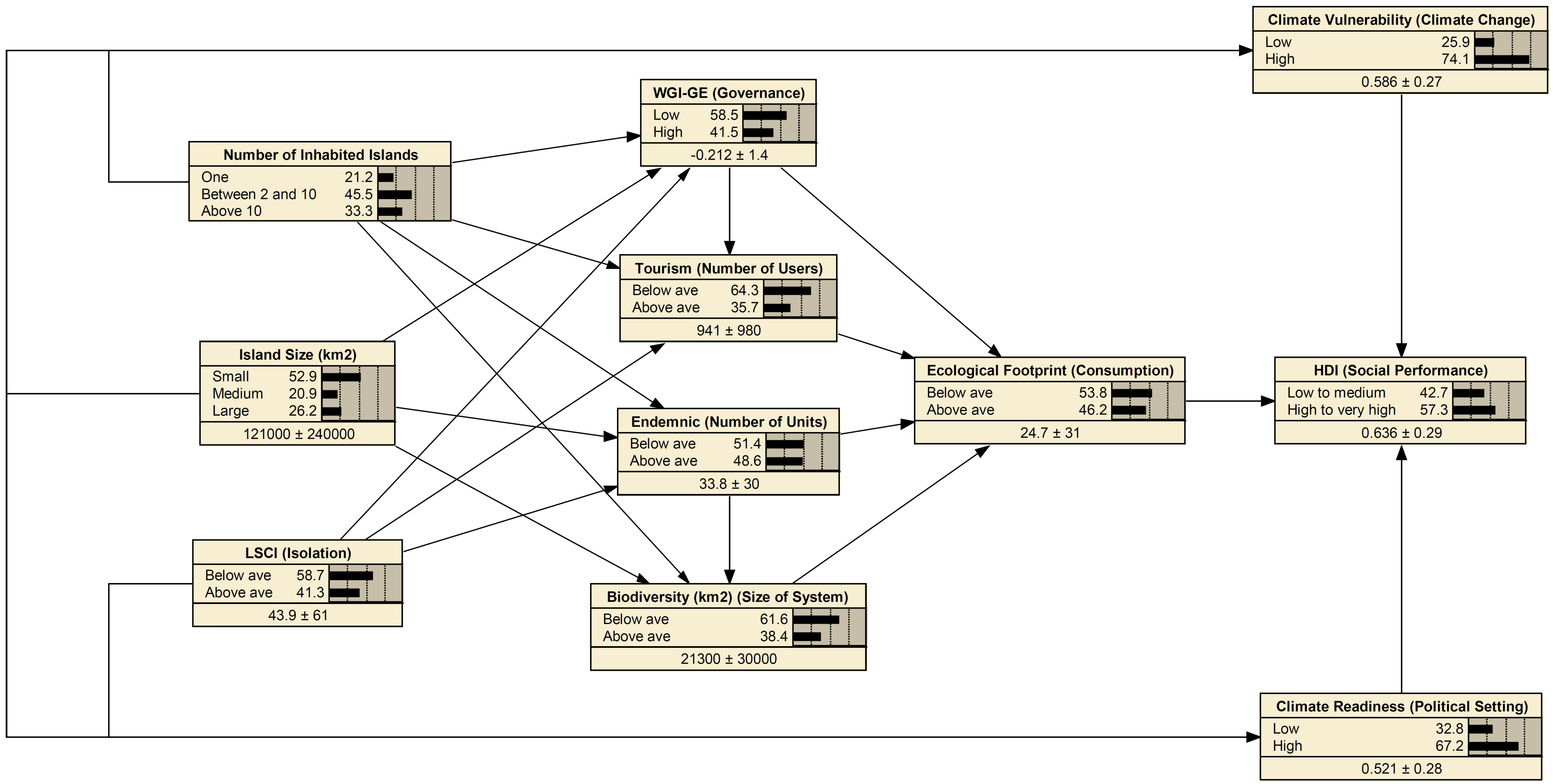


Figure 3-8: SEI BBN: Size of System vs. Social Performance

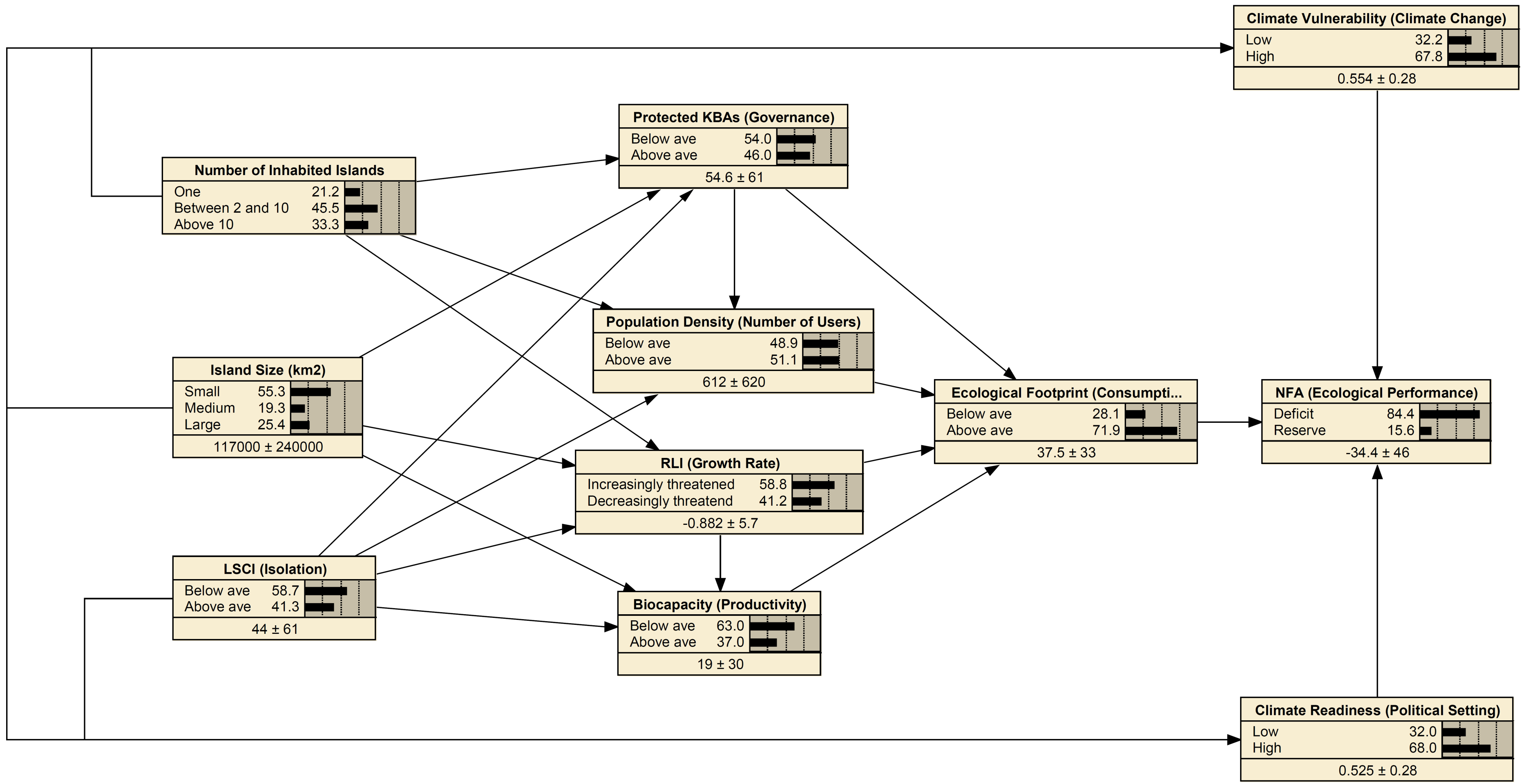


Figure 3-9: SEI BBN: Productivity vs. Ecological Performance

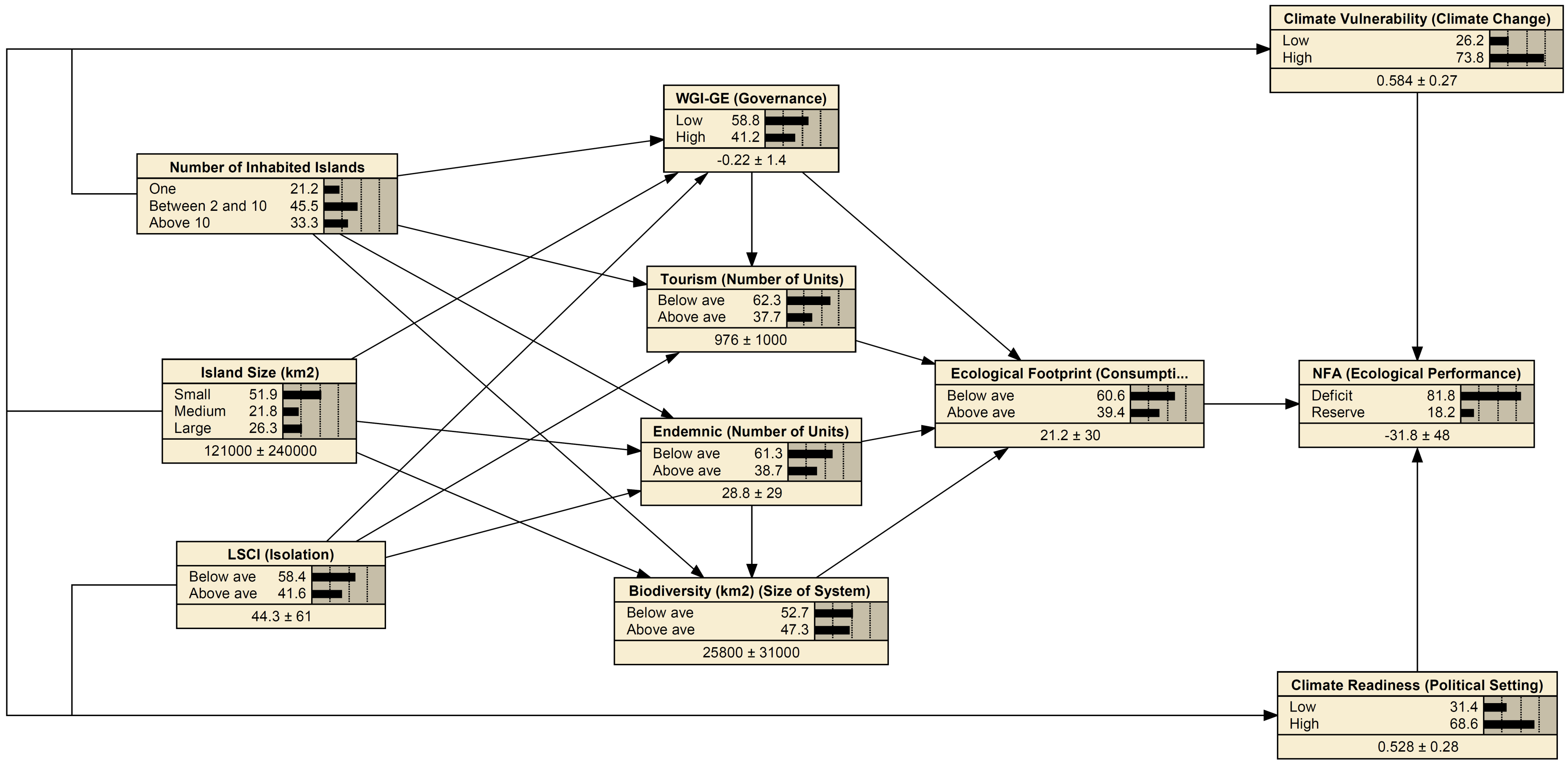


Figure 3-10: SEI BBN: Size of System vs. Ecological Performance

3.3.4.1 Validation

A three-fold validation process, whereby data were divided into three groups by randomly splitting the SIDS, after which two of the groups were used to train the network, and the third was used for testing (i.e. 22/11 different SIDS for training/testing) (Forio et al., 2015), to determine how accurately the model can predict an outcome and how it would perform in representing knowledge of the system. A cross-validation process was conducted on all SEI BBNs to determine their mean accuracies. All networks were tested for their ability to predict the outcome node (i.e., HDI or NFA). To ensure only accurate networks were utilised in the analysis, a threshold of 70% accuracy was used. The accuracy, based on the cumulative error rate calculated for each network, is shown in Figure 3-11. As shown, all networks were more than 70% accurate, with the SEI BBN: Productivity vs. Ecological Performance achieving 82% accuracy in predicting NFA.

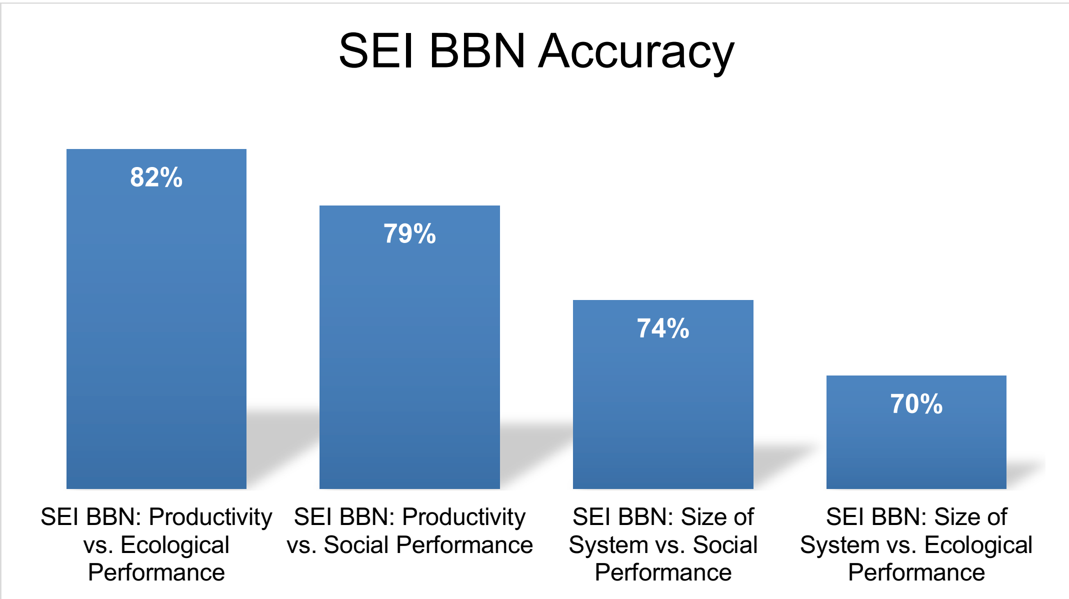


Figure 3-11: SEI BBNs' accuracies (results of the three-fold validation process)

3.3.4.2 Application

The SEI BBNs contain substantial information about how a socio-ecological islandscape may materialise in a real-world context. In addition, given the networks' accuracy, the models were used as an integral part of the subsequent Socio-Ecological Islandscape Resilience Capacity Index (SEIRCI), developed to provide evidence of the value of the socio-ecological islandscape concept. The SEI BBN:

Productivity vs. Ecological Performance, as well as the SEI BBN: Size of System vs. Social Performance, based on their accuracy and model structures, were used as theoretical frameworks in the development of the SEIRCI.

3.3.4.3 CPT analysis

To account for the limited training samples, the potential for CPTs to be untrained or trained deterministically was assessed directly in Netica by recording case counts for each node of the SEI BBN: Productivity vs Ecological Performance and the SEI BBN: Size of System vs Social Performance models. Based on the CPTs of the SEI BBN: Productivity vs. Ecological Performance model, 5% of the CPT rows were considered to be untrained, 11% deterministic with minimal support (<2 cases), 52% deterministic with substantial support (>2 cases), and 32% non-deterministic probability distributions. Similarly, the SEI BBN: Size of System vs. Social Performance had 7% of the CPT rows being considered as untrained, 8% deterministic with minimal support (<2 cases), 55% deterministic with substantial support (>2 cases), and 30% non-deterministic probability distributions.

While the majority of deterministic rows are supported by multiple cases, it should be noted that repeated observations of the same SIDS over the timeframe may drive some rows, provided these values remain stable throughout the study period, as some rows may reflect the behaviour of only a small number of distinct SIDS. However, given the heterogeneous nature of SIDS, several parent-state combinations describe specific structural characteristics that only apply to a small subset of islands; in these cases, the influence of a limited number of SIDS on a given row is considered a feature of the model, accurately representing distinct socio-ecological systems rather than a sampling deficiency. The model allows these distinct systems, and their effect on target nodes, to be analysed, thereby providing insights into how these variables shape socio-ecological systems in specific island contexts.

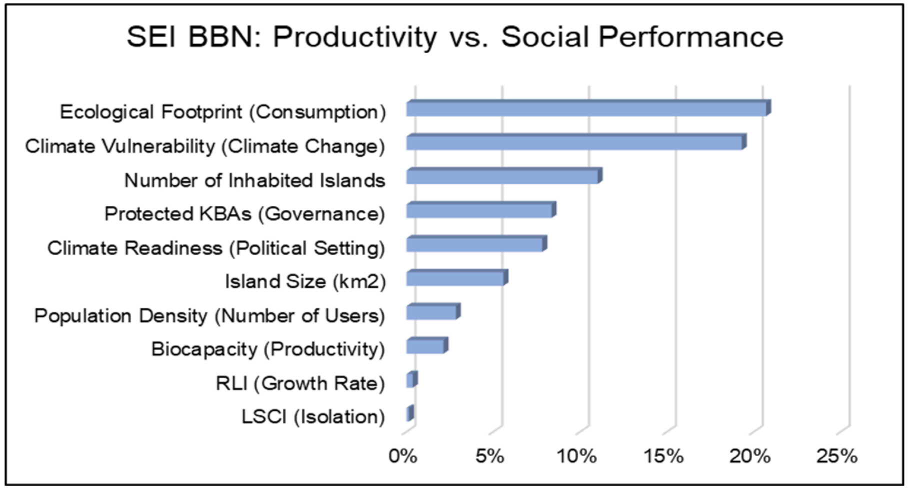
However, the model is unable to distinguish between a CPT row reflecting a stable subgroup and a coincidental pattern that has arisen for a limited sample size. This would require external validation. Therefore, the model is limited in the types of scenarios it can be utilised for, and in the degree of uncertainty and information that can be derived from its findings. The BBNs should be used as an informative model, highlighting risks and issues for further investigation, rather than a decision-making tool. Lastly, the untrained and minimally supported rows remain a limitation to the current parameterisation.

3.4 BBN analysis and discussion

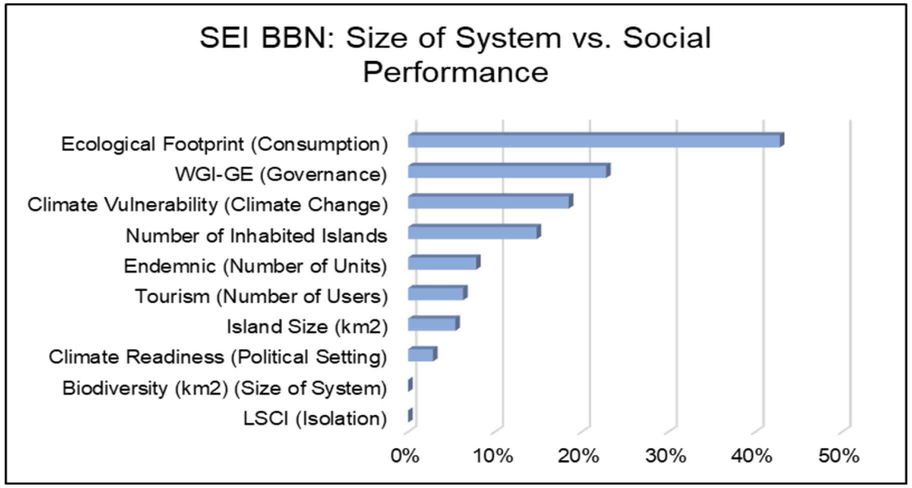
The analysis of the various BBNs is done in three phases. Initially, a sensitivity analysis was undertaken to highlight the influential variables within a system, a notable step toward understanding the role of "islandness" and providing evidence for the socio-ecological islandscape concept. Secondly, an analysis was conducted based on differing island scenarios and NFA (i.e., deficit vs. reserve) scenarios. This type of analysis further allows for understanding the effects of changes in the system based on different scenarios. Lastly, the probabilities derived from the SEI BBNs were evaluated to understand the general likelihood of how a socio-ecological islandscape may materialise in the real world. This review of the information provided valuable insights for further use in the study and highlighted possible gaps in understanding that should be researched in the future.

3.4.1 Sensitivity analysis

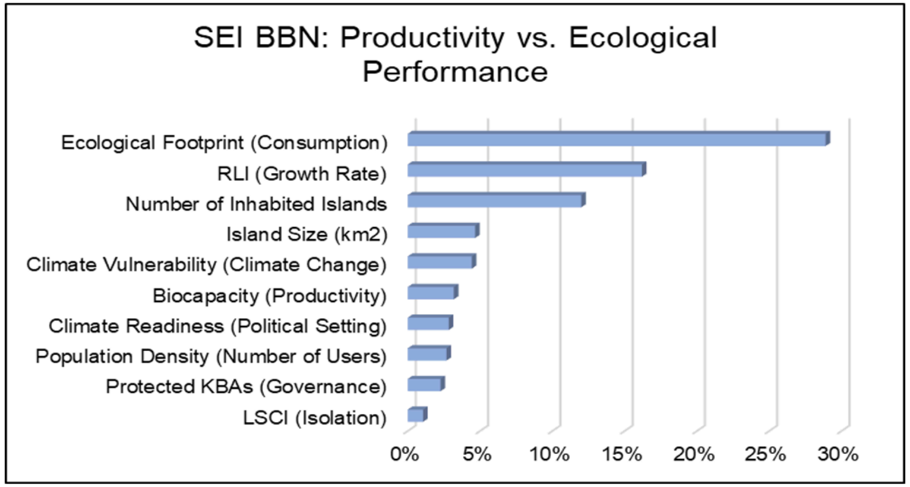
A sensitivity analysis, using Netica's Sensitivity to Findings tool, emphasises the important variables within a system by demonstrating the informational influence input variables have on the final output node (Landuyt et al., 2014). Moreover, it indicates whether a model is behaving as expected, where the sensitivity of a variable represents the expected outcome (Marcot et al., 2006). A sensitivity analysis (Figure 3-12) was undertaken on the output nodes (i.e. HDI (social performance) or NFA (ecological performance)), respectively, for the different networks, to compute the node's sensitivity relative to the other nodes within the SEI BBNs, thereby determining the magnitude to which the variables within the network are informative of, or associated with, the identified variable of concern.



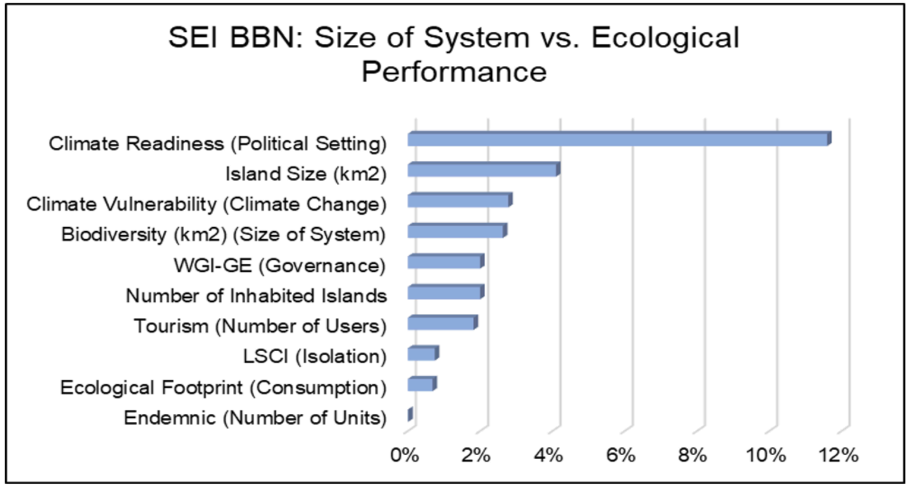
(a) SEI BBN: Productivity vs. Social Performance - Sensitivity to HDI



(b) SEI BBN: Size of System vs. Social Performance - Sensitivity to HDI



(c) SEI BBN: Productivity vs. Ecological Performance - Sensitivity to NFA



(d) SEI BBN: Size of System vs. Ecological Performance - Sensitivity to NFA

Figure 3-12: Sensitivity analysis (expressed as percent of variation reduction) performed on the 4 SEI BBNs illustrating the order of informative variables

The results of the sensitivity analysis performed on the different SEI BBNs provided the following insights into the socio-ecological islandscape concept:

- "islandness" and sensitivity: an evaluation of the respective sensitivities indicates that "islandness" variables were consistently associated with socio-ecological systems outputs, lending support to the notion of the socio-ecological islandscape concept. As demonstrated, "islandness" variables were some of the more sensitive variables in all the versions of the SEI BBNs. However, the "islandness" variable with the greatest sensitivity was the number of inhabited islands, followed by island size. LSCI, which was intended to measure isolation, had little impact on the system. This implies that, although island size has a fair degree of sensitivity in the system, the fragmentation/distribution of land surface area/population in terms of the number of inhabited islands is a more critical aspect of socio-ecological systems in a SIDS context. Therefore, the interaction between islands within an archipelago holds more weight in the model than the ways in which SIDS interact with continental countries;
- Island variability: several of the variables provide a measure of island variability through either ecological complexity (endemic) or local impact (population density and tourism). These variables generally had lower sensitivity on the system and may be due to the greater sensitivity of governance and climate change. Governance variables often shape the magnitude of the local impact, which seems to have had a greater effect on the system. Climate change is a significant issue for SIDS; the impact of climate vulnerability on the system is expected; and
- Interactions: As mentioned, Ecological Footprint is highly related to both HDI and NFA; therefore, its consistently high sensitivity across most networks verifies the model's behaviour.

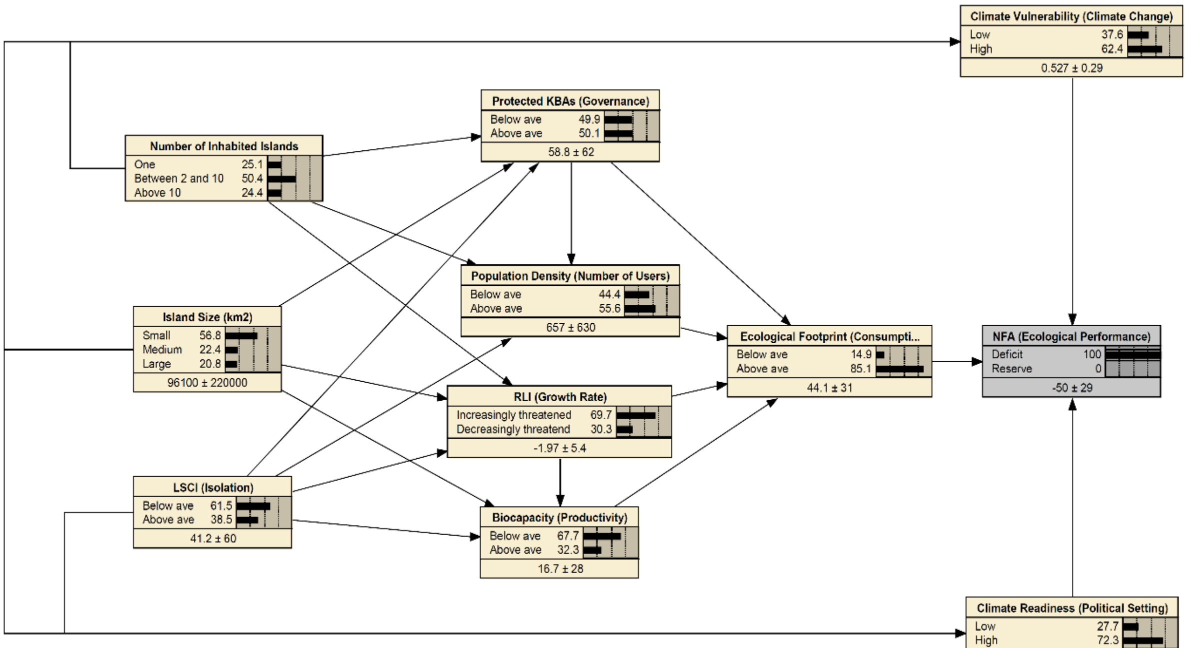
Upon further investigation into the role of "islandness" within the system, a sensitivity analysis was conducted across several aspects of the system to determine whether key issues are further affected by "islandness". These inquiries produced additional findings, such as the relative effect of (1) LSCI on actors (i.e. tourism and population density), (2) the number of inhabited islands on governance (i.e. WGI-GE and KBA coverage) and (3) island size on aspects of ecological complexity (endemic and biodiversity). These findings further lend to the validity of a socio-ecological islandscape concept.

3.4.2 Scenario analysis

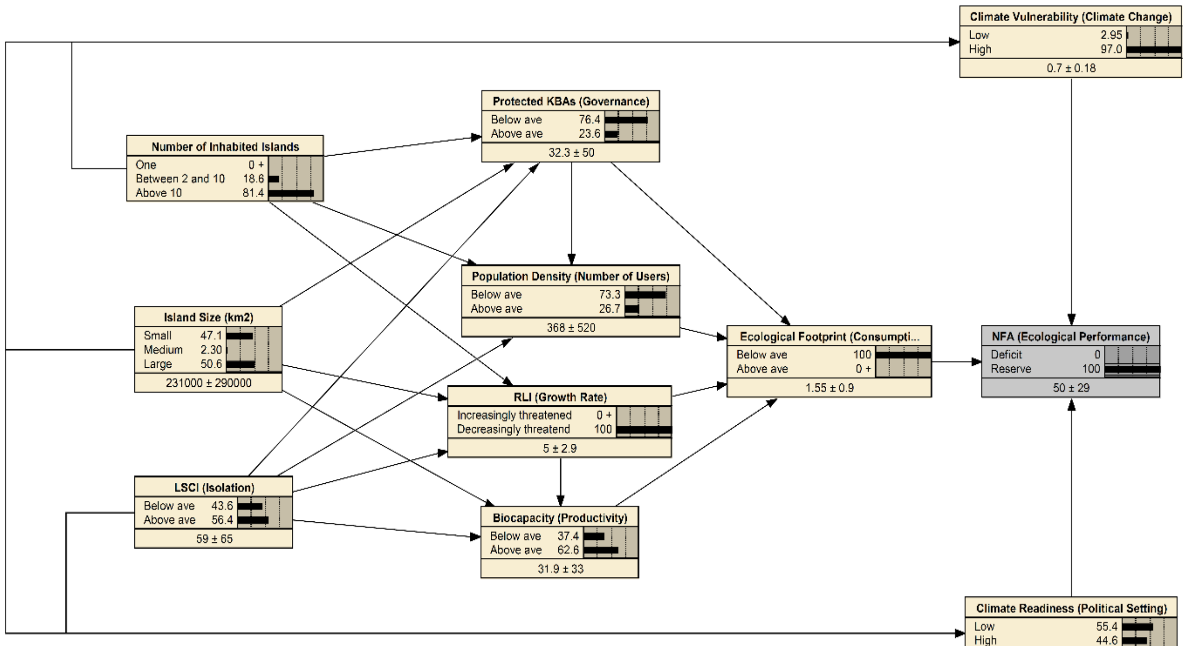
Based on the use of the most accurate SEI BBNs, two separate scenario analyses were used to explore probable differences in the respective networks with the goal of (1) understanding how parent and intermediate variables are affected by a changing state in the output nodes and (2) discerning the compounding effects of the collective "islandness" variables based on alternative island scenarios. As discussed, a single BBN model cannot fully capture all aspects of a socio-ecological islandscape. Therefore, ecological and social performance BBNs were used in the scenario analysis to gain insights into how islandness affects both aspects and what other insights can be ascertained.

The first scenario is a diagnostic scenario, which is derived from changing the state of the output node (NFA) in the SEI BBN: Productivity vs. Ecological Performance to either represent a deficit or a reserve (Figure 3-13). There are a few inferences that can be drawn from the diagnostic scenario's findings, such as the importance of the growth rate (RLI) and the number of users (population density) in determining the likelihood of a reserve. In addition, the probable difference in the "islandness" variables further underscores their importance and influence within the system (e.g., a>50% probability that the number of inhabited islands is>10).

The second scenario analysis defines two possible island scenarios, namely a large isolated archipelago measured against a fairly connected single small island, based on the SEI BBN: Size of System vs. Social Performance (Figure 3-14). The scenario analysis essentially provides further supporting evidence of the effect of "islandness" on the system, highlighting that within a large, isolated archipelago scenario, the probability of a low to medium HDI is markedly higher (>70%) than in a connected single small island scenario, which results in a greater probability (98.8%) of high to very high HDI. Additionally, during the analysis, LSCI was shown to have a stronger influence than the initial sensitivity analysis showed, significantly affecting the influence of the number of inhabited islands and island size on HDI. This suggests that the collective “islandness” variables exert a compounding influence that should be considered in the socio-ecological islandscape concept.

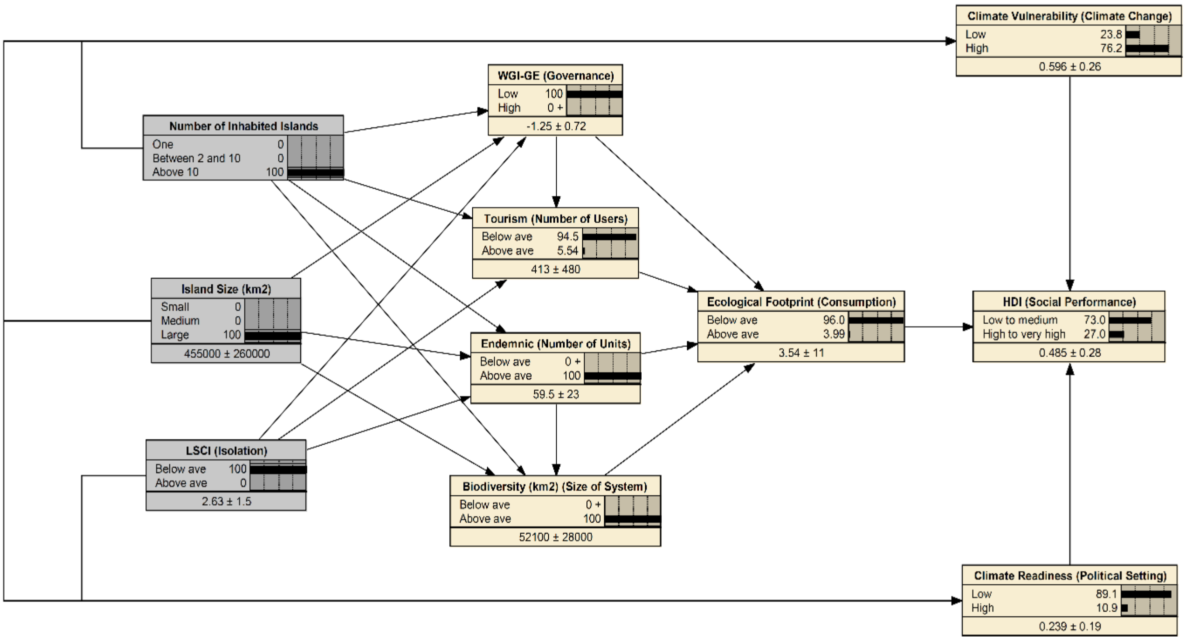


(a) SEI BBN: Productivity vs. Ecological Performance - Deficit

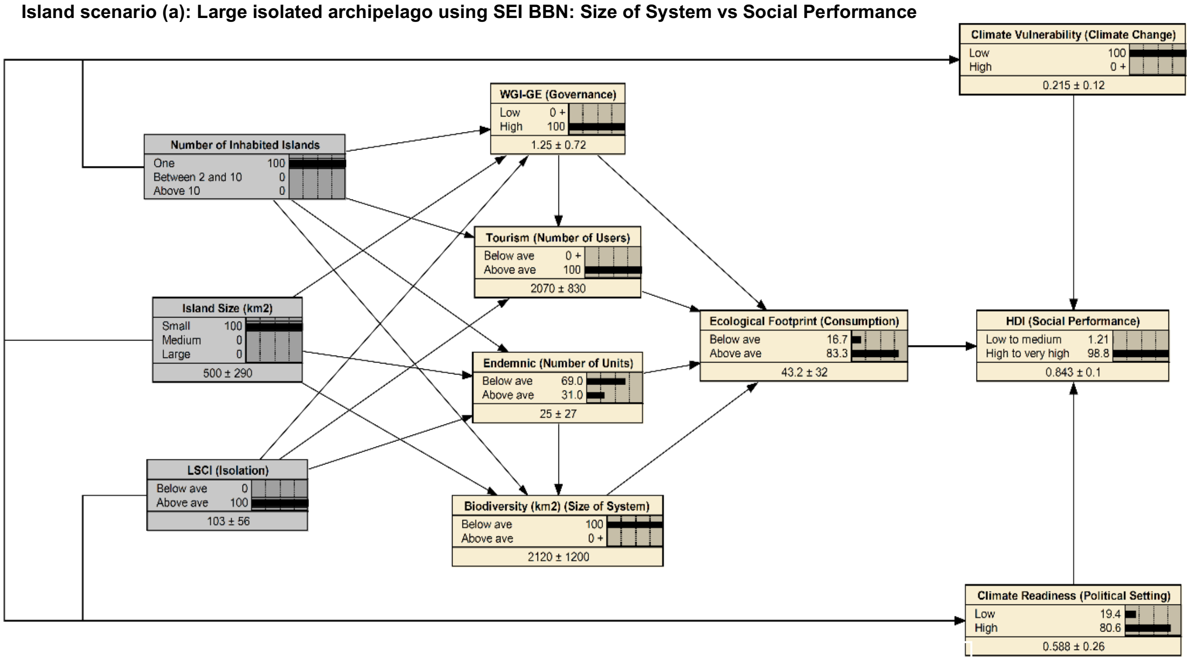


(b) SEI BBN: Productivity vs. Ecological Performance - Reserve

Figure 3-13: Comparison between a deficit and reserve scenario using SEI BBN: Productivity vs. Ecological Performance



Island scenario (a): Large isolated archipelago using SEI BBN: Size of System vs Social Performance



Island scenario (b): Small connected single island using SEI BBN: Size of System vs Social Performance

Figure 3-14: Comparison between island scenarios using SEI BBN: Size of System vs. Social Performance

3.4.3 Probability analysis

The probability analysis considered general trends in the probabilities derived from the respective nodes of the SEI BBN: Productivity vs. Ecological Performance and the SEI BBN: Size of System vs. Social Performance, and, based on the information embedded within these networks, the following insights were gained:

- The majority of SIDS are probably composed of an inhabited archipelago that is >1 000 km^2 in size and is fairly isolated in terms of global trade networks;
- Generally, SIDS have not had good governance, in terms of government effectiveness or conservation, over the 10-year study period;
- The number of users (population density and tourism) remains below average for the majority of SIDS;
- The ecological component of the socio-ecological islandscape has been under sustained pressure and has generally not been productive enough to deal with demand, as indicated by the high deficit probability for SIDS; and
- The SIDS, however, do often have high to very high levels of social performance (HDI). This indicates that currently a trade-off is taking place between social and economic development vs environmental protection in the SIDS context.

3.5 Methodological discussion

The socio-ecological systems framework provided a good point of departure, as it was essentially developed as a diagnostic tool intended to understand the causes of sustainability in complex socio-ecological systems (McGinns & Ostrom, 2014), and, combined with the diagnostic capacity of BBNs, provided significant rationale for their collective use. The BBNs are limited in their ability to consider feedback loops, as generally reflected within the socio-ecological systems framework; however, the BBNs were not developed as a comprehensive representation of a socio-ecological islandscape, but rather to provide the evidence required to support the notion. The BBNs were noted as being suitable for modelling processes and systems that are more novel (Landuyt et al., 2016), such as the socio-ecological islandscape concept. Furthermore, data on SIDS are often incomplete, as was found within this study. Although the PCA provided meaningful benefits in variable selection and initial insights into the influence of “islandness”, its inability to analyse observations with missing data required a modelling approach that could assimilate real-world data, which necessitated the use of BBNs. However, the usefulness of a PCA is further explored in Chapter 4, with respect to index development and, in particular, as a method for determining variable weightings.

The SEI BBNs contain substantial information about how a socio-ecological islandscape may materialise in a real-world context, as 33 SIDS were employed. The SEI BBNs showed considerable value in understanding the association of “islandness” and could be used to estimate the probability of several issues in SIDS based on unique island characteristics, especially in SIDS with limited data and that did not form part of this study. However, additional research into other “islandness” characteristics (e.g., island type or climatic zone) will be needed to provide a more comprehensive understanding of socio-ecological islandscapes.

However, the use of BBNs to support the notion of a socio-ecological islandscape is accompanied by a set of limitations that ultimately prevent its use beyond an informative tool for socio-ecological islandscape analysis. The nature of the discretisation of continuous data in BBNs, especially when using means as a parametrisation, carries a trade-off between loss of information within a node state and a model that is interpretable. Furthermore, the limitation of the SEI BBNs and the prevention of its use as a direct decision-making tool is also a consequence of both the uneven and under-reporting on SIDS, creating a scenario where comprehensive modelling is hindered.

The SEI BBNs provide a simulated socio-ecological islandscape, structured according to the theoretical framework of relationships and interactions suggested by McGinnis and Ostrom’s (2014) multitier socio-ecological systems framework. Therefore, the implied causal relationships that are embedded in the network structure are derived from this theoretical framework rather than being demonstrated by the BBNs. The BBN allows for probabilistic patterns to be discovered, which provide supporting evidence, rather than independent empirical proof of causation.

3.6 Summary

This chapter describes achieving the objective of providing evidence for the role of “islandness” in shaping socio-ecological systems on SIDS, thereby validating further investigation into the socio-ecological islandscape concept. “Islandness” has been shown to influence both social and ecological components of the system, with the number of inhabited islands exerting the greatest overall influence on a socio-ecological islandscape. However, island size and even isolation have a degree of influence on how a system interacts.

These inferences are vital for several reasons. Firstly, the socio-ecological notion provides an augmented perspective in assessing socio-ecological systems on islands. This proposes that each SIDS issue investigated should consider “islandness” in its methods and analyses. The aspect of “islandness” considered would depend on the research conducted and its applicability. Secondly, the number of inhabited islands has been shown to be the most notable factor related to “islandness”. Therefore, taking a socio-ecological islandscape perspective should always consider the possible interplay between islands in an archipelago. The previous case by Bunce et al. (2009) supports this presumption, as interactions among islands within an archipelago can have substantial positive or negative effects on the islands. Banos-González et al. (2015a), for example, developed a robust tool for sustainability assessment in island socio-ecological systems, using Fuerteventura in the Canary Islands as a case study. However, the socio-ecological islandscapes concept advocates investigating whether the tool could be improved by considering interactions with adjacent Arrecife and their influence on aspects of sustainability on Fuerteventura, or vice versa. Lastly, several indications of noteworthy relationships between “islandness” and other aspects of socio-ecological systems on SIDS are implied by the PCA and the SEI BBNs. Therefore, it should be emphasised that the analysis within this study has by no means fully developed the role of “islandness” in the evolution of socio-ecological systems on SIDS.

Additional components of “islandness” and possible relationships with aspects of socio-ecological systems that may occur have not been covered within this study. However, the intention is to adopt a new perspective on island socio-ecological systems studies, supported by the evidence provided. The importance of this is grounded in the relatively limited research that factors “islandness” into the socio-ecological systems on SIDS, and the ramifications of continued global environmental change on the current and future sustainability of these systems. As stated by Herrero-Jáuregui et al. (2018), global change and the ensuing environmental crisis have created a need for research into the complex intersection of ecological and social systems. The socio-ecological islandscape framework advances a research agenda focused on the SES-landscape-SIDS-islandness nexus, given its apparent impact on the economic disadvantages and ecological fragility faced by SIDS, which threaten their sustainability.

Moving to the next stage of the research requires operationalising the socio-ecological islandscape concept to highlight its potential benefits. To this end, the next chapter will detail the development process for an index that will be a measure of SIDS' resilience capacity and a means to understand trends in the socio-ecological islandscape-resilience nexus.

CHAPTER 4. SEIRCI METHODOLOGY

4.1 Introduction

Composite indicators have been used in numerous studies as a measure of complex systems, multifaceted properties, and as a means to explore and understand a collection of different indicators (Beynen et al., 2018; Gao et al., 2023; Du & Huang, 2024; Yao et al., 2024; Mozaffaripour et al., 2025). This chapter details the development of the socio-ecological islandscape resilience capacity index (SEIRCI), which is intended to provide a quantitative observation in key aspects of the resilience capacity of Small Island Developing States (SIDS), providing an easier-to-interpret measure that can be assessed over time. A more simplistic and easier-to-interpret time-series observation is highly beneficial for highlighting a country's performance, enabling it to be addressed at a policy-making level (Nardo et al., 2008). To ensure that the most effective and reliable SEIRCI is developed, several steps in its development need to be undertaken, as shown in Figure 4-1, and as discussed in this chapter.

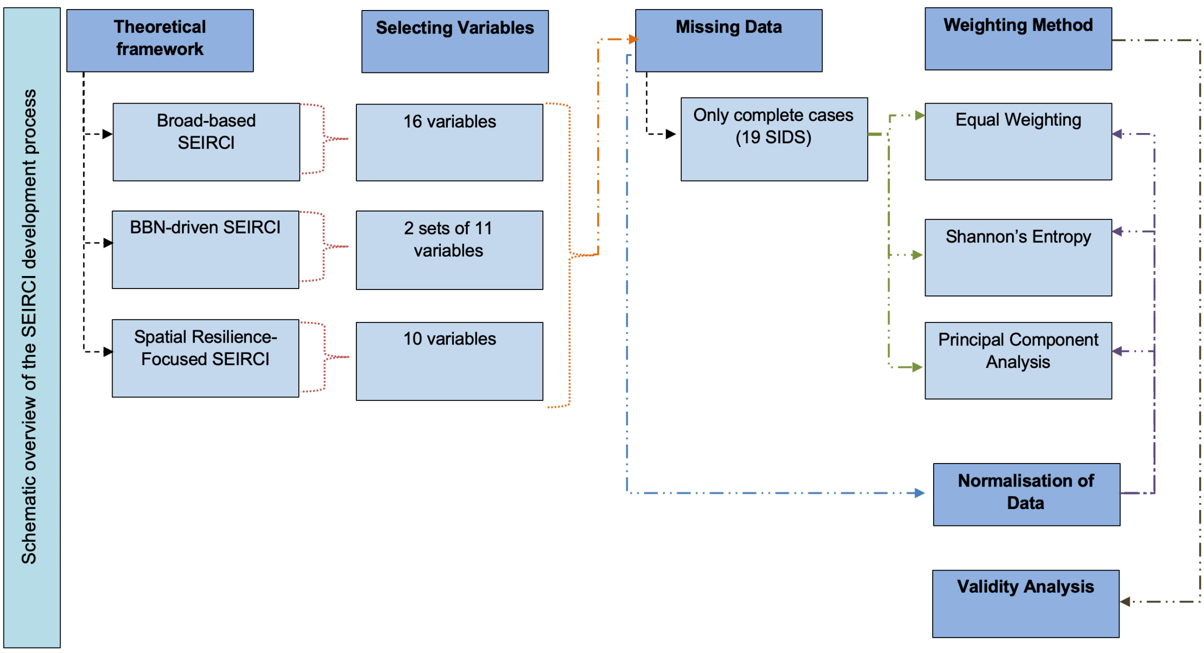


Figure 4-1: Overview of the SEIRCI development process

4.2 Theoretical framework

The theoretical framework for the SEIRCI is needed to provide a foundation for selecting appropriate variables and amalgamating them into a composite indicator that provides a meaningful measure of the resilience capacity of SIDS (Nardo et al., 2008). The overarching theoretical framework under which the SEIRCI will be developed is the previously mentioned socio-ecological islandscape (SEI) framework. The SEI framework is built on the ideas of the socio-ecological system (Ostrom, 2007); however, it ensures that the influence of “islandness” will be incorporated into the composite index. To ensure that the most robust SEIRCI is developed that can be used as a rapid evaluation tool for informing decision-making, three different approaches were undertaken.

4.2.1 Broad-based SEIRCI

The broad-based SEIRCI comprises the largest set of appropriate variables available for its development. This approach aims to incorporate as much valuable information as possible into the composite index, allowing it to serve as a simple measure of many variables that affect the resilience capacity of SIDS, thereby acting as a catch-all method.

4.2.2 BBN-Driven SEIRCI

Within the previous chapter, Bayesian Belief Networks (BBN) were developed to show the influence of “islandness” on socio-ecological systems. These networks provide clear relationships between variables, and several were developed to model differing aspects, namely, environmental and social performance. Creating a SEIRCI that measures environmental and social performance in parallel, providing a value for each, then aggregating them into a singular measure, allows for two important features. Firstly, the number of variables being assigned to each aspect is reduced, ensuring a reduction in unwanted variability in the data, and secondly, thereby providing more transparency for decision-making. Establishing two measures allows decision-makers to understand where the potential root cause of the declining resilience capacity is situated, i.e. with the social performance dimension or the environmental performance dimension.

4.2.3 Spatial Resilience-Focused SEIRCI

The spatial resilience-focused approach distils the variables into categories associated with spatial resilience theory, thereby serving as the analytical method for spatial resilience. As previously discussed, spatial resilience refers to the characteristics of a system as they pertain to its spatial context (Allen et al., 2016; Rescia & Ortega, 2018). The spatial resilience-focused SEIRCI examines the links between SIDS and the internal and external elements of spatial resilience (Cumming, 2011b) and identifies relevant variables that are representative of these spatial elements.

4.3 Selecting variables, multivariate analysis and missing data

4.3.1 Variable selection and multivariate analysis

The selection of variables for this study has already been extensively covered in section 3.21 of Chapter 3, where variables underwent a Principal Component Analysis (PCA) to reduce the number of variables from 24 to 16 (refer to Table 3-3 and Table 3-4). However, it is essential to note that between the development of the BBNs and the SEIRCI, several changes in the assessment and collection methods for these variables had occurred. Therefore, to ensure comparability of data over time and to provide a measure of the latest resilience capacity of SIDS, the datasets for these variables were updated for 2014 and 2022. The time series was determined by the availability of data for the largest number of possible islands.

4.3.1.1 Variable selection – Broad-based SEIRCI

As previously discussed, the broad-based SEIRCI approach attempts to utilise a larger number of variables to determine the resilience capacity of SIDS. When evaluating a complex phenomenon such as resilience capacity, combining several variables that represent different dimensions acts as a proxy for resilience capacity (Mazzoitta & Pareto, 2013). Using more variables allows the index to draw on more information about these different dimensions of resilience capacity. Therefore, the broad-based SEIRCI utilises the full battery of 16 variables identified through the multivariate analysis undertaken on the original 24 variables (refer to Table 3-5). In contrast, too many variables may cause overfitting of the data as well as issues related to redundancy (variables that may be measuring similar dimensions, resulting in overlap)

(Schlossarek et al., 2019). The variables utilised for the broad-based SEIRCI are shown in Table 4-1.

Table 4-1: Variables used in the Broad-based SEIRCI approach

Broad-based SEIRCI Variables
Number of Inhabited Islands
Island Size (km^2)
Linear Shipping Connectivity Index (LSCI)
Government Effectiveness (WGI-GE)
KBA Coverage (% coverage)
Tourism (Inbound expenditure)
Population Density (per km^2)
Endemic (Number of species)
Red List Index (RLI)
Biodiversity (km^2 of KBAs)
Biocapacity
Ecological Footprint
Climate Vulnerability
Climate Readiness
National Footprint Account (NFA)
Human Development Index (HDI)

4.3.1.2 Variable selection – the BBN-driven SEIRCI

The BBNs that were identified as most representative of a socio-ecological islandscape were the SEI BBN: Productivity vs Ecological Performance and the SEI BBN: Size of System vs Social Performance. Therefore, these two networks were selected as frameworks for the BBN-driven SEIRCI. Providing two parallel measures for resilience capacity (i.e. environmental performance and social performance) provides a clearer indication of where potential changes in resilience capacity are taking place when measuring the index over time.

Moreover, aggregating the two performance scores provides a robust measure of the influence of “islandness” on the resilience capacity. However, similarly to the issues stated in the broad SEIRCI, the overuse of variables may lead to “double counting” within the index and may overvalue the contribution of repeated variables. Nonetheless, there are potential benefits of retaining an index containing parallel dimensions that can be analysed separately, as this will allow for greater transparency during the decision-making process. The variables that were included in the BBN-driven SEIRCI are provided in Table 4-2.

Table 4-2: Variables used in the BBN-driven SEIRCI approach

SEI BBN: Productivity vs Ecological Performance	SEI BBN: Size of System vs Social Performance
Number of Inhabited Islands	Number of Inhabited Islands
Island Size (km^2)	Island Size (km^2)
Linear Shipping Connectivity Index (LSCI)	Linear Shipping Connectivity Index (LSCI)
KBA Coverage (% coverage)	Government Effectiveness (WGI-GE)
Population Density (per km^2)	Tourism (Inbound expenditure)
Red List Index (RLI)	Endemic (Number of species)
Biocapacity	Biodiversity (km^2 of KBAs)
Ecological Footprint	Ecological Footprint
Climate Vulnerability	Climate Vulnerability
Climate Readiness	Climate Readiness
National Footprint Account (NFA)	Human Development Index (HDI)

4.3.1.3 Variable selection – Spatial Resilience-Focused SEIRCI

The spatial resilience-focused SEIRCI aims to reduce redundancies in the index, focusing on key indicators. A smaller set of variables will allow for a more simplistic approach, while potentially maintaining important information related to the resilience capacity of SIDS. It should be noted that whenever variables are removed, there is a risk of information loss, while the remaining variables inevitably increase in importance (Schlossarek et al., 2019). To select the smaller set of variables, indicators were either removed on the grounds of parsimony or were retained due to their theoretical importance (Schlossarek et al., 2019). In the case of the spatial resilience-focused SEIRCI, theoretical importance is related to how effectively a variable can act as a proxy for internal and external elements of spatial resilience (Cumming, 2011b). The table below provides the internal and external elements of spatial resilience linked to SIDS, and the variables that are used as proxies within the Spatial Resilience-Focused SEIRCI (refer to Table 4-3).

Table 4-3: Variables used in the Spatial Resilience-focused SEIRCI approach

Spatial Resilience	Links to Small islands developing states	Variable
	Primary internal elements	
Spatial arrangement	The configuration of communities in relation to the archipelago in SIDS will affect both the type of resources relied on by the communities as well as	Number of inhabited islands

Spatial Resilience	**Links to Small islands developing states**	**Variable**
	access to resources these communities will have. This spatial arrangement can often be influenced by the configuration of other elements within the SIDS, such as services, natural capital, and topography.	
System properties (e.g., size, shape and the number and nature of the boundaries)	Several system properties have effects on SIDS, such as the size of the island, which will significantly affect the number of available resources and prevent economies of scale. The SIDS, by nature, have a hard boundary that encompasses the entirety of the system (i.e. surrounded by the sea).	Size of island
Temporal dynamics	An example of temporal factors that influence the functioning of the socio-ecological system on SIDS includes climate vulnerability, which affect both exposure and sensitivity to climate change and provides a measure of adaptive capacity.	Climate Vulnerability
Location	Location refers to the specific unique properties (i.e. physical, environmental or socio-economic) of the system that can directly contribute to their resilience capacity. Due to the finite resources available to SIDS (both in terms of human and natural resources), this aspect is of particular importance.	Biocapacity, HDI
Primary external elements		
Context	Context refers to the spatial surroundings, which can include aspects of governance and global economic influences on the local system. Considering SIDS political and economic position within the global arena, these aspects contribute considerably to their overall resilience capacity.	WGE-GI, Climate readiness
Connectivity	An important aspect of functionality of a socio-ecological system is the connectivity between people and resources, either social resources (economic opportunities, services) or ecological resources (natural capital). Connectivity within a SIDS can include hard	LSCI

Spatial Resilience	Links to Small islands developing states	Variable
	boundaries, due to the dominance of the sea. The most influential aspect of connectivity related to SIDS is their isolation. The distance of the islands from the mainland has significant effects on the economy, biodiversity, and politics of SIDS.	
Spatial feedback	Considering population dynamics as an example, spatial feedback that influences this is migration, either between islands within the same archipelago or to the mainland. Spatial feedback from spatial variations can either positively or negatively affect the system. In the case of migration, the social resilience decreases, however, the pressure of natural capital also decreases.	Ecological Footprint
Spatial subsidies	Subsidies within SIDS are limited because of their location in space and their inherent hard boundaries. One significant subsidy that affects several SIDS is tourism, which is a major contributor to both the economy and the consumption of resources.	Tourism Expenditure

4.3.2 Missing Data

Missing data can cause considerable issues in creating a composite index. Several methods are available to address missing data, including implicit modelling (e.g. substitution) and explicit modelling (e.g. regression imputation) (Nardo et al., 2008). However, due to several approaches taken in the development of the SEIRCI, only complete cases were used. This decision allowed for the most precise measure of the SEIRCI to be provided for a particular SIDS without being skewed by approximations. Including approximations may not provide an accurate representation of that dimension for a particular SIDS, resulting in an incorrect reporting of overall resilience capacity. The decision to use only complete cases highlighted a significant issue affecting research on SIDS. The number of complete cases for the SEIRCI was reduced to only 19 SIDS (refer to Table 4-4). The SIDS indicators are significantly under-reported, which acts as a significant barrier to both research and policy decision-making, both at a country and a global level.

Table 4-4: SIDS with complete datasets

SIDS – Complete Cases
Antigua and Barbuda
Bahamas
Bahrain
Barbados
Cape Verde
Cuba
Dominica
Dominican Republic
Fiji
Grenada
Haiti
Mauritius
Samoa
São Tomé and Príncipe
Singapore
St. Lucia
Timor-Leste
Tonga
Trinidad and Tobago

4.4 Normalisation of Data

Normalisation of data is commonly used to ensure that data from different variables are scaled for comparability (Nardo et al., 2008; Ghanem et al., 2025). The min-max normalisation method (refer to Equation 4-1) was selected for scaling the data used in the development of the SEIRCI. This method has been frequently used in the development of indices (Verma et al., 2022; Du & Huang, 2024; Mozaffaripour et al., 2025) and was selected to ensure that the units of measurement for each indicator are scaled from 0 to 1. Min-max normalisation allows for more effective comparisons between indicators and is effective with datasets that have a large range (Yin et al., 2025). The selection of the min-max normalisation method was driven by the proposed use of Shannon's entropy-weighting technique, which requires a consistent scale for valid entropy calculations and comparisons (Yin et al., 2025). In addition, when applying weights from a PCA or an equal weighting approach to normalised data, the index scores will range from 0 to 1, allowing for easier interpretability in decision-making.

$$\boldsymbol{x'} = \frac{\boldsymbol{x} - \mathbf{min}(\boldsymbol{x})}{\mathbf{max}(\boldsymbol{x}) - \mathbf{min}(\boldsymbol{x})}$$ **Equation 4-1**

Where (x') is the normalised value of the country, and $\min(x)$ is the minimum value across all countries and $\max(x)$ is the maximum value across all countries.

To ensure comparability between the 2014 and the 2022 index scores. The normalisation of the 2022 data was conducted using the minimum and maximum values for 2014 (refer to Equation 4-2). This enables the data to be standardised into the same range, facilitating more comparable index scores and better interpretability of changes in index scores over time.

$$\boldsymbol{y'} = \frac{\boldsymbol{y} - \mathbf{min}(\boldsymbol{x})}{\mathbf{max}(\boldsymbol{x}) - \mathbf{min}(\boldsymbol{x})}$$ **Equation 4-2**

Where (y') is the normalised 2022 value of the country, and $\min(x)$ is the minimum 2014 value across all countries and $\max(x)$ is the maximum 2014 value across all countries.

Once the datasets were normalised, several variables that have a negative effect on the resilience capacity of SIDS, and thus would negatively impact the SEIRCI index score, were inverted using Equation 4-3 and Equation 4-4. This step ensured accurate contributions of specific variables (Table 4-5) to the index (i.e. a high-valued negative variable would be inverted so a low score would be incorporated into the index).

$$\boldsymbol{x'_{inj}} = \mathbf{1} - \boldsymbol{x'_{j}}$$ **Equation 4-3**

$$\boldsymbol{y'_{inj}} = \mathbf{1} - \boldsymbol{y'_{j}}$$ **Equation 4-4**

Where (x'_{inj}) and (y'_{inj}) are the inverse normalised values for 2014 and 2022 values of variable (j), respectively.

Table 4-5: Variables that negatively affect resilience capacity

Variables Negatively Affecting Resilience Capacity
Number of Inhabited Islands
Ecological Footprint
Climate Vulnerability

4.5 Weighting Method

According to Mazziotta and Pareto (2025), explicit weighting aims to define the relative importance of a specific variable within the index by assigning it a numerical value; consequently, this will have a substantial influence on the values generated by the composite index for a country. Therefore, the weighting of variables within the index is crucial to its usability.

In this regard, a set of weighting techniques was identified for testing within the development of the SEIRCI, which includes equal weighting (EW), the use of a PCA (PCA) and Shannon's Entropy (Ent). These data-driven weighting methods were selected to highlight statistically significant indicators in the absence of subjective judgements based on expert knowledge (Robles et al., 2026), especially in the development of a new interdisciplinary concept, where importance can be driven by an expert's focus area. It should be noted that variables were selected based on a literature-driven approach as proxy indicators of resilience. Data-driven weighting is used to determine how these variables are rated relative to one another, rather than to determine which variables represent resilience. The weighting method assumes that indicators which better differentiate SIDS should have greater relative weight in representing differences in resilience capacity. These are described as follows:

4.5.1 Equal weighting

Many composite indicators rely on the use of equal weighting for variables, such as the Human Development Index (HDI) (Ghanem et al., 2025), thereby assigning an equal level of relative importance to each. An example is given in Salvati and Carlucci (2014), in which several weighting methods, including various equal weighting approaches, were used to develop a composite sustainable development index at the local scale.

Equal weighting does not inherently mean that there are “no weights” but rather that there is no statistical or empirical reason for alternative weighting (Nardo et al., 2008). In terms of its selection and use in the development of the SEIRCI, it may be beneficial for a spatial resilience-focused approach, where a smaller number of variables linked to the internal and external elements of spatial resilience contribute equally to resilience capacity. Additionally, equal weighing provides a simpler approach that reduces added uncertainty and subjectivity in the index (Ajtai et al., 2023). The formula used in equal weighting is shown in Equation 4-5.

$$\boldsymbol{SEIRCI = \frac{1}{n}\sum_{j=1}^{n} x'_j \; (j = 1, 2, \dots, n)}$$ **Equation 4-5**

Where (n) is the total number of variables; and
(x'_j) is the normalised value for the (j^{th}) variable, where (j) ranges from 1 to n

4.5.2 Principal Component Analysis

A principal component analysis (PCA) is a commonly used statistical technique in the development of composite indices (Ajtai et al., 2023). For example, a study by Verma et al. (2025) utilised the factor loadings from a PCA to identify key soil parameters and provide respective weightings for the development of a soil ecological index, while Balaganesh et al. (2020) opted for using a PCA to determine weights for a composite vulnerability index of climate change-induced drought in Tamil Nadu, India.

Using a PCA allows for dimensionality reduction while retaining variability by converting a set of correlated variables into a set of uncorrelated variables. These uncorrelated variables are known as principal components and are arranged according to the amount of variance (spread or dispersion) each accounts for in the data (Bucherie et al., 2022; Robles et al., 2026).

The use of a PCA in index construction and in the determination of weightings for variables is driven by its objectivity (Ghanem et al., 2025). A PCA provides a statistically driven method for determining weights by basing the weights on the variables' contribution to the total variance, i.e. the variables that explain more variances will be considered as having more contribution in a particular principal component (Bucherie et al., 2022) and therefore provide more statistical information in measuring the construct under investigation (e.g. resilience capacity of SIDS). The degree of contribution these variables have within a principal component is represented by their factor loadings. The higher the factor loading, the more that variable contributes to the variance represented by the principal component (Robles et al., 2026).

To undertake a PCA, the data were normalised using z-score standardisation (refer to Equation 4-6) (Ghanem et al., 2025; Robles et al., 2026), so that variables at different scales are adjusted to be comparable (Farrugia, 2008).

$$\boldsymbol{Z_{ij}} = \frac{\left(\boldsymbol{x_{ij}} - \boldsymbol{\mu_j}\right)}{\boldsymbol{\sigma_j}}$$ **Equation 4-6**

Where (x_{ij}) represents the original observation (i) of variable (j);
(Z_{ij}) is the converted standardised value;
(μ_{ij}) is the mean of variable (j); and
(σ_j) is the standard deviation of variable (j).

Once the data have been standardised, a covariance matrix (correlation matrix) is created (Nardo et al., 2008) in order to redefine the correlated variables into a new set of uncorrelated variables, as illustrated in Equation 4-7 (Robles et al., 2026):

$$\boldsymbol{C_{ov}} = \frac{\boldsymbol{1}}{\boldsymbol{n-1}}\boldsymbol{Z^T Z}$$ **Equation 4-7**

Where (Cov) is the covariance (correlation) matrix;
(n) is the number of observations;
(Z) represents the standardised data matrix, and

(Z^T) is the transpose of the standardised data matrix (i.e. $Z^T Z$ will result in a new matrix that summarises relationships between variables).

Once a covariance (correlation) matrix has been calculated, the eigenvalues (λr) and the corresponding eigenvectors ($\mathrm{E}r$) are computed using Equation 4-8.

$$\boldsymbol{C_{ov}E_r = \lambda_r E_r}$$ **Equation 4-8**

Eigenvalues are then sorted from highest to lowest, with the associated eigenvectors arranged in the same order (refer to Equation 4-9). The first principal component (PC1) is considered the eigenvector with the highest eigenvalue, as it represents the most variance (Ghanem et al., 2025).

$$\boldsymbol{\lambda_1 \geq \lambda_2 \geq \ \ldots \geq \lambda_m}$$ **Equation 4-9**

To create weights for the SEIRCI, factor loadings from PC1 are used (because this PC explains most of the variance). Using factor loadings of the first principal component is a commonly used approach to index development (Robles et al., 2026). Weighting of the factor loadings (v_{jr}) was done using Equation 4-10. This normalised the weights to a scale of 0 to 1 to maintain consistency and comparability.

$$\boldsymbol{w_j = \frac{|v_{jr}|}{\sum_{j=1}^{m} |v_{jr}|}}$$ **Equation 4-10**

The SEIRCI was calculated by multiplying the weights (w_j) by the normalised values (x') of each variable (refer to Equation 4-11).

$$\boldsymbol{SEIRCI_i = \sum_j w_j \times x'_{ij}}$$ **Equation** 4-11

4.5.3 Shannon's Entropy

Shannon's entropy, first derived by Claude E. Shannon in 1948, originates in information theory and measures a system's uncertainty or disorder (Zhou et al., 2024; Yin et al., 2025). However, in the context of composite indicator development, Shannon's entropy provides a measure of the diversity of information within a given variable in a dataset (Verma et al., 2022). In using the commonly used data-driven Entropy Weighting Method (Zou et al., 2006; Yue & Yang, 2020; Verma et al., 2022; Yin et al., 2025), an inverse approach to entropy is considered, where variables within high uncertainty or disorder (higher entropy) will provide less useful information to the index, and, therefore, will have a lower weighting (Hansan & Ra, 2020; Zhou et al., 2024; Robles et al., 2026). Essentially, variables with high entropy have less discriminatory power than variables with lower entropy, which contain more information about the construct being measured by the index (high entropy = low weight; low entropy = high weight). An example of the use of entropy in weighting is given in Zhou et al. (2024), in which entropy was used to derive weights for variables within a Pressure-State-Response resilience assessment model for Xishuangbanna Community Conserved Areas, southwest China.

The entropy weighting was undertaken on a min-max normalised dataset (refer to section 4.4). The next step of undertaking Shannon's entropy was to undertake a proportion calculation (transforming the normalised values into a probability distribution representing the relative contribution of an observation to an indicator), which is done using Equation 4-12, where (p_{ij}) represents the proportion of observation (i) for indicator (j) and (x'_{ij}) are the normalised data.

$$\boldsymbol{p_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{m} x'_{ij}}}$$

Equation 4-12

The proportions are then used to quantify entropy information (i.e., an entropy value for each specific variable, showing their respective degrees of uncertainty or disorder).

The entropy calculation was carried out using Equation 4-13 (Verma et al., 2022):

$$\boldsymbol{e_j = -K\sum_{i=1}^{m} P_{ij}\,\mathrm{In}P_{ij}} \qquad \textbf{Equation 4-13}$$

Where (e_j) refers to the entropy of indicator (j)

(K) is the normalisation constant ($K = 1/\mathrm{In(n)}$) and ensures that the maximum entropy will be 1, therefore keeping the entropy range at [0,1]; and

(P_{ij}) represent the proportions.

Finally, the weights for each variable are derived from the inverse entropy values to represent the usefulness of information provided by each variable for the index (refer to Equation 4-14).

$$\boldsymbol{w_j = \frac{(1 - e_j)}{(m - \sum_{j=1}^{m} e_j)}} \qquad \textbf{Equation 4-14}$$

4.6 Validity Analysis

Two methodologies were utilised in analysing the validity of the SEIRCI, namely, through internal agreement and by confirming external validity.

4.6.1 Internal Agreement – Spearman's rank correlation coefficient

Gauging internal agreement using Spearman's rank correlation coefficient is a nonparametric measure (i.e. no assumptions about the distribution of the data) of the correlation between the rankings of the different index scores for the same country (Wu et al., 2018) and evaluates the degree of convergence or divergence between the ranks. This was achieved by ranking each SIDS based on the index score given by the different calculation methods applied and using these rankings in Equation 4-15 (Wu et al., 2018).

$$p = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2 - 1)}$$ **Equation 4-15**

Where (d_i) is the difference in rank given by two different index scores for each country, and (i) and (n) are the number of countries.

Using Spearman's rank correlation provides a measure of internal validity through identifying similarities and differences in the rank ordering of SIDS between the different weighting methods and SEIRCI approaches, giving the index development process a degree of transparency and robustness (Robles et al., 2026). Understanding whether the rankings diverge significantly clarifies how the methodological decisions made during the SEIRCI development process influence the final index score, confirming whether the index measures the intended construct consistently (Salvati & Carlucci, 2014; Robles et al., 2026). An example of using Spearman's rank correlation coefficient is given in Salvati and Carlucci (2014), where it was used to select the model for the development of a composite sustainable development index at the local scale.

4.6.2 Pragmatic Benchmarking – Average Shift in Rankings

As proposed by Nardo et al. (2008), using the idea of the average shift in rankings between the index score and an established index score that measures a similar, but distinct, construct gives an additional analysis of the degree of sensitivity and uncertainty within the various index development approaches (Öztürk et al., 2024). Suárez et al. (2024) illustrated the use of the average shift in rankings calculations to evaluate the sensitivity of the proposed urban resilience index. The average shift in rankings was calculated using Equation 4-16.

$$\bar{R} = \frac{1}{n}\sum_{c=1}^{n}\left|Rank_{ref}(EPI_c) - Rank(SEIRCI_c)\right|$$ **Equation 4-16**

Where $(\bar{R})$ is the average shift in the rankings of the countries;
$(Rank_{ref}(EPI_c))$ represents the country rank in the reference index; and
$(Rank(SEIRCI_c))$ represents the country rank in the SEIRCI.

The Environmental Performance Index (EPI) was selected as the reference index for pragmatic benchmarking, as it measures a country's sustainability (Block et al., 2024) and is linked to overall resilience. A $\bar{R}$ value closer to 0 will indicate correlation between the rankings of countries within the EPI compared to the SEIRCI.

4.7 Summary

The development of a composite index is a common approach in providing an easily interpretable and comparable measure of complex constructs (Salvati & Carlucci, 2014; Wiréhn et al., 2015; Wu et al., 2018; Öztürk et al., 2024; Mora-Motta et al., 2025; Robles et al., 2026), and can be undertaken through several methods (Nardo et al., 2008), depending on factors such as the construct being measured, the variables used and the availability of data.

Each stage of the SEIRCI development process was crucial in creating a composite index that could accurately and reliably measure the intended construct (i.e. the inherent resilience capacity of a SIDS), from the normalisation of data that ensured comparability between indicators to Spearman's rank correlation coefficient, which analysed sensitivity. These processes ensured robustness and transparency in the development of the SEIRCI.

CHAPTER 5. SEIRCI DEVELOPMENT RESULTS AND DISCUSSION

5.1 Introduction

There are considerable benefits of having a measure that can be easily interpreted for both research and policy-related decision-making. The Socio-Ecological Islandscape Resilience Capacity Index (SEIRCI) aims to provide such a measure, allowing for trends in the general resilience capacity of SIDS to be monitored over time, as well as illustrating the benefits of taking a socio-ecological islandscape perspective. These trends can provide information, for example, on either the impacts of policies implemented or as a measure of how the "status quo" continues to impact general resilience, possibly prompting the need for action. However, to ensure that the SEIRCI is a robust tool that can be used for its intended purpose, the index has undergone substantial development, including numerous variations based on theoretical frameworks and weighting methodologies. The following chapter describes and discusses the results of the SEIRCI development process.

5.2 Analysis of weighting methodologies

5.2.1 Principal Component Analysis

Several key informational elements can be derived from the results of a PCA. These elements include the percentage of variance captured for each principal component, the dimensional structure of the variables, and the variable factor loadings.

The percentage of variance captured by each of the PCA-driven indices is shown in Figure 5-1. The range of variance captured by the first principal component for any of the indices was between 41% and 49%, which is consistent with the percentage variance explained by the first principal component in environmental indices that utilise PCA in their development (Wiréhn et al., 2015; Lessy et al., 2025; Robles et al., 2026). This is likely due to the multifaceted nature of socio-ecological systems (Berkes, 2017), as many of the variables used are constructs for multiple dimensions that are interconnected, but not necessarily correlated. This dimensional structure of the variables is illustrated through PCA biplots in Figure 5-2.

Each variable analysed through the PCA is given a set of factor loadings (Table 5-1) that range from -1 to +1. These factor loadings represent the correlation of the variable to the derived principal component. Variables that have been given a high absolute factor loading score contribute more to that principal component, and consequently, when developing the weights for any of the PCA-driven indices, the factor loadings of the first principal components were used. Due to variables with a high factor loading value having a higher contribution, variables with a high factor loading value were also given a higher weight in the associated index. Furthermore, the percentage variance captured by PC1 for each of the PCA-driven indices justified using the PC1 factor loadings for the associated variable weightings. This approach is common in index development when the main variability is accounted for within PC1 (Robles et al., 2025), as is seen in all the PCA-driven indices (Figure 5-1).

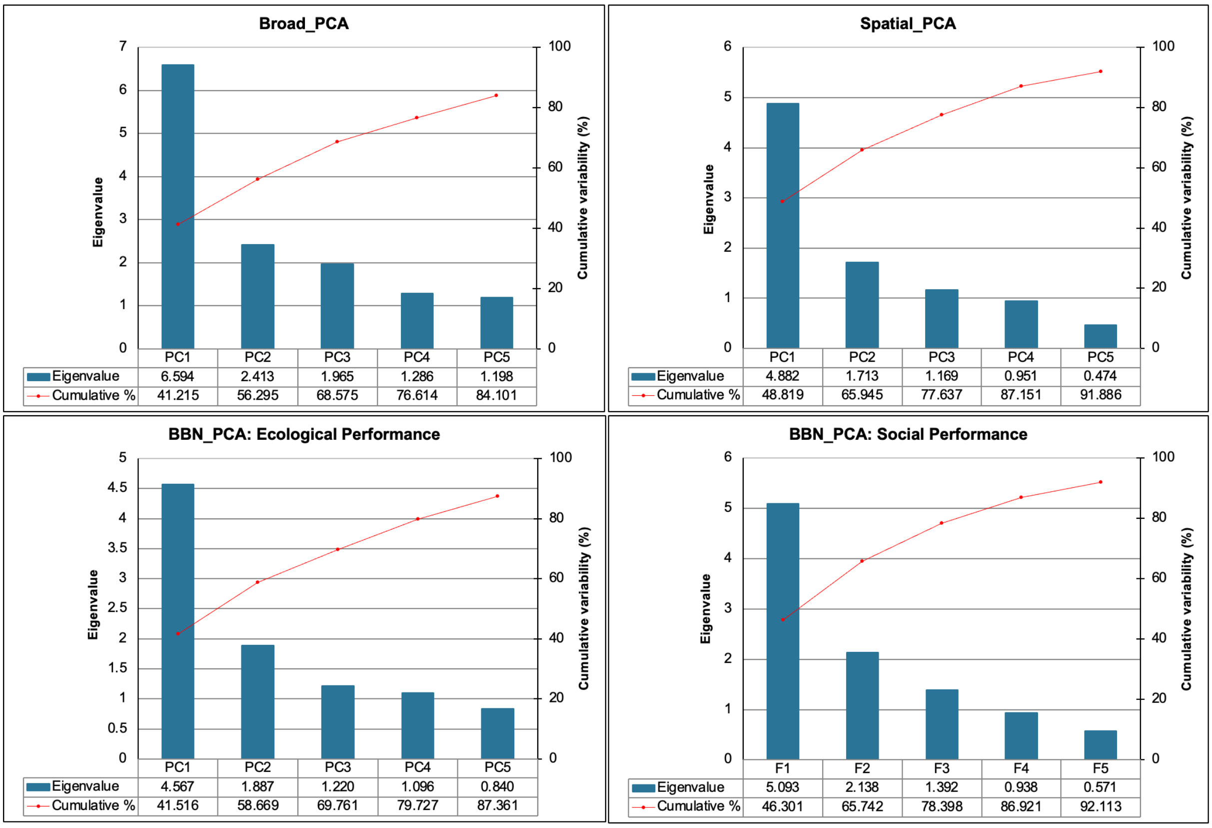


Figure 5-1: PCA-driven index scree plots (created using XLSTAT (Lumivero, version 2025.2.0)

Table 5-1: PC1 Factor loadings for the PCA-driven indices

Variable	PC1 Factor Loadings			
	Broad_PCA	**Spatial_PCA**	**BBN_PCA: Ecological Performance**	**BBN_PCA: Social Performance**
Linear Shipping Connectivity Index (LSCI)	**0.818**	**0.816**	**0.814**	**0.786**
KBA Coverage (% coverage)	-0.376		-0.403	
Ecological Footprint	**0.869**	**0.869**	**0.830**	**0.858**
Biocapacity	-0.180	-0.056	-0.305	
Red List Index (RLI)	0.181		0.237	
Human Development Index (HDI)	**0.817**	**0.861**		**0.845**
National Footprint Account (NFA)	**-0.829**		**-0.882**	
Climate Readiness	**0.838**	**0.858**	**0.823**	**0.845**
Climate Vulnerability	-0.544	-0.584	-0.528	-0.587
Population Density (per km^2)	**0.868**		**0.888**	
Government Effectiveness (WGI-GE)	**0.824**	**0.883**		**0.861**
Island Size (km^2)	-0.333	-0.254	-0.355	-0.335
Number of Inhabited Islands	-0.470	-0.415	-0.505	-0.468
Endemic (Number of species)	-0.380			-0.422
Tourism (Inbound expenditure)	**0.766**	**0.788**		**0.755**
Biodiversity (km^2 of KBAs)	-0.340			-0.383

Several variables appear to have a consistent, substantial contribution to PC1 within all PCA-driven indices, with factor loadings all above 0.75. Such variables include LSCI, ecological footprint, and climate readiness. This indicates that, across the theoretical frameworks governing index development and within the PCA weighting methodology, some variables are consistently assigned high importance in explaining variance. This demonstrates methodological consistency between indices and provides evidence that the indices are all measuring a common underlying dimension of resilience capacity across SIDS.

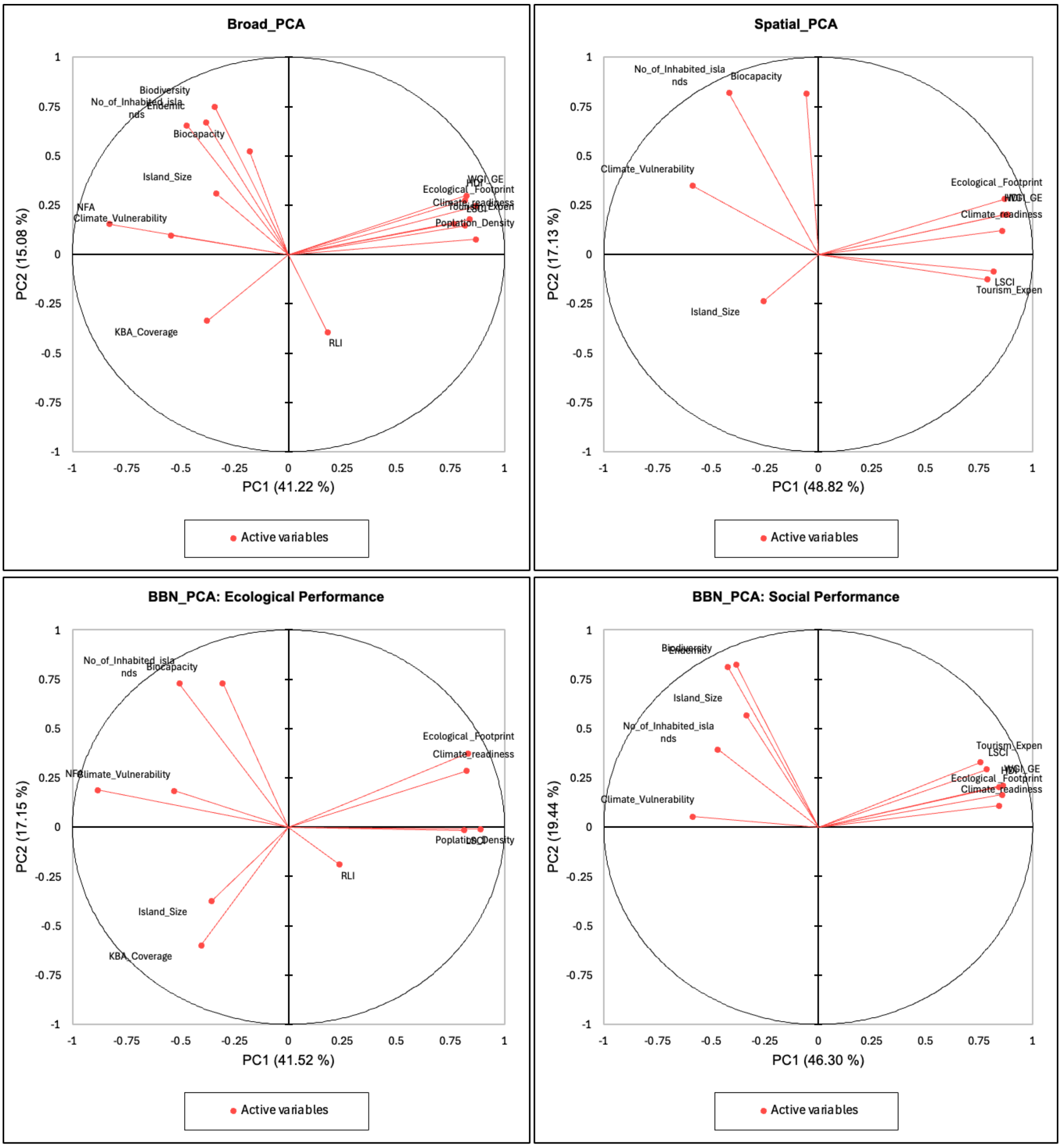


Figure 5-2: PCA-driven index biplots (created using XLSTAT (Lumivero, version 2025.2.0)

The PCA biplots (Figure 5-2) indicate the extent to which variables are correlated, based on their clustering, where variables that are grouped are positively correlated, those that are moving in the opposite direction are negatively correlated, and those that are angular are uncorrelated. The results of the PCA for each theoretical framework indicate that there are highly correlated variables, both positively and negatively, and this is particularly evident in the spatial resilience-focused PCA, where variables that are expected to be correlated cluster together, such as HDI, WGI-GE and climate readiness.

These clusters provide evidence for the theoretical frameworks used in the development of the SEIRCI, as these clustered variables are expected to measure a particular underlying dimension. In contrast, there are also several variables that are presenting as being negatively correlated, such as climate vulnerability (which negatively correlates with climate readiness), further substantiating the theoretical framework. However, it should be noted that variables present within the PCA biplots are evenly distributed (uncorrelated), lending credence to the notion that socio-ecological systems are complex and multi-dimensional, especially the idea of a socio-ecological islandscape.

5.2.2 Entropy

As previously discussed in Chapter 4, the commonly used data-driven Entropy Weighting Method (Zou et al., 2006; Yue & Yang, 2020; Verma et al., 2022; Yin et al., 2025) results in variables with high uncertainty (higher entropy) being assigned lower weightings due to having less discriminatory power than variables with a lower entropy. Provided in Figure 5-3 are the entropy values and the corresponding information utility values for the 16 variables used in the entropy-driven indices.

The results of the entropy analysis indicate that a few variables have some discriminatory power, namely population density and island size, while the majority of variables exhibit an entropy value >0.8, indicating less discriminatory power. Consequently, entropy-driven indices may be dominated by a small number of variables, especially the spatial resilience-focused and BBN-driven entropy indices, which have fewer variables. This may affect the ability of the Entropy-driven indices to distinguish between countries, resulting in similar country index scores with minimal variation.

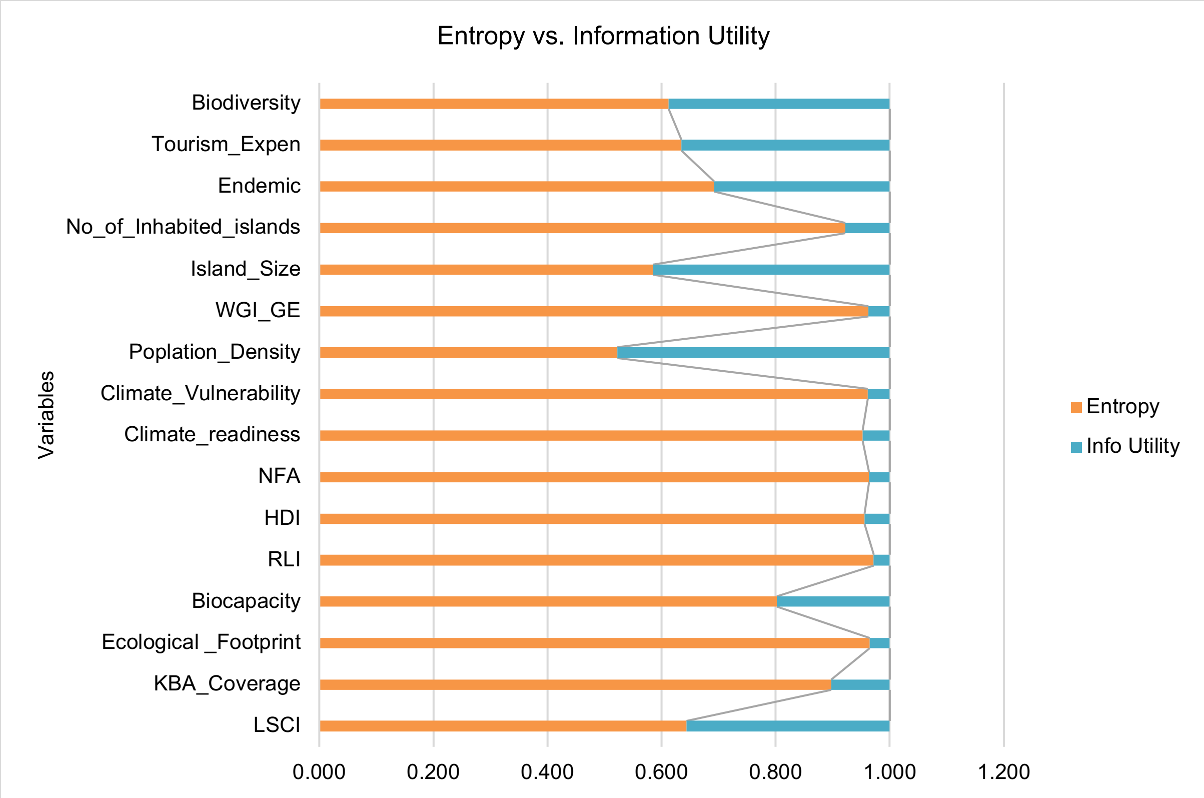


Figure 5-3: Entropy and associated information utility values

5.2.3 Equal Weighting

Within the equal weighting methodology, each variable is assigned an equal importance relative to the total number of variables. Although the weight assigned to a common variable present within all the theoretical frameworks will be different, the variable's relative contribution to the corresponding index will remain constant. However, a key consideration in constructing indices with equal weighting is the presence of many highly correlated variables, all assigned the same contribution to the index, which may introduce a degree of measurement redundancy into the index (Farrugia, 2008).

Depicted in Figure 5-4 are the Pearson correlations for the variable sets used in the respective equal weighting indices. As shown, moderate to high correlations between variables are present throughout these indices. This is especially evident in the spatial-resilience-focused and the BBN Social Performance variable sets. This potential redundancy in indicators may result in clustering, where the indices are unable to discriminate between countries, leading to similar index scores (Wu et al., 2018).

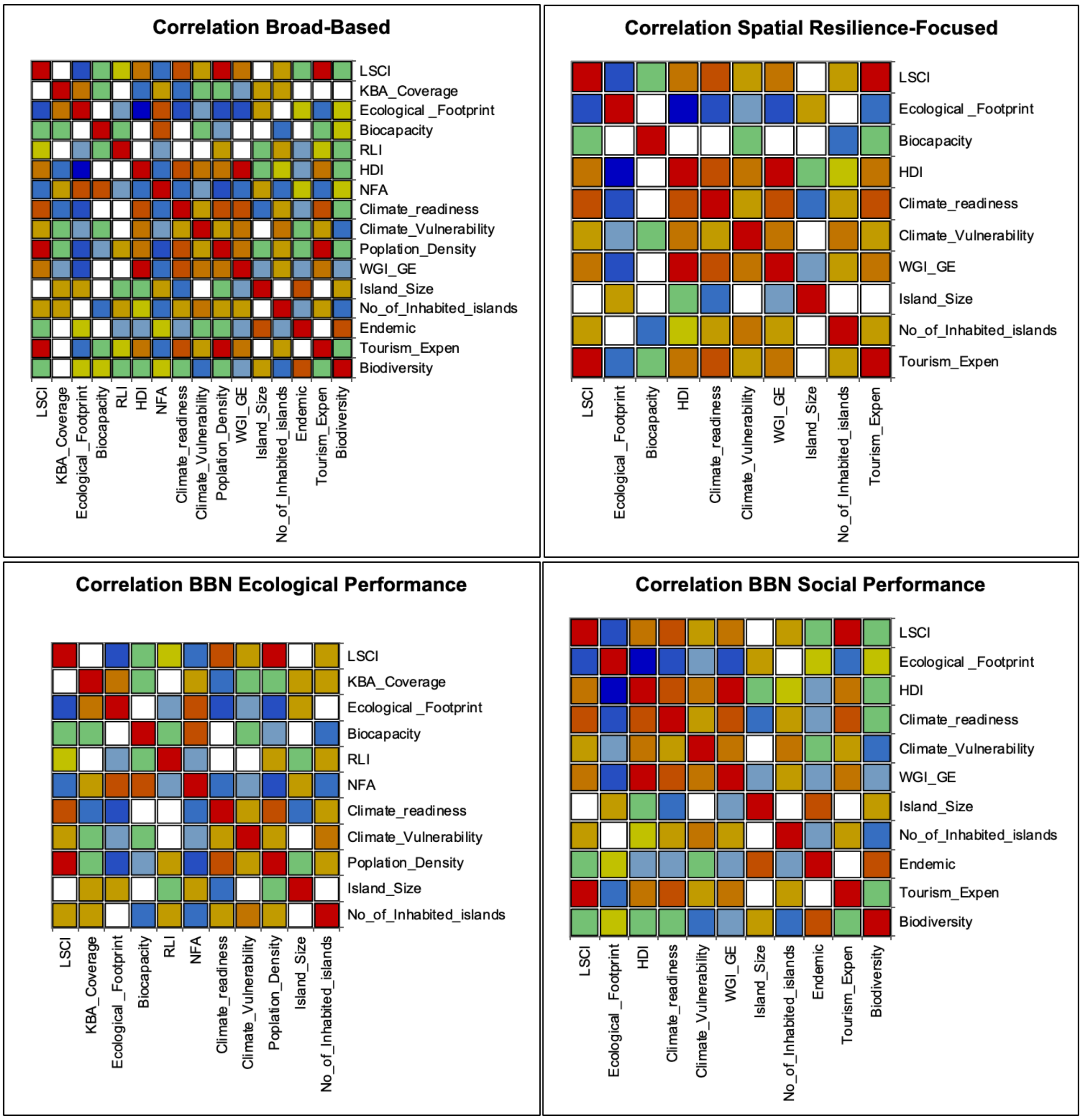


Figure 5-4: Pearson correlations of variables used in the theoretical frameworks (created using XLSTAT (Lumivero, version 2025.2.0)

5.2.4 Comparative analysis of weightings

Comparing the final weightings (refer to Table 5-2, Table 5-3, and Table 5-4) assigned to common variables across the different weighting methodologies and theoretical frameworks will provide insights into how these variables contribute to the respective indices. Furthermore, ascertaining the dominant variables within the indices also provides insights into the major contributors to a particular index, which is useful for identifying foundational elements that could substantially alter the index score if changed. This is important for (1) interpreting temporal changes in index scores, and (2) in policy decision-making, where possible actionable recommendations can be strategically targeted at high-impact indicators.

Table 5-2: Variable weights for the broad-based indices

Variable	Variable Weights		
	Broad_PCA	Broad_EW	Broad_Ent
Linear Shipping Connectivity Index (LSCI)	**0.087**	0.0625	**0.120**
KBA Coverage (% coverage)	0.040	0.0625	0.035
Ecological Footprint	**0.092**	0.0625	0.012
Biocapacity	0.019	0.0625	0.067
Red List Index (RLI)	0.019	0.0625	0.009
Human Development Index (HDI)	**0.087**	0.0625	0.015
National Footprint Account (NFA)	**0.088**	0.0625	0.012
Climate Readiness	**0.089**	0.0625	0.016
Climate Vulnerability	0.058	0.0625	0.013
Population Density (per km^2)	**0.092**	0.0625	**0.162**
Government Effectiveness (WGI-GE)	**0.087**	0.0625	0.013
Island Size (km^2)	0.035	0.0625	**0.140**
Number of Inhabited Islands	0.050	0.0625	0.026
Endemic (Number of species)	0.040	0.0625	0.104
Tourism (Inbound expenditure)	0.081	0.0625	**0.124**
Biodiversity (km^2 of KBAs)	0.036	0.0625	**0.131**

Table 5-3: Variable weights for the spatial resilience-focused indices

Variable	Variable Weights		
	Spatial_PCA	Spatial_EW	Spatial_Ent
Linear Shipping Connectivity Index (LSCI)	**0.128**	0.1	**0.220**
Ecological Footprint	**0.136**	0.1	0.022
Biocapacity	0.009	0.1	0.123
Human Development Index (HDI)	**0.135**	0.1	0.027
Climate Readiness	**0.134**	0.1	0.029
Climate Vulnerability	0.092	0.1	0.024
Government Effectiveness (WGI-GE)	**0.138**	0.1	0.023
Island Size (km^2)	0.040	0.1	**0.257**
Number of Inhabited Islands	0.065	0.1	0.048
Tourism (Inbound expenditure)	0.123	0.1	**0.226**

Table 5-4: Variable weights for the BBN-driven indices

Variable	Variable Weights					
	BBN_PCA: Ecological Performance	BBN_PCA: Social Performance	BBN_EW: Ecological Performance	BBN_EW: Social Performance	BBN_Ent: Ecological Performance	BBN_Ent Social Performance
Linear Shipping Connectivity Index (LSCI)	**0.124**	**0.110**	0.091	0.091	**0.196**	**0.168**
KBA Coverage (% coverage)	0.061		0.091		0.056	
Ecological Footprint	**0.126**	**0.120**	0.091	0.091	0.020	0.017
Biocapacity	0.046		0.091		0.109	
Red List Index (RLI)	0.036		0.091		0.015	
Human Development Index (HDI)		**0.118**		0.091		0.021
National Footprint Account (NFA)	**0.134**		0.091		0.020	
Climate Readiness	**0.125**	**0.118**	0.091	0.091	0.026	0.022
Climate Vulnerability	0.080	0.082	0.091	0.091	0.021	0.018
Population Density (per km^2)	**0.135**		0.091		**0.263**	
Government Effectiveness (WGI-GE)		**0.120**		0.091		0.018
Island Size (km^2)	0.054	0.047	0.091	0.091	**0.229**	**0.196**
Number of Inhabited Islands	0.077	0.065	0.091	0.091	0.043	0.037
Endemic (Number of species)		0.059		0.091		**0.146**
Tourism (Inbound expenditure)		0.106		0.091		**0.173**
Biodiversity (km^2 of KBAs)		0.054		0.091		**0.184**

5.2.4.1 Comparative analysis of weightings: Overarching influential variables

A notable trend in these tables is that the Linear Shipping Connectivity index (LSCI) has consistently received a high weight across all data-driven weighting methodologies (PCA and entropy) and theoretical frameworks (broad-based, BBN-driven, and spatial-resilience focused), indicating a considerable cross-cutting pattern. This variable serves as a suitable proxy for the isolated nature of SIDS and a fundamental part of their spatial resilience. The consistent importance of LSCI, an indicator of connectivity (a core measure of "islandness"), lends further credence to the previously described socio-ecological islandscape framework and illustrates that this measure of connectivity has emerged as an indicator that may contribute meaningfully to the measurement of the general resilience capacity of SIDS.

5.2.4.2 Comparative analysis of weightings: Dominant variables

As previously mentioned, insights into the dominant variables within a particular index provide information on what the dominant contributors are in the index scores, thereby providing an understanding of why temporal changes in index scores occur. The dominant contributors observed within the different data-driven indices are described as follows:

<u>PCA-driven indices</u>: The PCA-driven indices indicate some commonality in the weighting of variables, with LSCI, ecological footprint, HDI, NFA, climate readiness and WGI-GE being assigned higher weights in all theoretical frameworks. Several insights can be gained from this trend:

1) Methodological stability – The PCA consistently identifies variables that are core indicators of the underlying dimension being measured. This further validates its use in index construction.
2) Core indicators – Through the PCA, it can be inferred that several core variables contribute to the index scores and, therefore, drive variability in the resilience capacity of SIDS. If considerable changes take place within these indicators, there is a high probability that they would affect the index score and, therefore, affect the general resilience capacity of SIDS. Although a change in a single variable may not result in a considerable change in the index scores,

compounding changes across the core indicators will result in a significant change.

3) Dominant Contributors– An insightful pattern has emerged from the allocation of weights in the PCA-driven indices. Policy-related variables, such as climate readiness, HDI, WGI-GE and ecological footprint, are predominantly the primary contributors of these indices, highlighting that government intervention and policy decisions appear to be key determinants of variability in resilience capacity of SIDS.

Entropy-driven indices: The trends in the entropy-driven indices show some expected outcomes, such as the dominance of population density and island size, which were the variables with the lowest entropy values in the larger 16-variable dataset. However, in general, the relatively small difference (less than 0.2) in entropy scores between population density (0.523) and the other prevailing variables, such as island size (0.586), biodiversity (0.612), tourism expenditure (0.632), LSCI (0.644) and endemic (0.692) suggest that several variables act as key determinants of variability in general resilience capacity of SIDS, based on an entropy-driven approach. In contrast to the PCA-driven indices, which emphasised policy-related variables, the emergent dominant contributors are inherent characteristics of the SIDS, such as island size, biodiversity and tourism. Therefore, a central theme that developed from the entropy-driven data analysis is that variability in resilience capacity is linked to the inherent characteristics of SIDS, and the temporal erosion of these inherent characteristics will impact resilience capacity.

5.3 Comparative analysis of indices by index score

By analysing the index scores across the different indices, some trends emerge that provide evidence of the robustness of the index development process and substantiate the selection of a model for the SEIRCI. Insights from the index scores are as follows:

Highest-ranking county: As seen in Table 5-5 and Table 5-6, which provide the index scores for 2014 and 2022, respectively, Singapore has consistently been identified as the country with the highest resilience capacity rank in the sample of SIDS used in this study. This internal agreement between the different indices adds further credence to the index development process.

Lowest-ranking country: There is less internal agreement within the indices regarding the lowest-ranked country, with most indices classifying Tonga as the lowest-ranked, while there is also agreement between some indices on Antigua and Barbuda and on Haiti as being the lowest-ranked SIDS in terms of resilience capacity. This provides further evidence towards the robustness of the index development process, albeit not as convincing as the internal agreements related to the commonality observed with the highest-ranked country.

Country distributions: The potential discriminatory power of the respective indices has been discussed at length within this chapter. The kernel density plots and histograms depicted in Figure 5-5 (2014) and Figure 5-6 (2022) illustrate the distribution of country index scores for each index, thereby indicating discriminatory power. As shown, the PCA-driven and equal weighting indices both had a more even distribution of country index scores, with a wider kernel density curve and relatively low density (<10) in any given band, denoting good discriminatory power. The entropy-driven indices, however, could not differentiate well between countries, with a vast majority of countries clustered together in the 0.1–0.2 index score range (i.e., these indices had a very narrow kernel density curve).

From a theoretical framework perspective, no single approach shows a definitively better distribution shape (i.e., a very wide curve), though all follow a positively skewed distribution (i.e. all indices tended to assign lower index scores to SIDS, with a few higher-valued outliers). Furthermore, in most indices, a country has the highest probability of having an index score of <0.5, as indicated by the kernel density curve.

The last insight regarding country distribution patterns that can be ascertained is that the majority of indices are unimodal in their distribution, meaning that in each iteration of the SEIRCI, there is a distinct cluster around which countries are distributed. This provides additional internal agreement between the different indices.

Table 5-5: 2014 index scores for all indices (red is the lowest score, while green is the highest score)

Country	2014 Index Scores								
	Broad_Ent	Broad_EW	Broad_PCA	BBN_Ent	BBN_EW	BBN_PCA	Spatial_Ent	Spatial_EW	Spatial_PCA
Antigua and Barbuda	**0.087**	0.298	0.303	**0.093**	0.305	0.311	0.117	0.330	0.374
Bahamas	0.194	0.385	0.392	0.189	0.363	0.383	0.279	0.427	0.411
Bahrain	0.123	0.291	0.319	0.127	0.303	0.321	0.143	0.354	0.407
Barbados	0.112	0.367	0.383	0.129	0.405	0.412	0.155	0.451	0.496
Cape Verde	0.109	0.335	0.345	0.116	0.362	0.377	0.113	0.344	0.391
Cuba	0.392	0.470	0.436	0.426	0.490	0.449	0.401	0.457	0.442
Dominica	0.115	0.359	0.379	0.130	0.397	0.413	0.142	0.414	0.448
Dominican Republic	0.260	0.433	0.425	0.296	0.468	0.453	0.339	0.459	0.466
Fiji	0.339	0.384	0.356	0.283	0.359	0.349	0.158	0.288	0.321
Grenada	0.109	0.335	0.367	0.118	0.363	0.392	0.135	0.389	0.432
Haiti	0.160	0.269	**0.257**	0.174	0.296	0.291	0.142	0.226	**0.226**
Mauritius	0.133	0.301	0.363	0.138	0.329	0.374	0.158	0.396	0.460
Samoa	0.109	0.330	0.340	0.114	0.336	0.351	0.123	0.333	0.372
São Tomé and Príncipe	0.114	0.310	0.299	0.113	0.314	0.317	0.080	0.243	0.271
Singapore	**0.506**	**0.565**	**0.650**	**0.517**	**0.586**	**0.644**	**0.596**	**0.685**	**0.802**
St. Lucia	0.121	0.382	0.391	0.138	0.424	0.429	0.148	0.429	0.462
Timor-Leste	0.120	0.316	0.310	0.134	0.330	0.338	0.134	0.283	0.300
Tonga	0.145	**0.261**	0.269	0.118	**0.234**	**0.253**	**0.069**	**0.209**	0.267
Trinidad and Tobago	0.126	0.327	0.312	0.136	0.332	0.318	0.156	0.350	0.374

Table 5-6: 2022 index scores for all indices (red is the lowest score, while green is the highest score)

Country	2022 Index Scores								
	Broad_Ent	Broad_EW	Broad_PCA	BBN_Ent	BBN_EW	BBN_PCA	Spatial_Ent	Spatial_EW	Spatial_PCA
Antigua and Barbuda	**0.087**	0.289	0.288	0.092	0.293	0.306	0.115	0.317	0.357
Bahamas	0.204	0.367	0.360	0.194	0.337	0.365	0.283	0.397	0.376
Bahrain	0.134	0.287	0.315	0.129	0.292	0.342	0.158	0.362	0.416
Barbados	0.111	0.359	0.375	0.130	0.403	0.440	0.154	0.443	0.487
Cape Verde	0.108	0.333	0.340	0.115	0.360	0.365	0.112	0.343	0.389
Cuba	0.383	0.462	0.427	0.419	0.486	0.434	0.379	0.442	0.424
Dominica	0.111	0.331	0.340	0.124	0.365	0.377	0.137	0.385	0.406
Dominican Republic	0.283	0.447	0.444	0.314	0.476	0.458	0.382	0.488	0.503
Fiji	0.346	0.419	0.402	0.290	0.396	0.388	0.169	0.341	0.385
Grenada	0.108	0.332	0.364	0.116	0.359	0.399	0.135	0.391	0.435
Haiti	0.160	0.272	**0.257**	0.173	0.298	0.254	0.129	0.219	**0.218**
Mauritius	0.132	0.297	0.361	0.138	0.332	0.389	0.157	0.400	0.462
Samoa	0.106	0.322	0.336	0.113	0.331	0.326	0.118	0.324	0.367
São Tomé and Príncipe	0.116	0.324	0.319	0.116	0.329	0.300	0.084	0.264	0.300
Singapore	**0.464**	**0.517**	**0.586**	**0.491**	**0.542**	**0.656**	**0.518**	**0.628**	**0.727**
St. Lucia	0.115	0.354	0.354	0.130	0.390	0.407	0.141	0.398	0.423
Timor-Leste	0.120	0.320	0.316	0.132	0.333	0.302	0.130	0.291	0.312
Tonga	0.105	**0.241**	0.257	**0.091**	**0.221**	**0.211**	**0.074**	**0.215**	0.271
Trinidad and Tobago	0.121	0.341	0.337	0.131	0.353	0.371	0.147	0.361	0.391

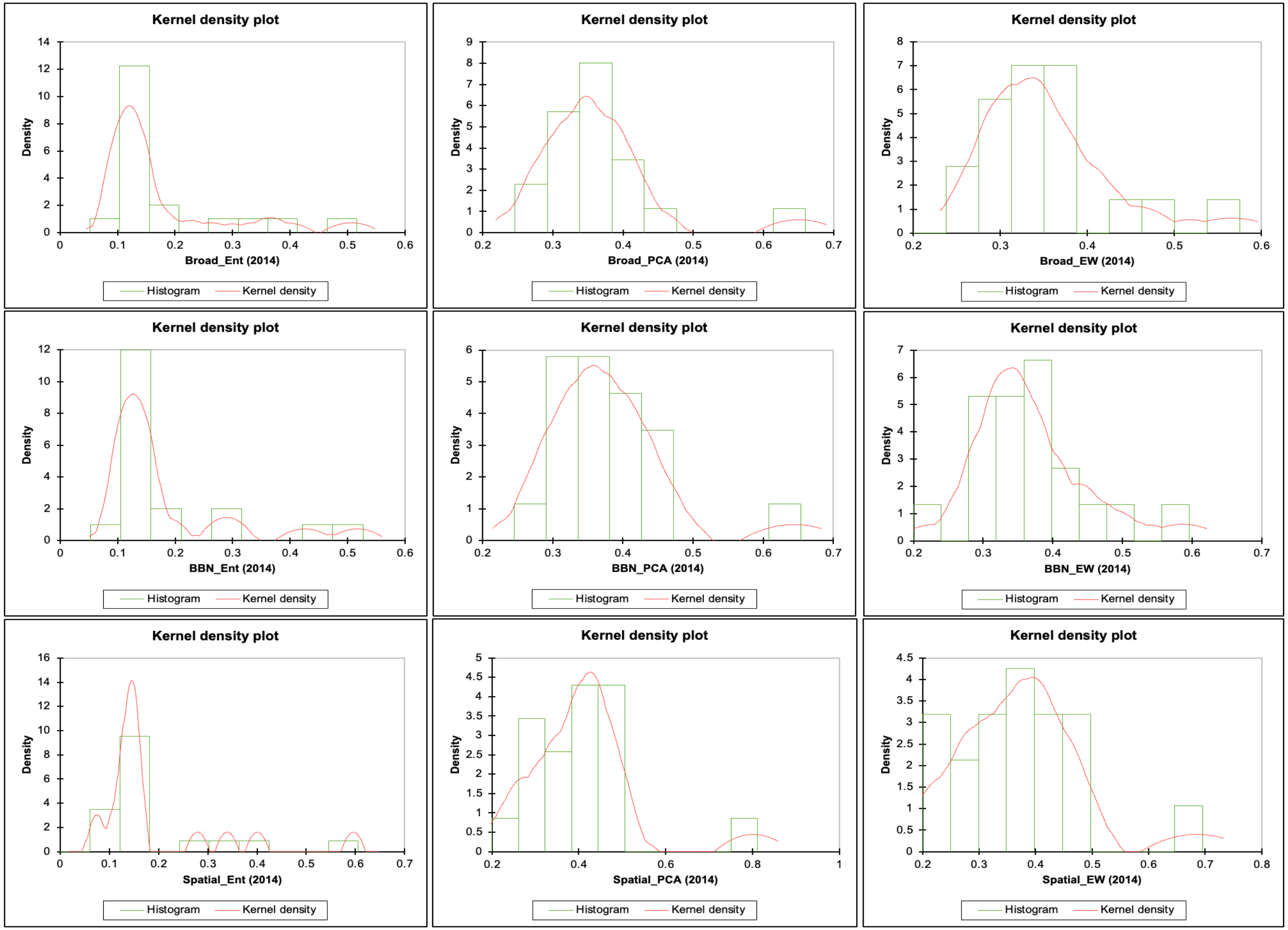


Figure 5-5: Kernel density plots of the 2014 index scores for all indices (created using XLSTAT (Lumivero, version 2025.2.0)

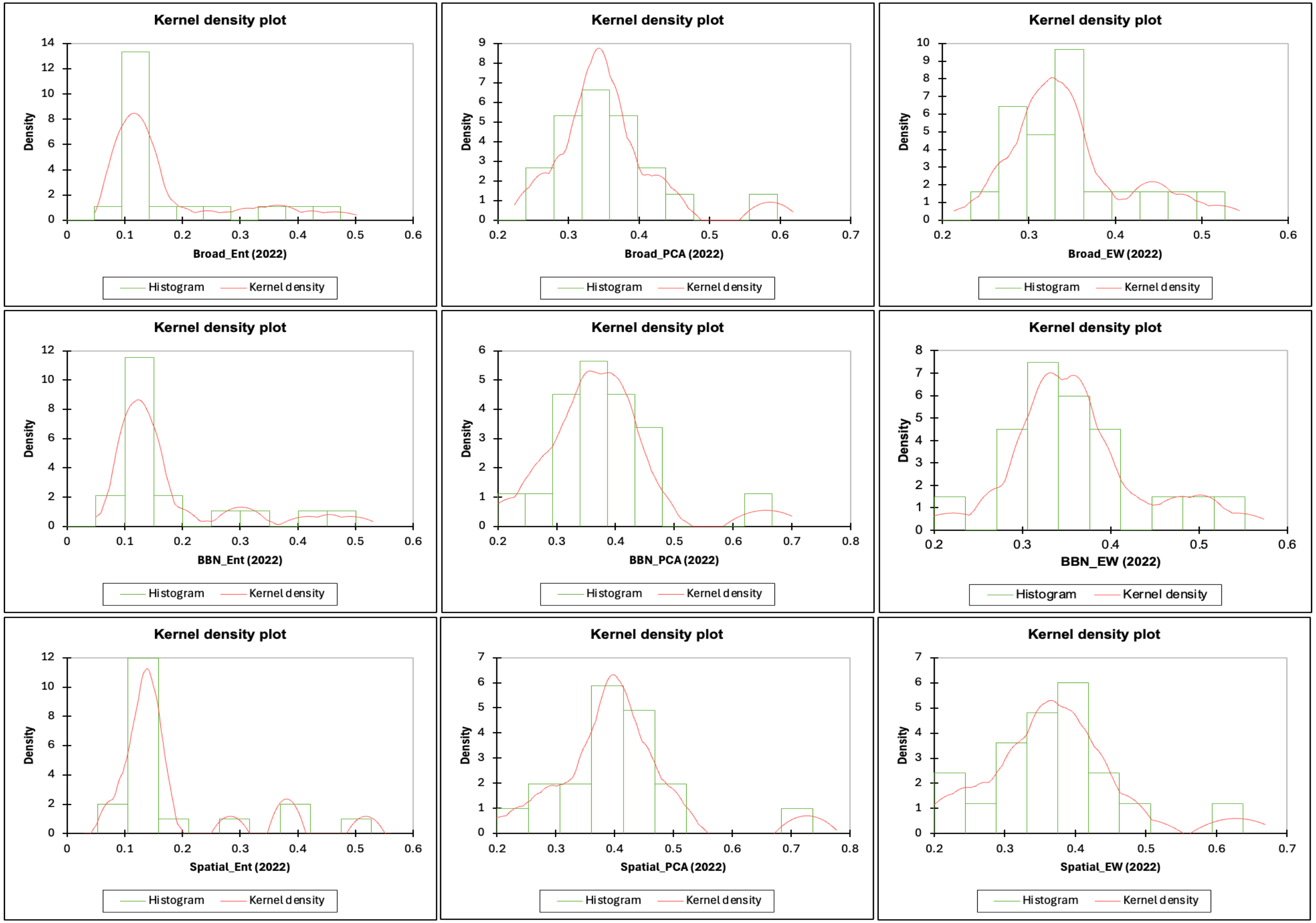


Figure 5-6: Kernel density plots of the 2022 index scores for all indices (created using XLSTAT (Lumivero, version 2025.2.0)

5.4 Validity analysis of indices

5.4.1 Spearman's Rank Correlation

Several studies have used Spearman's Rank Correlation to evaluate the robustness of the index development process by identifying similarities and differences in the rank orders associated with the index scores (Wu et al., 2018; Karagiannis & Karagiannis, 2020; Öztürk et al., 2024; Robles et al., 2026). As illustrated in Figure 5-7 (further detailed in Figure 5-8 and summarised in Table 5-7 and

Table 5-8), there is generally a good level of internal agreement between the different methodological approaches and theoretical frameworks used in the development of the SEIRCI. This internal agreement provides support for the transparency and robustness of the SEIRCI development process by revealing how consistently the indices rank SIDS in terms of their general resilience capacity, and where they do not, by what degree the deviation is present.

Through analysing trends derived from Spearman's Correlation, the following observations can be made:

1) Weighting methodologies: There are slight differences between the PCA-driven and equal weighting approaches; however, both resulted in consistently high correlation coefficients (Table 5-7). The average correlation coefficient for the different entropy-driven indices, on the other hand, was inconsistent, with the broad-based Entropy index scoring moderate to moderately low correlation coefficients compared to the BBN-based entropy and spatial resilience-focused entropy indices.
2) Theoretical frameworks*:* The only entropy-driven index that resulted in high correlation coefficients was the spatial resilience-focused entropy index. This provides some support for the use of this approach, which appears to be robust enough to allow for internal agreement irrespective of the weighting methodology being employed. This is in addition to the spatial resilience-focused indices having the highest average correlation across all theoretical frameworks for both 2014 and 2022 (Table 5-8).

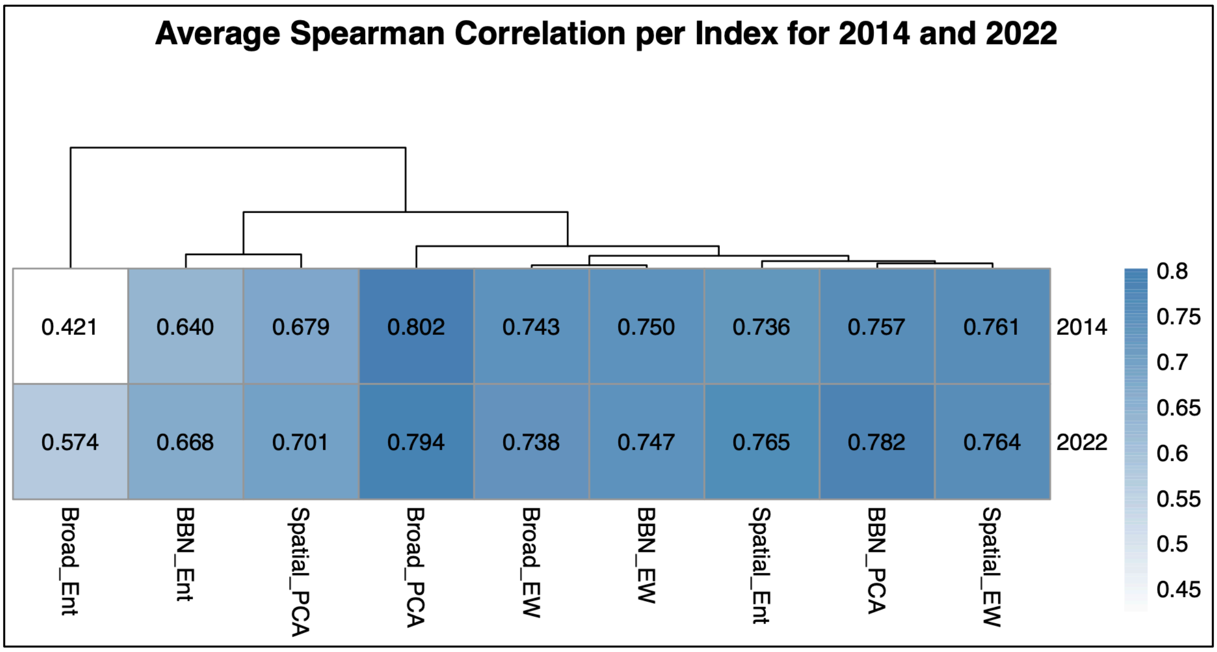


Figure 5-7: Average Spearman Correlations per index for 2014 and 2022 (created using R (RStudio Team, 2025[5])

Table 5-7: Average Correlation by Weighting Methodology (2014 & 2022)

Weighting Method	Average Correlation	
	2014	2022
Entropy	0.599	0.669
Equal weighting	**0.752**	0.750
PCA	0.746	**0.759**

Table 5-8: Average Correlation by Theoretical Framework (2014 & 2022)

Theoretical framework	Average Correlation	
	2014	2022
Broad-based	0.655	0.702
BBN-driven	0.716	0.732
Spatial resilience-focused	**0.726**	**0.743**

[5] AI was used to assist in developing code for automating the creation of several visuals in RStudio, such as the radar graphs etc. This use, however, did not replace any original work, analysis of information or critical thinking on the part of the researcher. All calculations for the indices were completed in excel and all analysis of the results were done by the researcher.

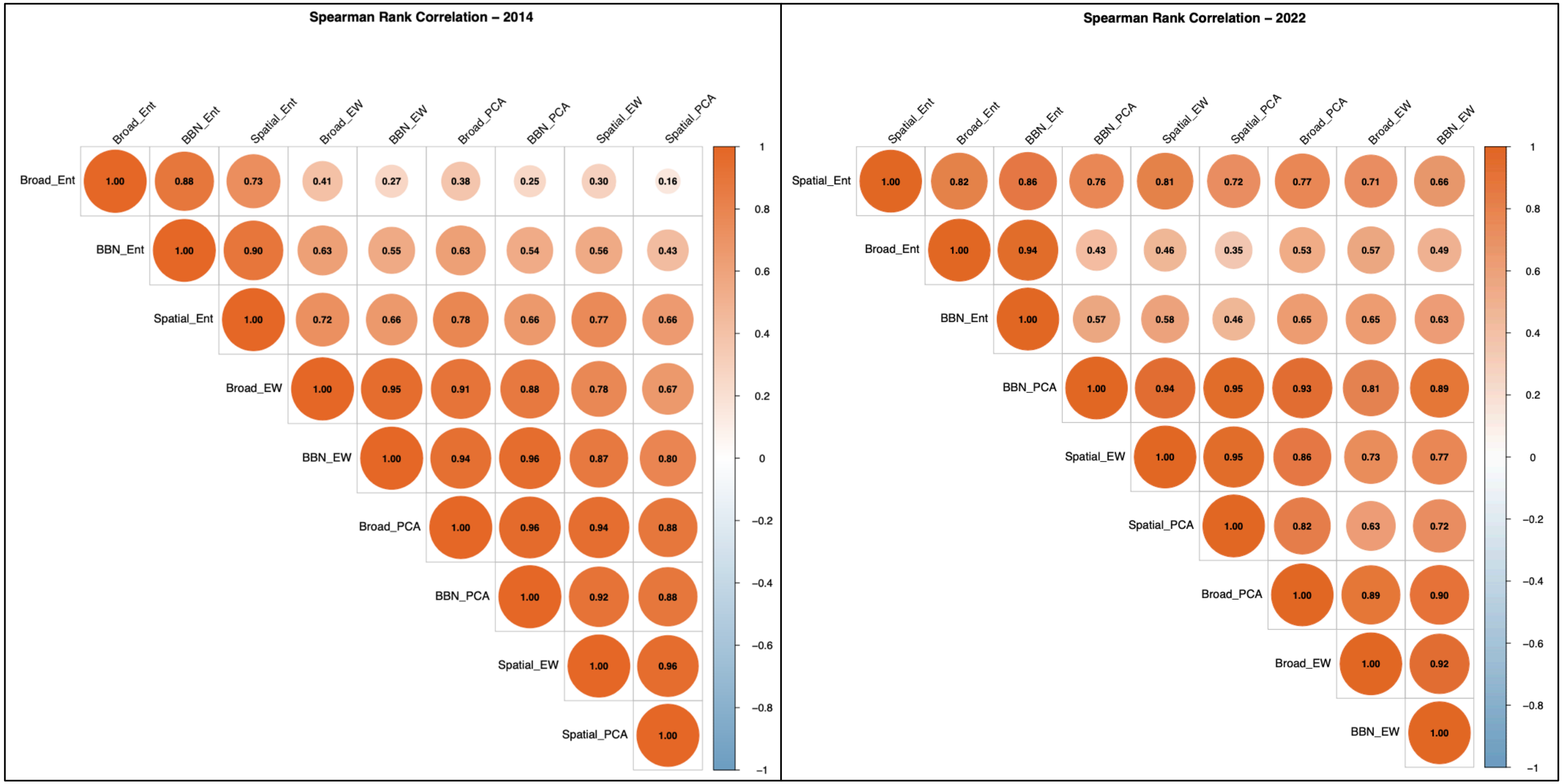


Figure 5-8: 2014 and 2022 Spearman Rank Correlations for the different indices (created using R (RStudio Team, 2025)

5.4.2 Pragmatic Benchmarking - Average Rank Shift

The EPI is a global index that provides a measure of sustainability driven by how countries are progressing towards established environmental policy targets that include climate change mitigation, ecosystem vitality and environmental health (Block et al., 2024). The average rank shift between the EPI and each index approach is given in Figure 5-9, and provides a useful and practical point of reference against an existing index. As illustrated, there is generally a moderate to high shift between rankings in the EPI and the various index approaches. This shift in rankings could result from the different approaches of the indices, where EPI aims at progress towards policy targets, and the SEIRCI is driven by a socio-ecological islandscape perspective. Although no index showed a minimal rank shift, the information provided remains useful in determining which index offers the highest degree of alignment for pragmatic benchmarking purposes. As depicted in the graph, the indices with the highest shift in rank were the entropy-driven indices, while the PCA-driven and equal weighting indices had generally higher degrees of agreement with the EPI. The theoretical framework demonstrating the highest degree of agreement was the spatial resilience-focused indices, with the spatial resilience-focused equal weighting and the spatial resilience-focused PCA scoring 4.74 and 5.16, respectively.

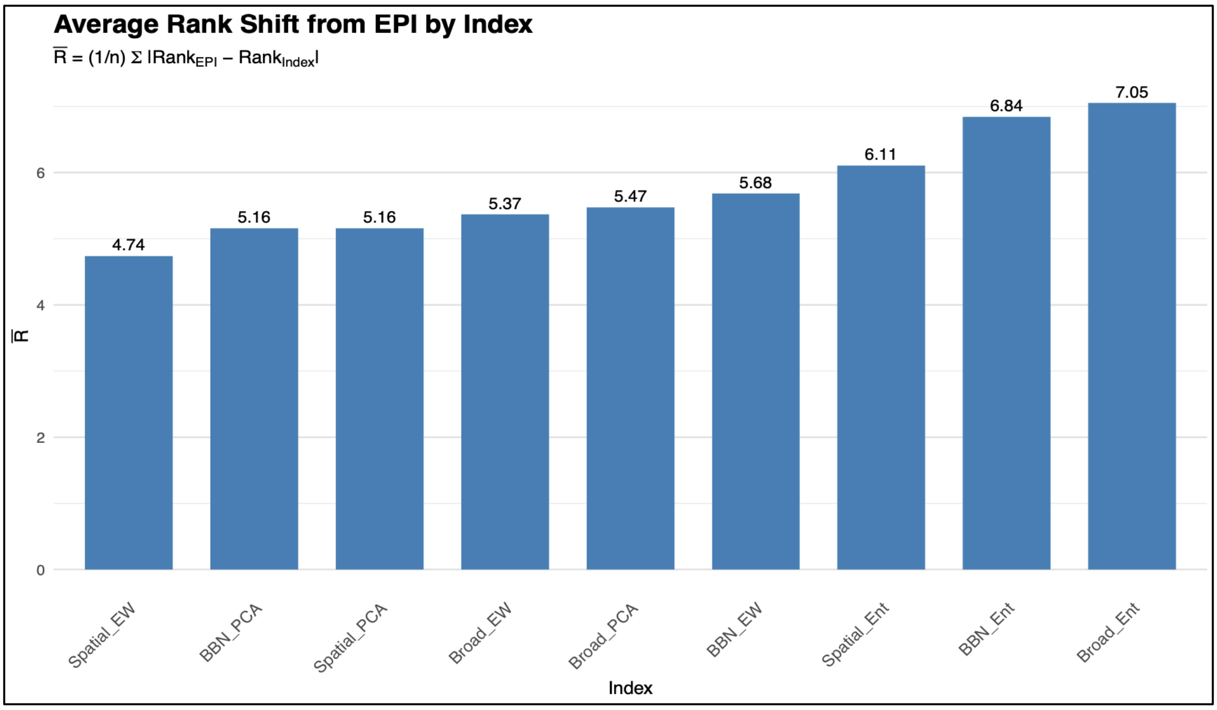


Figure 5-9: Average rank shift from the EPI by index (created using R (RStudio Team, 2025))

5.5 SEIRCI selection

Through considering the results of various analyses undertaken in the SEIRCI development process, the spatial resilience-focused equal weighting was determined to be the most appropriate. The justification for using this approach is as follows:

1) Elimination of the entropy-based indices: The entropy-based indices were clearly unable to distinguish between countries within the index, as evidenced by their concentrated distribution (Figure 5-5 and Figure 5-6). This is likely because of the small number of variables that had significantly high dominance in their weighting. Furthermore, as a collective, the entropy-based indices had the lowest degrees of internal agreement between the various indices (Figure 5-7) and the lowest degree of external agreement with the EPI (Figure 5-9).
2) Theoretical framework selection: The selection of the spatial resilience-focused approach is the culmination of both the quantitative evidence and consideration for the intended use of the SEIRCI. From a statistical perspective, the spatial resilience-focused approach illustrated a high degree of robustness through:
    a. having a high level of discriminant power, as evidenced by the more even distribution of countries within the index (Figure 5-5 and Figure 5-6);
    b. having the highest internal agreement across all indices (
    c. Table 5-8); and
    d. having the lowest average range shift from EPI, thereby having the highest external validity (Figure 5-9)

    When considering the intended use of the SEIRCI, which is to provide policy and decision-makers a simple measure of the general resilience capacity of SIDS that can be monitored over time, the spatial resilience-focused approach is the most in line with that ideology. In addition, fewer variables simplify both the requirements for the index and for data collection, leading to fewer potential issues regarding missing data, which is prevalent in SIDS datasets.
3) Spatial PCA vs. Spatial EW: Ultimately, both the spatial resilience-focused PCA and the spatial resilience-focused equal weighting indices could have been adequate choices for the SEIRCI. However, the spatial resilience-focused equal weighting index proved to be slightly more effective, with better discriminatory power (Figure 5-5 and Figure 5-6) and higher levels of internal (Figure 5-7) and

external agreement (Figure 5-9). In addition, using an equal weighting approach enables a simpler method of tracking outcomes over time, allowing a rapid evaluation to inform policy and decision-making. Lastly, as no single variable carries a higher weight in the index, trends associated with driving variables are not artificially inflated.

5.6 SEIRCI results, analysis and discussion

The following sections will delve deeper into the outcomes of the SEIRCI to understand what trends, consequences and potential recommendations can be ascertained for the performance of the 19 SIDS between 2014 and 2022. This is fundamental in illustrating how the SEIRCI achieves the aim of understanding trends in the socio-ecological islandscape-resilience nexus. However, cognisance is given to the limited nature of the SEIRCI resulting from the limited number of SIDS forming part of the study.

5.6.1 SEIRCI results and analysis

5.6.1.1 Overarching trends in resilience capacity

As previously discussed, the distribution of SEIRCI scores was positively skewed (Figure 5-5 and Figure 5-6), resulting in a majority of the countries exhibiting moderate to low SEIRCI scores. Therefore, the resilience capacity of SIDS can be considered to be moderate to low, as only Singapore received a score above 0.5. This aligns with several authors' (Bunce et al., 2009; Hay, 2013; Jupiter et al., 2014; Plieninger et al., 2018) viewpoint on the vulnerability of SIDS and the continued special acknowledgement by the United Nations (UNCED, 1992).

5.6.1.2 Regional trends and SIDS clusters

The SIDS are grouped according to the region in which they are situated (refer to Table 5-9). Analysing the similarities and differences in the SEIRCI scores between countries within a particular region can provide insights into whether there are trends in the resilience capacity of the SIDS in that region, and subsequently determine whether there is an underlying cause that is either supporting or impeding their resilience capacity.

Table 5-9: SIDS grouped by region (UNDESA, n.d)

Caribbean	Pacific	Atlantic, Indian Ocean, and South China Sea (AIS)
Antigua and Barbuda	Fiji	Bahrain
Bahamas	Samoa	Cape Verde
Barbados	Tonga	Mauritius
Cuba	Timor-Leste	São Tomé and Príncipe
Dominica		Singapore
Dominican Republic		
Grenada		
Haiti		
St. Lucia		
Trinidad and Tobago		

To clearly analyse the regional trends of the SIDS, hierarchical clustering of the SIDS based on their SEIRCI score was undertaken. Hierarchical clustering is a multivariate statistical procedure that can be used to assemble the index scores into clusters according to their similarities, with the aim of creating clusters that have a high degree of internal uniformity, while amplifying the divergence between different clusters (Wijitkosum, 2025). This unsupervised machine learning technique allows for the examination of natural groupings within the SEIRCI.

The dendrograms depicted in (Figure 5-10) represent the hierarchical clustering of the SIDS based on the 2014 and 2022 SEIRCI scores, respectively. The hierarchical clustering was done by means of Euclidean distance (absolute difference between two scores based on using a single variable) between the SEIRCI scores and through ward's linkage method (clusters countries with similar scores). From the clusters illustrated, there is a clear grouping of Caribbean Islands for both 2014 and 2022, with 7 of the 10 assessed Caribbean SIDS being grouped together. These Caribbean SIDS are within a cluster of countries with the highest SEIRCI scores (with the exception of Singapore, which remains an outlier), with the lowest-scoring country within the cluster being Grenada in 2014 (0.389) and Dominica in 2022 (0.385), while the highest-scoring country was the Dominican Republic for both 2014 (0.459) and 2022 (0.488). A closer examination of the variables driving these scores (Figure 5-11 to Figure 5-15) reveals that there is one particular commonality between the countries within this cluster, namely a higher inverted climate vulnerability value (i.e. a low raw climate vulnerability value). This indicates that resilience capacity within several Pacific SIDS is driven by internal elements of spatial resilience, aligning with the concept that intrinsic features of a SIDS (Allen et al., 2016) influence its resilience. In contrast to the Caribbean SIDS cluster, but supporting the idea that internal elements of spatial resilience drive resilience capacity, is the cluster of SIDS comprising the lowest-performing countries. The lowest-scoring country for 2014 and 2022 was Tonga (0.209 and 0.215), while the highest-scoring country was Fiji (0.288) in 2014 and Timor-Leste (0.291) in 2022. Notably, these SIDS have relatively low inverted climate vulnerability values.

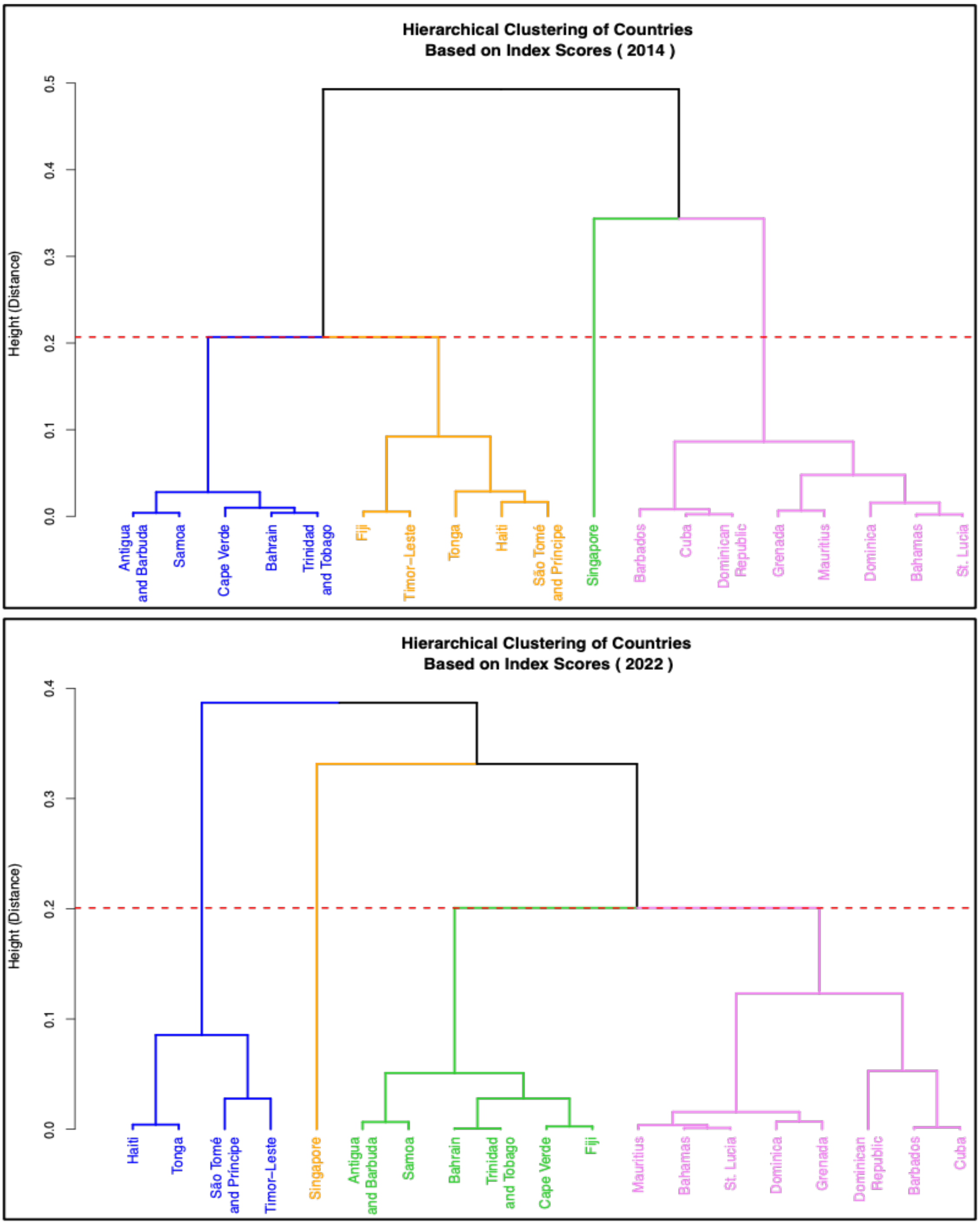


Figure 5-10: Hierarchical clustering of countries based on SEIRCI scores (2014 & 2022) (created using R (RStudio Team, 2025))

5.6.1.3 Time-series trends

Taking a holistic perspective, there is no discernible trend in the SEIRCI scores between 2014 and 2022. An almost equal number of SIDS saw their scores decrease, as did see their scores increase, revealing the dynamic nature of resilience in SIDS.

In addition, the changes in scores were also quite varied, with Cape Verde only experiencing a -0.2% change between 2014 and 2022 (Figure 5-12), while Singapore had the greatest negative drop (-8.4%) between 2014 and 2022 (Figure 5-14). In examining the countries that exhibited significant negative changes in their SEIRCI performance, a notable trend is that these countries all either experienced a change in their inverted ecological footprint values, meaning that increased consumption is placing a higher strain on their socio-ecological system, or, as a result of falling tourism expenditure, highlight the importance of external spatial subsidies in their resilience.

A notable change that occurred between 2014 and 2022 is the decrease in the number of countries within the worst-performing SIDS cluster, with Fiji having a considerable increase (+18.3%) (refer to Figure 5-13), driven by a marked increase in its inverted climate vulnerability and WGI-GE values. This trend continues within countries that had an increased performance in the SEIRCI, with several demonstrating increases in policy-related variables, such as HDI, WGI-GE and climate readiness, which introduces a notion that, even when inherent characteristics contribute to a lower resilience, such as climate vulnerability, effective governance and policies directed towards improvement will strengthen resilience capacity.

5.6.1.4 “Islandness” trends

The effects of “islandness” on the resilience capacity can be discerned from the SEIRCI performance trends (Figure 5-11 to Figure 5-15) on the 19 SIDS. The LSCI had some degree of influence on the resilience capacity, with the SIDS that had the highest LSCI values also performing the best in 2014 and 2022, while some of the poorest performing SIDS had much lower LSCI values. However, the more noteworthy trend is related to the effects of their spatial arrangement (i.e. the number of inhabited islands that would create a fragmented society). For the 2014 SEIRCI, SIDS that are comprised of a single island all had high relative scores. However, this trend shifted in 2022, with a number of these islands observing a reduction in performance in the SEIRCI, resulting from various circumstances, such as increased consumption (ecological footprint) and a decrease in tourism.

5.6.1.5 The multiple pathways to resilience

Upon close examination of Figure 5-12 and Figure 5-14, discernible differences between the way in which resilience capacity in Cuba and Singapore, both of which are among the highest-ranked SIDS in terms of the SEIRCI, take shape. This does provide an indication that there is potentially no single pathway towards resilience on SIDS, that the baseline resilience capacity can be structured differently between SIDS, and an improved resilience capacity can be achieved through different avenues.

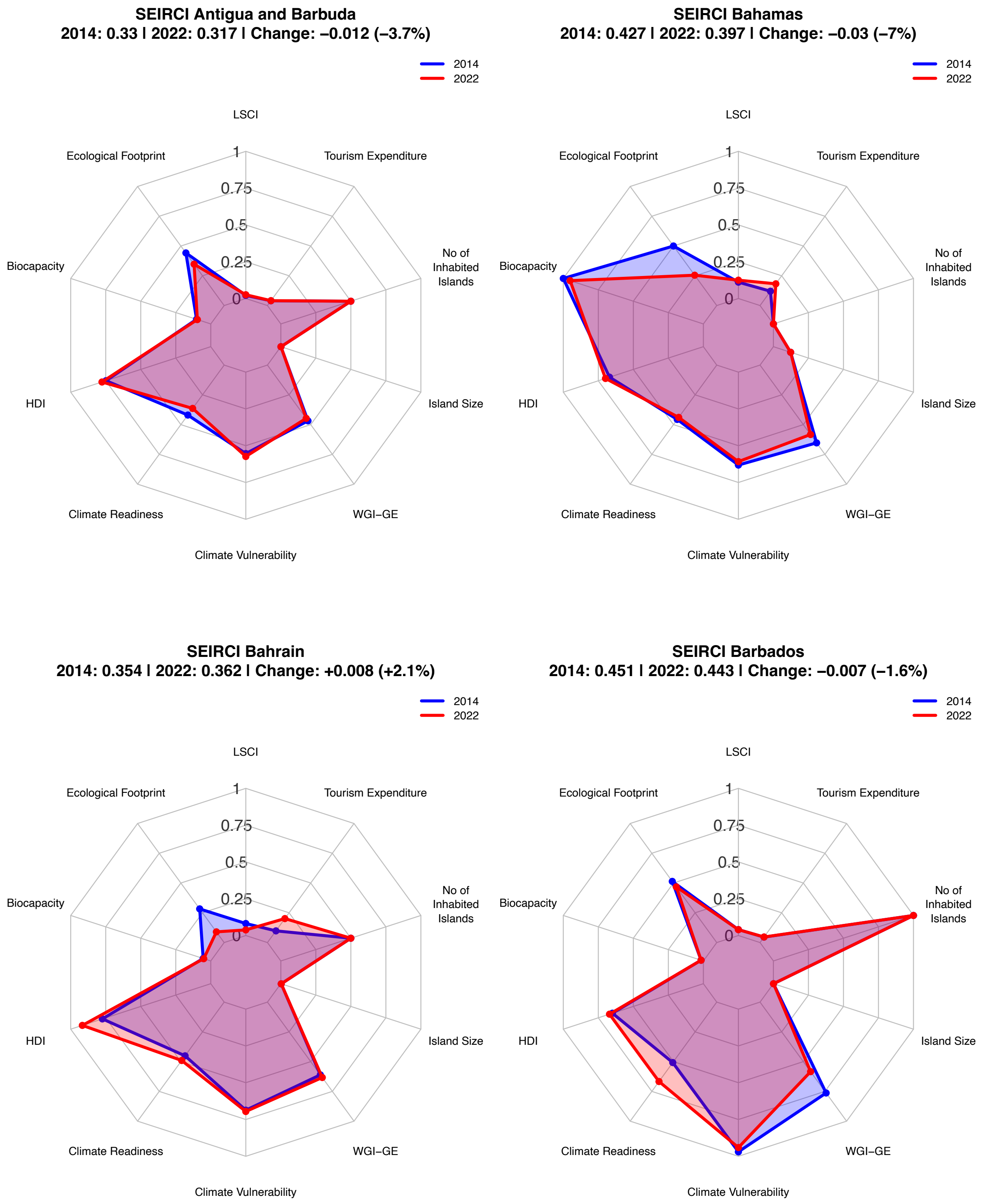


Figure 5-11: Radar graphs for Antigua and Barbuda, Bahamas, Bahrain and Barbados (created using R (RStudio Team, 2025))

Figure 5-12: Radar graphs for Cape Verde, Cuba, Dominica, and the Dominican Republic (created using R (RStudio Team, 2025))

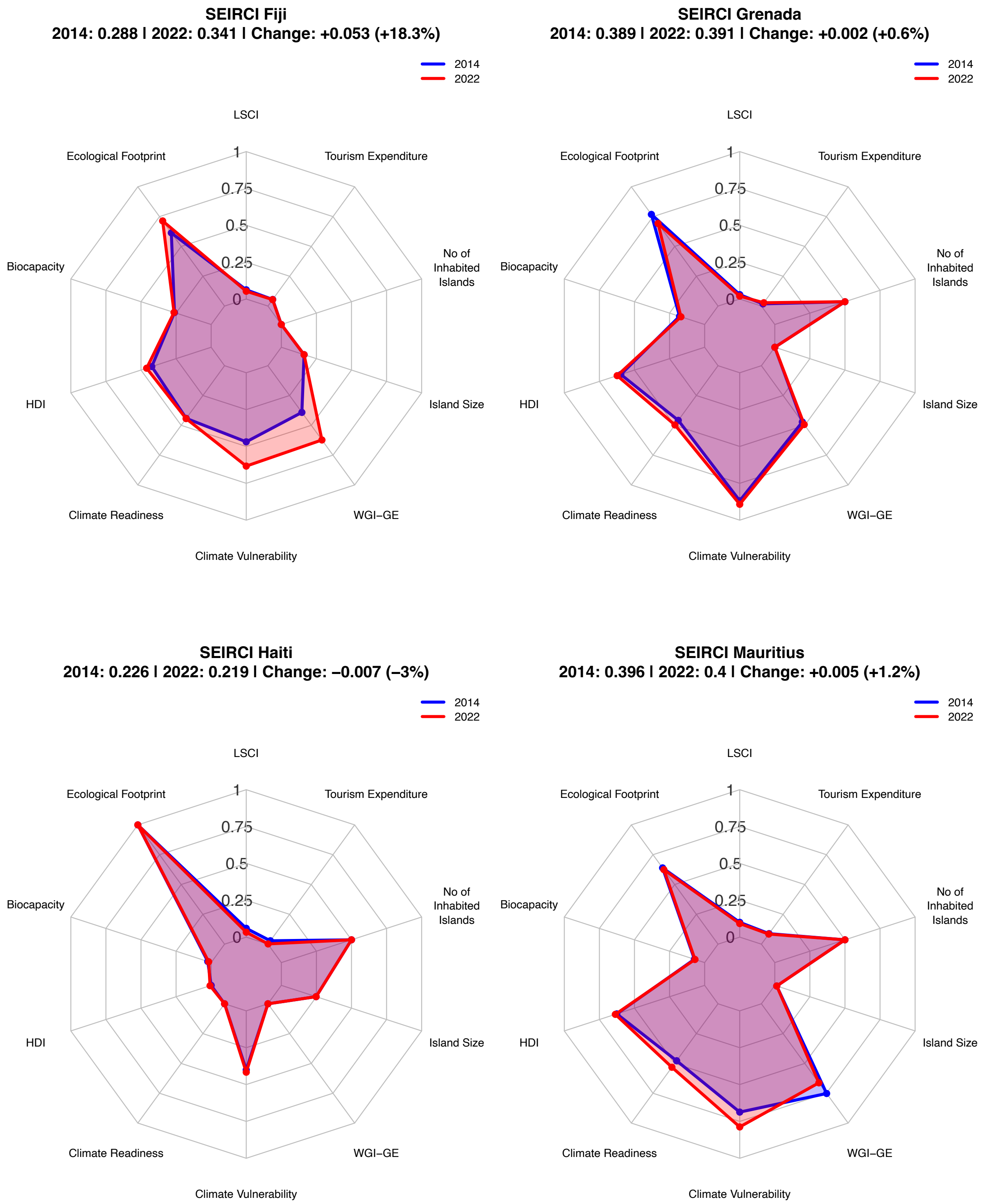


Figure 5-13: Radar graphs for Fiji, Grenada, Haiti and Mauritius (created using R (RStudio Team, 2025))

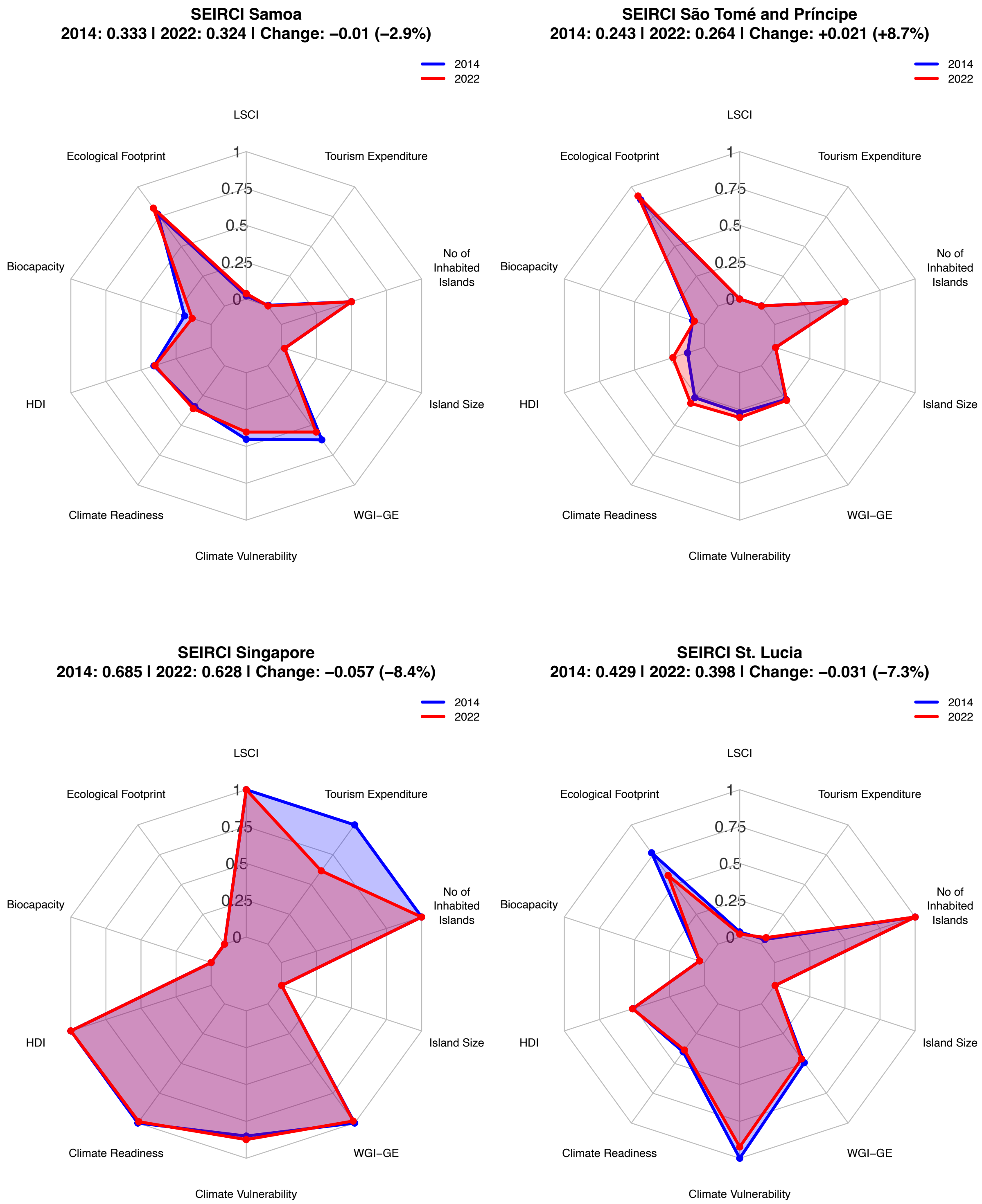


Figure 5-14: Radar graphs for Samoa, São Tomé and Príncipe, Singapore and Saint Lucia (created using R (RStudio Team, 2025))

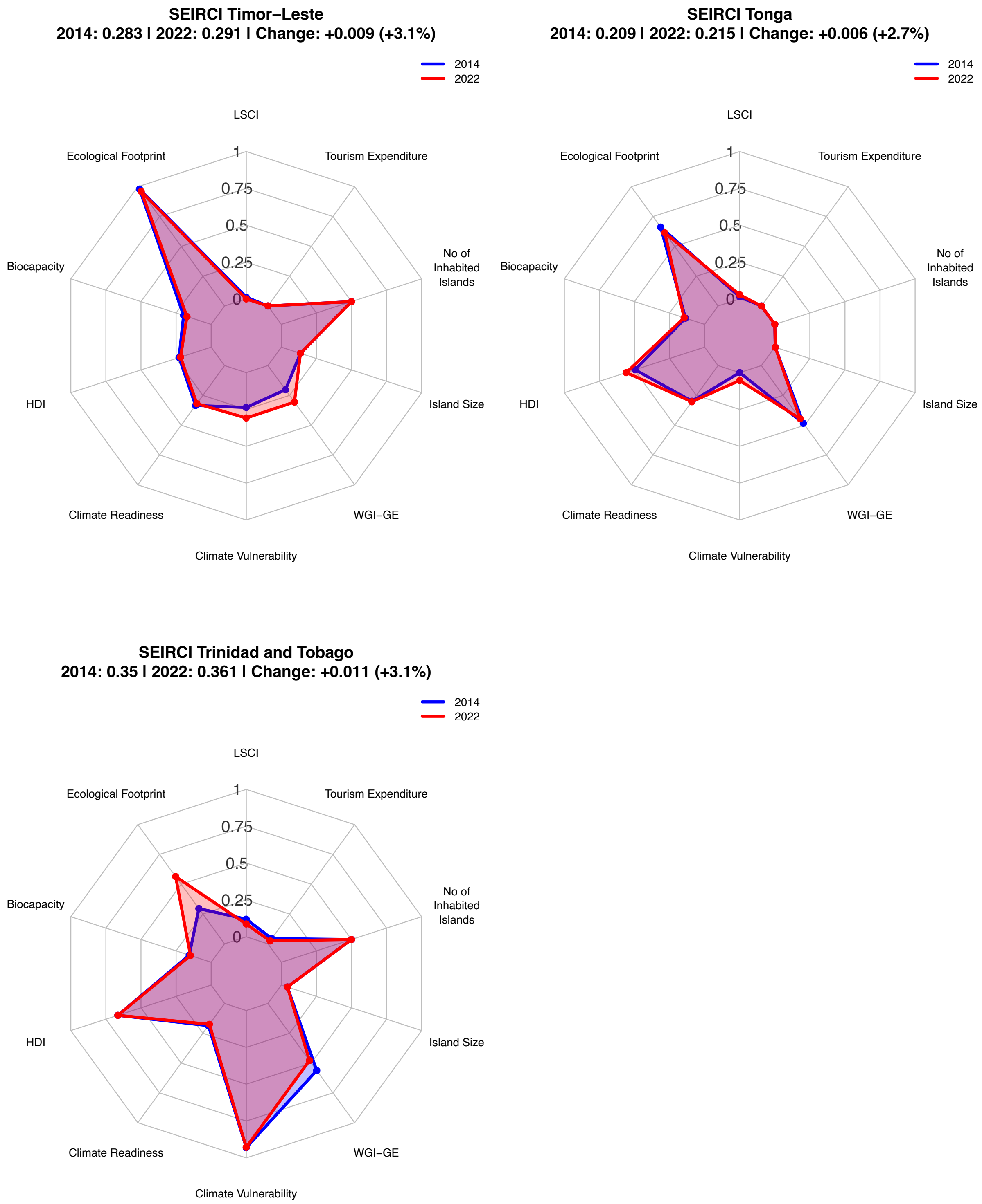


Figure 5-15: Radar graphs for Timor-Leste, Tonga and Trinidad and Tobago (created using R (RStudio Team, 2025))

5.6.2 SEIRCI discussion

The trends observed from the SEIRCI performance on the 19 SIDS achieved a critical aim of the study, namely, to illustrate the benefits of taking a socio-ecological islandscape perspective in examining sustainability issues on a subset of SIDS, such as their resilience capacity. The justification for this statement is detailed by the following key points:

1) There are a very limited number of indices that are solely focused on SIDS, with the majority of indices grouping SIDS along with countries that do not share the same unique “islandness” characteristics, which have resulted in their being recognised as special cases. This uneven comparison may make it difficult for SIDS to use these indices, as actionable changes that could be implemented by other countries evaluated by the index may not be viable for SIDS. This is evidenced in a discussion paper on the development of a Multidimensional Vulnerability Index (MVI) published by the United Nations Development Programme (Assa & Meddeb, 2021), which argues against using more traditional indicators, such as Gross National Income (GNI), for assessing SIDS due to their distinctive features. Similar to the SEIRCI, the proposed MVI considers the unique characteristics of islands, such as remoteness, in the development of the index. The SEIRCI, however, utilised the LSCI as it considered that even if a SIDS is far from the mainland, being highly connected to shipping routes would be more valuable than an island situated closer to the mainland but lacking the infrastructure to take advantage of the more beneficial geographic position.
2) The issue regarding the inclusion of SIDS in broadly designed indices is exacerbated when considering that the normalisation of data is both a common and recommended methodological step in index development (Nardo et al., 2008). Whereas the normalisation of SIDS data along with more developed mainland countries’ data, which do not share their unique characteristics, may result in the obfuscation of SIDS true nature (i.e. index scores may see all SIDS being clustered as lower performing in comparison to their mainland counterparts). This even raises a potential weakness in the SEIRCI, in that

Singapore emerged as a pronounced outlier, and was often the benchmark value for several of the variables used in the study (Figure 5-14).

3) When SIDS-focused indices are developed, these indices tend to have an insular testing method, focusing on a single or a few islands and not in a larger context, such as the sustainability index for Small Island Developing States (Van Beynen et al., 2018), which only used Trinidad and Tobago as its test case. These types of indices are often heavily data-driven, which precludes their use on SIDS that have limited data availability or the mechanisms to collect such data, which, as highlighted in this study and by other authors (Foley, 2018; Hillbom et al., 2023), remains a substantial issue for SIDS. However, these types of indices remain highly valuable for further developing more detailed country-specific actions that can be implemented. The benefits of the SEIRCI, however, are in the easily interpretable method and results, allowing for a more rapid review of SIDS performance over time, as it is based on a smaller number of composite indicators. While an index developed by Van Beynen et al. (2018) is used to determine what can be done, the SEIRCI can be used to identify changes occurring in a particular aspect of SIDS resilience, sounding the alarm for action to be taken (i.e. rather than being able to ascertain what must be done, it identifies that something needs to be done and in which area policy and decision-makers should be focusing on).
4) Observations from the time-series analysis indicate that the resilience capacity of SIDS is dynamic in nature, with no discernible trend regarding a general increase or decrease in the overall resilience capacity of SIDS. This can be viewed both positively and negatively. From a positive perspective, growing issues such as climate change and the impacts of COVID-19 have not significantly affected the overall resilience capacity of SIDS within the study, although changes in individual country scores do provide evidence that these factors may have influenced their performance. However, the negative viewpoint is that, over 8 years, there was not a substantial enough overall improvement in the effectiveness of governments and their policies on SIDS to drastically change the general SEIRCI performance; therefore, not improving on the resilience capacity of SIDS.

5) The SEIRCI and its development process have reiterated the influence of "islandness", with key "islandness" variables, such as the LSCI and the unique spatial arrangements of archipelagos, seemingly being contributory drivers to resilience capacity on SIDS.
6) Lastly, the performance by the subset of SIDS within the SEIRCI also echoes the special case designation given by the United Nations. Even when assessed solely against other SIDS, the general distributions of SIDS within the SEIRCI indicated moderate to low resilience capacity. This signals the need for sustained efforts in improving the current situation for SIDS. This issue is even more prominent given the possible selection bias of using SIDS with data-gathering infrastructure (a consequence of using complete cases only).

5.6.3 Summary

The outcomes of this chapter provide a considerable amount of valuable information that can be considered as contributors to several of the objectives set out for this study, as well as gaining insights that can be taken for further investigation. The index development process illustrated the importance of undertaking a robust process for creating a usable index, as some of the more common weighting methodologies, such as entropy, proved not to be appropriate for the dataset and, therefore, for the index being developed. The dataset seems to contain clusters within several variables, which affects the effectiveness of using entropy as a weighting method. This is a result of entropy assigning entropy values based on dispersion or variability (Yin et al., 2025). These natural groupings may result from the data being selected for the SEIRCI. Composite indicators, such as HDI, WGI-GE, etc., may have a similar flaw to any indicator that is not specifically aimed at SIDS, in that the SIDS may be compared to their mainland counterparts, causing them to group (Massa et al., 2023). However, the index development process did highlight that, although statistical modelling methods such as the PCA were originally eliminated as a means to simulate the socio-ecological systems on SIDS, these proved to be useful in deriving weights for the SEIRCI and in providing additional evidence supporting the notion of a socio-ecological islandscape.

The SEIRCI ultimately provides evidence of the benefits of taking a socio-ecological islandscape perspective when researching SIDS. The SEIRCI illustrated the potential effects of “islandness” factors on the resilience capacity of SIDS and, more importantly, provided an easy-to-interpret and measurable proxy of the potential resilience capacity of SIDS. The SEIRCI has emerged as a useful tool for the rapid evaluation of SIDS, providing a monitorable indication of their resilience capacity. Allowing for determining that a problem has arisen and where action should be directed to address said problem. As seen in the results of the SEIRCI, policy-related variables played a substantial role in the changes observed within the overall resilience capacity of SIDS being measured.

The following chapter aims to provide a detailed conclusion to the study, identifying possible limitations and recommending further research to improve the socio-ecological islandscape concept and its implementation. Furthermore, it is important to provide a synthesis of the study, giving an overview of its importance and where it fits into the body of literature.

CHAPTER 6. SYNTHESIS, RECOMMENDATIONS AND CONCLUSIONS

6.1 Introduction

This study initially posed a research question seeking to gain insights into how the intersection of socio-ecological islandscapes and resilience affects the sustainability of Small Island Developing States (SIDS). This chapter seeks to address this socio-ecological islandscape-resilience nexus by (1) providing a concise synthesis of the key findings and contributions of the study, (2) illustrating how the aims and objectives of the study have been achieved, and (3) identifying potential actionable recommendations that could be taken. In conjunction with highlighting the potential importance of the study and its place within the broader SIDS literature, the chapter will consider the study's limitations and shortcomings and propose further research directions.

6.2 Synthesis and reflections

6.2.1 Socio-ecological islandscape concept

The socio-ecological islandscape concept originated from the growing evidence that islands were inherently vulnerable to changes to their economies, societal structures and environmental systems (Bunce et al., 2009; Hay, 2013; Jupiter et al., 2014; Plieninger et al., 2018), and that the growing threat to their sustainability was directly linked to their unique "islandness" characteristics, bringing about the "special case" designation by the United Nations (UNCED, 1992). However, even though the plight of SIDS was recognised, there remained a notable absence of SIDS studies that addressed these vulnerable systems (Christensen & Mertz, 2010), especially studies that consider their unique "islandness" characteristics (Yanez et al., 2014; Banos-González et al., 2015b; Ciftcioglu, 2017; Schmitz et al., 2017).

The social, economic and environmental systems of islands can be assessed through the lens of a socio-ecological system framework (Berkes, 2017), though in this study, it was argued that a typical socio-ecological system perspective may not be sufficient to fully evaluate these systems on SIDS. A fundamental aspect of the study is the conceptualisation of a socio-ecological islandscape framework. This socio-ecological islandscape concept argues that, due to the ensuing special case designation for SIDS, a framework that is underpinned by the understanding that SIDS are affected by unique "islandness" is more beneficial for evaluating sustainability issues on SIDS, as opposed to the currently adopted socio-ecological systems approach that is recognised as incorporating "islandness" features. Therefore, the socio-ecological islandscape framework does not aim to replace the socio-ecological systems framework, which is ingrained in the socio-ecological islandscape framework's design, but rather aims to provide an explicit viewpoint for augmenting current thinking and approaches. Augmenting the existing socio-ecological systems framework ensures that, when SIDS are being evaluated, attention is drawn to their unique "islandness" features and that a common point of departure exists for researchers and policymakers.

The importance of having an island-focused approach was highlighted by Chandler and Pugh (2018), who argued against the idea that islands should be used solely as the "canary in a coal mine" for the rest of the world. Ultimately, the socio-ecological islandscape framework provides an important new outlook for research and policymaking on SIDS. Furthermore, the study has not only justified the framework's development through a comprehensive review of literature, but also through the observed influence of "islandess" in socio-ecological systems on SIDS. The evidence and its importance in rationalising the socio-ecological islandscape concept are further explained in the subsequent sections, along with a synthesis of how the study has demonstrated the benefits of implementing a socio-ecological islandscape perspective.

6.2.2 Modelling socio-ecological systems

A foundational element in justifying the socio-ecological islandscape was to simulate how "islandness" factors affect socio-ecological systems on SIDS, which would provide a rationale for their explicit inclusion in the socio-ecological framework and validate further investigation into the socio-ecological islandscape concept. To this end, the study investigated how a Bayesian Belief Network (BBN) could be used to model the socio-ecological systems of SIDS, and whether, in using a BBN, the role of “islandness” within these socio-ecological systems could be ascertained. The results of the modelling process have meaningful implications, by providing both supporting evidence for the socio-ecological islandscape concept and by reinforcing the potential use of the BBN as a valuable tool in modelling socio-ecological systems. The socio-ecological islandscape modelling process found sufficient evidence that factors such as island size, isolation and whether islands consist of an archipelago influence how socio-ecological systems materialise on SIDS. Establishing empirical support for the socio-ecological islandscape concept lays a strong foundation for its continued investigation.

While the development of the BBNs contributes to the growing body of research on their potential use in the field of environmental science and management, their use in the study has also added to the analytical foundation regarding future development of BBNs in the pursuit of socio-ecological systems research. The developed BBNs provide a “proof of concept” for how a socio-ecological islandscape can be simulated and also provide an alternative means of assessing SIDS. A common theme that emerged from the literature analysis and within this study was the significant lack of data for SIDS. The BBN can provide some measure of the probable outcomes for an island with specific characteristics, under specific scenarios. This is a potential alternative predictive means available to data-poor SIDS for analysing the risks related to changes that may take place from ensuing policy recommendations or circumstances that result in negative changes to the system.

6.2.3 Socio-Ecological Islandscape-Resilience Nexus

The socio-ecological islandscape-resilience nexus provided an important focal point for the initial implementation of the socio-ecological islandscape framework, as this continues to be a significant issue for SIDS, attributable to growing threats such as climate change, overexploitation of limited resources and unfavourable trade agreements. Resilience, a key component of the nexus, is broadly defined as the ability of a system to withstand change before the system moves into a new state (Angeler & Allen, 2016; Berkes, 2017), and a subset of the theory of resilience that is often used in understanding the capacity of landscapes to withstand change is spatial resilience (Nyström & Folke, 2001; Li et al., 2014; Lucash et al., 2017; Rescia & Ortega, 2018).

Therefore, the intersection between spatial resilience and socio-ecological islandscapes was considered a more valuable central element for investigation. A foundational assumption of the study is that, when considering any issue related to the socio-ecological systems on SIDS, taking a socio-ecological islandscape perspective would enrich the process. Therefore, in understanding the socio-ecological islandscape-resilience nexus, a key concept of spatial resilience was viewed through this socio-ecological islandscape lens, namely, how the primary internal and external elements of spatial resilience (Cumming, 2011b) may be transposed into the socio-ecological islandscape concept. For example, a component of connectivity that manifests on SIDS is their isolation from the rest of the world, contributing to aspects such as biogeography, resource availability and social dynamics. Defining how these spatial resilience attributes could be observed on SIDS not only provided an initial example of the perspective required for using the socio-ecological islandscape framework, but also emerged as an important evaluation of how “islandness” can be perceived within the bounds of spatial resilience. This evaluation had significant implications for the development of the Socio-Ecological Islandscape Resilience Capacity Index (SEIRCI) and ultimately provides an important initial link between “islandness” and spatial resilience in the SIDS context.

6.2.4 Development of the Socio-Ecological Islandscape Resilience Capacity Index (SEIRCI)

The development of the SEIRCI arose from the need to provide an operationalised example of how the socio-ecological islandscape perspective is beneficial when conducting assessments related to SIDS. In doing so, several key insights emerged, not only for the study as a whole but also as a contribution to the broader body of research.

Firstly, empirical evidence from the SEIRCI further corroborated the influence of “islandness” on SIDS. This observational evidence emerged in the form of “islandness” factors, such as the Linear Shipping Connectivity Index (LSCI) being assigned higher weights across the data-driven weighting methodologies, or through the unique spatial arrangement attribute associated with islands (i.e. number of inhabited islands) being a dominant contributor in the index scores. The aim of the SEIRCI was not to provide supporting evidence for the influence of “islandness” on a socio-ecological system.

Furthermore, some of the statistical modelling processes (e.g., PCA) that were fundamental in its development were initially eliminated from use when modelling the influence of “islandness” on socio-ecological systems, due to their inability to deal with missing data. However, its development still provided incidental insights that could be used as supplementary evidence to support the socio-ecological islandscape concept.

The index weighting procedure had several findings of relative importance. Firstly, a robust process for selecting an appropriate weighting methodology is paramount in the index development process. This is not a new or original idea; however, the study provided quantitative and empirical evidence in support of this approach to index development. In determining the most adequate weighting methodology, it became evident that, due to the nature of data generated for several SIDS, weighting methodologies that are reliant on variability, such as using Entropy, are less valuable in socio-ecological islandscape research. This is due to SIDS often being measured against mainland counterparts. Secondly, the process also highlighted the usefulness of using a data-driven weighting process, such as the PCA and using a simpler equal weighting method, when there is insufficient knowledge or consensus to assign weights. Ultimately, either the PCA-driven index or the equal weighting index could have been used in the SEIRCI, but the decision ultimately lay in the intended use of the index (i.e. easily replicable and interpretable for a rapid time series analysis).

Ensuring a robust index development process is echoed by the decision to evaluate multiple theoretical frameworks intended to guide the SEIRCI development. Testing different theoretical approaches for the SEIRCI reduced researcher bias in framework selection by requiring empirical validation, rather than relying on a preferred theoretical framework, whose suitability had yet to be quantitatively tested. Resulting from this empirical review of the theoretical frameworks, the spatial resilience-focused approach emerged as the most suitable for the SEIRCI. This has broader implications for the study, as it provides empirical evidence for the links between “islandness” factors and spatial resilience on SIDS, an important finding for initial conceptualisation of the socio-ecological islandscape-resilience nexus. From a methodological standpoint, the emergence of the spatial resilience-focused approach as being the most suitable lends to the idea that indices should be simplistic, with fewer variables. The inclusion of too many variables introduces issues around multicollinearity and substantial data collection requirements.

The SEIRCI ensured an island-centric measure of resilience capacity on SIDS, driven by variables that were linked to elements of spatial resilience on SIDS. The findings of the SEIRCI results showed the benefits of taking the socio-ecological islandscape perspective in evaluating SIDS. Even with islands being concentrated towards the lower end of the SEIRCI based on their relative index scores, there was a substantial distribution of countries, illustrating the discriminatory power of the index.

The study results provide a usable measure of the resilience capacity of numerous SIDS, allowing for the rapid identification of changing conditions and the aspect of resilience in which this change is taking place. The SEIRCI provided an overall assessment of SIDS that formed part of its initial development, indicating that the resilience capacity of SIDS is generally on the lower end of the SEIRCI. The results also indicated that, although at the country level there are cases of marked shifts in index scores, the general trend remains the same (i.e. the overall resilience capacity of SIDS within the study did not substantially change between 2014 and 2022). This has both positive and negative implications for SIDS, where no change means that although the overall situation has not deteriorated, neither has it improved.

6.2.5 Summary of contributions to the body of knowledge

The three primary contributions that can be extracted from this study include:

- A theoretical framework (socio-ecological islandscape framework) on how to incorporate “islandness” into socio-ecological systems;
- The operationalisation of incorporating “islandness” through the SEIRCI; and
- An initial investigation into the socio-ecological islandscape-resilience nexus.

The first primary contribution of the study was the development of the SEI conceptual framework, which provides both a theoretical foundation for how “islandness” influences socio-ecological systems and guidance on how socio-ecological systems on SIDS should be assessed. New theoretical contributions are always subject to future refinement; however, this initial iteration of the socio-ecological islandscape framework is able to establish key dimensions and relationships for socio-ecological systems evaluation on SIDS. The second primary contribution was the operationalisation of the socio-ecological islandscape framework through the SEIRCI. The SEIRCI represents the first systematic attempt to provide an empirical analysis of the resilience capacity of SIDS through incorporating “islandness” linked spatial resilience elements. The final primary contribution of the study was an initial investigation into the socio-ecological islandscape-resilience nexus and the important intersections between “islandness” and the elements of spatial resilience.

Among the secondary contributions of the study are the analytical foundations provided by the BBN models and their potential use in scenario analysis, the empirical evidence towards the need for a robust index development process, and comparative analysis between the different weighting methodologies. These contributions have been referred to in detail in the preceding sections.

6.3 Aims and objectives

To provide a clear indication of how the study achieved the aims set out in the introductory chapter, a brief discussion on each aim is provided below:

- Aim 1 – Investigate the role of “islandness” in influencing socio-ecological systems: There was a clear investigation into the role of “islandness” in influencing socio-ecological systems, with both the BBNs providing substantial empirical evidence, as well as supplementary evidence from the SEIRCI development process. The aim was achieved through using a PCA to assist in establishing a set of 16 variables used in the construction of multiple BBNs that modelled socio-ecological systems on islands.
- Aim 2 – Determine the trends in the socio-ecological islandscape-resilience nexus using the Socio-Ecological Islandscape Resilience Capacity Index (SEIRCI): The cumulation of a robust and transparent index development process has resulted in the creation of the Socio-Ecological Islandscape Resilience Capacity Index (SEIRCI). The index development process ensured that relevant variables linked to different theoretical frameworks were established. These theoretical frameworks were used to derive appropriate variable weightings through a comparative analysis of weighting

methodologies. Lastly, the SEIRCI was used to ascertain changes in resilience capacity across 19 SIDS between 2014 and 2022.

- Aim 3 – Demonstrate the benefits of taking a socio-ecological islandscape perspective: Illustrating the benefits of the socio-ecological islandscape perspective was not solely confined to the results of the SEIRCI, though the results and the possible continued use of the SEIRCI are meaningful demonstrations of said benefits. The benefits of the socio-ecological islandscape perspective have continually emerged throughout the entire study, from the BBN model design, the links drawn between "islandness" and the elements of spatial resilience, to the island-centric focus of the index development process.

6.4 Limitations and shortcomings

The study endeavoured to be as robust as possible in achieving its aims and objectives. However, there will inevitably be limitations and shortcomings in any research process. The limitations and shortcomings of this thesis are described in detail below:

- There was a delay between the BBN model data collection and the SEIRCI development data collection. This led to the need to use a revised SEIRCI dataset that is more "up to date" than those used in the BBN models. However, this time-delay resulted in the SEIRCI being able to include 19 SIDS, while the PCA used for the BBN model development only utilised 12 SIDS. However, this meant that the PCA process had to be repeated for the broad-based PCA index, as the factor loadings generated in Chapter 3 were no longer valid for use in the index. Due to time constraints, the BBN modelling process was also not revised based on the revised dataset. Ultimately, this did not have a major bearing on the study as a whole, as these processes are connected but could be done separately.
- The BBNs provided a roadmap for the development of the BBN-driven SEIRCI and therefore could be done with two different dataset timeframes. However, it is acknowledged that, if all the BBNs were re-evaluated based on the revised

data, another model structure may have been identified as being more accurate.

- ❖ Cognisance should be given to the timeframe used in the BBN (2004 -2014), coupled with the potential uncertainty in the BBN modelling process, in using the BBNs as a decision-making tool. The BBNs are limited to an informative tool to assist in highlighting issues for policy and decision-makers.
- ❖ There is a significant lack of data available for SIDS. Only a very small number of SIDS (n=19) formed part of the SEIRCI development, compared with the number of SIDS (n=33) used in the BBN model development. This creates selection bias toward countries with the data infrastructure to collect useful information, which limits the possibility of the SEIRCI becoming a widely adopted index for SIDS at the moment. Several methods are available to account for missing data (Nardo et al., 2008), such as either using imputation by a single substitution (e.g. mean or regression) or multiple imputation (e.g. Markov Chain). Exploring these methods would have added an extra layer of complexity to the study, and due to time limitations, the accepted complete cases only were used for the SEIRCI development process.
- ❖ The SEIRCI is not only limited by the availability of data, but also by the type of data that is available. The SEIRCI is a composite index, comprised of other global indicators and indices. To some degree, the SEIRCI is also affected by how these measures are established, such as the LSCI, in which SIDS are grouped with their mainland counterparts. However, the SEIRCI only uses SIDS in normalising data and in determining the index score, coalescing these indicators into a more island-centric perspective.
- ❖ Another shortcoming of the SEIRCI is the lower levels of external validity observed with the Environmental Performance Index (EPI). The EPI was selected as it also measures a dimension of sustainability. However, the study established that broadly used indices may not correlate as well with a more island-focused index. Consequently, even though the average range shift analysis proved useful in determining the most appropriate approach for the SEIRCI, it remains unclear how much external agreement the index has with other indices that measure similar dimensions of sustainability.

- The SEIRCI is not intended to provide in-depth information that can be used to develop comprehensive action plans and strategies. The high-level data and smaller number of variables used allow for the SEIRCI to be a rapid evaluation tool, rather than an extensive measure of resilience capacity. This is not a shortcoming of the SEIRCI, but rather a limitation in its application.

6.5 Recommendations and further research

The following section provides recommendations and further research directions that have become apparent during the study.

Stemming from the SEIRCI being focused on a global scale, policy recommendations for specific countries have not been proposed. Rather, these recommendations are for global policymakers to consider for improving the overall resilience capacity of SIDS. The recommendations are as follows:

- A data collection programme for SIDS needs to be established to assist these countries in collecting timely and appropriate data that can be used to ensure that these countries are evaluated by the major global indices. These indices provide notably useful information, not only for all spheres of government within SIDS, but also for global decision-making.
- Global indices need to be revised to consider the socio-ecological islandscape perspective, such as the UN's Multidimensional Vulnerability Index (Massa et al., 2023). This will ensure that the value being assigned to SIDS is not obfuscated by their mainland counterparts.
- Strong governance had a considerable bearing on the results of the SEIRCI; thus, any progress towards improving aspects of governance of SIDS (e.g., climate readiness) will improve the general resilience capacity of SIDS.

Throughout the study, numerous methodological limitations, shortfalls and gaps have been identified. Further work on these will strengthen future implementations of these methods, and include:

- Test alternative discretisation methods for continuous variables to further refine the robustness of the model (e.g. median, entropy-based binning).

- The SEIRCI development process can be further iterated upon by assessing the applicability of techniques that deal with missing data, such as single and multiple imputation. This may aid in providing SIDS that do not have complete datasets with a provisional SEIRCI score that may provide some degree of guidance for policy and decision-making.
- As more data become available, the SEIRCI can be revised to include more SIDS. This will further enhance its global applicability and usefulness as a measure of SIDS resilience capacity.
- Conduct further validation of the SEIRCI against independent resilience outcomes to strengthen confidence in the index.
- Analyse the effects of removing outlier countries (e.g. Singapore) from the SEIRCI to understand how differently the rankings may perform under this scenario.

The study provided a new theoretical framework, an initial investigation into the socio-ecological islandscape-resilience nexus and the SEIRCI; however, this has also provided numerous avenues for further study. Recommendations for further research are as follows:

- Additional studies using the socio-ecological islandscape framework should be conducted to further evaluate its usefulness and provide recommendations for possible improvements. These studies should be done at different scales (e.g. local and regional) to ascertain if the framework can be used in its current form for each level or if adjustments need to be made.
- Further research into the socio-ecological islandscape-resilience nexus is needed. This study presented an important initial investigation, though a more in-depth investigation would provide greater clarity regarding the connection between "islandness" features and the concept of internal and external elements of spatial resilience. A more in-depth investigation may strengthen our understanding of spatial resilience from a SIDS perspective.
- The use of the BBNs for modelling the socio-ecological islandscape can be expanded by creating BBN models for more localised SIDS studies. A BBN could be developed using information for SIDS that does not have data issues. This model may then be used as a predictive tool for more fine-grained socio-

ecological islandscape issues, which could then be used for SIDS that lack the required data.

- Additional BBN analysis can be conducted on future BBN models to further validate and enhance investigations, for example, assessing both predictive accuracy and certainty of predictions for localised SIDS studies.

6.6 Concluding statement

This thesis set out to determine how the intersection between resilience and socio-ecological islandscapes affects the sustainability of SIDS. Through a robust statistical and computational modelling process, augmented by a comprehensive literature review, the study has illustrated that the unique island features are resilience-shaping factors on SIDS, thereby affecting their overall sustainability. The socio-ecological islandscape framework removes the "canary in a coalmine" label from SIDS and rather places them firmly into their own unique category, which should be assessed through its own unique lens, while the SEIRCI was developed as an island-centric measure for their resilience capacity, allowing their sustainability over time to be rapidly evaluated and potential issues highlighted[6].

[6] It should be noted that AI tools (such as Grammarly) were used in a few chapters to assist in spellchecking, grammar, and with some proof editing, such as refining phrasing. However, professional proof editing was used in the final stages of the PhD process.

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APPENDIX A. TURNITIN MEMORANDUM

Memorandum

From: Prof K Mearns

16 February 2026

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I hereby acknowledge that there is a higher than usual similarity percentage for the Doctoral Thesis by Ryan Nel. Having gone through the report, it emerged that the high similarity percentage is largely due to 2 journal articles published in the Scholarly journal Ecological Informatics by the candidate, supervisors and other mentors. To that end, the similarity report must be read and understood in that context. While this disclaimer is given, it remains the student's role to ensure that there are no incidences of similarity apart from the highlighted.

Nel, R., K. F. Mearns, M. Jordaan & P. Goethals (2022). The role of modelling in resource management within the livelihood-conservation nexus: A socio-ecological systems approach to Sand Forest harvesting, Northern KwaZulu-Natal. *Ecological Informatics*. 69, 1-13. https://doi.org/10.1016/j.ecoinf.2022.101600

Nel, R., K. F. Mearns, M. Jordaan & P. Goethals (2021). Towards understanding the role of islandness in shaping socio-ecological systems on SIDS: the socio-ecological islandscape concept. *Ecological Informatics*. 62, 1-17. https://doi.org/10.1016/j.ecoinf.2021.101264

Supervisor

Prof K Mearns   16 February 2026

APPENDIX B. TURNITIN REPORT

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Towards understanding the role of islandness in shaping socio-ecological systems on SIDS: The socio-ecological islandscape concept

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A R T I C L E I N F O

Keywords:
Socio-ecological systems
Small Island Developing States
Bayesian Belief Networks
Islandness
Sustainability

A B S T R A C T

Small Island Developing States are under significant threat from global change and unsustainable local practices. These issues are generally exacerbated by an inherent vulnerability to social, economic and ecological changes consequential to their unique island characteristics (e.g. limited resources), which is often described as "islandness". These unique island characteristics or "islandness" have shaped, and continue to shape, their socio-ecological systems which, from a real-world geographic perspective, the island and its communities form an integrated socio-ecological landscape. It can be argued that "islandness" contributes immensely to understanding the socio-ecological systems of an island, and in considering "islandness" as a fundamental element that significantly influences socio-ecological systems on islands, socio-ecological systems then materialise as socio-ecological islandscapes. This study ultimately sets out to initiate the development of the socio-ecological islandscape concept through (1) providing the preliminary framework, and (2) gaining insights into what impact each of the unique characteristics of "islandness" has on a system, both as individual components and as a collective, through the use of Bayesian Belief Networks. The results of the study provide evidence of the influence that "islandness" has on both the social and ecological components of a socio-ecological system. Differences in degree of influence between the unique island characteristics (e.g. size vs. isolation) also showed how some characteristics have greater impacts. The socio-ecological islandscape framework proposed in this study propagates a research agenda focused on the SES-landscape-SIDS-islandness nexus, due to its apparent effect on the economic disadvantages and ecological fragility faced by SIDS that threatens their sustainability.

1. Introduction

Currently, one of the most significant problems of global concern is environmental degradation, which has far-reaching consequences for both human health and environmental quality, as well as for the global economy (Rahman, 2020). A new era, dubbed the "Anthropocene", has been used to describe the augmented rate of global environmental change, compounded by climate change as well as biodiversity loss – which is the direct consequence of human activities (Berkes, 2017). Islands are currently being confronted with growing risks resulting from this global change, as well as from unsustainable local practices which are exacerbated by an inherent vulnerability to social, economic and ecological changes (Bunce et al., 2009; Hay, 2013; Jupiter et al., 2014; Plieninger et al., 2018). This inherent vulnerability has been acknowledged through the United Nations Conference on Environment and Development in June 1992,[1] where it was recognised that Small Island Developing States (SIDS) are "*a special case for both environment and development. They are ecologically fragile and vulnerable. Their small size, limited resources, geographic dispersion and isolation from markets place them at a disadvantage economically and prevent economies of scale*" (UNCED, 1992:193). SIDS face numerous issues related to the Anthropocene, such as climate change, over-exploitation, invasive species, habitat alteration and disease, which are often more prominent on islands, given their unique insular nature (Graham et al., 2017).

Recognising the growing global crisis brought about by the Anthropocene, the United Nations General Assembly established a collection of 17 global goals – the Sustainable Development Goals (SDGs), in 2015, with the ambition to ensure global sustainable development for both developing and developed nations, thereby improving human well-being and conserving the environment on a global scale

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[1] United Nations Conference on Environment and Development Rio de Janeiro, Brazil, 3–14 June 1992 – AGENDA 21.v

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The role of modelling in resource management within the livelihood-conservation nexus: A socio-ecological systems approach to Sand Forest harvesting, Northern KwaZulu-Natal

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A R T I C L E I N F O

Keywords:
Livelihood-conservation nexus
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Sand Forest
Bayesian belief networks
Resource management

A B S T R A C T

Divergences between community livelihoods and conservation efforts often result in changes to the access and use of natural capital in affected areas, negatively affecting the respective livelihoods. New tools and interdisciplinary approaches are more frequently required for solving these conflicts. In this paper, the socio-ecological systems (SES) perspective along with Bayesian Belief Networks (BBNs) have been used to model the interdependencies that exist within the livelihood-conservation nexus to determine if this method can improve synergy between community livelihood requirements and conservation targets in an era of unsustainable decline of natural resources, using the livelihood-conservation nexus of informal Sand Forest harvesting in Northern KwaZulu-Natal as a case study. Results suggest BBNs have great potential for use in socio-ecological and resource management studies concerning the livelihood-conservation nexus. The results of the sensitivity analysis of the BBN showed that employment and income are the greatest socio-economic drivers in terms of Sand Forest harvesting, while preference (i.e. behaviour) for energy sources and building materials has the greatest overall influence on Sand Forest usage. The BBN scenario comparison further demonstrated the influence of preference (i.e. behaviour) on the SES. Finally, the conservation effectiveness assessment using the BBN showed the significant contribution of accessibility and availability of Sand Forest (i.e. conservation) to the system. Information provided by the BBN allowed for suitable areas for conservation to be identified given conservation targets and the utilisation needs of the communities (i.e. greater synergy), through the mapping of two livelihood management approaches (i.e. community conservation and formal conservation). The results of mapping the different management objectives have shown that community conservation is more suitable for moving the system towards synergy and should be considered for a Sand Forest resource management approach to compliment any conservation planning.

1. Introduction

The new proposed era, recognized as the Anthropocene, is characterised as a period where significant environmental and social changes are taking place from increasing human expansion, consumption and extraction (Redmore et al., 2018). An issue that arises due to this occurrence of substantial change are conflicts between community livelihoods and conservation efforts (Nel et al., 2016), which frequently leads to trade-offs (Pradhan et al., 2017). Historically, communities have been separated from the natural capital that is an embedded part of their livelihoods due to conservation approaches taken (Redmore et al., 2018). These conservation measures often result in changes to the access and use of natural capital in affected areas, negatively affecting community livelihoods (Zafra-Calvo and Moreno-Peñaranda, 2018). This is indicative of the complexity that often exists in the nexus between livelihoods and conservation. Of particular importance, is the connection that exists between communities and wooded ecosystems, such as forests, which have been stated as a critical issue in conserving biodiversity, easing carbon emissions, promoting sustainable development (Harbi et al., 2018) and being of such significance that these resources can either prevent or cause further descent into poverty (Shackleton et al., 2007). In order to move from a trade-off towards a synergy between livelihoods and conservation, a better understanding of the complex interactions that exist within this livelihood-conservation

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APPENDIX E. ETHICAL CLEARANCE

UNISA university of south africa

CAES GENERAL RESEARCH ETHICS REVIEW COMMITTEE

National Health Research Ethics Council Registration no: REC-170616-051

Date: 10/03/2017

Ref #: **2017/CAES/055**
Name of applicant: **Mr R Nel**
Student #: **48160407**

Dear Mr Nel,

Decision: Ethics Approval

Proposal: Modelling the influence of island biogeographic variability on the relationship between climate change and vegetation dynamics

Supervisor: Prof K Mearns

Qualification: Postgraduate degree

Thank you for the application for research ethics clearance by the CAES Research Ethics Review Committee for the above mentioned research. Approval is granted for the project, *subject to submission of the relevant permission letters.*

Please note that the approval is valid for a one year period only. After one year the researcher is required to submit a progress report, upon which the ethics clearance may be renewed for another year.

Due date for progress report: 31 March 2018

Please note the point below for further action:

1. The researcher indicates that field visits will be made to the two islands. Before this can take place, permission must be obtained from the relevant authorities to do so. The Committee acknowledges that this may be difficult as these islands are remote; if permission cannot be obtained the researcher must submit an explanation of the procedures that were followed to obtain permission but failed. The field visits may

not commence until either the permission letters or the explanation has been submitted to the Committee.

The application was reviewed in compliance with the Unisa Policy on Research Ethics by the CAES Research Ethics Review Committee on 10 March 2017.

The proposed research may now commence with the proviso that:

1) *The researcher/s will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.*
2) *Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should be communicated in writing to the CAES Research Ethics Review Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.*
3) *The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study.*

Note:
The reference number [top right corner of this communiqué] should be clearly indicated on all forms of communication [e.g. Webmail, E-mail messages, letters] with the intended research participants, as well as with the CAES RERC.

Kind regards,

Signature
CAES RERC Chair: Prof EL Kempen

Signature
CAES Executive Dean: Prof MJ Linington