VULNERABILITY IS DYNAMIC

An interactive approach to enhance adaptation strategies to climate change for coastal tourism

Jillian Student

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Thesis committee

Promotor
Prof. Dr A.P.J. (Arthur) Mol
Professor of Environmental Policy
Wageningen University & Research

Co promotors
Dr M.A.J. (Machiel) Lamers
Associate Professor, Environmental Policy Group
Wageningen University & Research

Dr S.B. (Bas) Amelung
Assistant Professor, Environmental Systems Analysis Group
Wageningen University & Research

Other members
Prof. Dr E.H. (Edward) Huijbens, Wageningen University & Research
Dr E.N. (Erika) Speelman, Wageningen University & Research
Prof. Dr W.J.M. (Pim) Martens, Maastricht University
Dr J.H. (Jan) Kwakkel, Delft University of Technology

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Thesis

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INTRODUCTION

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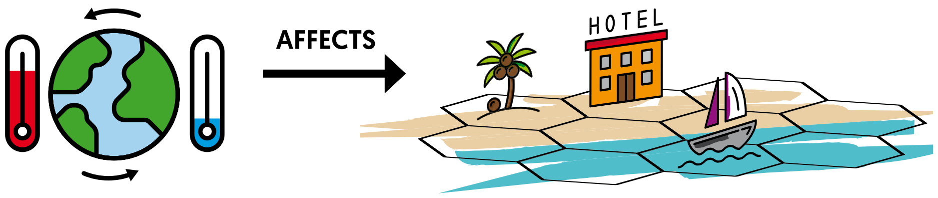
INTRODUCTION

GLOBAL CLIMATE CHANGE

COASTAL TOURISM DESTINATIONS

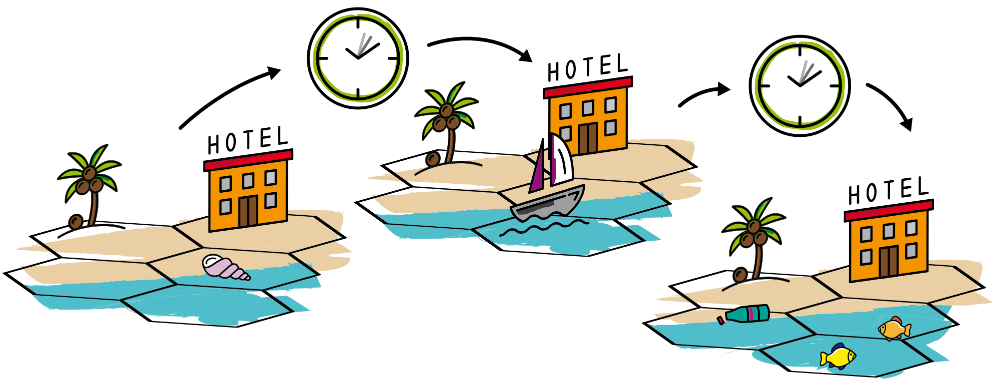


However, little is known about how vulnerabilities emerge at the destination level.

Why are coastal tourism vulnerabilities important:

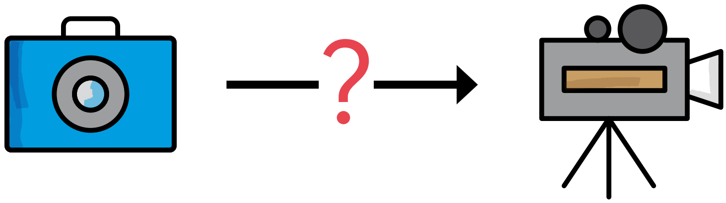
- IPCC recognise islands and the Caribbean region are vulnerable to climate change
- Coastal tourism destinations are understudied
- Caribbean coastal destinations are dependent on tourism for economic well-being
- Tourism is related to the Sustainable Development Goals

However, vulnerability is dynamic. Socio-ecological vulnerabilities change over space and time in a destination through interactions.



We therefore ask,

How can dynamic vulnerability be operationalised to inform adaptation strategies for coastal tourism?



We need:

- A new conceptual lens
- New methodological tools to capture emerging vulnerabilities
- Analysis of the insights from studying emerging vulnerabilities

This research:

- Develops a dynamic vulnerability approach on two coastal tourism destinations in the Caribbean: Barbados and Curaçao
- Introduces new methodological tools
- Provides new vulnerability and adaptation strategies insights

1.1. Global challenge of climate change and tourism

Dialogue on climate change, and its effects on our lives, continues to increase. Climate change has the potential to affect all aspects of our lives and brings uncertainties of how and what kind of futures we can think of. Tourism is not immune. Climate change is identified as one of the main challenges for tourism (e.g. Buckley et al. 2015; Scott & Becken 2010; Scott, Hall et al. 2012). Scott (2011) argues that tourism needs to confront climate change in order to be sustainable. Several large-scale vulnerability assessments focusing on tourism (Scott, Gössling et al. 2012; Scott, Hall et al. 2019; UNWTO-UNEP-WMO 2008) and coastal tourism have indicated national vulnerability hotspots for climate change. Clearly, tourism is vulnerable to climate change in many parts of the world. However, although tourism is an international and global phenomenon, it occurs at specific locations. This poses a challenge as "the differential climate change impacts faced by the tourism sector at the regional and destination country scale remains uncertain" (Scott Hall et al. 2019 p. 50). Scaling down these large-scale indicators of vulnerability to destination level is a persisting challenge (e.g. Nurse et al. 2014; Rhiney 2015). This is especially true in the case of coastal destinations in the Caribbean; climate change vulnerability is recognised, but adaptation strategies are limited (e.g. Kuruppu & Willie 2015; Nurse et al. 2014; UNWTO-UNEP-WMO 2008).

One of the challenges of scaling down to the destination level, is how to integrate the stakeholders with ongoing environmental change issues; most research on climate change is not integrative (Hall 2018). Scott, Hall, and Gössling (2016 p. 8) suggest that "major regional knowledge gaps persist. A lack of understanding of the integrated impacts of climate change and the effectiveness of adaptation strategies potentially hinder the development of resilient tourism operations and destinations". Tourism affects climate change through carbon emissions, resource use, and environmental degradation (Gössling & Hall 2006; Gössling & Peeters 2015) and climate change affects tourism by limiting and altering the possible tourism activities (e.g. Hopkins 2015; Santos-Lacueva et al. 2019). At the same time tourism is noted as a means to achieve the Sustainable Development Goals (UNDP-UNWTO 2017). However, climate change is expected to change tourism demand (Moore 2010), but it is uncertain how (Gössling et al. 2012). Scott, Hall, and Gössling (2016 p. 8) argue that "[u]ncertainties regarding tourist response to climate change impacts and mitigation policy impede predictions of tourism demand". Valls and Sardá (2009) claim that tourism destinations will have to manage constant and increasing uncertainty. Uncertainty about the ability to provide tourism activities and the responses of tourists to changing environmental conditions are challenges for tourism destinations.

Although climate change is largely recognised by academics as an issue for tourism (Gössling & Peeters 2015; Hall et al. 2014; Scott 2011; UNWTO-UNEP-WMO 2008), there is surprisingly little action by the affected population, especially the destination stakeholders who provide tourism services. Whether we start mitigating or experience more extreme scenarios of climate change, Scott et al. (2016) argue that the tourism sector does not understand nor is prepared for the changes already set in motion. Vulnerability approaches need to consider the social perception of contextual vulnerability (e.g. Hopkins 2015). This barrier to action is critical to understanding emerging vulnerabilities and potential actions and responses to mediate, deter, or adjust to these vulnerabilities.

1.2. Coastal tourism as a critical area for climate change research

Understanding emerging vulnerabilities is relevant across all tourism contexts. However, there are two contexts where climate change is most obvious: alpine tourism where less and uncertain snow coverage threatens viability of snow-related tourism; and coastal tourism, where activities occur at sites exposed to sea-level rise and constant ecological change (e.g. Hall 2018; Scott, Hall et al. 2012). Both require more research, but more studies of the former have been completed covering traditional ski and alpine destinations in North America and Europe as well as destinations such as New Zealand and China (Balbi et al. 2013; Beaudin & Huang 2014; Dawson et al. 2009; Fang et al. 2019; Hewer & Gough 2018; Hopkins 2014; Pons et al. 2012; Pons et al. 2014; Rutty et al. 2015, 2017; Scott, Steiger et al. 2019; Soboll & Dingeldey 2012; Steiger & Abegg 2016; Steiger & Scott 2020; Steiger et al. 2019), while research on the latter form of tourism is lacking (e.g. Becken 2013a). Snow-related tourism occurs mostly in developed nations that can fund climate change research. In addition, the challenges of timing and amount of snow coverage are relatively straightforward climate-related challenges compared to the multitude of challenges affecting coastal destinations discussed below. To help address this critical geographical knowledge gap, this research contributes to coastal tourism in the context of environmental change.

Coastal areas are identified as some of the more vulnerable regions to climate change (e.g. Moreno & Becken 2009; Perch-Nielsen 2010; Santos-Lacueva et al. 2017; Scott, Hall et al. 2019). In the context of this research, coastal tourism is defined as the tourism activities and infrastructure focused on the combination of sun, sand, and sea. Specifically, coastal tourism refers to the beach activities and infrastructure directly on or near to the beach area, the nearshore water activities, and the coral reef focused activities (e.g. diving, snorkelling and day excursion boats). As such, this research does not include deep sea fishing, inland nature-based activities or museum visits. In coastal destinations, two main stakeholder groups are those who supply tourism services and activitieies—tourism operators such as hoteliers and dive operators—and those who demand coastal tourism services, tourists. This research focuses on the tourism operators as they have lower coping abilities than tourists, have less alternatives, and are more physically dependent on the coastal tourism destination (Kaján & Saarinen 2013; Moreno & Becken 2009; UNWTO-UNEP-WMO 2008). As tourists are not the focus, this study does not differentiate between the types of tourists, i.e. air-based and cruise ship tourists. As such, the influence of cruise shipping is indirectly considered in terms of how cruise tourists affect the coastal area.

A criterion for selecting a region was the potential value that the insights of this research could offer. As such, the goal was to select an area where there was less research but a high need for it. Caribbean tourism has received relatively little scientific attention related to climate research (Becken 2013a; Filimonau & De Coteau 2019). Drought is a growing issue in the Caribbean (Cumberbatch et al. 2018). Increased water stress is expected in the Caribbean by mid-century (Scott et al. 2016). Scientific evidence indicates that the Caribbean is already affected by environmental change (Nurse et al. 2014; Rhiney 2015). This general information and reality that the Caribbean and tourism operators are vulnerable has unfortunately not provided enough information to limit their vulnerability. Thus, we require more specific information on this geographical coastal tourism context. As such, this research focuses on destinations in the Caribbean.

Generally, coastal tourism is resource dependent (e.g. beaches and coral reefs) and sensitive to several climate-related changes. Storm events, hurricanes, sea-level rise (SLR), drought, flooding, increased sea temperature, ocean acidification, erosion, and coral bleaching are the main identified biophysical threats (Hall 2018; Scott, Simpson, et al. 2012; Shakeela & Becken 2014). Storm surge is responsible for beach loss and infrastructure damage (Cumberbatch et al. 2018). Coral reefs, major attractors for coastal tourism (Biggs et al. 2015; Uyarra et al. 2005), are of critical ecological importance and are threatened (de Bakker et al. 2016; Leggat et al. 2019). In 2003, Gardner et al. (2003) found that over three decades coral cover in the Caribbean had decreased from an average of 50% to an average of 10%. This trend of coral decline was further corroborated by Jackson et al. (2014) who found the average coral cover in 88 observed locations in the Caribbean declined from approximately 35% to 19% over the period 1970-2011. De Bakker et al. (2016) also found a general decrease of coverage and abundance of most coral species over the period of 40 years on Bonaire and Curaçao, two islands reported to have healthier reefs by Jackson et al. (2014). Reefs in the Caribbean region seem particularly vulnerable to anthropogenic impacts including: tourism, increasing environmental pressure due to more people, overfishing, coastal pollution, and climate change (de Bakker et al. 2016; Jackson et al. 2014). Moreover, de Bakker et al. (2016) and Jackson et al. (2014) found that local actions are important for the health of coral reefs. Moore et al.'s (2017 p. 723) economic forecast models on storms and hurricanes in the Caribbean "suggest that [economic, social, and environmental] output losses due to hurricanes are likely to increase exponentially over the next century" but these findings are difficult to communicate to stakeholders due to the long time scale (Moore et al. 2017 p. 723). A prevailing paradox is that coastal tourism depends on environmental resources, but also harms those same resources (e.g. Gössling & Hall 2006; Santos-Lacueva et al. 2017). In Porter's review (2019 p. 195) of one of the more recent scientific books on climate change and coastal tourism *Global climate change and coastal tourism: recognizing problems, managing solutions and future expectations,* he notes "[t]he juxtaposition between climate change and tourism is neither new nor novel. Yet, for a tourism industry dependent on sun, sand and sea, the effects of climate change are now rapidly outpacing the responses".

Challenges related to climate change are further complicated on small island developing states (SIDs) and many Caribbean coastal destinations are SIDs. Small islands are identified to have the following major tourism-related climate challenges: limited land, environmental, financial, and technological resources; limited human resource capacity; GDP reliance on few income streams; exposure to climatic extremes such as storms; susceptibility to external economic shocks, unique ecosystems and biodiversity; SLR; drought and limited water resources; and limited accessibility (Nurse et al. 2014; Scobie 2018; Scott et al. 2016). Although SIDs have similar features, they experience unique manifestations of these stresses (Nurse et al. 2014; Rhiney 2015). This research responds to the urgent need to look at the local scale, acknowledge heterogeneities and complexity, take uncertainties into account, and to look at "a range of climate change-related projections beyond temperature and sea-level" by investigating the emergence of socio-ecological vulnerabilities on two SIDs in the Caribbean (e.g. Nurse et al. 2014 pp. 1643–1644; Rhiney 2015; Scott et al. 2019).

1.3. Addressing vulnerability in coastal tourism

The emergence of climate change on SIDs is of particular importance for climate change-related research. The IPCC AR5 report indicates high confidence, robust evidence, and high agreement that the "inherent physical characteristics of small islands" lead to "high level of vulnerability of small islands to multiple stressors" (Nurse et al. 2014 p. 1616). At the same time there is high confidence that small islands are not uniform in vulnerability: "their high diversity in both physical and human attributes and their response to climate-related drivers means that climate change impacts, vulnerability, and adaptation will be variable from one island region to another and between countries in the same region" (Nurse et al. 2014 p. 1616). In addition, climate scientists are starting to recognise the importance of tourism's role in climate change. IPCC working group II offered insights of the most important tourism sector related challenges: the need for integrated analysis at the destination level, climate change threatens sustainable development, assessments that "incorporate transboundary impacts, and the barriers to and limitations of adaptation (Nurse et al. 2014; Scott et al. 2016 p. 18). Although the most recent IPCC report includes more information on climate change in relation to tourism, more regional or destination information is required (Scott et al. 2016).

Addressing the knowledge gap of emerging vulnerabilities of climate change and tourism is not just in the interest of science, but is of critical importance to society internationally. Tourism is a substantial and growing contributor to GDP. The WTTC's (World Travel & Tourism Council) (2019b, foreward) report shows that "the sector accounted for 10.4% of global GDP and 319 million jobs, or 10% of total employment in 2018" and that 1 in 5 jobs created in 2018 were in the context of tourism. However, in the Caribbean, tourism is especially important. While the Caribbean ranks 12th (out of 13 regions) for GDP contribution in absolute terms, the Caribbean region ranks number one for travel and tourisms' total contribution to GDP to tourism (15.2%), employment (13.8%), investment (12.9%), and visitor exports (19.8%) relative to size (WTTC (World Travel & Tourism Council) 2018). Cleary, the Caribbean is dependent on coastal tourism.

Tourism is also seen, and sometime advertised, as a potential source of revenue for developing countries. Tourism is projected to grow in these areas and as such can contribute to Sustainable Development Goals (SDGs) (e.g. Scott Hall et al. 2019; UNDP-UNWTO 2017). According to the UNDP-UNWTO (2017 p. 49), "[t]ourism industries play a vital role in all 17 SDGs". For coastal tourism in SIDs, some of the most relevant SDGs include: no poverty (1), clean water and sanitation (6), building resilient infrastructure (9), reduced inequalities (10), climate action (13), life below water (14), life on land (15), improvement of justice and strong institutions (peace, justice and strong institutions) (16), and creating inclusive partnerships for achieving the goals (17) (UN 2015). Thus, understanding emerging socio-ecological vulnerabilities is not just relevant to the tourism sector, it has a wider relevance for the SDGs. However, some research scrutinises the claim that tourism contributes to achieving the SDGs. For example, Oviedo-García, González-Rodríguez and Vega-Vázquez (2019) findings suggest that the sun-sand-and-sea tourism in the Dominican Republic fails to contribute to poverty alleviation or equity. Tourism's contribution to development is further complicated by climate change (Scott et al. 2016 p. 18). The most environmentally vulnerable regions, including SIDs, are developing economies where tourism is expected to grow (Scott Hall et al. 2019).

On the one hand, tourism is as a tool for development. On the other hand, tourism development on SIDs increases dependence on foreign exchange to finance further economic development. At the same time, tourism development increases pressure on environmental resources, such as land, water, and marine life (Nurse et al. 2014). Tourism may kill or at least maim the golden goose through unintended effects on the environment. We need to recognise the negative effects of climate change and high investment costs to enable withstanding the effects (Cumberbatch et al. 2018; Hall 2018). Thus, environmental challenges related to coastal tourism are not just interesting for science, but are also critical for global and local economics, internationally recognised environmental vulnerabilities, and claimed opportunities for sustainable development.

1.4. Dynamic vulnerability

We want simple problems, tidy solutions. But that simply is not the reality for dealing with emerging vulnerability caused or derived from climate change, especially when we consider tourism, a sector which is complex, as it: operates at different scales, has varying and competing interests, depends on the natural resources that it tends to exploit, and is characterised by feedbacks and uncertainty (Baggio 2008; Farrell & Twining-Ward 2004; Hopkins 2015; Nicholls et al. 2017; Santos-Lacueva et al. 2019).

The definition of the term vulnerability in itself could be the subject of unending doctoral research. There is no singular accepted definition of vulnerability (Füssel 2007; Gallopín 2006; Hopkins 2015; IPCC Working Groups I & II 2012; Scott Hall et al. 2019). Many researchers have reviewed the diverging definitions of the term vulnerability (Adger 2006; Eakin & Luers 2006; Gallopín 2006; Hopkins 2015; IPCC Working Groups I & II 2012; Schröter et al. 2005; Smit & Wandel 2006). Despite the ongoing academic debate, a number of tourism studies use the IPCC 2007 definition as a starting point (Scott, Hall et al. 2019). The IPCC (2007 p. 21) states "[v]ulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity".

This research takes the IPCC definition as its starting point for the state of vulnerability. However, the definition is insufficient in helping conceptualise emerging vulnerabilities because it is unclear how exposure, sensitivity, and adaptive capacity interact. A further limitation of the IPCC's definition of vulnerability is that adaptation is part of the definition of vulnerability; it is ambiguous how adaptation interacts with vulnerability and what the boundaries (Gallopín 2006). This is further complicated by another vulnerability-related term, resilience. A limitation of many definitions is that how vulnerability, resilience, and adaptation interact is unclear (Eakin & Luers 2006; Gallopín 2006). Resilience is sometimes defined as the opposite of vulnerability, the ability to absorb shocks and reorganise under ongoing change (e.g. Gallopín 2006); but at the same time in the paradigm of ecological resilience, "vulnerability is seen as a dynamic property of a system in which humans are constantly interacting with the biophysical environment" (Eakin & Luers 2006). Folke et al. (2016 p. 42) define social-ecological resilience as "the capacity to adapt or transform in the face of change in social-ecological systems". However, in socio-ecological systems Gallopín (2006 p. 301) concludes that "resilience is an internal property of the system, not including exposure to perturbations. Resilience would appear to be more obviously related to one of the components of vulnerability, the same that is variously called adaptive capacity, coping capacity, coping, or capacity of response. But again[,] it is unclear whether resilience includes capacity of response, or is an element of the latter." Moreover, adaptation is ongoing: "[t]he degree to which a future climate change risk is dangerous depends greatly on the likelihood and effectiveness of adaptations in that system" (Smit & Pilifosova 2001 p. 885). As a result, it is very difficult to pull these three terms apart as one term tends to be included in the definition of the latter two.

In sum, the vulnerability of a socio-ecological system to climate change is defined in this thesis as its susceptibility to, and lack of ability to cope with adverse effects of climate change. Although the debate of what defines vulnerability is not over, the important aspects of vulnerability to note are the overwhelming consensus that it is dynamic and relates to human-environment interactions (e.g. Adger & Kelly 1999; Duvat et al. 2017; Eakin & Luers 2006; Füssel 2007; IPCC Working Groups I & II 2012; Smit & Wandel 2006). Vulnerability is a state (Adger 2006) as well as a process (Rhiney 2015). At any given moment, a (sub)population or environmental feature may be vulnerable to climate change, but this changes over time depending on further exposure to climate change, recovery time, and actions taken (Smit & Pilifosova 2001). Buzinde et al. (2010) notes that destination officials have to deal with the changing nature of the environment to devise long-term adaptation strategies.

1.4.1. Vulnerability-related terms in context of coastal toursim research

As per the IPCC (2007) definition, vulnerability in this research refers to the inability to cope with the adverse effects of environmental change in the coastal destination. Interactions over space and time are considered in this research. As such, vulnerability as a state (moment in time) and a process (ongoing trends) is analysed. In the context of this research, resilience refers to the ability for the tourism operators, sector, and/or environment to absorb and rebound from change. For adaptation, the focus in this research is on actions or strategies, whether or not deliberate, in response, prevention, and/or anticipation of environmental change. Capacities refer to possessing means and or ability to act on or respond to change. Resilience and adaptation strategies interact with vulnerability, and as such, also change over time. This research focuses on both human and environmental vulnerability in the coastal tourism destination to locally and globally induced environmental change. Locally-induced environmental change refers to local actions that harm or degrade the environment and globally induced refers to climate change.

Human vulnerability refers to their lack of capacity to respond to change. For this research in particular, the vulnerabilities of tourism operators, and by proxy the island destination, are researched. This is because of tourism operators' relatively high vulnerability to climate change as compared to tourists, and coastal destination island's economic dependence on tourism (section 1.3). As tourism operators are dependent on tourism for economic well-being, their inability to sustain their business is the main researched component of human-related vulnerability. The research does not limit the perception of what is vulnerable to a research perspective, but also includes coastal tourism stakeholders' perceptives to identify who is vulnerable to what and to what extent.

Environmental vulnerability refers to undesirable environmental conditions, specifically the loss of degradation of environmental resources, biodiversity loss, and increase in pollution. In Chapters 5 and 6, environmental vulnerability is measured as a decrease in environmental attractiveness. In Chapter 5, environmental attractiveness is visualised by loss of the environmental resources (coral reefs, sea turtles, fish), pollution, erosion, and environmental degradation. In Chapter 6, environmental attractiveness is increased by biodiversity and the geospatial type and decreased by pollution and environmental degradation.

As previously noted in section 1.2, climate change comes in many forms and island destinations are exposed to multiple types of events. Climate change is heterogenous in terms of timing, timescale (e.g. gradual or sudden), interval, severity, spatial setting, as well as who and what other parts of the coastal system it affects. Moreover. As described in section 1.2, two prevailing forms of expected climate change in the literature are sea-level rise (SLR) and increase intensity of storms for SIDs. Many Caribbean SIDs are already considered exposed to drought and there are general concerns about the health of coral reef. In many cases, specific data and links to tourism are currently unable. In lieu of specific data, identified environmental trends are used. These are general climate change-related concerns for coastal tourism destinations. This research is not limited to these forms of environmental change. The goal is to identify how these and other forms of climate change (identified by local stakeholders) interact with the tourism sector in the coastal destination. In other words, if we were to incorporate interactions between humans and the environment spatial and temporal dynamics in our understanding of vulnerabilities, what would this mean for our vulnerability assessments? How do we include a multitude of potential events when it is uncertain which events will occur, in what order, to what extremes and how individuals' capacities to respond and adapt?

1.5. Why do we need a dynamic approach?

We see that vulnerabilities are dynamic. The question remains: why should researchers take a dynamic approach? Intuitively, it makes sense to match our scientific conceptual lens and process to the problem, i.e. dynamic vulnerability. But the main reason why we need a dynamic approach is that how we frame vulnerabilities shapes the types of solutions or adaptation strategies we identify. A static vulnerability assessment assumes that if we identify the problems and the solutions, then we will solve our vulnerability issues by implementing the identified recommendations. However, vulnerabilities emerge as a result of human-environment interactions (e.g. Eakin & Luers 2006; Füssel 2007).

Moreover, the technical solutions that we identify through static approaches may not fit the local context (e.g. Solinska-Nowak et al. 2018). Multiple researchers have noted the limitations of top-down approaches to disaster risk management as they are too rigid and potentially counterproductive to address vulnerabilities and develop appropriate adaptation strategies (e.g. Pelling & Uitto 2001; Rhiney 2015; Solinska-Nowak et al. 2018). Solutions focused on infrastructure may give the false sense of control. However, solutions to one problem can aggravate other issues. In a coastal destination, for example, the building of a sea wall may help deter sea-erosion and mitigate sea-level rise; but, it also changes wave flow, sand redistribution along the coast, and can damage coral reef and other marine life. As such, it may limit or change different tourism activities such as surfing because sea walls change wave conditions as well as diving due the damage or limited access to reefs. We need to understand in what ways the coastal system and people interact, are vulnerable, what prevents people from acting, and how these vulnerabilities interact with people.

Another challenge identified of static vulnerability assessments is that the vulnerability information relating to timing and interactions remains too general (e.g. Hall 2018; Nurse et al. 2014; Rhiney 2015; Scott et al. 2016). Change occurs over different spatial and temporal scales. The aforementioned researchers cite the need to move beyond generic information on vulnerability. Valls and Sardá (2009) suggest more integrated management of coastal tourism, but this requires a more integrated understanding of interlinked problems. In spite of these critiques of vulnerability assessments, how to approach this gap between science and the practical needs of people is less evident. Nurse et al. (2014 p. 1640) question whether downscaled global climate analyses are appropriate as they do not "provide a complete or necessarily accurate picture of climate vulnerabilities on islands". Clearly, more needs to be done to better understand and limit where possible the emerging vulnerabilities that the islands are facing; we still have a big knowledge gap between practical needs of people and research (Santos-Lacueva et al. 2019; Scott & Becken 2010). Despite the clear risks to coastal tourism, little systematic effort has been taken to limit vulnerabilities to climate change and assist stakeholders in adapting to change.

As we see vulnerability as both a state and a process, we need more focus on the processes. Research on interactions, necessarily require future-looking dynamic approaches, so that long-term adaptation strategies for the future can be combined with actions in the present day. However, as previously noted, any future-looking study of a complex system is characterised by uncertainty. Nonetheless, the need to include humans in our understanding of vulnerabilities and adaptation strategies is highlighted by the IPCC's and the SDGs' recognition of people's well-being (e.g. Nurse et al. 2014; UNDP-UNWTO 2017). Buzinde et al. (2010) conclude that we require more information about human-environmental interactions in the context of tourism and climate change. Interactions suggests that we require more information regarding context. We need practical insights of who and what is vulnerable to what types of changes, in what ways people are influencing and influenced by the changing coastal setting, and what the implications can be for other stakeholders and natural resources. To this end, researchers advocate stakeholder involvement to improve understanding of vulnerabilities and adaptation strategies (Filimonau & De Coteau 2019; Santos-Lacueva et al. 2019). This research investigates how we approach dynamic vulnerabilities so that we can offer more practical insights for adaptation strategies.

1.6. Research aim and questions

Considering the importance of understanding emerging vulnerabilities to climate change affecting coastal tourism, this research endeavours to fill this persisting knowledge gap of how to approach the challenge of dynamic vulnerabilities.

As such, the overarching question of this research is:

How can dynamic vulnerability be operationalised to inform adaptation strategies for coastal tourism?

This question can be broken down into three parts:

- Research Question 1: How can we can conceptualise dynamic vulnerabilities in a coastal tourism context?
- Research Question 2: How can we operationalise dynamic vulnerability?
- Research Question 3: What are the implications of this approach on vulnerability assessments and adaptation strategies?

1.7. A dynamic vulnerability approach for dynamic vulnerabilities

1.7.1. New conceptual lens

We have established why we should take a dynamic approach, but how do we conceptualise dynamic vulnerability assessments? Vulnerability assessments aim to identify, quantify, and prioritise the vulnerabilities in a system, in this case a coastal tourism destination. We prioritise vulnerabilities so that we can focus on effective adaptive responses. However, our lens for vulnerability assessments is static; two examples of previous vulnerability assessments are Moreno and Becken (2009) and Perch-Neilsen (2010). A static understanding of vulnerability focuses on one moment in time and thus, a particular state of vulnerability. However, as vulnerability is also a process, we need to understand what processes lead to socio-ecological vulnerabilities.

Disaster risk management, which largely focuses on sudden shocks, is traditionally dominated by top-down approaches. However, Solinska-Nowak et al. (2018) argue that although this may work for simple or highly technical problems, it can be counterproductive when considering the consequences of how the solutions affect other aspects of the system. While sudden shocks are important, the interaction with slowly emerging events should not be underestimated. As previously indicated, coastal island destinations face a range of threats, which emerge on different time scales, spatial areas within a coastal system, and severity. Heterogeneity among and within islands has been identified by many researchers (Nurse et al. 2014; Rhiney 2015). Thus, our research lens needs to focus and should consider bottom-up approaches to better understand how vulnerabilities emerges at a destination or regional level.

Nurse et al.'s (2014 p. 1640) report states that although climate change is widely known to be "critical on small islands, few initiatives pay little more than perfunctory attention to the importance of awareness, knowledge, and understanding in climate change adaptation planning". This report suggests that vulnerability understanding among researchers alone is insufficient to improve adaptation and that we need to include stakeholders. As the problems affect people and we lack understanding of their perspectives and role in the challenges they face with dynamic vulnerability, we need a transdisciplinary approach to engage with them.

1.7.2. Methodological tools

We need methodological tools to help us involve stakeholders and capture the dynamic interactions that influence emerging socio-ecological vulnerabilities. Some existing tools, such as literature analysis and interviews, are useful for scoping and identifying the main stakeholders and environmental features in the coastal system (please see Annex 1 for an overview of the interviews). The interviews are part of the dynamic vulnerability process, were applied for scoping, are used as part of the illustration in Chapter 4. A description of the semi-structured interview questions following the ARDI (actors, resources, dynamics, and interactions) structure is provided in Chapter 4 section 4.5 and Table 4.2 as part of the process of a dynamic vulnerability approach (Étienne et al. 2011). The questions help identify the main actors, the main environmental resources they use, what different states actors and resources can experience (e.g. changes in resource abundance, changes in health, changes in location, changes in income), and how the different actors and environmental resources interact. By asking multiple stakeholders, an initial picture of the coastal system was sketched. Moreover, the individual concepts were brought together during two focus group sessions with post-its framed using ARDI. This led to the main tourism operator categories, their relative capacities (resources required to sustain their business as well as earnings from it), which were tested and modified during simulation guided interviews.

1.7.3. New methodological tools

For integrating the system and experimenting with future emerging vulnerabilities, we require additional tools for our approach. Two promising tools are simulation sessions and computational modelling. The results from simulation sessions are described in Chapter 5 and the results from computational modelling are described in Chapter 6.

The former, simulation sessions, fosters interactions with stakeholders. Simulations, also known as serious games or role-playing games, are "the imitation of the key characteristics, behaviours and functions of the selected physical or abstract system or process" (Solinska-Nowak et al. 2018 p. 1014). Instead of relying on desktop assumption, simulation sessions are a way forward to understanding how local stakeholders are affecting and affected by vulnerability in coastal tourism destinations. Serious gaming recently gained recognition as a new type of approach for dealing with research challenges in the tourism domain (Lalicic & Weber-Sabil 2019). Filimonau and De Coteau's (2019) findings indicate the value of including stakeholders in understanding vulnerability at (coastal) tourism destinations. During simulations, stakeholders can exhibit a wide range of actions within the game's context and experiencing. Companion modelling, also known as ComMod, is a process of engaging stakeholders in problem identification, development, and experiencing often using games as one of its transdisciplinary tools (Étienne 2014). Developing a serious game with the aid of companion modelling tools is a promising means of engaging stakeholders with a dynamic representation of their coastal system.

For the latter, agent-based modelling (ABM) is a potential form of computational modelling to simulate the complex human-environment interactions in the coastal tourism destination (Macal 2016; Macal & North 2010). One of the main benefits of ABM is it is "structurally an integrative modelling approach" (Le Page et al. 2017 p. 526). As such, ABM can help us explore system complexity (Boavida-Portugal et al. 2017). With ABM, we can expose a set of human and environmental parameters to multiple scenarios, many more times and more nuanced than is possible during a simulation session with people. One of the drawbacks of ABM, is although randomness and probability can be incorporated, the range of human behaviours and environmental processes must be simplified. However, in combination with methodological tools that include stakeholder participation, this tool shows promise for tourism vulnerability studies. Nicholls et al. (2017) illustrate the potential of ABM as a computational tool for tourism, which has been long used for complex ecological problems. Johnson and Sieber's (2011a p. 502) study finds that in comparison with other forms of modelling, agent-based modelling "can show the individual-based processes as they change over time and through space". In Student et al. (2016), the authors demonstrate how the future of tourism self-regulation can be explored in the Antarctic, without potential disasters having to occur first. Some of other early tourism examples explore how changing climates affects alpine tourism (Balbi et al. 2013; Pons et al. 2014; Soboll & Dingeldey 2012), water consumption and climate change (Soboll & Schmude 2011), changes to visitation numbers in Nova Scotia (Johnson & Sieber 2011a), and changes in tourism demand (Boavida-Portugal et al. 2017; Reintinger et al. 2016).

ABM is appealing as it caters to bottom-up studies, accounts for heterogeneities, includes interactions, and couples humans with their surrounding environment (Macal & North 2010). This provides the opportunity to include local stakeholders' behaviours and (perceived) capacities in responding to environmental change. Moreover, ABM is useful to apply potential future scenarios to parameters that have been identified has risks for coastal areas (e.g. sea-level rise, increased frequency and/or strength of storms).

While the first tool of companion modelling provides an opportunity for dynamic transdisciplinary engagement, the computational modelling enables experiments with similar settings to have a better idea of how certain vulnerabilities emerge from particular settings. Together, these tools have the potential to integrate individuals with their coastal environment and better capture the heterogeneous spatial and temporal changes offering a new lens for vulnerability research.

1.8. Case studies

To answer these research questions, research was conducted in two case study areas. Two main criteria informed case study selection: identified regional environmental vulnerability and dependence on tourism. SIDs are generally considered to be vulnerable to climate change (Nurse et al. 2014). As indicated in section 1.2, the Caribbean, in particular, is a region considered a vulnerability hotspot and is highly dependent on tourism for economic support (UNWTO-UNEP-WMO 2008) and most of the coastal destinations in the Caribbean are SIDs. Moreover, there is limited existing research on coastal tourism and climate change in general (Becken 2013a). This research attempts to address some of the missing data gap. As a result, both case studies are Caribbean SIDs: Barbados and Curaçao (please see Figure 1.1).

In recognition of the heterogeneities among islands (Rhiney 2015) two Caribbean coastal destination case studies were necessary. Moreover, two case studies help to demonstrate the flexibility of the approach to a range of coastal destinations. As the goal of this research was to develop a new approach to analysing emerging vulnerabilities, areas with access to stakeholders and research were considered. Barbados, with its long history of coastal tourism, and research on climate adaptation was a suitable destination to develop the first parts of the dynamic vulnerability approach. Curaçao was selected as the second case study. It is similar in terms of size and offers similar sun, sand, and sea attractions, but differs in distribution and proportions of tourism activities and environmental features. For example, many catamarans operate in Barbados while in Curaçao has a larger dive industry and few catamaran operators. In both locations, coastal tourism plays an important role in the economy: tourist receipts as percentage of exports is calculated to be 53.5% in Barbados and 25.5% in Curaçao (Hall 2018). Both islands have had relatively low exposure to hurricanes in the Caribbean.

The case study research took place in two phases per island. Two visits were planned on Barbados, one in 2015 and the following in 2016. Thereafter, Curaçao was visited in 2016 and 2017. A short description is provided in the following sections. More details on these islands will be provided the following chapters. Chapters 4, 5, and 6 expand on the methodology used and how data was collected.

Figure 1.1. Map of the Caribbean and two case study areas: Barbados and Curaçao (QGis- Natural earth pkg.)

1.8.1. Barbados

Barbados is an independent Caribbean nation since 1966 and a former British colony. Coastal tourism plays an important role in Barbados's economy; the tourism sectors contributes to almost 46% of jobs (WTTC (World Travel & Tourism Council) 2019a). Barbados offers a diversity of coastal tourism activities: catamaran trips, beach visits, surfing, diving, jetskiing. The white sandy beaches are an important attraction. Along with being dependent on coastal tourism, Barbados is exposed to many climate change-related challenges. Barbados's beaches are important for attracting tourists, but the island is vulnerable to losing beach areas and infrastructure to SLR (e.g. Fish et al. 2008; Scott, Simpson et al. 2012). Barbados is considered the 15th most water scarce country in the world (Ministry of Tourism and International Transport 2014). SLR, more frequent and longer periods of coral bleaching, drought, salt intrusion, and beach and infrastructure loss are future concerns for Barbados (e.g. Cumberbatch et al. 2018). Rhiney (2015 p. 108) notes that Barbados is "already seeing signs of saltwater intrusion into its coastal aquifers, which will seriously compromise its food and water security". Moreover, bleaching and ocean acidification "combined with other anthropogenic stressors would place Barbados' coral reefs at considerably great risk with consequential negative impacts on the quality and sustainability of the tourism product" (Cumberbatch et al. 2018 p. 163).

Although comparatively more data and research are available for Barbados than other Caribbean islands on climate change and tourism, "more public awareness and education [is] required about the potential threats of climate change to the industry, the island and the region" (Cumberbatch et al. 2018 p. 165). The tourism sector is not prepared to deal with climate change and awareness is low (Ministry of Tourism and International Transport 2014). A 2012 survey study of Barbadian tourism operators' awareness of and preparedness for climate change indicated that while 78% of respondents were able to "provide an acceptable definition or explanation of what global climate change is about", almost as many participants (76%) "stated that the industry was not prepared to handle any extreme climate event and a further 1% were uncertain" (Cumberbatch et al. 2018 pp. 164–165). The willingness to build a large hotel in a UNESCO world heritage site on the coastline without an Environmental Impact Assessment (Joseph 2018, 2019), indicates that many of the environmental implications of coastal development and climate change are being overlooked. Moreover, in the Barbados tourism master plan, the government (2014 p. 14) recognises that "[a] lthough protection of the island's primary coastal resources is a high priority, drainage outfalls still pollute prime beaches such as Carlisle Bay, discharging litter and runoff along the shoreline, and highlighting a need for improved environmental standards".

1.8.2. Curaçao

Curaçao is an independent nation within the Kingdom of the Netherlands since 2010. Coastal tourism is an important contributor to Curaçao's economy (e.g. CTB (Curaçao Tourist Board) 2015; Hall 2018). Curaçao is a popular dive destination and offers many opportunities for shore diving. It also offers other coastal tourism activities: beach activities, jetski rentals, stand up paddling, boat day trips, and some surfing. However, in spite of tourism's importance, there is little research linking tourism to the environment. One of the few examples of research in Curaçao that connects tourism to the environment is by de Groot and Bush (2010) on dive tourism and marine protected areas. For the environment, the Blue Halo project, a research collaboration between the Waitt Institute and the government, has identified five main threats for the coastal zone surrounding Curaçao: overfishing, mangrove deforestation, coastal development, water pollution, and coral bleaching (Waitt Institute 2019). Most of the climate change-related research focuses on the coral reefs (e.g. Bak et al. 2005; de Bakker et al. 2016, 2017) and notes a general decline in reef cover. Although anthropogenic stresses are recognised the research on more specific interaction between tourism and the coastal zone are missing. Moreover, the environment is not officially on the agenda for tourism in Curaçao; the Curaçao Tourism Board (2015) does not explicitly mention the terms *climate change* and *environment* (in context of the physical environment) in their 2015-2020 masterplan. As such, this research can contribute to this regional knowledge gap on climate change and tourism.

1.8.3. Stakeholder selection

This section uses Reed et al.'s (2009) stakeholder analysis method to describe who was included in this research and how they were approached. This method includes: identifying stakeholders, differentiating between and categorising stakeholders, and investigating relationships between stakeholders. As the methods applied in this research were new to the stakeholders, contact on multiple occasions occurred with some stakeholders.

Identifying stakeholders

The process of stakeholder identification in this research was iterative, but started as a top-down approach informed by scientific literature. Freeman (1984) describes a core group of stakeholders as those who are affected and affected by the problem. This research focuses on the supply side and specifically the tourism operators who provide coastal tourism-related services. These operators are identified in scientific literature as the most directly affected, but also underresearched destination stakeholders as noted in section 1.2. Tourism operators constitute the core group of stakeholders. A secondary group of stakeholders encompasses local (research) experts, government officials, NGO representatives, and tourism-related parties. This secondary group provided further information on tourism operators and the local coastal environment and helped verify, clarify and/or contextualise claims made by tourism operators. Tourists were not included in this research as participants although their influence on income and the local environment are incorporated. Moreover, involvement of the general public was not sought. Diverse means of stakeholder identification were used in the attempt to include multiple perspectives and reach as many core and secondary stakeholders interested in participating possible.

In the first phase of research in Barbados, tourism operators were approached as well as secondary stakeholders. A local expert group that at the time was working on climate change issues in the Caribbean, identified environmental issues related to coastal tourism and secondary stakeholders. Both the core stakeholder group and secondary stakeholder groups were interviewed. During the first visits to each of the islands, stakeholders were identified using semi-structured interviews and snowball sampling. At the end of every interview stakeholders were asked if there was anyone else they believed I should try to contact on the topics of climate change, the local environment, and coastal tourism. Further identification and access to stakeholders was gained through looking at business and government directories, participating in local events, reading local media, and walking and driving to coastal areas. Individuals who had participated in the interviews were invited to attend one of the two focus group sessions.

In the second phase in Barbados, the intention was to have simulation sessions with stakeholders. However, it proved difficult to bring stakeholders together. Instead, some stakeholders were revisited with a simulation-guided interview (described in section 4.5) to verify the four tourism operator categories made (please see the next subsection), the described capacities of each category, their relative capacities compared to other operator types, their location preference, the environmental resources used, responses to environmental events, the six external events (difficulty in gaining tourists, coral bleaching, drought, storms, erosion, and unknown events). Moreover, stakeholders who were not approached in the first phase also provided information on their roles in the context of the simulated coastal system. Two simulation sessions were completed in Barbados and used as a pilot and mutual learning experience for participants and the researcher, but were not included in the analysis.

For the first phase of Curaçao in 2016, the same types of stakeholders were identified. However, the prevalence of tourism operators and secondary stakeholders varied. Researchers familiar with Curaçao, provided information on potential core and secondary stakeholders. Along with the aforementioned modes of identification, semi-structured interviews, snowball sampling, directories, local media, visiting coastal areas, and participation in a local conference on waste were means to identify core and secondary stakeholders. The semi-structured interviews followed the format of simulation-guided interviews. This helped to identify key stakeholders and gauge the differences between the two islands: tourism operator community, spatial composition, and environmental resources. For example, there are more dive operators active in Curaçao than Barbados, but almost no catamarans in Curaçao. The deep-sea drop-off is closer to the shore in Curaçao than in Barbados, and there are areas along the coast with mangroves in Curaçao. One simulation session was completed as a pilot and mutual learning experience for participants and the researcher, but was not included in the analysis.

In the second phase of research in Curaçao, participation in simulation sessions was the focus. Along with verifying information and improving the simulation, simulation-guided interviews were used as a means to familiarise stakeholders with the concept of a game. Of the nine simulation sessions, in five cases one individual had participated in the simulation-guided interview, and in one case two individuals had participated in such an interview. Of the three remaining sessions, two were the result of someone recommending to a group of people that they should organise a moment to participate, and one session was as result of a short presentation of the research at a sustainability film viewing.

Differentiating and categorising stakeholders

Emerging vulnerabilities in tourism is a sensitive issue to destinations that are dependent on a positive image of their area to attract tourists. On SIDs, many stakeholders know or know of each other and organisation information makes it easy to identify individuals. Participatipation and expressed perspectives have potential ramifications for participants' work and livelihood. Stakeholders participation was under the condition of anonymity in order to facilitate involvement in this research and provide a safe space for stakeholders to share their perspective and participate. In lieu of specific organisation information for privacy reasons, tourism activities provided and areas of expertise are used to describe the involved stakeholders.

Coastal tourism operators had various backgrounds: hotels, beach cafes, beach bars, beach chair renters, beach restaurants, beach entertainment, beach activities and entertainment, dive operators, glass bottom boat operators, surf shops, kayaking, snorkelling, stand up paddling related activities, wind surfing, jet skis, banana boat operators, catamarans, day boat trips.

Researchers had expertise on marine biology including fisheries, coral reefs, marine policy and management, conservation, and tourism.

Governmental organisations held expertise on tourism, spatial and land-use planning, infrastructure, coastal planning, environmental protection, public health, fisheries, environmental clean-up, and environmental policy and law.

Non-governmental agencies and tourism related parties included: nature education, species conservation, clean-up, waste management, environment protection and conservation, insurance providers, financial services, and tourism operator interest groups.

Both core and secondary stakeholders participated in interviews, simulation development, and serious games sessions. Annex 1 describes the participants of the interviews. Chapter 4 provides a description of the participative research activities, and Table 5.2 provides details of the serious game participants. Only core stakeholders, tourism operators, are simulated in the serious game in Chapter 5 and computer model in Chapter 6. Tourism operators were lustered into four categories in the game (hoteliers, beach vendors, dive and boat operators, and nearshore operators) and five categories in the model (hoteliers, beach vendors, dive operators, boat operators, and nearshore operators).

Investigating relationships between stakeholders

Tourism operators of the same type compete for tourists and the revenues they provide, they also compete with operators for space and access to environmental resources. In some cases, tourism operators work together to offer complementary services. The semi-structured interviews provide further perceived examples of how stakeholders interact with each other and the environment. Secondary stakeholders describe their interactions with tourism operators and/or how tourism operators affect or are affected by the local environment. The focus group sessions provide an initial overview of by mapping the coastal system using the categories from ARDI (actors, resources, dynamic, and interactions). The serious game in Chapter 5 explores how stakeholders interact with each other and the environment in a dynamic coastal setting.

1.9. Outline of thesis

This thesis expands on the points of how we can conceptualise and operationalise vulnerability as a dynamic phenomenon, and consequently what this means for vulnerability understanding and adaptive measures (see Figure 1.2).

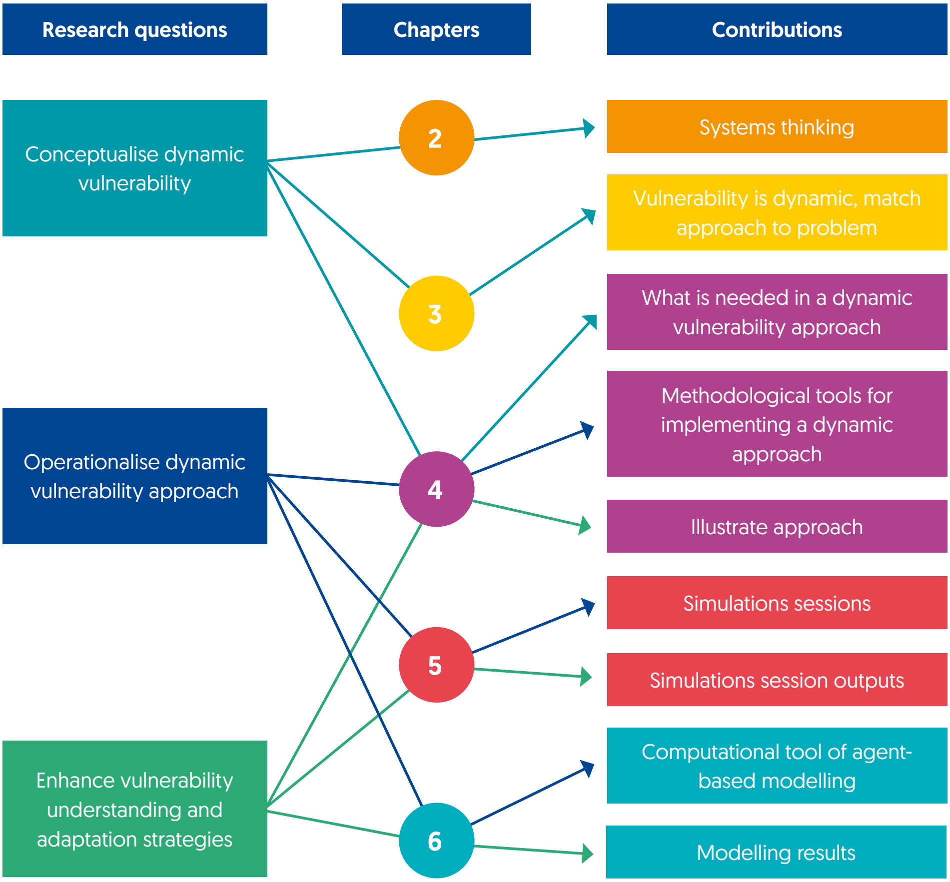


Figure 1.2. Schematic overview of the research presented in this thesis

This thesis is divided in the following chapters:

Chapter 2 discusses socio-ecological systems thinking for tourism and how that helps structure a dynamic understanding of the interactions in a system setting. It proposes two tools, agent-based modelling and role-playing games (simulation sessions) as means for combining the social system with the ecological system.

Chapter 3 argues that as vulnerabilities are dynamic, a dynamic approach to assessing vulnerabilities is necessary. The chapter reviews current tourism vulnerability assessments and discusses the limitations of a static conceptual lens. Finally, this chapter provides insights on what we need to consider when doing a dynamic vulnerability assessment instead of a static one.

In Chapter 4, we transition from the conceptual makings of a dynamic vulnerability approach to how such an approach can be implemented. Five principles of a dynamic system are identified that are necessary as part of a dynamic vulnerability assessment lens. The principles are complemented by five methodical tools, which help scope the dynamic interactions, bring the systems components together, and finally enable exploration and testing of the system in a dynamic and potentially interactive context. An illustration of the principles and the application of the tools is provided in the context of Barbados and Curaçao.

Chapter 5 offers the first empirical example of experiencing and experimenting as part of the dynamic vulnerability approach. The focus of this chapter is the methodological tool simulation sessions, which are assessed from sessions carried out in Curaçao. The simulation sessions involve stakeholders in a dynamic interactive setting. This chapter shows that what we can learn from stakeholders about how the cumulative effects of interactions, and how these interactions contribute to emerging socio-ecological vulnerabilities.

In Chapter 6, emerging vulnerabilities in the context of the coastal destination Curaçao are further explored using the computational simulation tool agent-based modelling (ABM). The heterogeneities of the modelled stakeholders (tourism operators), the coastal environment, and gradually emerging and fast onset climate stresses are examined. To consider deep uncertainties prevalent in complex systems, a wide range of human-related and environmental parameters are considered in its analysis of emerging socio-ecological vulnerabilities. This chapter reveals patterns of vulnerabilities for tourism operators and the local environment in the computer simulated dynamic system.

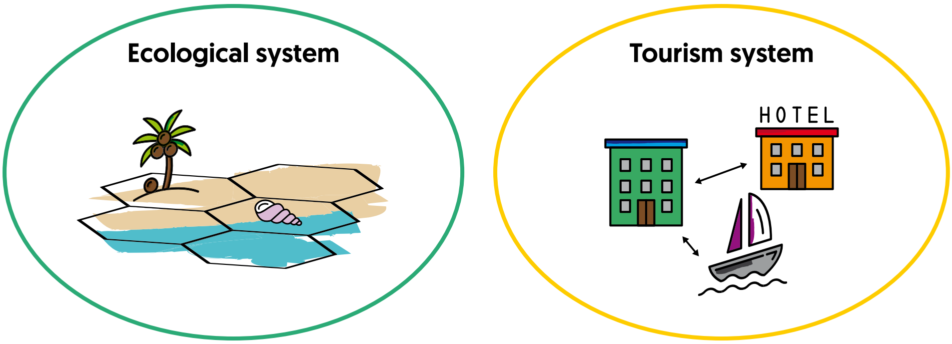
In Chapter 7, the findings of the previous chapters are discussed in light of their contributions to answering the research questions. The contributions and limitations of the methodological tools are dynamic approach are then reflected upon. Wider implications of this research are discussed in terms of vulnerability approaches, adaptation strategies, and tourism's contribution to the SDGs. Lastly, future avenues of research stemming from the approach and findings are identified.

THE VALUE OF AGENT-BASED MODELLING FOR ASSESSING TOURISM-ENVIRONMENT INTERACTIONS IN THE ANTHROPOCENE

2

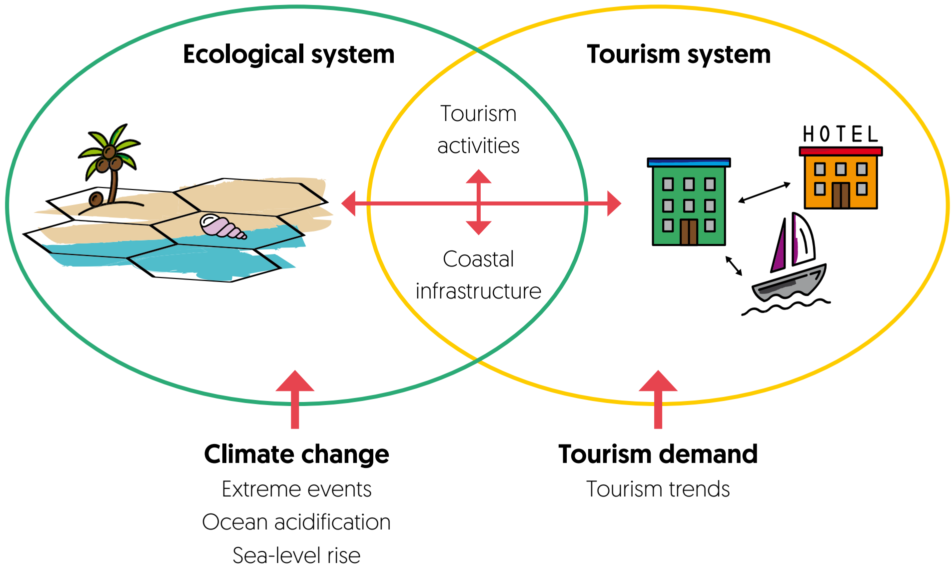
THE VALUE OF AGENT-BASED MODELLING FOR ASSESSING TOURISM-ENVIRONMENT INTERACTIONS IN THE ANTHROPOCENE

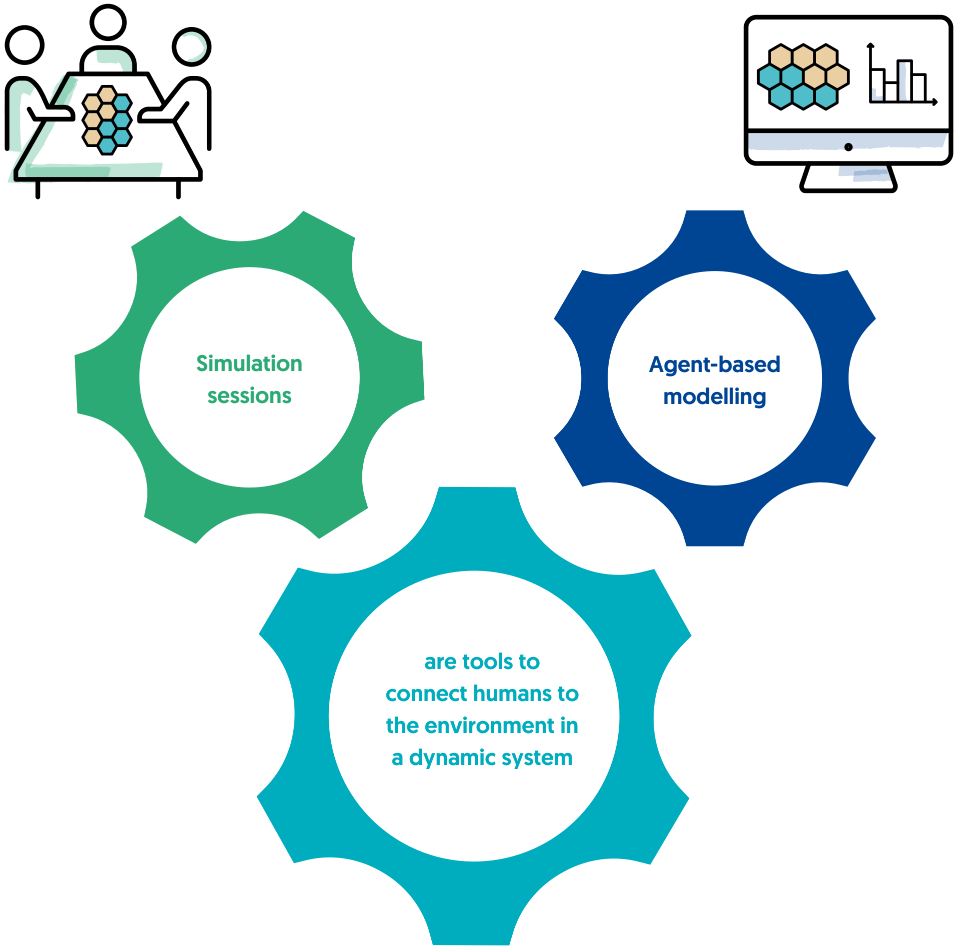
Tourism affects and is affected by emerging environmental problems including climate change. However, environmental problems are often treated separately from tourism stakeholder behaviour.



We need to integrate the two systems

Tourism destination interactions





These tools improve understanding of interactions between humans and the environment. They highlight the environmental challenges affecting and affected by the tourism system.

A systems approach can inform strategies to address tourism's problematic environmental performance.

Abstract

Tourism is one of the prime manifestations of the 'great acceleration of humankind' since the Anthropocene started around 1950. The almost 50-fold increase in international tourism arrivals has substantial implications for environmental sustainability, but these have not yet been fully explored. This paper argues that a full exploration requires the study of tourism as a complex socio-ecological system. Such an approach integrates environmental processes and stakeholder behaviour and puts feedbacks in the spotlight. Systemic insights can inform strategies to address tourism's problematic environmental performance. The paper finds that systems approaches in tourism research are rare and identifies a number of challenges: the large number of stakeholders involved; the heterogeneity of stakeholders; and the lack of transdisciplinarity in tourism research. The paper then argues that agent-based modelling can help address some of these challenges. Agent-based modelling allows to run simplified tourism systems with heterogeneous stakeholders and explore their behaviour, thus acting as living hypotheses. They do this by: (1) representing tourism's dynamics in a systemic, intuitive and individual-based way; (2) combining theories from different domains; (3) unpacking the link between stakeholder behaviours and emergent tourism system patterns; and (4) connecting researchers and stakeholders. Agent-based models allow representation of heterogeneous agents driven by plausible needs, who perceive local context and interact socially. Companion modelling is identified as a promising tool for more effective stakeholder inclusion.

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2.1. Introduction

Tourism is one of the largest industries in the world, generating 10% of global GDP and accounting for 1 in 11 jobs, 7% of all exports and 30% of service exports in 2015 (UNWTO 2015). The growth of international tourism, from 25 million international arrivals in 1950 to 1.2 billion in 2015 (UNWTO 2016), is one of the twelve socioeconomic trends included by Steffen et al. (2015; 2005) in their 'Great Acceleration' in human activity since 1950. As their work illustrates, the phenomenal growth in the human enterprise since 1950 (as also represented by dramatic increases in factors, such as population, urbanisation, income, transportation, and telecommunications) corresponds closely with substantial shifts in the structure and functioning of Earth's ecosystems. According to these and other authors (e.g. Zalasiewicz et al. 2012), the beginning of this Great Acceleration also marks the beginning of a new geological epoch, the Anthropocene, an era driven by human influence. Tourism scholars have recently started to explore the role of tourism in the Anthropocene (Gren & Huijbens 2016).

Tourism benefited disproportionately from the large increases in disposable income in the western world post-World War II. Rapid advances in transportation and communication technologies increased the extent of travel and lowered prices, making short-haul and long-haul travel affordable for a large share of the population in developed countries. More recently, the desire and ability to travel has spread throughout much of the world; the number of international tourist arrivals is projected to double between 2010 and 2030, with arrivals in emerging economies growing at double the rate of those in advanced economy destinations (UNWTO 2015).

In the first decades of post-WWII growth, tourism was often depicted as a benign industry with substantial social and economic benefits and limited environmental impacts. In more recent years, however, the negative social and environmental effects of tourism have been clearly exposed (Ruhanen et al. 2015), for example in the *Journal of Sustainable Tourism*. Most work in this field consists of qualitative studies in local case study areas, as controlled experiments are difficult to execute in the context of tourism. Until a decade ago only a few studies had addressed the global scale of tourism-environment interactions. Gössling (2002) was arguably the first to quantify tourism's global environmental impacts. More recently, Gössling and Peeters (2015) provided an accounting of tourism's total global resource utilisation, incorporating tourism-related fossil fuel consumption and associated CO_2 emissions, as well as fresh water, land, and food use (c. 16 700 PJ of energy, 138 km^3 of freshwater, 62 000 km^2 of land and 39.4 Mt of food, causing emissions of 1.12 Gt CO2). Further, their analyses indicated that resource use associated with tourism may double for water and triple for land use in the period 2010-2050.

In addition to contributing to the Great Acceleration and its environmental impacts, tourism is also affected by them. In the context of climate change, Scott et al. (2012) discern four categories of potential impacts on tourism: direct (e.g., changing weather patterns and sea-level rise), indirect environmental (e.g., biodiversity distribution and water availability), indirect societal (e.g., political stability and economic growth), and mitigation-policy-related (e.g., taxation of fuel, which affects travel costs). Substantial changes in the climatic attractiveness of tourism destinations have been reported for both summer tourism (see e.g. Amelung & Nicholls 2014 for Austalia) and winter sports. Snow reliability has already changed for winter sports destinations such as the European Alps (Beaudin & Huang 2014) and further change is anticipated (Steiger & Abegg 2013). The ultimate effects of global environmental change on tourism demand patterns will depend on perceptions, institutional flexibility, and other societal factors that are currently poorly understood (Amelung & Moreno 2012). This knowledge gap is illustrative of a wider issue. A basic understanding of some of the main relationships between tourism and the global environment has emerged, but insights pertaining to the various issues have not been connected. In addition, feedbacks are under-represented. Studies of changes in tourism resources, such as climate, typically provide little insight into the stakeholder adaptation that such physical changes entail. In their turn, studies of stakeholder adaptation typically include rudimentary representations of environmental change at best. In short: an integrative, systemic approach is lacking. The key issues may be clear, but not the trade-offs between them nor the effects of changes in policy and behaviour (e.g., changes in destination choice, installation of snow-making equipment). Knowledge of these feedbacks is crucial for effective interventions to foster sustainability. Determining "institutional, economic, and behavioural changes to enable effective steps towards global sustainability" is one of the grand challenges in global change research (Reid et al. 2010 p. 917).

This paper therefore makes the case for studying the phenomenon of tourism as a socio-ecological system. It argues that a systemic approach of tourism and its environmental ramifications requires integration of tourism research and the environmental sciences, and internal integration of the disciplinarily and geographically fragmented research field of tourism. A systemic approach also requires strong stakeholder involvement regarding problem formulation, problem analysis, and implementation of solution strategies. Agent-based modelling is put forward as a promising integrative approach to understand how individuals relate to environmental change.

The remainder of the paper is structured as follows. Section 'The need for systems thinking and transdisciplinarity in tourism research' introduces the need for transdisciplinary research in tourism and the key challenges associated with that. Section 'Agent-based modelling' suggests agent-based modelling (ABM) as a solution to some of these challenges, highlighting examples of ABM application. Finally, section 'Taking stock and moving forward' signals a way forward for tourism sustainability research.

2.2. The need for systems thinking and transdisciplinarity in tourism research

Tourism is studied from numerous disciplinary perspectives, including geography, sociology, anthropology, and economics, with limited integration. Faulkner and Russell (1997) and McKercher (1999) revolted against the dominant conceptualisation of tourism as a well-behaved phenomenon that can be controlled and managed. They emphasised tourism's nature as a complex phenomenon and system. A handful of authors, including Baggio and Sainaghi (2011) and Becken (2013b), have proposed to study tourism as a socio-ecological system (SES) or complex adaptive system (CAS) to capture the dynamics and complexity that characterise tourism's relationship with sustainability. The transnational character of tourism involves diverse social systems, such as socioeconomic and legal institutions, transportation, accommodation, and attractions. These social systems rely on a range of environmental resources (e.g., biodiversity, land, energy, water) as well as sinks (e.g., atmosphere, ocean) and thereby contribute to environmental impacts and change. At the same time, environmental change is increasingly affecting the direction and volume of transnational tourism mobility. Taking these feedbacks into account is essential for tourism research in the Anthropocene.

Only a handful of studies have actually applied CAS or SES approaches to tourism in a sustainability context. Strickland-Munro et al. (2010) and Ruiz-Ballesteros (2011) focused on the interactions between protected areas, tourism, and communities. Becken (2013b) explored the resilience of tourism sub-systems impacted by climate change. Lacitignola et al. (2007) and Petrosillo et al. (2006) studied the interlinkages between tourism destinations and the quality of ecosystem goods and services.

Global environmental change research, in contrast, has a well-established tradition of complex systems approaches. It also has a 30 year history of integration (Rice 2013), progressing from disciplinary through multidisciplinary to interdisciplinary and then transdisciplinary research. Interdisciplinarity within the natural sciences started in the 1980s and 1990s, followed by the incorporation of the social sciences in the 2000s and 2010s, and the current transition towards transdisciplinarity (Leemans 2016). Whereas interdisciplinarity crosses disciplines but remains exclusively grounded in science (Rice 2013), transdisciplinarity refers to the "unity of intellectual frameworks that transcend disciplines and involves stakeholders" (Turner et al. 2016 p. 163). Transdisciplinarity enables researchers to better establish the role of human action and decision-making in environmental change. Stakeholder involvement is essential when addressing complex problems, to improve the problem definition, and devise and implement strategies for improvement. A complex systems approach has been part and parcel of all three stages of integration, acknowledging the dynamic, non-linear, and largely unpredictable nature of environmental change.

The sharp contrast between global environmental change research and tourism research in the uptake of complex system approaches can be partly explained by the specific characteristics of the tourism phenomenon and of tourism research. As an industry, tourism is notoriously fragmented and diverse, consisting of a variety of primary (e.g., accommodations, transportation, attractions) and intermediary (e.g., sales and marketing) segments. Members of the tourism industry hail from the public, private, and not-for-profit realms, with substantial variations within each. Private enterprises, for example, can range from multinational corporations to family-owned and family-operated concerns. The continuing emergence of the sharing economy (think of Airbnb and Uber) has multiplied the number of stakeholders active on the supply side.

Also outside the tourism sector, the heterogeneity among tourism stakeholders is large. Tourism patterns and impacts emerge from the visits of billions of international and domestic tourists to countless destinations. Tourists and destination residents are critical stakeholder groups, each of which can exhibit widely differing motivations, preferences, and behaviours. Moreover, the recent advances in communication technologies have relaxed many space and time constraints so that stakeholders traditionally out of the destination bounds are now actively engaged, making a destination an even more complex ecosystem. A tourist, in turn, often does not travel alone and decisions on where to go and what to do are typically made among multiple people, perhaps further influenced by additional layers of actual and online relatives, friends, and peers. To complicate matters further, many stakeholders are not exclusively part of the tourism system. Restaurants and supermarkets, for example, cater to both tourists and locals. Fragmentation also characterises the tourism literature. Much of that literature focuses on discrete sub-sectors, locations, elements of the travel experience or events rather than taking a more holistic approach that crosses scales, boundaries, and ecosystems.

The key characteristics of the tourism system, as outlined above—including its multiple and heterogeneous stakeholders and fragmented disciplinary approach—impose challenging requirements on the research tools used. Addressing the grand challenges of the modern day requires tools that: transcend disciplinary differences, integrating quantitative and qualitative knowledge from multiple domains; invite stakeholder participation; and explore the effects of potential developments and policy choices on society and the environment. In other words, we need transdisciplinary and exploratory rather than disciplinary and predictive tools, but such tools are largely absent from the methodological toolbox currently used in tourism research. Pons et al. (2012 p. 199), for example, note that "one of the main challenges in climate change impacts studies has been to relate the physical impacts and changes in the environment with their human implications such as socioeconomic impacts or human responses".

Simulation modelling of socio-ecological systems is particularly well-suited to "advance the understanding of dynamic correlations among various human and environmental factors, including impacts and responses to environmental change" (Pons et al. 2014 p. 2474), especially in cases where the potential for experimentation is limited. Sustainability encompasses both a goal state and the durability of this state over time (Waring et al. 2015), model-based computational experiments are thus employed to explore possible futures (Kwakkel & Pruyt 2013). There are several simulation modelling methods, such as system dynamics, agent-based modelling, and discrete event simulation. Of these, system dynamics is arguably the most commonly used method in tourism research (for a recent example, see Provenzano 2015). In other fields, system dynamics (SD) has been used from the mid-fifties with the purpose of incorporating dynamic processes and events. SD models represent a system under study with a large number of attributes evolving in time. This evolution is mathematically formalised using difference or differential equations. SD has limitations when it comes to representing heterogeneity and social interactions as it is characterised by a lumped representation of processes. Agent-based modelling transcends these limitations of SD as it can represent not just an entire system, but each one of the elements interacting within that system and thus causing its behaviour. These so-called agents can all differ from one another. They can interact with each other and with their surrounding—with a rich repertoire of changeable behaviour rules—just like tourism stakeholders do in reality. We therefore argue that ABM represents a more accurate ontology of actual tourist systems and is a promising tool for tourism sustainability research.

2.3. Agent-based modelling

Agent-based modelling (ABM) has been defined as "the set of techniques [in which] relations and descriptions of global variables are replaced by an explicit representation of the microscopic features of the system, typically in the form of microscopic entities ('agents') that interact with each other and their environment according to (often very simple) rules in a discrete space-time" (Gross & Strand 2000 p. 27). ABM is therefore one possible methodology via which to simulate the coupling of tourists, the tourism industry, and other tourism stakeholders with the environment in which they operate so as to improve system-level understanding. ABM is a form of computational modelling that incorporates both agents (e.g., tourists, tourism businesses) and an environment (e.g., a tourism destination), and allows analysis of the range of outcomes resulting from interactions among these entities as they emerge based on individual decision rules or behaviours (e.g., a tourist choosing whether or not to visit a ski resort). The outcomes are emergent patterns of system behaviour that are not under any central control. A recent overview of existing and potential applications of ABM in a tourism context (Nicholls et al. 2017) highlights its utility in a range of tourism planning, development, and management contexts.

As described above, one of ABM's strengths is the coupling of multiple heterogeneous agents or stakeholders with environmental features (see Balbi & Giupponi 2010). Typical ABM studies consist of computationally intense, detailed dynamic simulations where many heterogeneous human and natural agents interact at multiple temporal and spatial scales. Agent-based modelling lends itself to graph and network analysis allowing not only to capture the network of flows between agents, but more importantly, to attribute heterogeneous roles and behaviours to the agents themselves (Baggio 2008). In a tourism context, agents might include tourists, residents of tourism destinations, tourism businesses, marketing entities, and government agencies, while the environments in and with which these agents interact would most likely be an attraction or destination, whether a specific site or resort, or a city, county, state or nation (see e.g. Li. et al. 2015). Figure 2.1 identifies possible relevant agent classes for the study of tourism as a social-ecological system across multiple geographical levels. The four quadrants capture the domains (or sub-systems) that the agents can belong to: governance, commerce, transport (industry), and natural resources. The three bands capture the three geographical levels: micro (destination), meso (region), and macro (international).

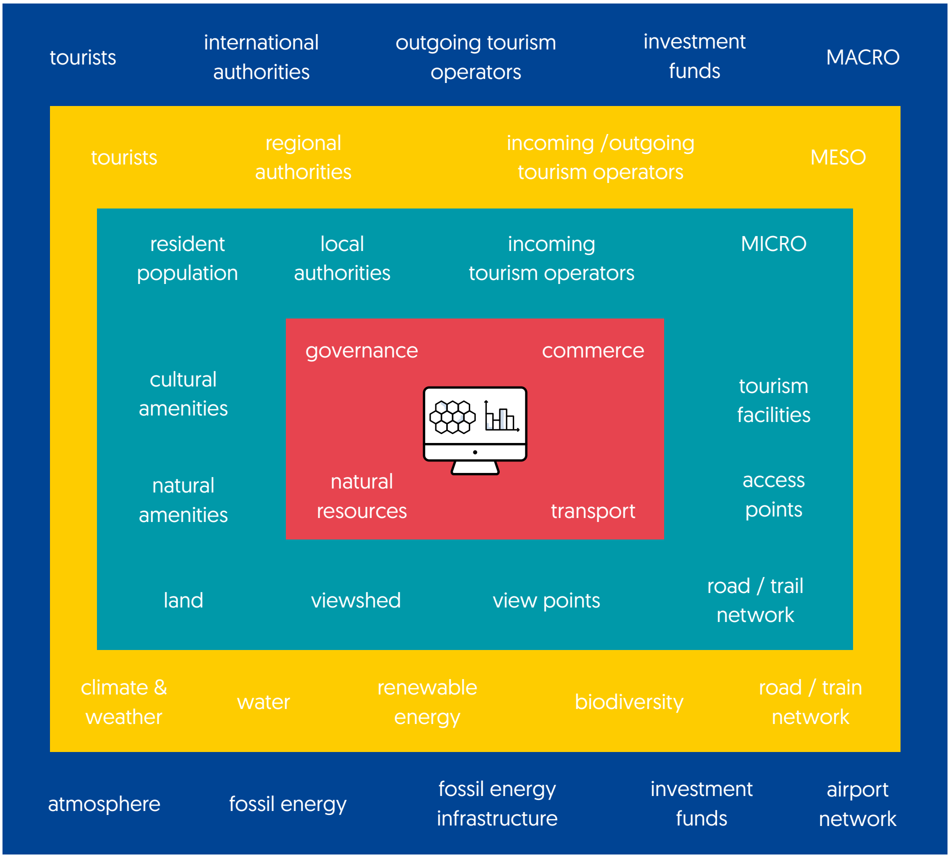


Figure 2.1. Possible agent classes for the study of tourism as a social-ecological system across multiple spatial scales

Further model mechanisms could include such things as social contagion in destination choice and sustainability-related behaviour of tourists and of hospitality professionals. The boundaries of the model can be adapted to suit the purpose of the research question. For example, tourism boundaries employed in studies to date include the Canadian province of Nova Scotia (Johnson &

Sieber 2011a), a well-established European skiing area (Pons et al. 2014), an Italian Alpine municipality (Balbi et al. 2013), a Portuguese coastal NUTS III region (NUTS is the Nomenclature of Territorial Units for Statistics, a European Union standard for referencing the subdivisions of countries for statistical purposes) (Boavida-Portugal et al. 2017), an abstract representation of Antarctica (Student et al. 2016), the Galapagos islands (Pizzitutti et al. 2014), and 109 European destinations (Reintinger et al. 2016). Further, ABM allows for a variety of exploratory uses, including as a tool to investigate hypothetical future outcomes of a specific policy change, to better balance tourists and resources (Shi et al. 2016), assess the impact of changing connectivity between destinations (Johnson & Sieber 2011a), or to refine understanding of a system to support further model development (Johnson & Sieber 2010).

ABM also offers a platform for researchers working on different parts of the tourism system to share and integrate disciplinary information. Recent ABM projects on European alpine tourism (e.g. Pons et al. 2012, 2014; Soboll & Dingeldey 2012) demonstrate the success of the approach, uniting experts from geography, ABM, economics, climatology, and behavioural science. Prior research on the supply side analysed the impacts on snow reliability of a number of extraordinarily warm winter seasons (Dawson et al. 2009) and potential impacts in the future using climate change scenarios (e.g. Steiger & Abegg 2013). Prior research on the demand side investigated potential impacts of climate change on the behaviour of ski tourists (e.g. Rutty et al. 2015). Key insights were integrated with ABM.

Using ABM, Pons et al. (2012, 2014) combined weather scenarios (changes in snowfall, glacier retreat), changes to biodiversity and policy measures (artificial snowmaking). Their ABM approach enabled exploration of tourism demand and behaviours in response to climate change scenarios and snowmaking policies within the same geographical region. In this model, tourists were able to change location or activity. The results indicated what types of resorts under what circumstances would be affected in terms of changing visitor numbers, and what the limits of artificial snowmaking are for ensuring sufficient snow for skiing. Moreover, Balbi et al. (2013) found that in response to climate change, traditional ski hill focused tourism may not attract more tourists and that energy efficiency improvements are necessary before adding any tourism infrastructure. These alpine tourism studies illustrate how ABM can provide an integrated story of the environmental challenges facing the socio-ecological tourism system while exploring adaptation measures (e.g. shift of activity, snowmaking).

2.4. Taking stock and moving forward

The impact of tourism on global environmental sustainability continues to grow. The relative eco-efficiency of tourism may be improving on some accounts, but the tourism's absolute environmental impacts continue to increase as a result of steeply growing travel volumes (Gössling & Peeters 2015). Global environmental assessments for tourism have not yet been effectively connected to local developments and action perspectives for stakeholders. We argue that ABM can translate theoretical knowledge to practitioners and decision-makers. By taking a systems perspective, providing a platform for knowledge integration and stakeholder participation, and having a focus on individual stakeholders, ABM has the potential to link the exploration of grand challenges of sustainability and tourism with practical implementations and interventions at micro, meso, and macro scales. It provides an interface between stakeholders to examine the impact of policies geared at a sustainability transition. In this way, ABM functions as a virtual laboratory to explore a range of possible futures. For example, with ABM, scenarios that industry deems 'uneconomical' can be tested and refined to both improve decision-making and stakeholder buy-in.

Though vital for tourism research, effective stakeholder involvement in ABM projects is difficult to achieve. Key bottlenecks include ownership, time requirements and variable expectations about the outcomes of ABM research. Stakeholders typically expect predictive results and point estimates, whereas ABM is better suited for the exploration of alternatives and providing range estimates of outcomes (Johnson & Sieber 2011b). This contrast can give rise to disappointment amongst model users looking for quick predictions to guide on-the-ground decisions. In addition, stakeholders are often unwilling to invest substantial amounts of time in research participation, in particular when the benefits for them are unclear and ownership is low.

A modelling approach that can link ABM more closely to stakeholders is the companion modelling approach. Companion modelling explores complex problems through a process of engaging stakeholders in problem definition, in understanding of the system, for design inputs and use of the (model) simulation, and in the analysis thereof (Étienne 2014). This iterative process uses model simulations (often ABM) and/or role-playing games to represent the socio-ecological system. Companion modelling has been developed to further institutionalise stakeholder participation in resource management and facilitate the transition to transdisciplinarity (Salvini et al. 2016), while increasing the transparency of model outcomes. At the core of tourism's complex system are the interactions of people and the environment. As such, stakeholder inclusion is often necessary to understand the human part of the system and develop policies that affect tourism practices. Companion modelling can support understanding of the socio-ecological system by favouring stakeholder inclusion, including their tacit system knowledge as well as preferences and gaining support for transformations of the tourism system.

In this paper we argue that ABM has both proven and potential value in environmental sustainability research for tourism. At the same time, it faces a number of challenges. Johnson et al. (2016) discuss three categories of challenges regarding ABM adoption in tourism research: technical, communication and novelty. Other challenges relate to ABM's societal relevance and acceptability. Waldherr and Wijermans (2013) review criticisms levelled at ABM by peers and distinguish lack of understanding and academic territorialism as causal factors. Yet there are real challenges as well. A key challenge in this category is validation. Models of complex systems are inherently difficult to validate as a result of the unpredictability of complex systems and also the lack of suitable independent datasets for comparison. With an increasingly instrumented world pushing the availability and use of 'Big Data', the challenge of appropriate data for both parameterisation and validation may be partially solved. Nevertheless, it remains difficult to determine whether the difference between observed data and modelled data represents a real result, is due to system complexity, or is an artefact of modelling error. Recent work in this area recommends the robust testing of all model parameters for sensitivity as a partial solution to validation concerns, and as a way to increase confidence in ABM results (Filatova et al. 2013; ten Broeke 2016). Validation is further served by confronting domain experts with the system-level patterns generated by the models (Osinga 2015).

2.5. Conclusions

Tourism is a key manifestation of humanity's accelerating interaction with the environment, as part of the Anthropocene. Over the past decade, a body of literature has emerged on some of the main links between tourism and the global environment, including tourism's CO2 emissions and water use and the climate change impacts on tourism resources. Important environmental challenges for tourism have been identified and partly quantified. These challenges have, however, not been sufficiently connected to stakeholder behaviour. An approach is needed that connects the various environmental issues and takes the social and environmental feedbacks into account: a systems approach.

Introducing systems thinking to tourism research is challenging in its own right. Tourism research has little experience with systems approaches and is strongly fragmented along disciplinary lines. Fortunately, tourism researchers can benefit from the 30 years of experience with systems thinking of the global environmental change research community. In addition, a range of complexity-based tools have become available that provide new opportunities. Of these, agent-based modelling (ABM) is found to be particularly suitable for studying tourism-environment interactions. ABM represents tourism's dynamics in a systemic, intuitive, and individual-based way. It provides a window for linking together phenomena identified in separate case studies and a platform for involving researchers from diverse disciplinary backgrounds and stakeholders. ABM can build up from local case studies to look at macro phenomena, realising synergies by integrating and comparing insights. This resonates with McKercher and Prideaux's (2014 p. 26) observation that "if trained well, [a new generation of scholars has] the potential to synthesize ideas from many perspectives to develop an epistemological basis for tourism studies". In due time, tourism can become an example for other industries of how complex sustainability concerns can be addressed through the adoption of tools that support problem identification and analysis across scales, industries, jurisdictions, and ecosystems.

VULNERABILITY IS DYNAMIC! CONCEPTUALISING A DYNAMIC APPROACH FOR TOURISM DESTINATIONS' VULNERABILITY

3

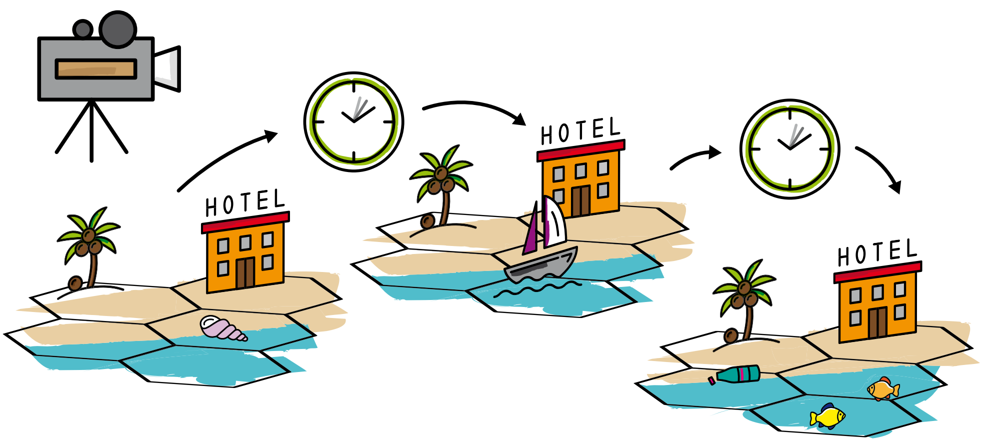
VULNERABILITY IS DYNAMIC! CONCEPTUALISING A DYNAMIC APPROACH FOR TOURISM DESTINATIONS' VULNERABILITY

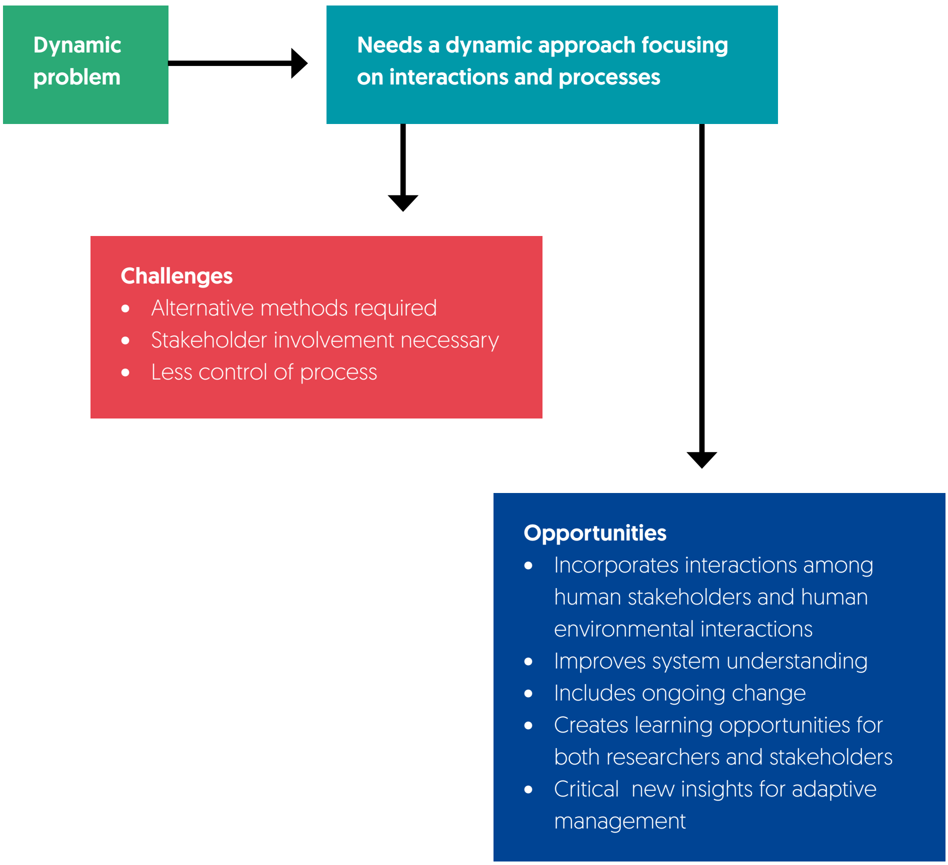
Vulnerability assessments take a static approach, which is similar to taking a snapshot of vulnerability issues.

We have control and can be very detailed, BUT we make large assumptions about feedbacks, ongoing processes, peoples' capacities, and potential adaptation strategies.

However, vulnerability is dynamic...vulnerabilities change over space and time

We need a scientific lens that captures this change




Dynamic problem
Needs a dynamic approach focusing on interactions and processes
Challenges
• Alternative methods required
• Stakeholder involvement necessary
• Less control of process
Opportunities
• Incorporates interactions among human stakeholders and human environmental interactions
• Improves system understanding
• Includes ongoing change
• Creates learning opportunities for both researchers and stakeholders
• Critical new insights for adaptive management

Abstract

Coastal regions and islands are among the most popular tourist destinations. They are also highly vulnerable to climate change. Much of the literature on vulnerability, including IPCC reports, states that vulnerability is dynamic. However, vulnerability conceptualisations in the tourism realm have so far taken a static perspective. Static conceptualisation underestimates inherent uncertainties stemming from actor interactions (with one another and their environment) and processes. The interactions and processes are important for developing adaptation strategies in a dynamic world. Hence, frameworks for analysing tourism vulnerability as a dynamic phenomenon are urgently needed. This paper outlines the first steps taken towards a dynamic approach for analysing vulnerability of Caribbean coastal tourism. The approach consists of (1) a conceptual framework focusing on human-human and human-environment interactions at the actor level and (2) an evolutionary methodology. The methodology engages both Caribbean climate change experts and regional actors. Regional actors both respond to and help develop the framework through interactive, or companion, modelling. By focusing on interactions and processes, the approach is expected to yield key insights into the development of vulnerability through time, which is crucial information for adaptive management.

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3.1. Introduction

Have we adapted to climate change? The simple answer is "No". The current array of research on climate change, scenarios, vulnerability and vulnerability assessments is a clear signal that humans have not adapted to climate change. If the answer were or could be "Yes", then it would presume that one set of (already executed) actions is sufficient to deal with future problems. However, climate change is a complex and dynamic process influenced by human mitigation and adaptation strategies where uncertainty persists.

Tourism is a useful setting to study the global impacts of vulnerability and adaptive capacity in a local context. Tourism is a complex human-environment system (e.g. Moreno & Becken 2009) with many interdependencies (e.g. on resources, among tourism operators) and many crossovers with other industries (Csete & Szécsi 2015). At the same time, different individuals are exposed to different types of harm and cope with these types of harm in different ways (Turner et al. 2003). For example, tourists and local tourism operators are exposed to different types of harm and coping mechanisms. On the one hand, tourists have relatively high coping abilities (UNWTO-UNEP-WMO 2008) as they can stay away from destinations or engage in other activities (e.g. boat cruises instead of fishing and diving excursions). On the other hand, local tourism operators and the surrounding community have low coping abilities as they cannot easily change the tourism activities they offer or change their location (e.g. Kaján & Saarinen 2013; Moreno & Becken 2009). Some types of tourism and geographic regions are more vulnerable than others. Coastal tourism is highly vulnerable to extreme weather events, sea-level rise, beach erosion, and ocean acidification (Moreno & Becken 2009; Shakeela & Becken 2014). For example, Caribbean islands are a 'hotspot' for climate change impacts due to high exposure levels and economic dependency on tourism (UNWTO-UNEP-WMO 2008). Tourism contributes 14.0 % to regional GDP and 12.3 % to regional employment in the Caribbean (WTTC (World Travel and Tourism Council) 2013).

Adaptive capacity and vulnerability are intricately interconnected. In order to analyse and develop adaptive capacity, vulnerability needs to be understood. Vulnerability to climate change is a global issue illustrated by international research collaborations of the IPCC and UN political alliances. Nevertheless, it requires local action. The IPCC definition of vulnerability is the "degree to which a system is susceptible to and is unable to cope with adverse effects (of climate change)" and uses exposure, sensitivity, and adaptive capacity of a system as key components (Adger 2006 p. 269). The IPCC definition does not specifically describe the three components nor the relationships among the components (Eakin & Luers 2006). Many definitions of vulnerability exist with different disciplines focusing on different factors e.g. climate scientists focus on likelihood of occurrence and social scientists focus on socio-economic indicators (e.g. Adger 2006; Brooks 2003; Füssel 2007). Along with type of vulnerability, there are different temporal focuses: historical, present and future (Füssel 2007). These different definitions and emphases result in a range of conceptual frameworks trying to clarify the meaning of vulnerability. A complete review of the concept and development of the term vulnerability is beyond the scope of this paper (for reviews see Adger 2006; Eakin & Luers 2006; Schröter et al. 2005). The scope of this paper is to provide evidence for the need of dynamic approaches to vulnerability and adaptive capacity and to outline initial steps on how to operationalise a dynamic approach in the context of Caribbean coastal tourism.

Adaptation strategies are influenced by the static approaches to vulnerability. Adaptation strategies are typically ad hoc, short-term focused, reactive (e.g. repairing damaged items), and event specific (Kaján & Saarinen 2013). Adaptive capacities are dynamic processes made up of actions at the household, regional, and national level (Smit & Wandel 2006). Adaptation often requires collaboration at social, political, and spatial levels and adjustments to the local context (Csete & Szécsi 2015). Thus, future-looking vulnerability approaches and adaptation strategies are required in order to move beyond reactive short-term measures (Kaján & Saarinen 2013).

This paper explores the application of a dynamic approach to a dynamic problem. A growing body of literature recognises that vulnerability is dynamic (e.g. Adger 2006; Turner et al. 2003) and context dependent (e.g. Brooks 2003; Füssel 2007). Scientific approaches, however, do not match the definition of vulnerability—static approaches are applied to a dynamic problem. Climate change and tourism destination vulnerability continually shift; thus adaptation measures must be continuous and flexible (Brown et al. 2012; Csete & Szécsi 2015). Challenges for adaptation strategies are understanding interconnections, translating understanding into action, focusing on the long-term future, and considering local levels and context (Turner et al. 2003). Moreover, current methodologies have not helped many local actors identify the importance of emerging vulnerability challenges. Local actors often do not understand scientific conceptual frameworks and are uncertain about how and whether they may personally be affected (Klein & Juhola 2014). This uncertainty lowers the importance of understanding vulnerability and delays decision-making and implementation. Therefore, engaging local actors in designing a dynamic conceptualisation of vulnerability is fundamental for developing long-term adaptation strategies.

3.2. Current frameworks and their limitations

Vulnerability, in the context of tourism, is traditionally assessed using a top-down approach of a tourist destination's exposure, sensitivity, and adaptive capacity to climate change (e.g. Moreno & Becken 2009; Perch-Nielsen 2010; Polsky et al. 2007; Schröter et al. 2005). Research has focused on specific events (e.g. severe storms and sea-level rise) with predictable consequences (Csete & Szécsi 2015). These approaches analyse individual pieces of the system. In tourism, the most common adaptation strategies involve diversifying destination's activities and product portfolio (Kaján & Saarinen 2013). All of these approaches have useful ideas for inventorying the risks and hazards, but they do not provide a framework to understand how people and the environment interact with each other and with emerging risks and hazards. Moreover, local actors are not often included and represented in the process of making and analysing vulnerability assessments and considering adaptive capacity.

Eakin and Luers (2006) identify three main streams that have emerged in the debate on vulnerability definitions and assessments: (1) biophysical risk/hazard, (2) political ecology and/or political economy, and (3) ecological resilience. Classic approaches resulting from the risk/hazard stream include determinism (nature causes hazards) and mechanistic engineering (technology reduces vulnerability) (Füssel 2007). This stream takes an instrumental natural science-based perspective. For example, Disaster Risk Reduction (DRR) (Thomalla et al. 2006) takes an engineering approach focused on singular events, exposure, and technological solutions, but does not focus on interactions among people. Typically, this approach takes a historical perspective (Mercer 2010) and aggregates known hazards and impacts (Füssel 2007). Relying on a risk-based understanding of vulnerability provides a limited perspective on adaptation because interconnectedness is not taken into account (Kaján & Saarinen 2013). A further limit of this approach is that it does not provide increased understanding of the different impacts on the system and its sub-sets nor what adaptive measures may be applied (Turner et al. 2003). Moreover, adaptation involves a mixture of tools, the specific mixture is location and context specific (Csete & Szécsi 2015), and requires the buy-in of local actors.

The political ecology definition focuses on people (individuals, households, communities, etc.). The definition and approach asks how and which people are affected and what are the causes and outcomes of the heterogeneous adaptive capacities (resulting from different entitlements and capabilities) (Eakin & Luers 2006). This definition does consider agency, the capacities of individuals to act and effect change. However, it does not look at the broader scope of vulnerability in settings such as a coastal beach destination nor does the definition focus on what actions can be taken and what capacities are needed to reduce future vulnerabilities (ibid).

Ecological resilience, in contrast, focuses on a coupled human-environment system (Turner et al. 2003) and is informed by complexity theory. This definition and framework asks the questions why and how systems change (Eakin & Luers 2006). Ecological resilience focuses on thresholds and tipping points, and is future-looking. Although the ecological resilience perspective does consider the interactions between humans and the environment, the perspective is less decisive on human-human interactions. The human dimension of adaptation involves actions, processes and outcomes, and adjusting to changing conditions (Smit & Wandel 2006). These changes also come about because of interactions among actors (Csete & Szécsi 2015). Preferences, adaptation mechanisms, and strategies of individuals and groups influence each other (Kaján & Saarinen 2013). Combined, these streams take into account agency, broader risks, human-environment interactions, thresholds and future scenarios. However, none of these three streams consider what defines a desirable state (Eakin & Luers 2006), which requires local actors to co-design the objectives and conceptual framework.

Static approaches identify different parts of the systems, but do not encourage systems thinking. Academic discussions have circled around dynamic approaches, however operationalising this thinking has been difficult (Becken 2013b). For example, current frameworks help identify actors, possible adaptation activities (Csete & Szécsi 2015), possible hazards, and indicators. According to UNWTO-UNEP-WMO (2008), adaptation strategy types are technological, management, behaviour, education, and/or political. The current frameworks focus more on technological adaptation strategies and focus less on the other four adaptation strategies. In order to get beyond this scientific challenge of defining vulnerability in the local context, local peoples' tacit knowledge needs to be combined with scientific knowledge. Participatory approaches with local actors help relate science to the societal issue in a process of joint knowledge production. Analysing vulnerability and how it changes, gives opportunity to build adaptive capacity and limit harm to local people.

3.3. Operationalising a dynamic approach

A dynamic definition of vulnerability suggests the need for a dynamic approach. The approach and the conceptualisation of vulnerability and adaptive capacity are dynamic. Dynamic suggests a focus on the interactions among different variables. Thus, a dynamic approach is process-oriented, transdisciplinary and iterative. A dynamic approach for dynamic problems requires the use of a different range of tools than those currently being applied to vulnerability issues in tourism. The tools currently applied provide insights on key variables (actors, biophysical challenges, possible scenarios, potential risks and extreme events predictions)(e.g. Moreno & Becken 2009; Perch-Nielsen 2010). Understanding system interactions in a local context requires local knowledge and participation. Transdisciplinary research endeavours to provide a holistic approach involving multiple disciplines and local participation to improve system understanding. Many levels and forms of participation exist (Barreteau et al. 2010; Hegger et al. 2012). The role of actors in this process is different than what has been done to date for vulnerability in tourism. This participatory process sees local actors not just as the end users or informers of the system, but also actively involves individuals in the process of learning, co-creating, modifying, and analysing the process. The following sections describe a means to operationalise a dynamic approach for this dynamic problem.

This paper responds to the need for new approaches to study the complex relations between tourism and climate change (Becken 2013a) by asking how dynamic vulnerability can be conceptualised in a coastal tourism context, what are the implications of this framework and how it can inform adaptive governance strategies. In this study, interactive modelling refers to two-way communication and learning between stakeholders (experts and local actors) and researchers through modelling and simulations. Simulations developed through role playing games and agent-based modelling (ABM) will be used because ABM provides an actor-oriented modelling environment for analysing the emergent properties of actor interactions over time.

3.4. Implications for process

Dynamic approaches require learning and iteration. Adaptation studies have thus far limited focus in community perceptions (Kaján & Saarinen 2013). Many methodologies exist for studying vulnerability (e.g. economic modelling, surveys, Delphi surveys, workshops) (Becken 2013a). However, interactive modelling approaches are new to the tourism domain and provide different tools to include community perceptions. The process designed for studying dynamic vulnerability and adaptation of Caribbean coastal tourism destinations is inspired by companion modelling (e.g. Étienne 2014), which engages local actors in problem definition, determining the objective and forming the conceptual framework. The process appears linear, but is in fact made up of feedback loops in which the original objective, conceptual model, and modelling tools can be altered as a result of interactions with local actors, altered objectives, and better system understanding (Étienne 2014). The continual feedback loops operationalise researchers' suggestions that vulnerability approaches include built-in reflexivity (Hegger et al. 2012). The two main objectives of companion modelling processes are to (1) create knowledge of the system (interactions, interdependencies, patterns, etc.), in this case understand emerging vulnerabilities and the implications for adaptation, and (2) enhance decision-making by analysing what processes are available or could be considered to address these challenges. All companion modelling approaches explore objective one, but some do not include objective two. The objectives of companion modelling are in line with what researchers have identified as the information gap of vulnerability—lack of understanding of the system and limited decision-making capabilities.

The first phase focuses on inventorying existing knowledge: understanding the context, local actors' objectives and identifying relevant actors. The second phase involves co-constructing the conceptual framework using a combination of scientific, technical, and local knowledge. The third phase involves operationalising the framework in the form of a role-playing game and/or computer simulations such as ABM. The fourth phase involves exploring different scenarios with local actors, and the fifth phase involves monitoring and evaluation (adapted from Étienne 2014).

As local context is crucial for analysing vulnerability and adaptive capacity, case studies on two separate Caribbean islands are used. The first destination case study shows the learning process of joint knowledge production and what the implications are of a dynamic process on improving decision-making. The second case study demonstrates what has been learned by the process of the first case study and offers a comparison study to analyse what the similarities and differences are in the process of understanding local vulnerabilities and adaptive capacities.

3.5. Implications for tools

The interactive process is supported by a range of tools. In the earliest stages, a fuzzy cognitive model provides a rough understanding of the scientific understanding of the system and the possible interactions and interdependencies. The conceptual framework combines scientific knowledge of the system and uses earlier frameworks to identify key actors and biophysical variables. A panel made up of experts on climate change (in the tourism context) provides information on the Caribbean coastal tourism context. Role-playing games executed in focus groups help make the problem, how the system interacts and how other actors behave more tangible. Role-playing games have the added benefit of being more approachable than computer simulations and help remove the perception of dealing with a black box, which is a common complaint of computer simulations (e.g. Barreteau et al. 2000). This enables actors to more easily contribute to monitoring and evaluating the system and its emergent properties.

Operationalising the same conceptual framework as role-playing games, computer simulations can help show how individual decisions result in different macro patterns. ABM is a useful simulation type as it is designed to describe heterogeneous and autonomous actors' interactions with each other and their local environment while offering a flexible platform to explore global tourism and climate change scenarios within a local tourism destination context (Bonabeau 2002). ABM has seen limited applications in tourism. A few examples of ABM applications in tourism include Balbi et al. (2013), Johnson and Sieber (2011a), and Soboll and Schmude (2011). The computer simulation can be done one-on-one or can have multiple users. One-on-one interviews using simulations can look at multiple scenarios. Computer simulations enable applying multiple scenarios (climate change, tourist projects) and collecting data from different scenarios in a short period of time. Moreover, they help identify how individual decisions, actions, and different practices can affect the system.

3.6. Participation

A gap exists between research on vulnerability, adaptation, decision-making, and actions taken at a local scale (Klein & Juhola 2014). Climate change is not one of the main vulnerabilities that locals respond to (Shakeela & Becken 2014). One explanation is that climate change at a local scale is difficult to conceptualise (Klein & Juhola 2014). By involving actors throughout the process, their real concerns about their local environment can become more explicit and they can actively engage in learning about their problems and the process. Moreover, involving local actors throughout the process provides opportunities to share their tactic knowledge (Hegger et al. 2012). The companion modelling approach provides guidelines for involving actors. The companion modelling charter states: equal accounts of identified actors' knowledge and perspectives; transparency of ideas used; iterative and adaptive processes; and evaluation of learning outcomes (evolution of actors' perspectives and interactions) as well as technical outcomes (Étienne 2014).

Local actors are heterogeneous; they have different roles in the community, different perceptions of climate change, different vulnerabilities, and varying abilities to adapt (Scott et al. 2012). In the context of tourism, little is known on which actors must be involved in participatory processes (Hegger et al. 2012). As a baseline for participation, two types of actors should be involved in the participatory process: individuals affecting and affected by destination vulnerability, and individuals who can make decisions to address vulnerabilities or develop adaptive capacity. Hegger et al. (2012) suggest success conditions for joint knowledge production to facilitate a productive participatory process. In terms of actor selection, they recommend the broadest actor involvement feasible within strategic and practical limits. Actor identification matrixes, scientific literature, and snowballing techniques aid in identifying relevant participants for coastal tourism vulnerability. Involving experts helps to get access to existing scientific and policy information on the study.

3.7. Discussions

This study has indicated that vulnerability is dynamic and that current scientific approaches for tourism are static. If decision-makers and researchers want to understand who and what is vulnerable and how these vulnerabilities are attenuated or amplified through human-human and human-environment interactions and what can be done to limit vulnerabilities, a dynamic approach that considers diverse and complex interactions is essential (Turner et al. 2003). A few similar studies within tourism indicate the potential of exploring interactions and involving actors. For example, Balbi et al. (2013) used ABM to explore various actor strategies and climate scenarios to study the effects on tourism in the Italian alps and Soboll and Schmude (2011) explored the supply side of tourism ski areas and adapted their agent-based model to analyse human-environment interactions. Outside of the tourism domain are examples of the companion modelling approach. For example, in a study of Senegalese farmers, Barreteau et al. (2000) indicated the usefulness of combining ABM with role-playing games to improve coordination among local actors in a companion modelling approach.

Static approaches offer a sense of control and clarity by developing indicators and measurements for evaluating risk. By looking at specific events or assuming that new vulnerabilities do not emerge (that current vulnerabilities are an indication of future vulnerabilities), the variety of adaptive measure taken are limited, and promotes choosing and supporting/maintaining one best solution. With individual events assessments, it is very likely that eventually the event will occur and that the approach predicts that event and how individuals can prepare for that single event. However, critical events are only a part of the vulnerability that local actors experience. The approach also assumes that the people, resources, and abilities available at the current moment of time will be available in the future and during the critical event.

Dynamic processes are not focused on prediction. Rather, the focus is on improving understanding of the system. A dynamic approach is not reinventing the wheel. Instead, it takes aspects that static approaches have taught us and puts them in motion. Transdisciplinarity improves the adaptive process as it enables a different range of solutions and approaches. Vulnerability does not affect the biophysical environment nor people in isolation. Rather, vulnerability affects the interactions among people and their environment. One knowledge domain is insufficient to understand these interactions. Transdisciplinary approaches incorporate a wider body of knowledge, which helps assess the transdisciplinary challenge of climate change (e.g. Hegger et al. 2012). Interactive modelling through tools such as companion modelling aids transdisciplinary collaboration. The joint conceptual framework and exploration of role-playing games and computer simulations leads to an understanding of the underlying processes.

Despite including major human-human and human-environment interactions, it is not feasible to comprehensively consider the whole system and all its interactions (Turner et al. 2003). It remains important to be aware that each system is complex, involves stochasticity, and is nonlinear. Dynamic future-focused research necessarily deals with uncertainty. However, uncertainty should not paralyse decision making processes (Kaján & Saarinen 2013; Scott 2011). Understanding of where uncertainties lie and how they can develop is more helpful than incomprehension of the unknown.

Taking a dynamic approach necessitates researchers giving up control of the end product and sharing ideas with non-experts. Nonetheless, focusing on vulnerability's dynamic nature enables more flexibility in thinking. Both actors and researchers learn more about the system during interactive processes. Aggregate information is less useful for decision-making in a local context. Vulnerability approaches are more effective in understanding vulnerabilities and improving adaptive capacities when the local context is considered, when some of the interactions and complexity are identified, and when the approaches provide a means for improving decision-making and implementation (Turner et al. 2003).

3.8. Conclusions

Vulnerability and adaptation are continual processes as they affect and are affected by human-human and human-environment interactions. Research has shown that vulnerability and adaptive capacity are dynamic, and demonstrate a growing need for new approaches to study this challenge. This research responds to the need for a dynamic conceptualisation of vulnerability as aggregate vulnerabilities are not enough for us to understand who and what is vulnerable and how these vulnerabilities emerge. This paper has argued that a dynamic problem (vulnerability) requires a dynamic approach. Understanding interactions is crucial, but how to approach this problem is less clear. The study has identified possible ways to operationalise a dynamic approach using interactive modelling and engaging local actors. Interactive modelling (using a companion modelling approach) is a promising tool to conceptualise vulnerability and adaptive capacity as dynamic phenomena. Engaging local actors and experts throughout the process of conceptualising improves understanding of the system for both researchers and local actors.

Moreover, this study also aligns with previous research that suggests that tourism destinations' adaptive capacity deserves more focus (Kaján & Saarinen 2013). Few studies have focused explicitly on adaptation for coastal tourism and most climate change tourism literature to date has focused on North America, Western Europe, New Zealand, and Australia (Becken 2013a). Moreover, transdisciplinary studies are limited (ibid). By engaging local actors in the process, both researchers and those affected by climate change gain a better understanding of the macro problem and the interconnectedness. Diverse transdisciplinary approaches help manage complex questions such as vulnerability (Eakin & Luers 2006). Improved understanding of vulnerability may lead to new insights for adaptive management in tourism destinations.

This process will be further adjusted to coastal tourism and will focus on a local tourism destination. Nonetheless, wider applications of this approach exist. First, by adjusting and applying the approach to other local Caribbean destinations, similar and/or distinct patterns and interactions can be identified. This dynamic process even has applications outside of tourism science. Companion modelling has largely been used for agricultural human-environment systems, but can be adjusted to analyse vulnerability in other human-environment contexts.

A DYNAMIC VULNERABILITY APPROACH FOR TOURISM DESTINATIONS

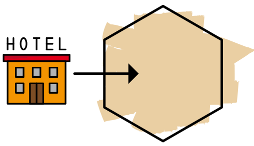
4

A DYNAMIC VULNERABILITY APPROACH FOR TOURISM DESTINATIONS

We understand that vulnerabilities are changing for tourism destinations, but what do we need to consider? Using a coastal tourism destination as an example, we show five principles needed for dynamic vulnerability assessments.

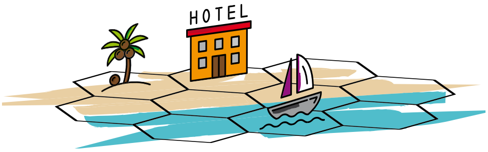
Five Principles

1 HUMAN AGENCY



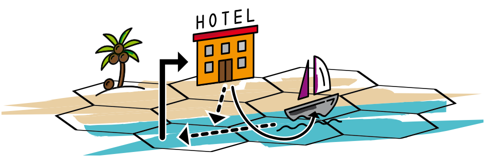
Tourism operators (e.g. hoteliers) affect the coastal destination with their decisions and actions

2 HETEROGENEITY



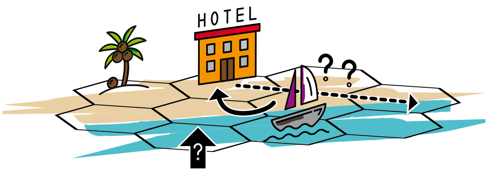
Destinations have varied operators (hoteliers, boat companies) and natural resources (sand, sea)

3 FEEDBACKS



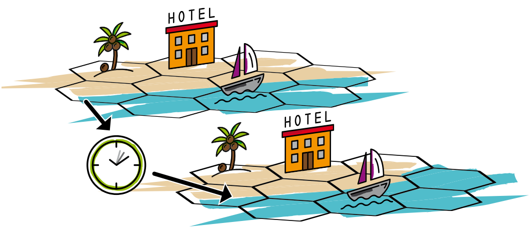
Operators and the coastal environment are interlinked bringing about individual and destination level change

4 UNCERTAINTY



How, when, to what extent, and who will be affected by internal and external change is unknown

5 ITERATION



Change is ongoing and vulnerability is a moving target

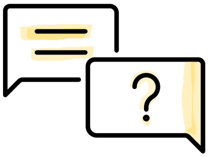
But how can we research these changes?

Methodological tools of a dynamic vulnerability approach

DESKTOP RESEARCH

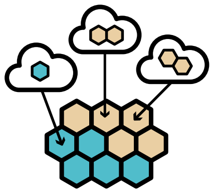
Identifies key operators and natural resources features related to agency, heterogeneity, feedbacks, and uncertainty

INTERVIEWS



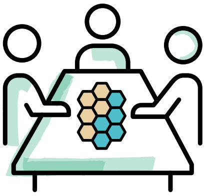
Identifies stakeholders' perceived agency, natural resources, their interactions, and uncertainties

SIMULATION DEVELOPMENT



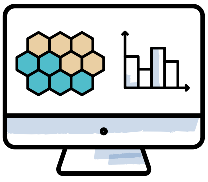
Combines and integrates individual perceptions with the environmental context to investigate how it functions at the destination level

SIMULATION SESSIONS



Identifies key operators and natural resources features related to agency, heterogeneity, feedbacks, and uncertainty

COMPUTATIONAL MODELLING



Explores and experiments with multiple scenarios of uncertainty applying different levels and types of heterogeneity and feedbacks on destination vulnerability

Involving stakeholders and using these methodological tools enable us to explore and better understand emerging vulnerabilities such as sea-level rise

Abstract

Tourism destinations are vulnerable to increasing environmental change. The available scientific knowledge, however, is of little practical use as it is too aggregate, too conceptual, or too static. Various authors have called for dynamic vulnerability assessments, but the principles for dynamic vulnerability assessments have not been specified nor is it clear how to operationalise these principles. This paper formulates five principles: human agency, heterogeneity, feedbacks, uncertainty, and iteration. To address these principles, it proposes a dynamic approach that involves stakeholders. The approach's proposed methodological tools enable system integration as well as the opportunity for both researchers and stakeholders to experience and experiment with dynamic vulnerabilities, which is key to moving beyond aggregate and static assessments. To demonstrate some of the approach's added value for tourism destinations, a short illustration is provided of the critical challenge of sea-level rise for coastal tourism in the Caribbean islands of Barbados and Curaçao. Future application of the approach can extend well beyond Caribbean coastal destinations to any other tourism destination vulnerable to environmental change.

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4.1. Introduction

Climate change has been identified as one of six mega trends affecting tourism (Buckley, Gretzel, Scott, Weaver, and Becken (2015). Some of the main segments of the tourism market, in particular alpine winter tourism and coastal tourism, rely heavily on environmental features that are vulnerable to climate change (Scott, Gössling et al. 2012; UNWTO-UNEP-WMO 2008). In recent years, tourism researchers have started to address tourism's vulnerability to climate change. Perch-Nielsen (2010) conducted a country-by-country analysis of vulnerability based on high-level indicators such as GDP, Moreno and Becken (2009) designed a destination-level vulnerability assessment based on hazard-activity pairs, Calgaro and Lloyd (2008) identified 13 key interlinking factors that contributed to vulnerabilities to external shocks, and Santos-Lacueva et al. (2017) provide an overview of vulnerability assessments. While these studies represent significant advances in scientific knowledge, the practical applicability of this knowledge has so far been limited. As Cashman, Cumberbatch and Moore (2012 p. 27) note: "one of the barriers facing the adaptation of the tourist industry is the lack of data generated by appropriate research and development". Given the prominence of tourism in many coastal areas and the potential magnitude of climate change impacts, the disconnect between research and practice is a critical problem.

Triggered by the lack of practical knowledge about vulnerability, Calgaro, Lloyd and Dominey-Howes (2014 p. 347) were the first to systematically map out and categorise the "factors and processes that create and perpetuate destination vulnerability and resilience, along with the social actors and agenda that drive action and non-action". They created the Destination Sustainability Framework (DSF) and applied it in a follow-up publication (Calgaro, Dominey-Howes et al. 2014). DSF has further been applied to other tourism vulnerability case studies by Van der Veeken et al. (2016) and Pyke et al. (2018). The studies informed by Calgaro, Lloyd, et al. (2014) are examples of systems approaches in tourism research, which as Becken (2013b) and Amelung et al. (Chapter 2) note are rare. Espiner, Orchiston, and Higham's (2017) analysis of tourism sustainability and resilience concepts highlights the need to include complex socio-ecological systems thinking. Systems approaches can provide insights on the emergence of environmental and social vulnerabilities, resulting from the many interactions in socio-ecological systems, i.e. complex adaptive systems linking people and the environment (Levin et al. 2013). The impacts of climate change on destinations, for example, become manifest at very different moments in time (Gössling et al. 2012), depending on the kind of impact and the destination's characteristics. As a result, vulnerability is a constantly moving target and must therefore be understood as a dynamic phenomenon (Adger 2006; Rhiney 2015). Accepting that vulnerability is dynamic changes the framing of destinations' vulnerability challenges and their set of appropriate responses. It also changes the kind of research that is needed to support destinations' decision-making processes and adapt destination management strategies. Without knowledge of vulnerability dynamics, decision-makers have limited scope when creating and applying measures to reduce vulnerabilities and improve resilience (Calgaro Lloyd et al. 2014; Duvat et al. 2017; Rhiney 2015).

The dynamic nature of vulnerability is closely connected to the high prevalence of climate inaction in many sectors, including tourism (Bruno et al. 2018). Climate change's reality and disruptive potential is now beyond dispute, but the type, severity, and timing of its impacts on places is uncertain and often unpredictable. Climate change is oftentimes not experienced directly, which makes it an elusive phenomenon (Giddens 2009) that is difficult to connect with everyday choices. This inspires inaction as it delays mitigation actions of governments, companies, and citizens. Santos-Lacueva et al. (2019) examined the influence and limitations of stakeholders' understanding of climate change risk on public action in coastal tourism destinations. Winn et al. (2011) observe that companies' persistent belief that "current economic and social conditions will continue to flourish regardless of unfavourable biophysical conditions in Earth's natural and climate systems" inspires a risk management approach that is incompatible with the scope, scale, and systemic uncertainty that characterise climate change impacts. Moreover, a growing literature is devoted to understanding the psychological and sociological drivers of inaction in response to climate change (Amel et al. 2017; Cohen et al. 2013; Gifford 2011). The recent 'climate services' literature builds on this work, attempting to overcome some of the barriers of inaction (Lemos et al. 2012) by bridging the gap between producers and end-users of climate information. In a sense, climate services address the lack of personal sensory experience of climate change and the difficulty of identifying and evaluating the available courses of action; climate services make climate impacts more personal and 'tangible' and provide stakeholders with a scope of action to base their decisions on, so that learning can take place. Filimonau and De Coteau's (2019) findings suggest that collaboration with stakeholders in tourism is key to breaking this gap between climate information and effective action. We argue that better addressing these same two elements (i.e. making impacts tangible and providing a scope of action) are key conditions for producing more meaningful and usable vulnerability assessments, and that we need different methods in order to do so (Lalicic & Weber-Sabil 2019).

In its basic form, dynamic vulnerability involves people, environmental resources, space, and time, and most importantly, the interactions among these factors. These factors and interactions are all part of Calgaro, Lloyd, et al.'s (2014) seminal and hitherto unmatched work, which clearly advances our conceptual understanding of what to take into account when studying dynamic vulnerability. However, its guidance on how to do that is limited.

Calls for systemic and dynamic approaches to vulnerability assessments in tourism are not uncommon (Becken 2013a; Cinner et al. 2018; Duvat et al. 2017), but attempts to formulate the principles of such assessments and provide practical guidelines to performing a dynamic approach are. This paper aims to address that knowledge gap by answering the question "How can we research vulnerability as a dynamic phenomenon in (coastal) tourism destinations?" It lays out a new approach for performing dynamic vulnerability assessments that emphasises interaction and change, and illustrates the merits of the approach by applying it to the two Caribbean case study areas of Barbados and Curaçao to assess their vulnerability to sea-level rise (SLR), one of the better known consequences of climate change (e.g. Nurse et al. 2014; Rhiney 2015; Scott, Simpson et al. 2012). The dynamic vulnerability approach and tools presented in the paper can also be applied to other tourism destinations, while the underlying concepts can be applied to vulnerability challenges in other sectors.

The paper has the following sections. The first section formulates a set of key principles pertaining to a dynamic vulnerability assessment, taking Calgaro, Lloyd, et al.'s (2014) Destination Sustainability Framework (DSF) as its point of departure. The second section describes a dynamic approach with concrete methods to achieve these principles. The third section illustrates the added value of the approach. Subsequently, the discussion explores the approach's merits and notes limitations. Lastly, the conclusion highlights the scientific and societal relevance of the approach for tourism destinations and indicates promising avenues for further research.

4.2. Principles for dynamic vulnerability assessments

A vulnerability assessment is a process of identifying, quantifying, and prioritising the vulnerabilities in a system. Vulnerabilities in highly dynamic systems, such as the socio-ecological systems underlying coastal tourism, are in constant flux, so that static assessments are of limited use. Effective assessments take account of what vulnerabilities change, how that happens, and who is affecting and affected by change. They consider how the interactions among space, environment, people, and time emerge. To use a camera metaphor, we need our scientific lens to act like a video camera that captures emerging vulnerabilities rather than like a photo camera that takes a snapshot of vulnerabilities at a specific moment in time.

Sticking with the camera metaphor, this section aims to formulate some of the technical specifications that our video camera should possess in order to be effective, based on the current level of technology. It aims to formulate key features that dynamic vulnerability assessments should possess in order to be effective. Such assessment principles have not yet been described explicitly, but several of them strongly emerge from the literature. Calgaro, Lloyd, et al.'s paper (2014), which integrates much of that literature, clearly implies that vulnerability assessments for tourism systems should account for human agency, heterogeneity, feedbacks, and uncertainty, even though it does not explicitly state these principles. To this list of four principles inspired by Calgaro, Lloyd, et al. (2014), we propose to add iteration as a fifth, to acknowledge the necessity of accounting for ongoing interactions and the preference of repeated engagement with stakeholder communities. The five principles of human agency, heterogeneity, feedbacks, uncertainty, and iteration are described in the following section.

4.3. Principles

4.3.1. Human agency

Humans play an undeniable role in socio-ecological systems and need to be considered in dynamic vulnerability assessments. Humans create and perpetuate many feedbacks of these systems (Larsen et al. 2011), and by doing so, shape future options for development (Folke et al. 2016). A pragmatic approach to complex socio-ecological issues therefore requires stakeholders' information and collaboration (Pahl-Wostl et al. 2007). It also requires stakeholders' perspectives. According to Pahl-Wostl et al. (2007), people use mental representations of their physical and social environments to attach meaning to these environments and to information about them. Adger (2006 p. 276) even suggests that vulnerability could be "measured directly through perceptions of those that are vulnerable". In a similar vein, Calgaro, Lloyd, et al. (2014) recognise that human agency influences differential vulnerability patterns.

Tribe and Liburd (2016) signal a lack of local and tacit knowledge in tourism research and highlight a mismatch between scientific knowledge on the one side and local knowledge and stakeholder perceptions on the other. The Barbadian coral reef use for tourism serves as an example. Oxenford et al. (2008) conclude that Barbados depends on coral reefs and needs a management plan. In contrast, Uyarra et al. (2005) find that tourists do not value the Barbadian coral reefs as highly as the reefs in Bonaire, a popular dive destination; sea turtles and water clarity are more important for enjoyment in Barbados. As tourism service providers (e.g. hoteliers, water-sports, beach activities) tend to respond to tourist demand, their actions may not align with what would appear logical from an expert perspective. Understanding this potential mismatch can help unveil emerging vulnerabilities, barriers to act, and potential opportunities to improve adaptive capacity.

Stakeholders face a variety of obstacles when responding to change. In Barbados, for example, high financial investment costs and low perceived returns were found to be barriers to improving water systems (Charara et al. 2011). In the context of small island states, Becken et al. (2014 p. 955) conclude that the lack of investment in risk reduction "is interrelated with deficient planning processes, on-going demand for coastal products, lack of political will, and poor environmental conditions". Stakeholders can provide valuable input by identifying the obstacles and trade-offs they face, the resources they use, the opportunities they perceive, and the actors they interact with. Their participation in research is therefore critical to understanding human agency in the system.

Knowledge about stakeholder decision-making processes is crucial for devising effective governance arrangements for the (global) commons (Levin et al. 2013). Moreover, understanding agency is key for adaptation (Cinner et al. 2018). Most adaptation measures that address the local context not only affect stakeholders' livelihoods, but also need local support for implementation (Csete & Szécsi 2015; Pahl-Wostl et al. 2007). Incorporating stakeholders' understanding of the system and environmental challenges in which they operate is therefore critical, as is knowing which actions local stakeholders are willing to take and which environmental resources stakeholders are willing to protect.

4.3.2. Heterogeneity

Stakeholders, environmental features, and system interactions in the tourism system are inherently diverse. Heterogeneity refers to the range of diversity present in the system, which includes diversity within and among individual components across varying spatial and temporal scales. This heterogeneity contributes to non-linear change and increases system complexity (Darbellay & Stock 2012; Levin et al. 2013) as they combine in divergent ways. Since heterogeneities imply the need for context specific adaptation measures rather than general ones (Duvat et al. 2017; Rhiney 2015), accounting for heterogeneities is a key principle of dynamic vulnerability assessments.

Destination actors differ from one another in many aspects, including resource use, coping capacities, decision-making, and power. This paper focuses on one particular type of actor: individuals working for (commercial) tourism businesses in coastal destinations. To refer to these actors, we use the term 'tourism operators', not to be confused with the distinct term 'tour operator', which refers to a company combining and packaging different tourism products and services. Tourism operators, then, vary with respect to the tourism services they provide, the parts of the coastal system they use (e.g. beach, nearshore waters, underwater areas), and their assets (e.g. permanent infrastructure or boats). Actors also have unique individual thresholds (Adger 2006). Tourism operators differ in their capability and willingness to attract tourists, prevent local environmental problems, and respond to new environmental challenges. Moreover, tourism operators can decide to act individually or collectively. They also differ in their connections and power relationships with other operators as well as local community and global markets. These heterogeneities strongly affect who is vulnerable to what, in what ways, and under which circumstances.

Heterogeneity is also ubiquitous in the environment. In the coastal system, for example, environmental features range from sand to nearshore water and coral reefs. Moreover, environmental change occurs at diverse spatial and temporal scales (Calgaro Lloyd et al. 2014). The scope of impacts ranges from individuals (e.g. coral deterioration at a dive site) to the industry as a whole (e.g. coral bleaching throughout the region). As Adger and Brown (2009 p. 110) point out, "virtually all natural hazards and human causes of vulnerability impact differently on different groups in society". Heterogeneity in time and severity are characteristic of vulnerability dynamics: "what is vulnerable in one period is not necessarily vulnerable in the next period" (Adger 2006 pp. 275–276). Environmental vulnerabilities themselves are heterogeneous as well, because the external threats that define them are. External threats can come in the form of shocks or stressors (Turner et al. 2003); shocks are quickly-developing events, whereas stressors are gradually developing phenomena that have increasingly serious consequences. To understand context specific dynamics of vulnerabilities as well as relevant adaptation measures, heterogeneity needs to be included.

4.3.3. Feedbacks

Another key feature of interactions is feedbacks. Humans and the environment interact in a system that has dynamic, interlinked components and processes (Turner et al. 2003). In the context of tourism, Perch-Nielsen (2010) observes that the interactions between environmental change and tourism are complex, including direct and indirect effects, and multiple possible responses. The possibility of response implies that relationships are not exclusively unidirectional, but also reciprocal, with the system feeding back into itself. Tribe and Liburd (2016) recognise that within a (tourism) system, feedbacks are key for linking inputs, outputs, and processes.

In socio-ecological systems, such as tourism systems, feedbacks are often nonlinear (Folke et al. 2016; Levin et al. 2013). Feedbacks bring about changes at the individual and system level. The collective effects of individual actions manifest at the system level, and in turn affect the options available to individuals (Levin et al. 2013; Scott Gössling et al. 2012). Adaptation is a form of feedback-driven co-evolution. Duvat et al.'s (2017) reveal path dependencies in adaptation, and Csete & Szécsi (2015) note that adaptation is not an isolated event but an ongoing process requiring actions at various spatial, institutional, and temporal scales. Thus, feedbacks help us consider nonlinearities of change effects on vulnerability, resilience, and adaptation, and are necessary in a dynamic vulnerability assessment.

4.3.4. Uncertainty

Tourism is recognised as a complex system (e.g. Chapter 2; Baggio 2008), characterised by uncertainty. Important contributors to uncertainty are the timing, scale/size, type and frequency differential of shocks and stressors (Calgaro Lloyd et al. 2014), of which climate change, accelerating socioeconomic development, globalisation (Pahl-Wostl et al. 2007), and tourism flow trends are of particular relevance. Uncertainty is also part and parcel of future-oriented approaches. For example, we do not and cannot know when climate change impacts will become relevant for tourism destinations (Gössling et al. 2012), how changes of sea-level rise can combine with other events such as droughts and shifts in the seasonal pattern of tourist demand, nor how external shocks and stressors interact with local dynamics (Folke et al. 2016). Since uncertainty in future-looking approaches cannot be avoided, it must be embraced when assessing vulnerability and forming adaptation strategies (Larsen et al. 2011). As such, dynamic vulnerability assessments necessitate considering how uncertainty affects and is related to human agency, heterogeneity, and feedbacks.

4.3.5. Iteration

Continuous change is an undeniable reality we face. Outcomes of feedbacks create cycles of procedural and structural change (Pahl-Wostl et al. 2007), which is something a dynamic approach must account for. Iterative processes enable learning, adaptation, and flexibility. Several authors see iterative processes as a key strategy in dealing with changes and uncertainty. In this context, Folke et al. (2016) highlight the need to accumulate knowledge, apply systems thinking, encourage learning, and increase participation. Duvat et al. (2017) argue for a dynamic understanding of vulnerability, including continuous reconceptualisation of problems and processes in order to better inform the design of adaptive measures. Pahl-Wostl et al. (2007) propose participatory approaches and adaptive management to speed up the learning cycle. A faster learning cycle would enable more rapid assessment and the incorporation of new insights into policies and research agendas (Adger 2006). Thus, iterative processes are not only essential for dynamic vulnerability assessments, but also for adaptation.

4.4. From principles to the dynamic vulnerability approach

This section outlines how the principles can be operationalised in a dynamic approach for tourism. The approach consists of three complementary phases. The first phase 'scoping' aims at investigating the space, environment, people, time, and interactions, and identifying key components of human agency, heterogeneity, feedbacks, and uncertainties. The second phase 'system integration' centres on bringing these components and interactions together, and raising awareness among stakeholders about their position in the system they are operating in. The third phase 'experiencing and experimenting' provides stakeholders and researchers with a virtual setting in which they can experience and experiment with changes to the system, including stakeholder interactions. In particular, the second and third phases set the dynamic vulnerability approach apart from traditional assessments.

The dynamic approach offers a set of tools that can be tailored to suit the requirements of the case at hand and be applied in different phases. For the purpose of this article, the approach is described in a linear format. However, future case studies do not necessarily need to follow this particular order nor use all of the methods presented. The process is iterative and each stage offers the opportunity for reflection and adjustments in approach, tools, and system representation. The insights required, rather than the order, should be prioritised when planning future research.

The dynamic vulnerability approach presented below consists of five main methods: desktop research, interviews, simulation development, simulation sessions, and computational modelling. The methods can be flexibly used in multiple assessment phases, but desktop research and interviews were used in the scoping phase, interviews and simulation development in the system integration phase, and simulation sessions and computational modelling in the experiencing and experimenting phase. This mix of methods is complementary; the information gained through one method (e.g. interviews) is used as an information source for another (e.g. simulation development). The methods provide multiple means to improve understanding of each of the principles.

The essential role of humans in tourism systems favours a participatory approach. Participation can be achieved through interviews, simulation development, and simulation sessions. All methods can indicate missing or contested information that hinders understanding of the system and its vulnerabilities, and these knowledge gaps can be targeted in subsequent iterations. Table 4.1 explains the connections between principles and recommended tools.

Table 4.1. Dynamic vulnerability approach insights- matrix of the five principles of dynamic assessments with methods

Principles	Desktop research	Interviews	Simulation development	Simulation sessions	Computational modelling
Human Agency	- Inventorise potential actors and actions	- Note stated perceptions	- Integrate actions with environmental context	- Apply perceptions in a dynamic group setting - State perceptions of actions of different participants - Observe actions and responses	- Apply and test of behaviour rules in scenarios
Heterogeneity	- Identify key potential human and environmental differences	- Identify key stated and perceived differences	- Explore different roles and scenarios - Include human, environmental, spatial, and temporal differences	- Experience changing heterogeneities - Explore participants' responses - Test the implications of different heterogeneities	- Apply human and environmental heterogeneities to virtual version of coastal setting - Experiment with different types and levels of heterogeneities
Feedbacks	- Identify existing observations	- Note perceived feedbacks	- Check implications of individual feedbacks on wider system	- Experience change - Observe participants' responses	- Test implications of feedback mechanisms on virtual world
Uncertainty	- Identify future potential scenarios and knowledge gaps	- Identify perceived uncertainties	- Incorporate uncertainties	- Stakeholders reactions to uncertainties	- Introduce uncertainties (e.g. added randomness) - Explore and experiment with different levels of uncertainties
Iteration	- Initial process set-up	- Combine interviews with system information (simulation-guided interviews)	- Companion modelling process - Revisit islands - Improve process - Adapt approach to new context	- Show stakeholders - Improve process - Update simulation to include insights from previous sessions	- Specify human and ecological mechanisms

4.5. The methods

Desktop research, based on secondary data, can be used to ascertain which regions most urgently require dynamic vulnerability assessments and what previous assessments have already accomplished. Insights of environmental feedbacks are often derived from available scientific literature. System mapping helps set up initial parameters of the research in terms of space, environment, people, and time. Local experts can indicate context specific issues as well as documents to review and stakeholders to contact.

Interviews aim to fill in knowledge gaps on human agency. They shed light on stakeholder heterogeneity, resource use, and perceptions of (environmental) trends, risks, and threats. Interviews can also reveal stakeholders' coping capacities, willingness to act, trade-offs, and perceived obstacles. The knowledge representation method ARDI (which stands for actors, resources, dynamics, and interactions) is a way for structuring interview questions to help stakeholders co-create system representation (Étienne et al. 2011). Moreover, ARDI enables the transfer of interview data into simulations or computational modelling such as agent-based modelling. Semi-structured interviews are a common interview format for collecting data. Simulation-guided interviews are an innovative way to generate more specific information on how and where stakeholders act in the systems and how they respond to changes. Simulation-guided interviews use parts of the physical simulation, such as the spatial setting, the environmental features, actors, and scenarios (see Figure 4.1). This enables stakeholders to position themselves and describe and co-construct the resources they use in the context of the larger (coastal) system.

Simulation development is the process of combining the various pieces of system information together with stakeholders. This process helps involve stakeholders and makes individual inputs to system change more tangible. Simulation development can result in a simulation (or serious game) or a model, but it can also simply be a tool to include stakeholders in understanding the

Figure 4.1. Simulation-guided interview with parts of the simulation represented

system and problem. Stakeholders, researchers, and technical experts can participate in simulation development. A particularly useful form is Companion Modelling (ComMod), an iterative approach to stakeholder engagement and simulation/model co-development (Étienne 2014). ComMod has been applied to a number of complex natural resource and land management problems, including forestry management (Simon & Étienne 2010) and watershed management (Souchère et al. 2010). The simulation-guided interviews help check how the current system representation aligns with stakeholders' perceptions and help make improvements. Alternatively, focus group sessions can be organised.

Simulation sessions, also referred to as serious games or interactive sessions, are meetings where people are given different roles and go through different rounds and scenarios in a particular spatial and temporal setting. The people invited to the simulation sessions can be selected experts as well as stakeholders. The roles they take may reflect their real-life roles or those of other stakeholders. During simulation sessions, participants are exposed to a sequence of events that stakeholders (need to) act on. Participants interact with their environment and other participants. Depending on the simulation's design, they may decide to respond individually or choose to collaborate or compete with others. Their actions may then change their capacities, their environment, actions available to them in the future, as well as how other participants (can) respond. Some simulations are reminiscent of board games, such as Catan® or other table top games (e.g. Souchère et al. 2010), while others use virtual platforms (e.g. Simon & Étienne 2010) or free-form role playing (e.g. Brown et al. 2017). Simulation sessions are new for many stakeholders, who are more accustomed to surveys and interviews. As a result, some may feel hesitant to participate. The use of simulation-guided interviews in the earlier stages can help stakeholders feel more comfortable to participate in simulation sessions. Moreover, pre-testing the simulation with simulation specialists, context experts, and stakeholders helps ensure the playability of the game and how well it is suited for studying the system of interest. Lalicic and Weber-Sabil (2019) provide an overview of serious game design for tourism.

Simulation sessions enable researchers to test the information about human agency, heterogeneities, and feedbacks provided by individual interviews, in a dynamic group setting. Researchers can observe how stakeholders respond to changes in their system, and how stakeholders change their behaviour and strategies. Also, researchers can explore the role of uncertainty, by introducing new events, actors, resources, or randomness in the simulation sessions. In the sessions, stakeholders experience change resulting from combinations of environmental processes, external pressures, and other stakeholders' decisions. Simulation sessions enable participants to perform their unique strategies within the system. Thus, they are a means of understanding and enabling human agency and social learning.

Computational modelling helps bring together knowledge about different parts of the system and test the effects of heterogeneity, feedbacks, and uncertainties under different conditions. Agent-based modelling (ABM) is a particularly useful approach for expressing complex human-environment systems in a model as it can represent individual entities (such as tourism operators) and their environment (e.g. a coastal destination with beach and sea) and enable interactions to occur over space and time. ABM can function as a platform for integration, helping to better understand the complex interactions in the tourism system (Nicholls et al. 2017). ABM allows for heterogeneity by accommodating a variety of actors, environmental features, and resources (Levin et al. 2013) instead of requiring an aggregate to represent all tourism operators' (e.g. capacities and resource use) and environmental characteristics.

ABM permits testing of feedbacks under different time frames and multiple scenarios. ABM can thereby help assess how these interactions result in different levels and types of vulnerability in different parts of the systems (e.g. loss of beach area), individual entities (e.g. number or type of operators that go bankrupt), or overall results (e.g. environmental degradation). With known factors and processes (e.g. of resource use, behaviours) as inputs, ABM facilitates the exploration of emerging patterns, such as what types of vulnerabilities emerge when the system is exposed to external shocks and stressors, ranging from environmental changes to changes in tourism demand. ABM can address uncertainty by enabling the user to explore multiple combinations of start-up values, actor and environmental actions, and scenarios, many more than can be addressed in a single simulation session. In addition, ABM can introduce different degrees of randomness, for example, in decision-making, and the occurrence, order, and intensity of events. However, application of ABM to tourism is limited. ABM requires time and technical skills to develop the conceptual framework and write code. Johnson et al. (2016) propose ways to improve the accessibility.

4.6. Illustrating the dynamic vulnerability approach: lessons from Barbados and Curaçao on sea-level rise

This section intends to give a flavour of the potential of the dynamic vulnerability approach by using it to assess the effects of sea-level rise (SLR) in Barbados and Curaçao, two coastal tourism destinations in the Caribbean (see Figure 4.2) where the approach for dynamic vulnerability

Figure 4.2. Map of the Caribbean case studies (QGis- Natural earth pkg.)

assessment was developed. Among the many climate-related challenges that coastal destinations face, SLR is a particularly critical issue for small islands, including those in the Caribbean (Nurse et al. 2014; Rhiney 2015). For example, Scott, Simpson et al. (2012) demonstrate that approximately 29% of Caribbean coastal tourism resort properties would be affected by 1m SLR and between 49-60% by the combination of SLR and coastal erosion. However, the differential effects of SLR to coastal tourism destinations require more attention (Rhiney 2015). What follows is a description of how the dynamic vulnerability approach was applied in Barbados and Curaçao, and a presentation of key findings that were gained about the tourism sector's vulnerability to SLR.

4.6.1. Overview of application of the approach

The Caribbean archipelago counts 13 sovereign island nations and 12 dependent territories. This abundance of potential cases allowed us to select based on a mix of substantive and pragmatic grounds. Access to local stakeholders and data availability through Barbados's extended history of coastal tourism and research made Barbados an attractive first case study to develop the approach. To test the generalisability of the approach to (Caribbean) coastal tourism destinations, Curaçao was selected as a second case. Curaçao faces similar climate challenges as Barbados, but the relative lack of research on climate change and coastal tourism is a critical knowledge gap. The case study on Barbados (with study visits in 2015 and 2016) was completed before starting research on Curaçao (with visits in 2016 and 2017). The phases of scoping, system integration, and experiencing and experimenting were completed on both islands, but with different levels of emphasis.

For this illustration, Barbados therefore provides the context for the first steps (literature review, interviews, simulation development), whereas Curaçao provides the backdrop for simulation sessions and computational modelling. The case studies focus on the relatively understudied supply side of tourism, and more specifically on tourism operators. Tourism operators have a critical impact on the coastal system and are characterised by high vulnerability and limited adaptive capacity (e.g. Kaján & Saarinen 2013; Moreno & Becken 2009). The studies focus on the present and the next 20 years until approximately 2040. This timeframe bridges the shorter time scales of island tourism policies (5-10 years) and the longer ones of different environmental change processes such as SLR.

4.6.2. Scoping

Scoping of initial parameters of space, environment, people, and time started with desktop research. Desktop research took multiple forms including literature review, contact with location experts, as well as initial system mapping of the key stakeholders, environmental resources, and likely environmental changes (e.g. SLR). Barbados, like many Caribbean islands, has been identified as being vulnerable to losing beach areas and infrastructure to SLR (e.g. Fish et al. 2008; Scott, Simpson et al. 2012). Location experts helped identify key government institutions and tourism-related stakeholders, pinpoint local studies, and some gave historical context of environmental challenges and climate policy. For both islands, tourism is an important economic activity; in Barbados tourism contributed approximately 40% of GDP in 2016 (WTTC, 2017) and, according to the Curaçao Tourism Board (CTB, 2015), tourism's share in Curaçao's GDP was approximately 18% in 2015. In addition to desktop research, 62 semi-structured interviews were conducted during the first fieldwork trip to Barbados to expand the knowledge-base. As the goal was to better understand emerging vulnerabilities in coastal tourism, most interviewees were tourism operators (39), but other individuals with coastal tourism expertise, such as local (research) experts (5), government officials (13), and NGO representatives and tourism-related parties (5), also participated. Table 4.2 details examples of the semi-guided interview questions.

Table 4.2. Example interview questions for understanding emerging vulnerabilities using ARDI

Focus	Questions
ARDI	
Actors	What is your role in tourism services? What do you need (information, other resources) in order to enable decision-making?
Resources	What resources do you need and how often do you use them?
Dynamics	What environmental conditions do you need to provide your tourism services? What changes to environmental resources/tourism have you observed?
Interactions	What types of tourists do you depend on? What type of (other) tourism operators do you rely on? How do you use environmental resources?
TOURISM OPERATORS' PERCEPTIONS	
Vulnerabilities	What vulnerabilities do you perceive? What changes or challenges do you anticipate for environment and tourism? In what ways can changes affect you?
Uncertainties	What are the most important uncertainties for you related to tourism? In what ways can uncertainties affect you?
Adaptation	What actions can be taken to lower vulnerability? By whom?

4.6.3. System integration

Simulation development brought the individual fragments of information together in a largely participative way. It was used to co-create the *Coasting* game, a simulation aimed at exploring emerging environmental vulnerabilities to a coastal tourism destination. Participation in simulation development took several forms: interviews (parameter identification through ARDI questions) (in Barbados and Curaçao), focus group sessions (two in Barbados), simulation-guided interviews (in Barbados and Curaçao), and game testing. The interviews provided the information to start developing the operators' profiles (e.g. decisions, trade-offs, interdependencies). During the focus group sessions, the participants collaboratively mapped and discussed their coastal system using the ARDI format. The simulation-guided interviews gave actors a visualisation of the system as a context to discuss their role in the system. Simulation-guided interviews further enabled stakeholders to describe and to physically co-construct the resources they use, their location, and inputs in terms of the larger coastal system context. This improved the set-up of the system representation and verified tourism operators' profiles and resource use. Moreover, they helped address the challenge of bringing people together for simulation sessions. In Barbados, stakeholders were approached with simulation-guided interviews so that data could be collected without requiring small groups. In Curaçao, simulation-guided interviews were used to familiarise stakeholders with the concept of simulations and adapt the game to Curaçao's context. Combined, these activities determined the set-up of the *Coasting* simulation, the input categories of the operators, and the flow of interactions. Tests of a beta-version of the *Coasting* game improved the game's flow, exposed inconsistencies, and identified questions stakeholders had.

4.6.4. Experiencing and experimenting

The information brought together was explored and tested in simulation sessions of the *Coasting* game and were used to observe tourism operators' behaviour and interactions in a dynamic setting. The sessions explored questions such as what (environmental) changes participants noticed; which environmental changes they were willing to respond to and how; when and how they changed their strategies; and if and when they decided to collaborate. The sessions involved three to eight stakeholders, each playing at least one of the four main types of tourism operator roles in the coastal system: hoteliers, beach vendors, nearshore operators (e.g. surfing, jet skis, stand-up paddling), and dive or boat operators. The physical features of the coastal system were represented by the *Coasting* game board, which consists of a flexible set of tiles (see Figure 4.3). The board embodies a simplification of the following environmental features: nearshore waters, deep sea, beach area, inland, coral reef, fish, sea turtles, and mangroves; these features are put together to reflect the general context of the tourism destination.

Figure 4.3. *Coasting* simulation

The *Coasting* game was played for three to five rounds, mimicking the passage of time. Each round, all players allocated their operational input categories in order to keep in business and the mobile operators decided individually about the location of their operations. Players were subsequently exposed to one of six different challenges with varying levels of severity: increased tourism inputs required, coral bleaching, coastal erosion, storms (varying from storm surge from a passing storm to a hurricane), drought, or a new unknown event. Coastal erosion was the proxy for SLR given the short playing time of the simulation. In the game, when coastal erosion occurred, the coastal tiles were replaced with randomly selected new tiles, many of which represented beach loss. Players then decided whether to respond to the challenges and how, either individually or collaboratively. Depending on the action taken, the challenge affected the next round of the game, either through changes in the environment or operational budgets.

During the simulations, behaviours and decisions were observed in multiple ways. Players filled in their operational input decisions on a form at the beginning of each round. If new challenges affected their operations, they recorded these changes in their input sheets. In addition, an observation protocol was used to code extra information about the players' behaviours. The simulation sessions ended with a debriefing, in which players could discuss what happened, what moments were important, and what influenced their decisions. In addition, they could reflect on the similarities and differences between the game and their real-life experiences.

The agent-based model, developed in NetLogo 6.0.4., mimics the *Coasting* simulation: it simulates tourism operators and the coastal setting has similar environmental features (e.g. beach, coastline, nearshore waters). The model's operator decision rules were based on behaviours observed during the simulation sessions: simulated operators have individual preferences for their input budgets, and can act alone, collaborate, or do nothing. To explore the emergence of vulnerabilities for tourism operators and the environment in relation to SLR, different levels of SLR were introduced into the system. The outputs of SLR scenarios show how many and which types of operators are affected by insufficient resources for operational budget and insolvency, and what the environmental effects are of loss of environmental resources and biodiversity, pollution levels, and environmental degradation.

4.6.5. Key findings

The application yielded a wealth of insights on SLR-induced vulnerability and vulnerability change. Table 4.3 shows some of those insights, ordered by assessment principle and method. The mixed methods approach resulted in consistent, complementary insights on some issues, but inconsistent and contradictory insights on other issues. This section describes three illustrative findings in further detail: the mismatch between scientific and local understanding of SLR, differences in human agency, and unintended feedback effects of traditional adaptation mechanisms.

Mismatch

The application illustrates the mismatch between the level of urgency attached to SLR in the scientific literature on the one hand and in the interviews with local stakeholders on the other. Few stakeholders who were interviewed considered environmental change an urgent issue, which contrasts sharply with the concerns the scientific community has. However, when stakeholders actually experienced the proxy of coastal erosion for SLR in the simulations, they expressed immediate concern. Stakeholders who played a land-based operator role (hotelier or beach cafe/vendor) and had available resources, would often opt for beach nourishment to replenish the beach. They would even act individually to regain beach instead of relying on collaboration to put together enough funds. Those who could not expend resources, expressed concern about the potential implications on income. The results imply that, although the greater issue of SLR may be missed by many stakeholders, participants quickly show understanding when confronted with losing beach during simulations. This illustrates that for stakeholders, experiencing environmental effects may be key to their understanding.

Differences in human agency

Heterogeneity in location and mobility contributed to the variation in participants' responses to coastal erosion in the simulation. Those directly affected were more willing to act than those situated elsewhere. Moreover, land-based operators (e.g. hoteliers) are fixed to their location while water-based operators can relocate when faced with a threat. The consequence of the difference in mobility was reflected in the simulation: water-based operators were less willing to collaborate when they could opt to move away. The iterations of the simulation sessions showed ongoing change, as participants had to deal with the consequences of previous rounds and changing available resources. Limited operational budgets, trade-offs, and uncertainties (whether events will occur and actions will be effective) were cited by many stakeholders as reasons for not acting when faced with coastal erosion as well as other challenges. The agent-based model explored the longer-term implications of differences in mobility, capacities, and operational input preferences in the context of SLR.

Unintended Feedbacks

Traditional methods of dealing with SLR and erosion include building sea walls, setting back beach amenities, and beach nourishment, or nature-based solutions, such as having mangroves. However, these are not simple solutions. Sea walls in combination with groynes (that prevent the transport of sand along the coast) create beaches in one area while keeping away sand from another. According to several interviewees, most sea walls have been placed without considering the impacts on other parts of the coastal system. This category of sea wall has the unintended effect of aggravating erosion on leeward beaches. During one of the simulations, damage to existing marine resources (including coral reefs) by building sea walls and groynes was discussed. During interviews, stakeholders noted that these structures also have an impact on tourism activities, as sea walls disrupt the wave patterns and make activities such as surfing difficult. Boat operators expressed concern about uncertain accessibility of harbours due to sand build-up, attributed to the placement of sea walls, since uninhibited harbour access is important for a smooth exchange of passengers.

Setting back amenities is difficult as many coastlines are already developed. Furthermore, when given the choice, both during the simulation-guided simulations and simulation sessions, most participants chose the closer beach areas for their business location instead of the safer areas farther in-land, which are potentially less attractive to tourists. Thus, even in areas that are not yet developed, the desire to place infrastructure as close to the sea as possible is prevalent. The unintended consequences of this location choice preference is further explored in the agent-based model under varying rates of SLR.

Table 4.3. Dynamic vulnerability insights for SLR

Principles	Desktop research	Interviews	Simulation development	Simulation sessions	Computational modelling
Human Agency	- Hotel and beachfront infrastructure affected (inundated)	- Unsure how they would be affected by 1m SLR - Not a clear plan on how to deal with SLR, unsure whether anything should be done - Concern about losing beach - Use beach nourishment to deal with erosion - SLR considered for height sea wall	- Unsure how they would be affected by 1m SLR - Not a clear plan on how to deal with SLR, unsure whether anything should be done - Concern about losing beach - Use beach nourishment to deal with erosion - SLR considered for height sea wall	- Option to use resources to increase beach size (input costs) - Some individuals consider beach nourishment - Recognise that beach loss is not good for tourism - People tend to build too close to the water even though it's not allowed and/or risky	- Tendency to place hotel or beach infrastructure as close as possible to the beach
Heterogeneity	- SLR affects land-based coastal tourism amenities more (directly)	- Some beach areas are currently growing while others are disappearing - Local researchers recognise more studies on SLR than other environmental threats	- Mangroves in some areas protect the coast to some extent from erosion (Curaçao)	- Coastal erosion used as a proxy for SLR; some areas of beach are gained, others are lost - Some individuals specifically chose not to be close to the beach - Some operators not directly affected - Location of lost and gained beach was different within and among simulations	- Use of different time scales and rates of SLR - Opportunity to act alone or collaborate - Some operators not directly affected (e.g. water-based operators)

Principles	Desktop research	Interviews	Simulation development	Simulation sessions	Computational modelling
Feedbacks	- Global climate change effects on Caribbean islands	- Need to preserve beach area to keep tourists	- Closer to the beach is easier to get more tourists, thus many motivated to be close to the beach - Sand covers coral/ causes damage - Less resources available for other inputs or actions	- Adding sand causes "pollution", in water area to mimic sand covering the reef - Lack of funds, unable to deal with coastal erosion - Beachfront properties most affected (e.g. revenues)	- Test how SLR relates to other internal island changes
Uncertainty	- Degree of SLR - How it will combine with coastal erosion	- Unsure if/how 1m SLR would affect them	- Beach erosion is one of the events that can occur in the simulation, the timing uncertain - Uncertainty whether beach will naturally change back or persist - Tiles that change the coastline are randomly selected	- How much beach loss will affect their incomes - Will it go away - Location of lost and gained beach - Consequences of actions to the system - How much resources are needed for future challenges	- Multiple scenarios of rate to proxy explore uncertainty in rate of SLR on system
Iteration	- SLR is one of the known key challenges for SIDS	- Interviews indicate that not much is known - Building plans do not significantly indicate a concern for SLR - Ongoing erosion problems, losing of beaches - Erosion which has some similar consequences is a concern	- Verifying how components are brought together with different stakeholders (e.g. location selection and reasoning therefore) - Applying different means to get participation in developing simulation (e.g. simulation-guided interviews instead of focus group sessions)	- May have less resources to deal with erosion due to previous challenges; thus unwilling or unable to pay themselves - May or may not be willing to collaborate based on previous events that participants faced, may be affected by other events that worsen effects	- Simplified behaviour choices of beach nourishment based on personal interest (i.e. owning a hotel) combined with limitations of personal resources and scenarios of SLR (timing and scale) to explore SLR vulnerability patterns

Desktop research and interviews indicated that reclaiming beach through beach nourishment is not only costly, but can negatively affect other aspects of the environment. Sea turtles that rely on the beaches are an important and endangered environmental resource that attracts tourists. Losing beach limits the options for sea turtles to successfully nest. At the same time, compacting of sand through beach nourishment can bury sea turtle nests, also resulting in lower hatching success.
In the simulation, participants could choose beach nourishment to regain beach. However, this choice caused a negative feedback effect in the form of pollution, which mimics sand covering the reef.

Mangroves are a nature-based adaptation that can serve to protect the beach from erosion. During interviews, few people detected the potential benefits of maintaining or adding mangroves. This was consistent with simulation sessions: although mangroves were present and prevented erosion, few participants decided to plant mangroves and those who did, had heated discussions about where and how many to plant, in order to avoid altering the beach aesthetics.

Through participating in simulation sessions, stakeholders could witness actual behaviours and feedbacks rather than hypothetical ones. Through reflection, stakeholders could increase their awareness of some of the consequences of location selection, erosion, and potential adaptation strategies.

4.7. Discussion

Practical information about climate change vulnerability constitutes vital input for effective climate change adaptation strategies in the Caribbean and other coastal destinations. This paper presents five principles of dynamic vulnerability assessments, introduces an approach to translate these principles into workable research action, and illustrates the approach's added value by applying it to SLR in a coastal tourism context. The approach shifts the focus of analysis away from external forces and destinations' aggregate features towards the internal structure of tourism destination systems and the features of and interactions among individual stakeholders and their environment. It shows how changes at the individual level play out together over time and affect system level vulnerabilities. Metaphorically speaking, it produces vulnerability motion pictures, showing the emergence of vulnerabilities over time, rather than static vulnerability snapshots. Although not all methods need to be applied nor in the order presented in the illustration, to really perform a dynamic assessment, experiencing and experimenting are essential. Thus, integrating system components and using some form of simulation session and/or computational model is required.

Our approach to studying vulnerability is similar to the four process steps of the tourism knowledge system proposed by Tribe and Liburd (2016): scoping, comparison, reflection, and abstraction. Desk research and interviews typically provide scope. Comparison of system features and processes can be done within as well as between case study areas. Reflection is achieved through the iterative process of interviews, simulation development, simulations, and computational modelling, leading to continuous co-creation of knowledge about system features and problems, and abstraction is achieved during debriefings and modelling. However, the approach takes it a step farther by integrating systems components as well as enabling researchers and stakeholders to experience and test complementary and contradictory insights of vulnerabilities.

The illustrative application of the approach to Barbados and Curaçao suggests that the approach has most to offer when its methods yield conflicting or contradictory insights that would have been missed by more aggregate top-down approaches. For example, the application clearly highlighted the contrasts between the alarmism about SLR among experts, the indifference about the issue expressed by local stakeholders in interviews, and the considerable willingness to act among these same stakeholders when experiencing the effects of SLR during simulations. The responses to SLR seem more straightforward than other climate change effects and yet the illustration highlighted trade-offs and unintended consequences when the ongoing interactions between tourism operators and environmental are considered.

The approach is rooted in transdisciplinary research. It combines and integrates knowledge from a variety of scientific and stakeholder sources and as such necessitates stakeholder participation. Stakeholders bring their beliefs, interests and (tacit) knowledge to the table, but they also benefit from participation (e.g. in the form of changed beliefs or new knowledge). The simulations in particular offer an important opportunity to learn from others, comment on previous knowledge assumptions, and experience the changing system, which was co-created with other stakeholders. Our approach supports Tribe and Liburd's (2016) suggestion for co-creating knowledge, and it resonates with appeals for more transdisciplinary research that promotes systems thinking, looks at interactions and various feedbacks, and encourages learning (see e.g. Chapter 2; Folke et al. 2016). Social learning is "considered to be more appropriate for integrated and adaptive management regimes needed to cope with the complexity of social-ecological systems" (Pahl-Wostl et al. 2007 p. 5). Insights remain not only in the hands of researchers; they develop in the minds of the very stakeholders that can take the actual action needed to build resilience and reduce vulnerabilities. Learning, facilitating agency, creating supportive collaborations, and enabling the flexibility to change strategies are important for building adaptive capacity (Cinner et al. 2018).

Advocating stakeholder participation is one thing, achieving it is another. Stakeholder involvement requires time, resources, presence in the case study areas, and, preferably, support from key local actors (see e.g. Étienne et al. 2011). Adger (2006 p. 268) recognises the challenges of incorporating "diverse methods that include perceptions of risk and vulnerability" in vulnerability research. In addition, bringing stakeholders together at one time and place is especially challenging. A flexible research design is therefore crucial to consider participant availability and realistic participant numbers for group sessions. Alternatively, researchers can use simulation-guided interviews to collect data one-on-one or consider virtual sessions. The combination of methods facilitates acquiring heterogeneous perspectives and learning from others without requiring everyone to participate simultaneously.

This dynamic vulnerability approach addresses some of the weaknesses of previous approaches. It goes beyond identifying high-level vulnerability indicators, as in Perch-Nielsen's (2010) work on the relative vulnerabilities of countries, by analysing who and what is vulnerable and how these vulnerabilities can emerge. The approach acknowledges the interconnectedness of problems and solutions in a complex system, which implies that one solution can produce a problem in another part of the system. Despite the advances, the approach can neither erase nor solve uncertainty and complexity. Nor does it strive to. It accepts uncertainty as an integral part of complex systems and creates a platform, through iteration, simulations, and modelling, that helps stakeholders deal with the unknown.

4.8. Conclusion

Many tourism destinations are vulnerable to environmental change. However, they are vulnerable in different ways. Vulnerabilities differ widely between local stakeholders, and change over time. This has direct consequences on how to manage tourism destinations. Therefore, traditional assessments based on snapshots of high-level indicators do not provide the kind of information that destinations need to inform their vulnerability policies. Systematic approaches that capture the principles of dynamic vulnerability assessments, while providing the flexibility to account for local specificities are urgently needed. This paper formulated five principles that tourism-related dynamic vulnerability assessments should possess in order to be effective: human agency, heterogeneities, feedback, uncertainty, and iteration. More importantly, it has laid out a flexible methodological approach to put these principles into practice for scoping, system integration, and experiencing and experimenting: desktop research, interviews, simulation development, simulation sessions, and computational modelling. Experiencing and experimenting is perhaps the most characteristic phase of the dynamic vulnerability approach, and is also a potential tool against climate inaction. For example, the simulation sessions provided clearer insights on how actions affect their coastal system, exposed barriers to act, as well as offered the chance to discuss opportunities for action.

The approach and tools presented in this paper can be easily adjusted to other Caribbean and international coastal tourism destinations. Each coastal destination or island is different but shares many types of environmental resources and tourism actors with other destinations. Insights, materials, and processes developed for Barbados and Curaçao can be reused and widened to apply to other coastal tourism destinations, especially in the Caribbean. For example, the *Coasting* simulation could either be used in its current form on other islands to see what similarities and differences participants experience or be adapted to reflect different coastal environments and/or composition of tourism operators. Similarly, the set-up of the coastal environment and tourism operators in the agent-based model could be changed to reflect a different coastal destination. The transfer of information and adaptation of the process from the Barbados context to Curaçao provide an example of how iteration and further application can be achieved. The approach's scope of application is, however, by no means limited to Caribbean or coastal destinations. The approach's generic set of principles and the flexible methodological tools make it applicable to any kind of tourism destination that faces environmental challenges.

The explicit formulation of the principles and approach is an invitation to others to replicate and further develop the approach in other spatial and temporal settings. This approach provides a flexible starting point to conceptualise and operationalise vulnerability as a dynamic phenomenon. Future applications to tourism destinations could assess the effect of the new information that stakeholders obtain during simulations or during the debriefing. By restarting the simulation again after debriefing or by adding another round, changes in behaviour can be observed, as well as stakeholders' ability to prevent or address some of the challenges and threats. More elaborate agent-based models can broaden the type of scenarios to be explored and address a new range of questions. Improving and accelerating the cycle of knowledge co-production is desperately needed to derive practical recommendations for the tourism industry and policy makers.

LOCAL INSIGHTS OF EMERGING ENVIRONMENTAL CHALLENGES THROUGH INTERACTIVE SIMULATION GAMES

5

LOCAL INSIGHTS OF EMERGING ENVIRONMENTAL CHALLENGES THROUGH INTERACTIVE SIMULATION GAMES

SET-UP

Participants select locations for their tourism operations in the coastal system.

GAME PLAY

Tourism operators (TOs) make decision on how to use individual resources (maintenance, tourism product, environment, savings).

Environmental challenge occurs.

Tourism operators decide whether to respond. If so, whether to act alone or collaborate.

New environment challenge may grow, disperse, or go away.

Tourism operators collect returns.

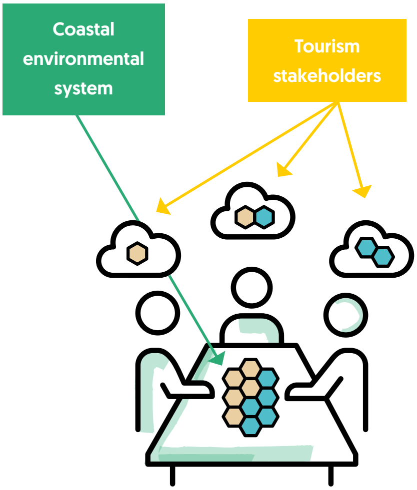
Pollution may be generated. Existing environmental problems may grow, disperse, or go away.

Mobile tourism operators can change location.

END OF ROUND

Need to understand emerging socio-ecological vulnerabilities at the destination level to improve adaptation strategies. We require insights on how people interact with their coastal system and respond ongoing environmental challenges.

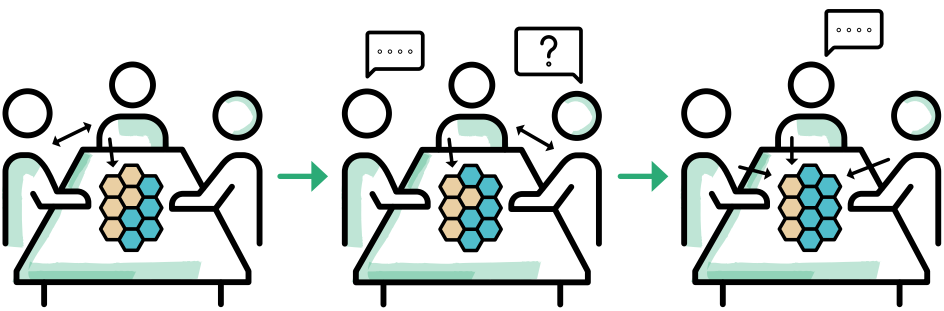
For this, we use the simulation game Coasting



- Simulation games are part of a dynamic vulnerability approach.
- Combines stakeholders with their coastal system.
- Played over a number of rounds simulating time.

Exposes participants to multiples challenges over the game: decreased tourism, erosion, drought, storms, coral bleaching, new unknown events

Captures changes at the destination level



Simulation sessions improve our understanding of how stakeholders respond to changes and view interactions, and indicate potential challenges and adaptation strategies.

Abstract

Coastal tourism faces an increasing array of environmental challenges. Tourism being affected by climate change is not new. However, this reality has not been translated into specific actions, as we know little about the people who are affected by climate change and how they are affecting and affected by this change to their local environment. A better understanding is missing of how to capture these interactions at the destination level (an appropriate scale for action) and how to improve our understanding of human interactions with environmental change. This research proposes a dynamic approach for capturing the interactions between tourism stakeholders and environmental change for the coastal island destination of Curaçao. The purpose of this study is to explore how actors' local knowledge can highlight emerging vulnerabilities and potential options for adaptation using simulation sessions of the game *Coasting.* The study method is part of a dynamic vulnerability approach and focuses on coastal tourism in Curaçao as the context for environmental change for tourism operators. The simulation sessions provide insights on individual trade-offs for personal resource use, collaboration, responses to environmental change, and learning.

Prepared for submission:

Jillian Student (for review) Local insights of emerging environmental challenges through interactive simulation games.

5.1. Introduction

Coastal destinations face increasing challenges, which are confounded by environmental change. Scott, Gössling, and Hall's (2012) identify the multifold vulnerability challenges of coastal island destinations: they are geographically exposed to risks; companies share common resources while acting in a highly competitive market; there is little motivation to recognise, address, or share information on environmental change; and uncertain and long-time frames obfuscate environmental change. This combination of factors result in a climate change knowledge gap that is particularly evident in relation to coastal tourism (Becken 2013a) and islands (Scott et al. 2016; Scott Hall et al. 2019). Lack of actions, collaboration, and uncertainty are prevailing issues with climate change on Small Island Developing States (e.g. Kuruppu & Willie 2015; Nurse et al. 2014). The Caribbean is a region with destinations dependent on coastal tourism and vulnerable to climate change (e.g. Rhiney 2015). However, this region is underresearched in terms of climate change vulnerability related to tourism (e.g. Becken 2013a; Rhiney 2015). More general awareness of climate change in the region, however, does not mean action (e.g. Filimonau & De Coteau 2019; Santos-Lacueva et al. 2019). Curaçao, an independent state within the Kingdom of the Netherlands since 2010, is one of the many Caribbean island coastal destinations where tourism is an important contributor to GDP (e.g. Hall 2018) and research on climate change effects and tourism is lacking. Kuruppu and Willie (2015) noted barriers to adaptation that apply to SIDs such as Curaçao include: governance, technical and financial resources, cognitive, and cultural barriers. Rhiney (2015 p. 110) argues that with "increasing yet varied vulnerabilities to climate variability and change, there is an urgent need to advance research into the human dimensions of climate change throughout the [Caribbean] region, in order to identify practical solutions and actions that may lead to true transformational change". Two main challenges emerge for the knowledge gap of coastal destinations' vulnerabilities: how do we capture changes at the destination level of Curaçao (an appropriate scale for action) and how to improve our understanding of the human interactions with that change.

Although we recognise that coastal tourism destinations are vulnerable at an aggregate level, we know little about the ways in which vulnerability can manifest itself within the destination (e.g. Hall 2018; Nurse et al. 2014; Scott Hall et al. 2019) and how vulnerabilities change over time (Chapters 3 & 4; Adger 2006). One of the challenges of aggregation in vulnerability is that changes affecting tourism stakeholders are heterogeneous (UNWTO-UNEP-WMO 2008). As such, knowledge of aggregate vulnerabilities says little about what adaptation strategies Curaçao needs to address potential emerging vulnerabilities. Vulnerability in coastal tourism systems will also display great diversity (e.g. Rhiney 2015; Scott Hall et al. 2019), even if we focus only on the supply or demand side of coastal tourism. Calgaro, Lloyd, et al. (2014) recognise that human agency influences differential vulnerability patterns. Moreover, Becken and McLennan (2017) argue that integrating the connection of multiple resource inputs and outputs may identify unwanted consequences, and lead to better resource use and decision-making. A prevailing challenge is how to combine these diverging components in a dynamic setting to get access to this improved understanding. We need to understand the cumulative effects of interactions in the system between humans and the environment and among humans themselves. A dynamic vulnerability approach is a means for integrating the system and understanding how these interactions contribute to emerging socio-ecological vulnerabilities (Chapter 4). A dynamic approach addresses two main challenges related to emerging socio-ecological vulnerabilities: how to include people and how to create a dynamic interactive setting to analyse emerging vulnerabilities.

First, including people in the system is important for identifying their perceived barriers and opportunities within the system (Kuruppu & Willie 2015; Santos-Lacueva et al. 2019). Studying emerging socio-ecological vulnerabilities requires more than objective knowledge of climate-related risk; the influences of the societal context of norms, values, perspectives, and interests cloud the boundary with universal science (van der Hel 2018), which researchers need to consider. In order to move beyond a generic understanding of tourism destination vulnerabilities, we want to have a more bottom-up understanding of how vulnerabilities emerge. Ruankaew et al. (2010) suggest that transdisciplinary approaches are needed to address emerging vulnerability challenges while Waligo, Clarke and Hawkins (2013) argue that stakeholder involvement is key for sustainable tourism.

Researchers identify many benefits from transdisciplinary approaches. For example, Pyke et al.'s (2018) research shows how involving stakeholders' knowledge is critical for identifying and addressing vulnerabilities related to bushfires in an Australian tourism destination. Pahl-Wostl et al. (2007) argue that stakeholder collaboration and perceptions are needed to create integrative action plans in situations of great uncertainty and complexity. Hassenforder et al. (2015) identify three advantages of participatory processes for bridging the gap between scientific knowledge and adaptive policy needs: coupling contextual knowledge with scientific systems thinking; involving stakeholders who will be affected by or be a part of decision-making to improve the adaptation strategies themselves and/or the readiness to accept the strategies; and, improving the likelihood that participants apply systems thinking beyond the participatory sessions. Moreover, participatory approaches can help move beyond silo understanding of the system and assist decision-makers in understanding stakeholders' expectations (e.g. Lalicic & Weber-Sabil 2019; Mochizuki et al. 2018; Solinska-Nowak et al. 2018).

For the second challenge, i.e. creating a dynamic interactive setting, we need to look at how stakeholders interact with their environment over a space and time. In coupling humans with their environment, we want to better understand how they interact with the environment, more specifically: what types of changes in the environment they respond to, what their reasoning is, and how they respond. If, for example, stakeholders do not act on certain types of environmental change, what are their reasons? Role playing games, serious games and simulation sessions are increasingly being used as part of interactive participatory processes (Mochizuki et al. 2018) for complex socio-ecological challenges. There is no clear distinction between games and simulations (Solinska-Nowak et al. 2018) and the terms will be used interchangeably in this paper. Role playing games have been found to be useful for other climate change problems, such as climate smart agriculture (Salvini et al. 2016) and urban climate risk (Juhola et al. 2013). Reckien and Eisenack (2013) provide an overview of 52 table top and online games related to climate change. Serious games offer a means to understanding the emerging vulnerabilities experienced by stakeholders. We can confront stakeholders with their individual mental representations through interactive dynamic representation of their system. More recently, opportunities for role-playing games have been identified within the context of tourism (Lalicic & Weber-Sabil 2019). As such, simulation sessions provide an opportunity to capture changes at the destination level and improve our understanding of how human-environment interactions lead to socio-ecological vulnerabilities. Simulation sessions are one of the methodological tools of a dynamic vulnerability approach (Chapter 4).The five principles of this approach help frame the main human-environmental interactions that need to be included as well as how to observe the findings (please see Table 5.1).

In addition to what researchers can learn about emerging vulnerabilities, a contribution of simulation sessions to research of complex environmental problems is the individual, social, and experiential learning of participants (Jean et al. 2018; Lalicic & Weber-Sabil 2019). Pahl-Wostl et al. (2007 p. 13) argue that "actors hold frames that determine how they give sense and meaning to information and their physical and social environments". Understanding how stakeholders frame their coastal system and environmental challenges is important to understand how they interact with the system. Rather than only presenting the results, involving stakeholders in the simulation experience can improve their understanding of their system. This is achieved by creating co-learning and reflection opportunities during the simulation experience. Participants experience the accumulation of interactions with the environment and other participants; participants can extrapolate the in-game experiences to their reality and reflect on their own individual contribution to problems and adaptation strategies (Solinska-Nowak et al. 2018 p. 1014). As such, simulation sessions facilitate communication among stakeholders about potential challenges and opportunities. By partaking in the simulation, "participants will enhance their understanding of the underlying model and improve their knowledge through collective interaction" (Barreteau et al. 2000 p. 186). As such, *social learning*—by interacting with others in this dynamic setting—and *experiential learning*—through participating in the dynamic setting—are two potential learning outcomes of the games.

This study focuses on the destination of Curaçao. It explores what we can learn from the interactive serious game *Coasting*, played with stakeholders in Curaçao. *Coasting* looks at tourism stakeholders' roles in the system, and how interactions with the environment relate to emerging vulnerabilities and potential adaptation strategies. More specifically, the paper focuses on: what insights does a dynamic setting provide for individual strategies, responses to environmental resources change, and collaboration? and, what do participants themselves learn from involvement in an interactive dynamic process?

5.1.1. The *Coasting* game as a means to operationalise a dynamic vulnerability approach

As noted above, the simulation game was co-developed as part of a dynamic vulnerability approach (see Chapters 3 & 4). The approach identifies five principles (1) *agency*, people's actions and decisions, (2) *heterogeneity,* diversity in the human-environment system including spatial and temporal elements, (3) *feedbacks,* consequences of interactions, (4) *uncertainty,* unknowns regarding timing, scale, and size when taking a future-looking approach, and (5) *iteration,* ongoing changes through continuous interactions and feedbacks. The gaming approach is a means to operationalise dynamic vulnerability principles and focuses on how stakeholders collectively experience changes in their simulated coastal system. The simulations facilitate knowing more about the individual capacities and trade-offs and consider the different environmental resources participants (simulating tourism operators) use and as such, their agency (Rhiney 2015). This research focuses on the tourism operators as they have been identified to have a higher vulnerability and lower adaptive capacity than visiting tourists (e.g. Kaján & Saarinen 2013; Moreno & Becken 2009). Moreover, tourism operators, the coastal environmental components, and the impacts of environmental change are heterogeneous (e.g. Calgaro Lloyd et al. 2014; Rhiney 2015; Scott Hall et al. 2019). As it is recognised that there are differences among local operators, specifically what contributes to individual strategies within a tourism destination and decisions to collaborate, the game enables us to explore both human heterogeneities while coupling them with environmental heterogeneities. As the game takes place over multiple rounds, we can explore feedbacks of different actions and environmental change on the coastal system and the participants. Stakeholder encounter uncertainty regarding the impact of their actions, what type and severity of environmental challenges they will encounter, and what the impact of their and other participants' action will be. Finally, as change is ongoing, a dynamic setting is needed to integrate changes over time and the changing states of operators and the coastal system. Table 5.1 indicates how the serious game incorporates agency, heterogeneity, feedbacks, uncertainty, and iteration to understand emerging vulnerabilities.

Table 5.1. Inclusion of the principles of a dynamic vulnerability approach in the *Coasting* simulation

Agency	Decide how to distribute personal resources, where to operate, whether or not to collaborate, whether or not to act individually
Heterogeneity	Operators: different types of operators, different resource inputs required, mobility (mobile vs immobile), different strategies to have tourism (determined by participant), Environment: resources (sand, nearshore, deep sea, coral reefs, sea turtles) Environmental events: order, severity, and type vary per game
Feedback	Operators: Pollution others emit affects environment, pollution limits returns, spending more on tourism increases profits, if tourism product spending is not balance with environment pollution increases Environment: addition of sand adds pollution to the marine area, bleached coral detracts fish and sea turtles, drought adds pollution into the environment, storms can damage reef and/or disperse pollution
Uncertainty	Randomness event order, not sure if actions will have desired effect (e.g. investing in unknown event, investing in getting rid of pollution) Unknown event-Effect of actions- personal input investments, investments in dealing with environmental challenges (e.g. will pollution go away, will unknown event go away without action)
Iteration	Each round builds on the context of the previous round, operators' capacities, and environmental health Among games elements are adapted in the game to make it clearer or improve flow

5.2. Methodology

The overall purpose of this serious game is to better understand emerging socio-ecological vulnerabilities in a coastal destination by exploring how participants in different tourism operator roles respond to environmental change. The game *Coasting* was co-developed with stakeholders in the Caribbean coastal tourism destinations of Barbados and Curaçao using a dynamic vulnerability approach (Chapter 4). The research approach was inspired by companion modelling (Étienne 2014), a process that guides transdisciplinary involvement of stakeholders in problem identification, development, and simulation/game play. This paper presents insights from the simulation sessions that were held in Curaçao as a part of this approach. For more details on this dynamic process please see Chapter 4 of this dissertation.

5.2.1. Case study description

The *Coasting* game simulates a coastal tourism destination and is adapted to represent the case study's local context, in this case Curaçao. The results are based on nine simulation sessions that took place in Curaçao in April and May of 2017 (please see Table 5.2). The simulations consisted of an hour and 30 minutes playing time followed by a 30-minute debriefing. Sometimes, it was necessary to accommodate shorter availability of participants. As such, playing time was reduced. For other sessions, participants carried on the debriefing discussions for longer than 30 minutes.

Table 5.2. Description of the simulation sessions

Simulation session	Rounds	Stakeholders types present	Number of players	Roles per participant	Participants know each other	Language
1	4	Tourism operators	3	2 roles for 1 participant 3 roles for 2	No	Dutch
2	5	Government officials	4	2 roles per participant	Yes	Dutch, some explanation in Papiamento
3	5	Government officials	4	2 roles per participant	Yes	Dutch
4	5	Local fishing/ beach community	8	1 role per participant	Yes	Dutch some explanation in Papiamento
5	5	Tourism operators, government official	3	2 roles per participant (6 operator roles)	No	English
6	5	Tourism operators, government officials, locals	8	1 role per participant	Some	Dutch
7	3 (discussion of the 4th)	NGO & tourism operators	4	2 roles per participant	Yes	English
8	4	Government officials, tourism operator	4	2 roles per participant	Yes	English
9	4	Tourism operators, NGOs	5	1 role for 3 participants 2 roles for 2 participants	Some	Dutch and English

5.2.2. *Coasting* simulation game play

This section gives a brief description of the game sessions (please see Table 5.3) and game play (please see Figure 5.1). For more information, please refer to Annex 2. First, in the *Coasting* game, the five different operators, and the environmental features are described. The set-up is initialised by participants selecting the location where they will be operating beginning with hoteliers, followed by beach operators, dive/boat operators, and nearshore operators. The land-based hoteliers and beach operators are fixed to their location for the duration of the game and there are maximum two operators per land tile. The water-based operators are mobile and can move to different locations in the marine environment throughout the game and there is no limit to the number of operators per tile. A dice is used to introduce uncertainty, by randomly determining the ordering, severity and location of environmental effects, and the level of success for actions addressing these events. This is common practice in simulation sessions (Solinska-Nowak et al. 2018).

Table 5.3. *Coasting* game details

Operators	Hoteliers Beach operators (cafes and other land-based beach vendors) Nearshore operators (NSOs) (surfing, stand-up paddling, glass bottom boats, jet skis) Dive and boat operators Water operators are mobile, land-based operators have a fixed location after initialisation
Input resources	Tourism product Maintenance Environment Savings (unallocated resources were considered savings)
Environmental features	Geospatial features: Nearshore waters, deep sea (marine boundary), coast (water meets land), beach area, nearshore area, inland (land boundary) Natural features: coral reef, fish, sea turtles, and mangroves
Potential challenges faced	Increased difficulty bringing in tourists (more inputs required in tourism product), coral bleaching, coastal erosion, storm (varying from storm surge to hurricane), drought, and new unknown event
Players	3-8, three player simulations have smaller world and less operators, with less than eight players, participants are For 3 player game*, (one less beach operator and nearshore operator) for 4+ player game*, 2 of each operator roles (hotelier, beach operator, nearshore operator, boat/dive operator) *participants have more than one role
Operator decisions	Where to set-up operators; how to allocate operational budget; whether and how to individually or collaboratively respond to new anticipated and experienced challenge; for mobile operators, where to move operators; whether to address pollution
Duration	2 hours: 1.5 of explanation and game play 30 minutes debriefing
Rounds	3-5, preferably 5
Player goal	To sustainably operate- are allowed to determine what sustainability means for them. Players are given resource tokens that represent time, energy, expertise, and financial expenditures to gain returns. They determine how they want to allocate their tokens.
Target group	Tourism operators, governing bodies, related NGOS, interested local stakeholders
Game elements	Tiles to indicate geospatial type and spatial dimension; markers to represent operators, resources (e.g. fish coral), wind direction, pollution, and environmental challenges; tokens; dice; input sheets

Figure 5.1. Set-up of a *Coasting* simulation session

After set-up, each round of the game play begins with the operators determining how they want to expend their resources. Based on interviews, three main input categories were identified as part of the trade-off individuals had to make on how to expend their resources: maintenance, tourism product, and environment. *Maintenance* refers to the upkeep of their infrastructure (e.g. building, equipment). *The tourism product* is an aggregate of the marketing efforts to bring in tourists as well as the resources used to enhance the quality of their guests' experience. *Environment* refers to the short-term actions such as educating tourists on reef care, removing debris from the ocean, and tidying up the beach. The resources are a proxy for time, energy, expertise, and finances. Each of the four operator types had a recommended input amount for each of the three expenditure categories. Figure 5.1 shows the set-up of one of the simulation sessions.

Then, a participant rolls the dice and an environmental challenge is introduced (e.g. a storm event). The challenges can have varying severity, determined by rolling the dice. Participants decide how to respond to the new challenge (adjust individual strategy, i.e. change resource allocation; collaborate with others; or do nothing). Based on the participants' actions combined with chance, an event may go away, get worse, persist, and/or affect income. Afterwards, participants receive revenue based on their operational inputs and the environmental conditions. If tourism product and environment expenditures are not in balance, pollution is introduced to the coastal system. If mobile operators choose, they can select another location. Then, the next round begins with the participants determining their operational budgets. The environmental challenges are randomly determined, and not all events occur every session nor in the same order. The unknown event is an exception. It was part of every session; it typically occurred in the third round if it had not already occurred in the first two rounds. Figure 5.2 provides an overview of the game play.

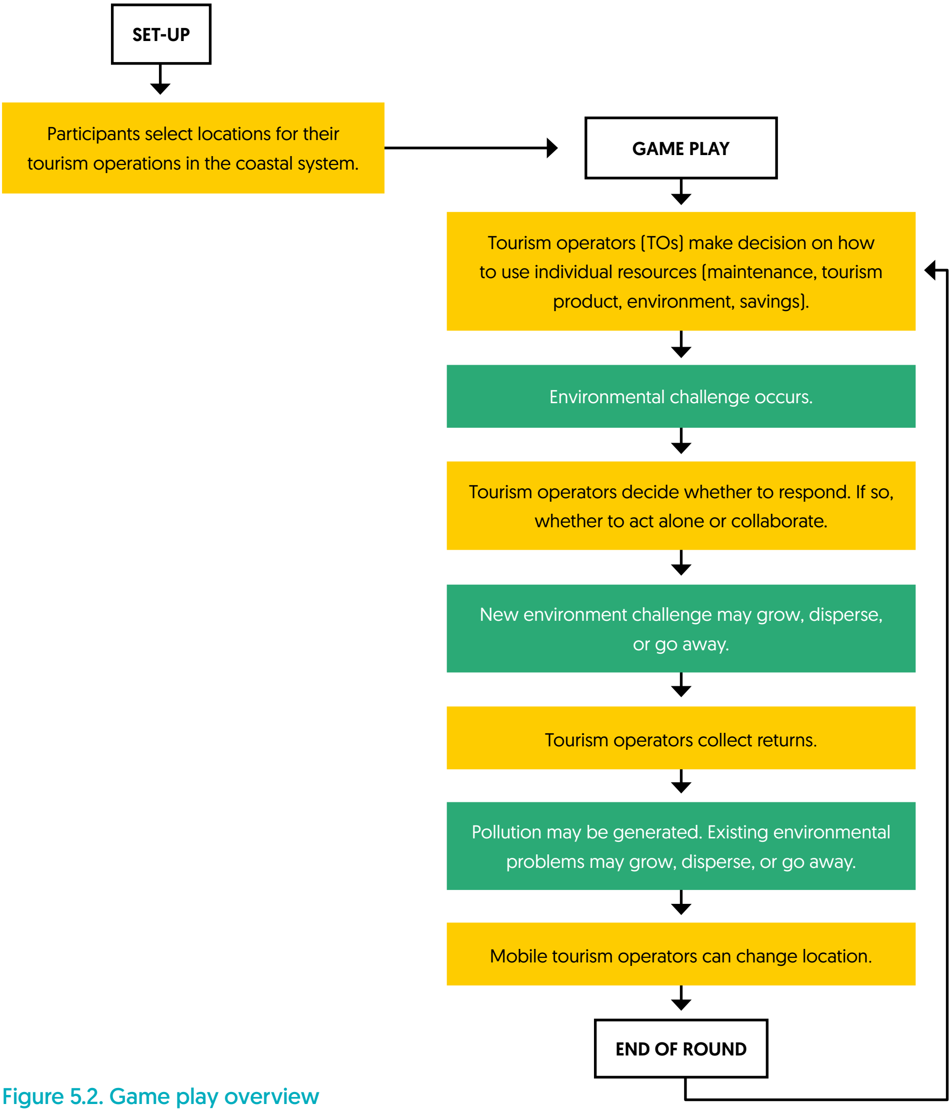


Figure 5.2. Game play overview

5.2.3. Means of observing the simulation sessions

Three different tools were used to analyse the human-environment interactions of the simulation session. The three tools were: individual input forms, an observational protocol, and debriefings. These tools enabled observations of individual (environmental) actions and strategies, emerging environmental challenges, collaboration, and learning.

Input forms are used for operational input decisions as well as a description of initial strategies and the role of individual participants in real-life (e.g. tourist operator, government official). They provide insights on individual actions and changes in strategies (agency, heterogeneities in individual actions, and feedbacks of events on individual strategies). At the beginning of each round, participants filled in their operational input decisions to plan their expenditures. If an environmental challenge affected their resources, participants would change the original values they had allocated and reassign their resources (please see Annex 2 for an example of an input form). An observation protocol was developed as a means for researchers to observe and analyse participants' responses, actions, interactions with the other participants and the coastal system, and statements made during the game play (please see Annex 3). The observational protocol also records actions and statements made during initialisation and the subsequent rounds.

The observation protocol set-up was inspired by the observation protocol used in the sustainability game "Lords of the Valley" (Centre for Systems Solutions (CRS) 2019). *Coasting's* observational protocol focused on: changes to personal resources, concerns about environmental resources, actions taken, information shared, and signs of collaboration and competition. The observations provide insights on heterogeneities in actions among players, responses to feedbacks and uncertainty, and how iterations affect participants' capacities and the state of the environment.
Most of the observation protocols were filled in by the researcher after the sessions with the aid of video and audio recordings.

The simulation sessions concluded with a debriefing, which is a common activity after gaming sessions to reflect on the process (Solinska-Nowak et al. 2018). The debriefing provides insights on learning, i.e. participants reflect on their agency (what they did, did not, or could (not) do), heterogeneities (different responses and outcomes for the participants), feedbacks (how changes affected the participants), uncertainties (how uncertainties impacted decisions), and iterations (how participants dealt with ongoing change). A debriefing is a moment led by the game master at the end of game where participants can reflect and discuss what occurred during the game; it is a critical opportunity for deeper reflection on the lessons and social learning (Crookall 2010; Solinska-Nowak et al. 2018). During this time, participants discussed what they experienced, their sentiments about what occurred, key moments, trade-offs, and how the game relates or does not relate to their real-life experiences. Debriefing questions were inspired by Ryan (2000) and his interpretation of Leberman's (1984) framework for post-experience examination of simulation experiences (please see Annex 4 for the guiding debriefing questions). Audio recordings were made and most of the sessions were also recorded by video. Some observational notes were written during the sessions.

5.3. Results

The results are shared in the following four sections to look at how accumulating interactions lead to socio-ecological vulnerabilities: individual environmental actions, emerging environmental challenges, collaboration, and learning.

5.3.1. Individual environmental actions

As mentioned in the methodology section, the participants (i.e. tourism operators) needed to invest their resources in maintenance, their tourism product, and the environment in order to earn revenue. Participants recorded this information in their operational input forms each round (Annex 2, Tables A2.1 & A2.2). Over the course of a simulation run (3-5 rounds), individuals invested different amounts in the environment. These expenditures do not include dealing with the environmental challenges and cleaning up of pollution already generated. Figure 5.3 is a stacked bar chart of all the individual operators environmental input expenditures per round per session. The numbers on the x-axis indicate the succession of rounds, i.e. time, for each of the nine simulation sessions; the y-axis depicts the amount of environmental expenditures, which can be compared with the recommended amount per round. Figure 5.3 shows the difference in environmental expenditures among the eight operators at each time step (note: NSO= nearshore operator); the figure further indicates changes to environmental expenditures for the individual operators, as well as the collective over the course of the simulations (3-5 rounds).

Participants had difficulty balancing their expenditures over time. For example, Figure 5.3 show that during round 1 in session 7, most participants put all their resources into the environment in their input forms as well unknown event. But the participants did not earn enough at the end of the round to continue investing in the environment nor to make other expenditures (maintenance, tourism product) in the second round. So even though participants stated they wanted to invest more in the environment, they had insufficient resources to do so. In other sessions (1,2,3,4,6), most participants chose to focus on revenue and work on tourism first, and environment later. This resulted in an accumulation of environmental issues to deal with at later stages.

During the simulation, participants motivated the strategy of working on the tourism product first and the environment later. One player in session 2 stated: "it's not good, but I think first earn money and then improve the environment. Without money, you can't do anything". In session 1, a similar sentiment was expressed by a participant, "first go for money, but at a certain point [you] are forced to pay for the environment because profits go down" and that "focus on tourism product is normal for businesses as they aren't NGOs". In session 9, participants conceded "that the environment is one of the factors that you need to take into account if you are in a coastal area. [...] Environment is very important, but that is [in] theory, but it is not all the same".

However, this strategy made it difficult to fix past problems when new challenges emerged. Some participants expressed frustration about being required to invest in maintenance every round (4,6,7,9). The people who expressed this were often not operators in real-life. In session 6, participants noted the difficulties of dealing with limited capacity and participants in Session 7 stated that they felt as though their hands were tied and that they could not do what they wanted. This indicates challenges of dealing with limited capacity and necessary inputs.

Over the course of the simulations, participants changed their investment strategies in the environment because of limited capacities (2,5,6,7,9). Sometimes, this was the result of participants investing so much in the destination's environmental issues that they did not have enough for their own general operations (5,6,7,9). Another barrier for investing in the environment was the inability of participants to recognise their own contributions to pollution. In the simulation, smaller operators did not have a required investment in the environment. Despite seeing that pollution was emitted by these smaller operators, in three sessions, the participants playing these roles (1,2,6) claimed that small operators do not contribute to pollution or environmental harm, and they were unwilling to invest in the environment. Similarly, some participants did not see the benefits

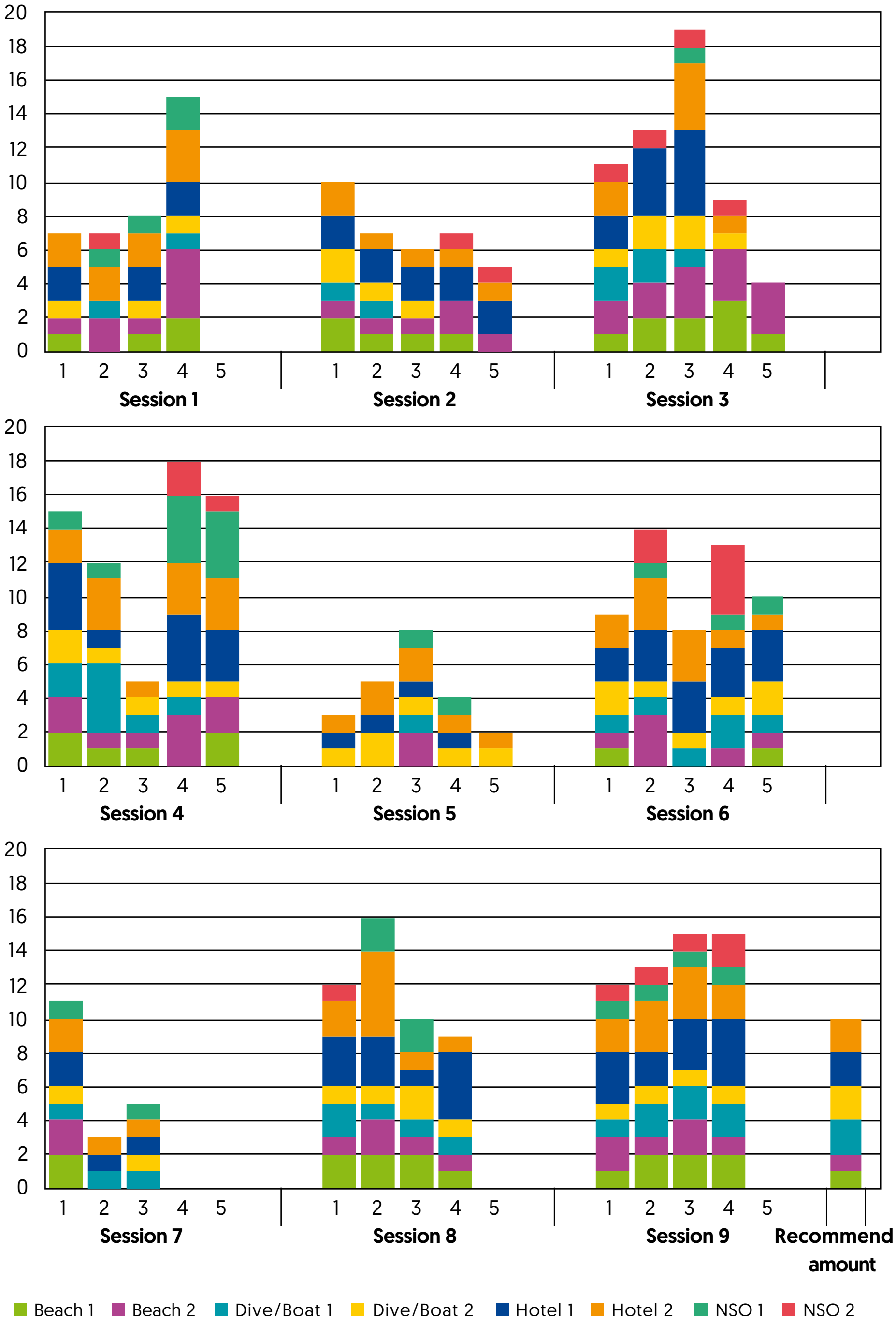


Figure 5.3. Resources expended by operators on the environment over the course of the rounds during the nine simulation sessions *Beach 1 and NSO 2 not present in session 5

of preventing pollution through their investments (4,6,7,9). In session 7, participants considered waiting till pollution occurred before spending resources on the environment as opposed to consistently investing in the environment.

5.3.2. Emerging environmental challenges

Figure 5.4 shows the ordering and severity of the events during each of the nine simulation sessions (middle row). For example, in session 1, in the first round more tourism efforts were required, then an unknown event occurred, followed by coastal erosion, and concluded with drought. The green arrows above indicate individual and collaborative actions to circumvent the challenges. The rows below depict obstacles for collaboration and actions by mobile operators to move away from the challenges. When participants acted on events, the environmental problems did not always go away. For example, pollution (2,4,5,6,7), coral bleaching (3,5), and unknown events (5,6,8) sometimes persisted, or participants were affected by storms even though they had selected safer locations farther from shore (6,7).

Of the six types of environmental challenges participants were exposed to (coastal erosion, coral bleaching, drought, storms, pollution, unknown sudden events), participants acted beyond their individual operational budgets on pollution (1,2,4,5,6,9), coastal erosion (4,8), and unknown events (2,5,6,9). Drought on the other hand, received relatively little attention from participants during the simulation and debriefing (1,2,3,5,7). When asked about drought, one participant responded "we don't have drought, we have a water shortage in Curaçao" (3). Participants stated that drought was not a visible problem, especially as they have a desalination plant in Curaçao; so, to them water shortage is more about cost than anything else (5,7). Moreover, a participant in session 3 stated that there is limited information on groundwater reserves and groundwater does not appear to be monitored. In sessions 3 and 5, there were discussions about saltwater intrusion. In session 8 participants claimed that drought was good because it improved visibility for diving. Damage to coral and coral bleaching events incited gasps, but did not generate conversation on what to do to ease pressure on the reef. There were two exceptions: in session 5, they wanted to remove pollution to alleviate stress (but had insufficient resources) and in session 9, mobile operators moved away from that part of the reef. Participants indicated that they felt prepared for storms (2,5,7,9), but were unhappy with the costs of repairs in the game (2,5,7). When coastal erosion occurred, tiles with mangroves were unaffected; nonetheless, the mangroves present went largely unnoticed. The three exceptions were: one participant who built their hotel specifically behind the mangroves (6); an operator who chose the mangrove area for water activities (9); and session 5, where participants considered planting mangroves. New unknown events caused debates among participants and were designed as an opportunity for operators to collaborate. Participants collaborated in some sessions (2,5,6,9). A common response was to know exactly what the unknown event was before action would be considered (1,3,6,8,9).

In all of the sessions, many participants found the accumulation of problems difficult to deal with. One reason was because their capacities to act lessened over the course of the simulation (1,5,6,7). In session 7, most participants wanted to invest more in the environment, but after receiving their returns in the first round, their limited resources prevented them from investing in the environment in subsequent rounds (see Figure 5.3). Moreover, participants were frustrated by pollution others generated [1,3,4,6]. In session 1, only one participant acted in the final round to remove pollution although all players had noticed increasing pollution throughout the simulation.

5.3.3. Collaboration

Figure 5.4 indicates the moments of collaboration and attempted collaboration during the simulations. In sessions 1 and 3 there were no collaborative actions. However, in session 3 participants individually invested more in the environment [see Figure 5.3]. Common factors that increased successive collaborative actions were a shared sentiment that they were in it together [2,5,6,8]; a belief that help should be reciprocated [4,5,6]; personal interest in dealing with the problem [1,2,5,6,7]; growing visibility of the problem [2,4,5,6,8]; and a proactive individual [5,9] who in some cases contributed more resources to deal with the problem [2,4,6]. In some cases, participants were willing to collaborate on some events, but not on others: erosion and pollution, but not unknown events [4]; unknown events, but not on pollution [8]; and unknown events, but not on pollution until after further discussion [9]. In a few sessions, participants came up with few unique collaborative actions: they agreed to plant mangroves [5], participants enlisted volunteers to help with beach clean-up so that there were no personal costs [7], and they agreed to move away from the reef to limit anthropogenic stress [9].

However, collaborative efforts were impeded under the following conditions: when individuals were not directly affected by the problem [1,3,4,6], could move away [2,3,4,6,8], had the opportunity to free ride [3,4,6,7], were directly competing with each other [3], strongly voiced objections to collaboration [1, 3], or wanted a guarantee that their actions would be successful [1,6]. Moreover, frustration from previous unsuccessful actions contributed to expressions of disillusionment and apathy [3,5,6,7]. Session 6 had a number of individuals who thought others should act but did not contribute themselves, which led to less expressed trust among participants. In four sessions, participants indicated they wanted to leave the island and start up elsewhere [1,3,6,7]. In some cases, participants wanted to collaborate, but had insufficient resources [2,5,6,7]. Moreover, some conflict emerged because of increasing polluting actions by some participants [1,6].

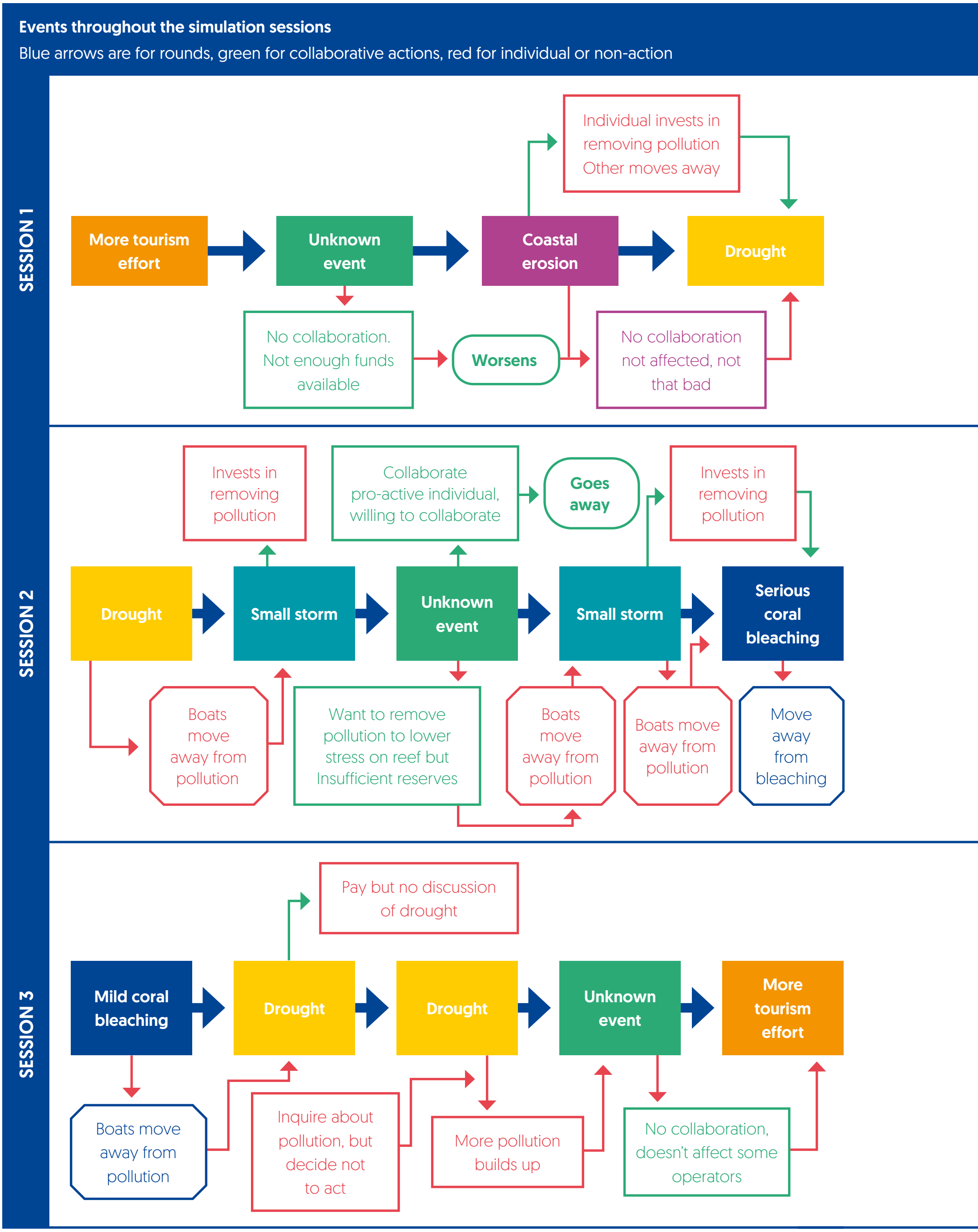
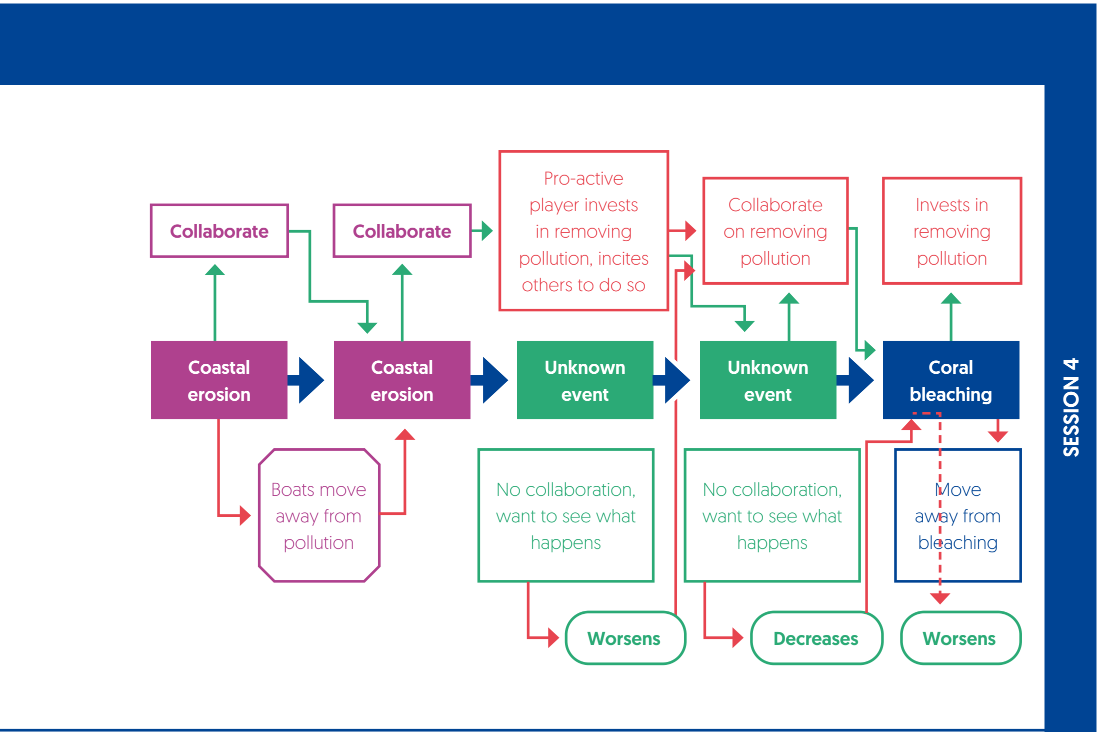
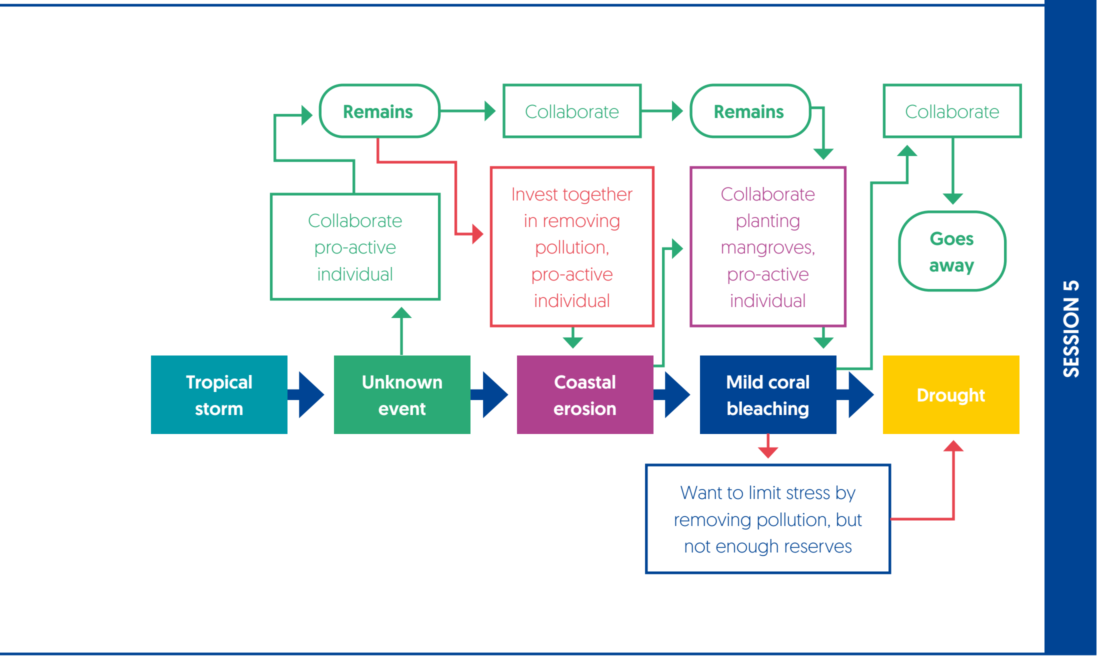


Figure 5.4. Environmental challenges and collaborative actions during the simulation sessions; box colour indicates events, blue arrows are the rounds, green arrows collaboration, red inaction



SESSION 4
Collaborate
Collaborate
Pro-active player invests in removing pollution, incites others to do so
Collaborate on removing pollution
Invests in removing pollution
Coastal erosion
Coastal erosion
Unknown event
Unknown event
Coral bleaching
Boats move away from pollution
No collaboration, want to see what happens
No collaboration, want to see what happens
Move away from bleaching
Worsens
Decreases
Worsens



SESSION 5
Remains
Collaborate
Remains
Collaborate
Collaborate pro-active individual
Invest together in removing pollution, pro-active individual
Collaborate planting mangroves, pro-active individual
Goes away
Tropical storm
Unknown event
Coastal erosion
Mild coral bleaching
Drought
Want to limit stress by removing pollution, but not enough reserves

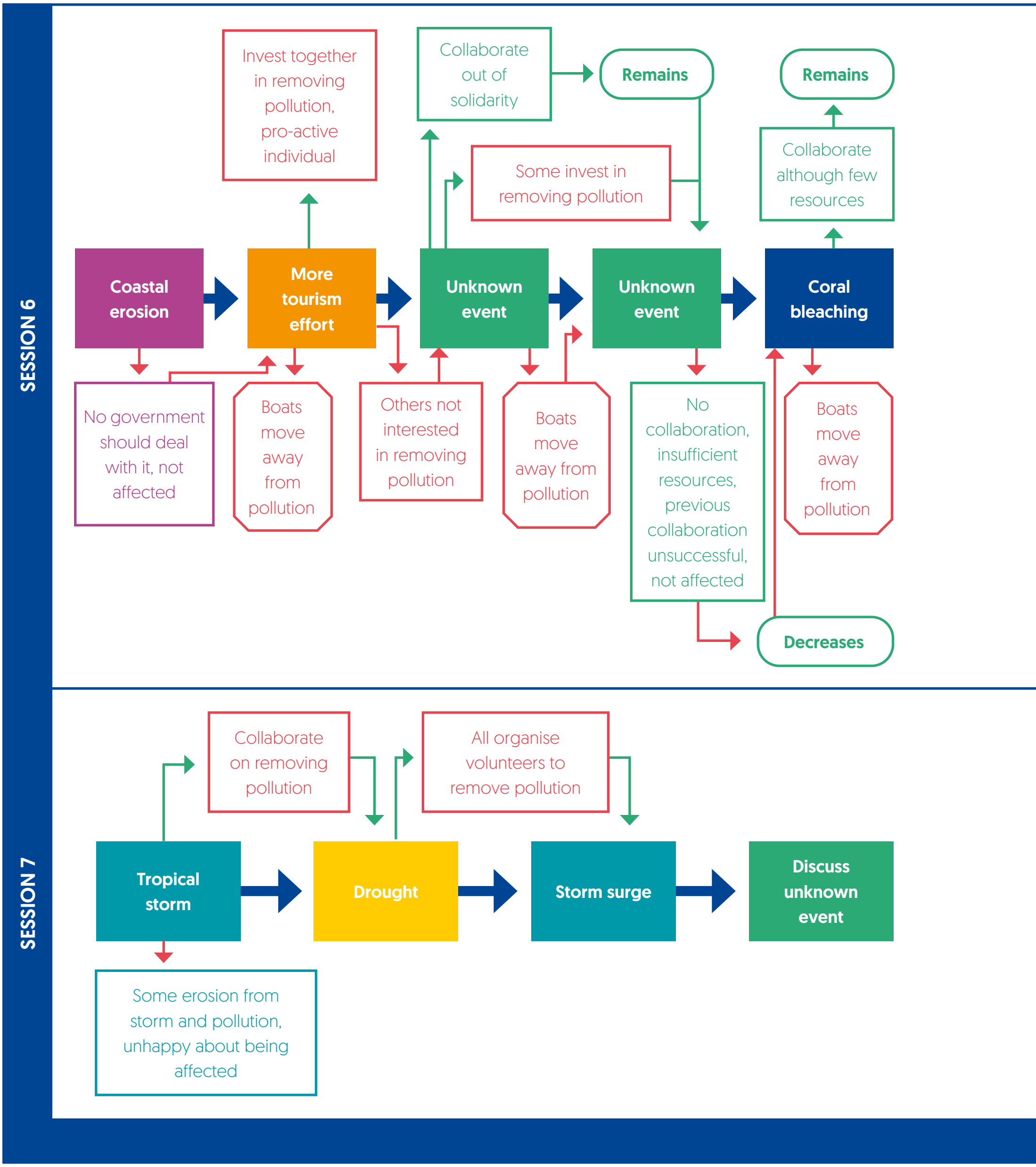
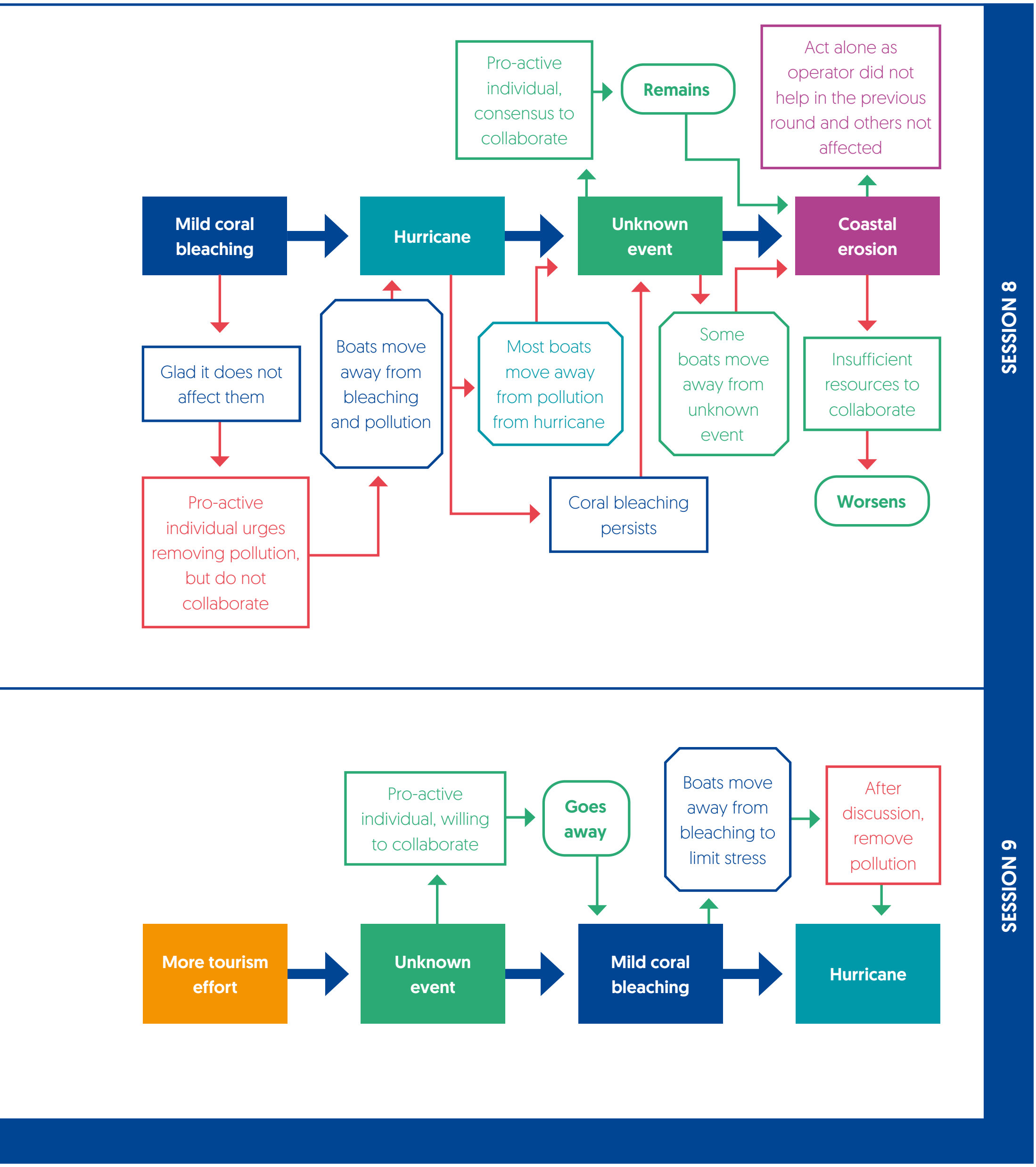


Figure 5.4. Environmental challenges and collaborative actions during the simulation sessions continued; box colour indicates events, blue arrows are the rounds, green arrows collaboration, red inaction


Pro-active individual, consensus to collaborate
Remains
Act alone as operator did not help in the previous round and others not affected
Mild coral bleaching
Hurricane
Unknown event
Coastal erosion
Glad it does not affect them
Boats move away from bleaching and pollution
Most boats move away from pollution from hurricane
Some boats move away from unknown event
Insufficient resources to collaborate
Pro-active individual urges removing pollution, but do not collaborate
Coral bleaching persists
Worsens
SESSION 8
Pro-active individual, willing to collaborate
Goes away
Boats move away from bleaching to limit stress
After discussion, remove pollution
More tourism effort
Unknown event
Mild coral bleaching
Hurricane
SESSION 9

5.3.4. Learning

During the debriefing, participants discussed what they learned from the *Coasting* simulation experience (which was guided by the questions in Annex 4). The individual experiences of playing their operator role, dealing with emerging environmental challenges, collaborating, and their reflections on a dynamic coastal setting are detailed in the following sub-sections

Individual environmental actions

Participants expressed difficulty in doing what they wished because they were forced to make more trade-offs as resources became scarce (all sessions) and they had to focus on survival (1,5,6). Achieving balance among the three investments (maintenance, tourism product, and the environment) was difficult (1,2,3,4,6): "you have three points and all three are rather important and you keep taking something from something else away and if you take this away then this happens (signalling environmental degradation on the board)" (1). Benefits for investing more in tourism were more obvious than investing in the environment (1,3,4,6,9). However, in two sessions (7,9) participants chose not to overinvest in tourism. For most participants, investing in the environment was less attractive, especially as they did not see the intended results of their actions (1,3,5,6) and it felt like a burden to continuously invest (1).

But the *tourism first, environment second* strategy did not always work because participants reflected that destinations still need clean beaches/coastal areas to offer tourists (1,2,3,6,7). In most sessions (1,2,3,6,9), participants saw the importance of keeping up with maintenance. A few participants—most of whom were not tourism operators in real-life—had more difficulty with the idea that ongoing maintenance was necessary (6,7). Some participants expressed concerns that others could benefit from their investments in the environment (3,5,6,7), and that others would either continue polluting or leave the island after earning revenue and claim bankruptcy. Moreover, participants reflected that destinations need to focus on attracting tourists because otherwise tourists will go to one of the competing islands (2,9). They also discussed whether it is better for the environment to concentrate tourism in particular areas or have tourism activities spread out over the entire coastal destination (3,7,9).

Emerging environmental challenges

Many participants found it difficult to keep ahead of environmental events, whether it was keeping up with pollution (2,3,4,6,8) or the accumulation of varied environmental challenges (1,3,4,6,9), especially as it required ongoing investment (1,2,4). In a number of sessions, they became aware of the pollution that others generated (1,2,5,6): "more tourism, more pollution" (participant statement session 2). Moreover, environmental actions by one operator, could be undone by another (1,2,3,6), especially in terms of pollution. In a number of sessions, participants reflected on the limits of control: pollution kept coming; participants (and operators) could do a lot of things, but nature kept changing, and actions did not guarantee favourable environmental results.

Individuals in many sessions commented on the lack of enforcement: tourists can do what they want with the reef (5,6), companies are not held accountable for environmental damage (3,6) or illegal activities (5), and those who alert the government or other enforcement bodies can be the one in trouble for calling out another person or company (5). Participants found that companies do not feel support from the government [5,6]. Some participants suggested that if tourism activities are harming the environment, that the businesses responsible should be required to invest in the environment, and that this should not be voluntary [3,5]. An easy to implement adaptation strategy identified in a few sessions was putting out more buoys to protect the reef [2,6,9].

Collaboration

Environmental problems experienced in the simulation and that can potentially unfold in real-life were viewed as larger than any one operator's capacity to deal with [5,6,7,8,9]. Within some sessions, participants found working together was better; successful collaborations grew trust [5,7,9] and motivated participants to work on other issues together [2,9]. However, participants mentioned that collaboration is more difficult in real-life as it was easier to discuss challenges face to face during the simulation and they were acting kinder to each other than competitors likely would [5,8,9]. During the games, some operators were generous with their contributions to collaborative efforts, while others kept quiet and took advantage [4,6,8,9]. Even in simulations where there were no collaborative actions [3] or no collaboration on certain events [1,4], participants recognised the importance of coordinated collaborative action. Ideas for collaboration in Curaçao included: concentrate tourism activities to some spots and leave other areas to rest as in Thailand [3]; communal funds for dealing with pollution [4,5,6], maintenance [6] and new environmental events [6]; and involving [5,7] or informing [3] locals.

At the same time, participants recognised that it is difficult to get enough resources together for collaboration; environmental problems are "everybody's problem, but [they are] nobody's problem" [session 1 participant statement]. Participants lamented that people, in general, are not interested in dealing with the environment [1,2,3,5,7]: "that's why there is a big bunch of plastic floating in the ocean" [session 1 participant statement]. Moreover, some believed that a catastrophe is needed for people to help each other [5], and that collaboration is more difficult to organise [5,9] and maintain [5,7] in real-life [5,9]. Moreover, coordination for some activities is easier than for others: in Curaçao, there is joint management for the land in some areas, but not for the sea, so the land is less polluted, but the sea adjoining areas of land-based tourism activities is some of the most polluted areas [6]. Similarly, in game sessions, there was coordination for some types of events, but not for others.

The dynamic coastal system

Participants reflected on many heterogeneities they experienced. They had different strategies: some focused on earning revenue, some participants tried to balance earnings with the environment, while others focused on the environment. There were also those who wanted to collaborate, while others chose to work alone, or be silent and let others resolve the issues. Heterogeneities in capacities and resources were also discussed [2,4,6]. For example, land-based operators found it difficult being stuck to one location: "you want to do things on the surroundings/environment and the tourists and maintenance but then the pollution comes to your door and you can't do anything" [participant statement session 6]. Moreover, some operators were affected less by certain events because of their location or the type of event (coral bleaching versus coastal erosion). In real-life, heterogeneities are difficult at an island level. For example, participants discussed how getting operators to pay taxes after years of tax breaks is difficult as other islands may offer them incentives to go there instead: islands end up "doing things because others are doing them" [participant statement session 3].

Participants found that people need more awareness of the value of nature and consequences (i.e., feedbacks) of individual and collective adaptation strategies (3,5,6). In a few sessions, operators explicitly chose to consider limiting the negative effects of their operations on the environment in their location selection (6,7,9). Some participants recognised anthropogenic stresses, in both the game and real-life, on the reef and how limiting stress could help the reef to recover (5,6,9). In only one session, a participant reflected on how instead of reacting to different changes, that they could act to prevent some of them (5).

Uncertainty was difficult for participants to contend with and often led to feelings of powerlessness, especially as there were external factors influencing the outcomes or events they could not prevent (e.g. storms) (1,3,5,6,7). A shared sentiment in multiple sessions was "you can do your part, but it doesn't matter if no one else does their part too" (participant statement session 1). Participants also expressed confusion; it seemed like no matter what they did individually for the environment, there was continually more pollution and environmental challenges (1,2,3,5,6,8,9). Moreover, their individual environmental actions could be undone by others (1,2,3,5,6,8). This caused frustration and made them question whether it was worthwhile to invest in the environment. Often, stakeholders did not realise the pollution that they had averted by investing in the environment, i.e. they saw the build-up of pollution when they did not act, but not the amount that was never emitted due to their investments in the environment (1,2,3,8,9). The need for more practical information on how to respond (adaptation strategies) was discussed among participants (2,3,5,6,7,9), e.g. what should they do when the coral reef is under stress and should one leave resolving new sudden events for later or act immediately.

5.4. Discussion

This paper focuses on the simulation and game play results that were held in Curaçao as a result of this process part of a dynamic vulnerability approach. The focus of these simulation sessions was to improve understanding of emerging vulnerabilities in a coastal tourism destination. These results of simulation sessions focus on individual actions, emergence of environmental challenges, collaboration, and learning. They illustrate the challenges faced at both the individual as well as collective level to act and the implications of a dynamic vulnerability assessment over a static one.

First, a static approach misses important changing aspects of agency: individual trade-offs and changing capacities. In developing adaptation strategies, the results indicate that we cannot take the individual trade-offs of acting as a business to earn money and looking after the environment second for granted. In most sessions, people decided to focus first on their operations and if and when they had enough reserves, work on the environment. The other extreme strategy was focusing only on the environment. Both individual strategies made long-term environmental actions difficult, the former because participants were not able to keep up with environmental change, and the latter because they did not have enough resources to keep investing in the environment. This further indicates how feedbacks create lock-in; thus, tourism strategies of first tourism and then the environmental are difficult to overcome. Local examples—non-enforcement of different environmental laws and the national strategy of tax rebates to certain types of operations—show that tourism-environmental actions are hard to change, especially as there is competition within and among islands for tourists.

Second, the approach highlighted the heterogeneities among types of emerging events that participants were willing to act on. Drought was not considered a major issue by participants. In session 3, although one player did not equate "water shortage in Curaçao" with drought, they did realise that a decreased water table would aggravate saltwater intrusion. Water experts in Curaçao have confirmed the lack of fresh water resources available. Curaçao relies on desalination plants, which require extensive energy resources (Becken & McLennan 2017). However, limited fresh water supplies is already an issue and is expected to worsen in coming years in the Caribbean (Rhiney 2015; Scott Hall et al. 2019). As such, drought is a critical issue that requires more visibility as people know they rely on desalination plants, but they do not seem to comprehend the potential consequences of increased water shortages combined with high water use.

Emerging pollution did capture the attention of participants in most sessions. However, there were disputes on what and who was causing it, and who should then contribute to solving it. Moreover, actions had consequences. For example, adding sand to the coastline resulted in damage to the reef. Participants in multiple sessions recognised the limits of their control. This is an important contrast to static approaches that give the feeling of control through engineering the coastline. In regards to collaboration, key conditions were having a pro-active individual, a sense that they were facing the problem together, reciprocation, and a personal interest in environmental improvement.

However, uncertainty of whether actions would be successful presented a barrier for individual and collaborative action. This was especially the case with unknown events. Participants were surprised that changes and results of their actions did not just depend on what they did and whether they worked together, they also depended on external factors. As such, uncertainties and unfavourable feedbacks did turn some pro-active participants into disenfranchised individuals. The simulation indicates the difference between what one may be doing at an individual level (e.g. investing in the environment) and what happens at the system level (e.g. increasing pollution). This is arguably one of the more important contributions of a dynamic approach over a static approach. The simulation sessions show the implications of ongoing human-environment interactions: opportunities to act and limits to control of outcomes (agency); heterogeneities in terms of actions, strategies, and changes to the environment; unintended feedbacks of actions; uncertainty regarding causes of and solutions to problems; and changes (iterations) in the system.

While the simulation sessions offer many critical insights for how stakeholders perceive and experience environmental change in the coastal setting, it remains a challenge to include all relevant views in the stakeholder process (Ducrot et al. 2015) in the time available. Barnaud and van Paassen (2013) show that power inequities and attempting equal participation are challenges in participatory processes. Moreover, not all the relevant stakeholders were willing to participate for various reasons including: lack of time, lack of interest in topic, discomfort with sharing information, and limited trust in the participatory process. Moreover, stakeholder involvement does not guarantee success for environmental issues (Ducrot et al. 2015); adaptation strategies in a dynamic system require ongoing action and reflection. This research would ideally follow up with the participating stakeholders, or hold other sessions where stakeholders could apply the knowledge gained from the previous session for acting on changes in the simulated coastal setting. Without continuation of vulnerability projects, ongoing learning depends on the stakeholders.

Another limitation of simulations is that some parts of the complex system need to be simplified in order to be playable (Rouan et al 2010; Solinska-Nowak et al. 2018). Premature bankruptcy, for example, was difficult to mediate. In the simulation, the goals were to have the participants experience and influence the different changes. In some combinations of the events and individual actions, players would go bankrupt quickly. This created the need to create situations where participants could continue the game with limited reserves.

Although *Coasting* is a simplification, it is able to capture some systems' complexity of dynamic vulnerability. The system's complexity is highlighted by the difficulty participants face in protecting the environment while having a sufficient income. Through simulations, participants can extrapolate their experiences to the real world (Solinska-Nowak et al. 2018). Moreover, simulations can help with system understanding and the emotions involved may help make the accumulation of challenges more real for stakeholders and also help stakeholders remember the experience (Solinska-Nowak et al. 2018). Creating interactive visual aids help stakeholders grasp the problems at hand (Spiegelhalter et al. 2011). As local support is required for implementing adaptation measures (e.g. Csete & Szécsi 2015; Rhiney 2015), simulations may contribute to greater support or adaptation measures that are better suited for the local context. The debriefing indicated an increased awareness of the individual trade-offs made, the ongoing challenge of dealing with environmental change, as well as the importance and challenges of ongoing collaborative action.

Typical assessments tend to focus on specific events and do not integrate the event with other challenges in the system. Emerging vulnerability issues, however, will not be limited to one type of event. One of the important results emerging from the iteration of rounds in the simulation is how responses change as a result of accumulating events. Participants expressed frustration after resources were depleted, collaborations did not go through, the number of challenges increased, or actions did not yield the expected results (e.g. pollution and unknown events). *Coasting* shows how capacity limits and trade-offs are factored into decision-making on environmental issues over time. Participants struggled with uncertainty, temporal delays in feedbacks as well as difficulty in determining which action pertained to which change. This is especially of importance on small islands where actor capacities and resources are limited. During fieldwork, many unexpected events unfolded. These developments, and stakeholder perceptions thereof, motivated explicitly incorporating uncertainties, not only by adding randomness to the simulation, but also by introducing an unspecified 'new unknown event'. The unknown event caused frustration and hesitation to act as players wanted to know what exactly it was, what the repercussions were, and whether their action would be successful or necessary for the challenge to be resolved. This indicates some of the difficulty of preparing people for unknown future vulnerability challenges.

5.5. Conclusion

Through engaging with the simulation, we can learn more about (local) stakeholders' perceptions of environmental changes, and when, under what circumstances and in what ways they are willing to act. In the simulation games, participants responded most strongly to increasing levels of pollution, coastal erosion, and unknown events, and less so to drought and coral bleaching. Moreover, *Coasting* illustrated the importance of visibility for determining participants' strategies. The benefits of investing in tourism were easily visible (measured through individual earnings). However, the benefits of investing in the environment were less clear and were often obfuscated by other participants' actions and environmental feedbacks in the coastal system. These sessions show that it is important to make the benefits of investing in the environment clearer in Curaçao. This finding likely applies to many other coastal destinations because of the complexity of the human-environmental interactions. Our focus on aggregate information for vulnerability implies that we expect a certain level of higher-level collaboration. But, the simulation sessions show how difficult it is to consider holistic concerns while at the same time having personal limitations and competition with others. We need to address these challenges of collaboration if we want to achieve synchronised measures of limiting vulnerability and improving adaptation. As such, it is crucial that people are empowered to act in order to improve adaptation strategies. Both the simulation sessions and field observations indicated that there is room for actors at tourism destinations to limit environmental stress. Although we cannot control all the outcomes, policy makers need to consider how to manage expectations, especially when limited resources are available.

One key benefit of simulation is the ability to create communication among the users during and beyond the game context (Barreteau Le Page & Perez 2007): "[e]xperience has shown that the involvement of stakeholders can increase public awareness, take account of local concerns, bring new options to light, delineate the space for agreement or compromise and, not least, enhance the credibility of public policies" (Mochizuki et al. 2018 p. 94). During the simulations, participants discussed the gaming experience as well as a range of challenges affecting Curaçao with people they do not usually discuss these issues with, if they discuss them at all. Although little is known about the long-term effects of these simulation sessions on the stakeholders, the diversity of stakeholders who did participate, the environmental challenges recognised through the game, and the discussions that followed, do indicate that the *Coasting* game was a useful medium for reflecting on emerging vulnerabilities. *Coasting* also challenged current assumptions of vulnerability and how stakeholders can adapt.

In complex situations, Stirling (2010) recommends embracing complexity and uncertainty instead of aiming to give simple, definitive answers. The simulation sessions indicate that focus on one type of event ignores destinations' limited ability to deal with other types of events. Limited capacities resulting from prior events during the simulations made it increasingly difficult to make trade-offs between personal needs and collective needs. Ignoring this, may give decision-makers a false sense of preparedness and control for what lies ahead. Participants from all sessions noted that the problems were bigger than any one individual and often cited powerlessness or frustration when desired results were not achieved. Accumulation of environmental events makes it difficult to decide on how and which events to use our resources.

Previous vulnerability assessments have identified destinations such as Curaçao as vulnerable. However, this alone is insufficient to encourage improved adaptation strategies. Static assessments do not consider the build-up of frustration, changing capacities, the pathways that block or lead to collaboration, nor include reflection on the consequences of stakeholders' actions. Bringing people together gives stakeholders the opportunity to interact with different viewpoints and acquire multidimensional understanding of the cumulative effects of environmental problems (e.g. Solinska-Nowak et al. 2018). This is practical application of dynamic vulnerability approach to gaining understanding of emerging socio-ecological vulnerabilities Chapter 4. Without necessarily experiencing the negative consequences of environmental change first, the game provides insights on the limitations and opportunities of developing individual and collective adaptation strategies in Curaçao and other coastal tourism destinations.

SIMULATING EMERGING COASTAL TOURISM VULNERABILITIES:
AN AGENT-BASED MODELLING APPROACH

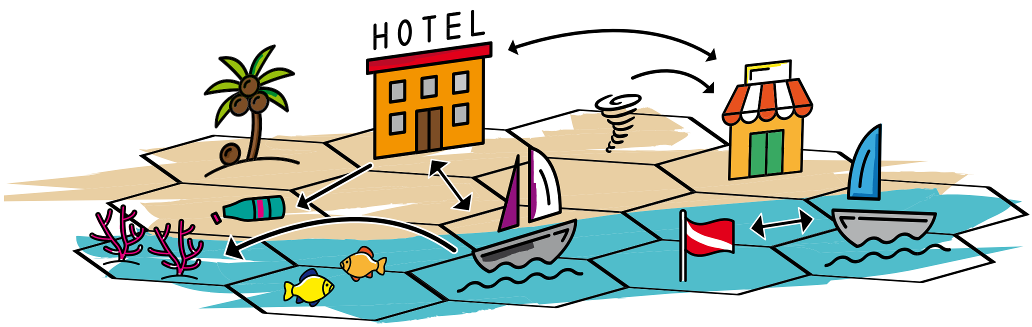
6

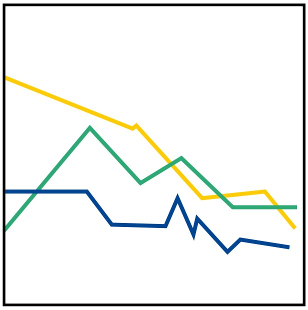
SIMULATING EMERGING COASTAL TOURISM VULNERABILITIES:

AN AGENT-BASED MODELLING APPROACH

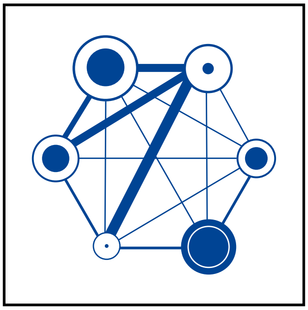
The agent-based modelling tool *Coasting*:

- Combines humans (tourism operators) with their environmental system to better understand emerging socio-ecological vulnerabilities in the destination of Curaçao
- Includes locally induced, slow onset, and sudden environmental changes
- Explores how tourism operators numbers, operator actions, and environmental attractiveness are affected by systems change

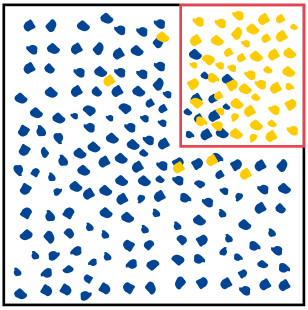




Changes of operator numbers and environmental attractiveness over time

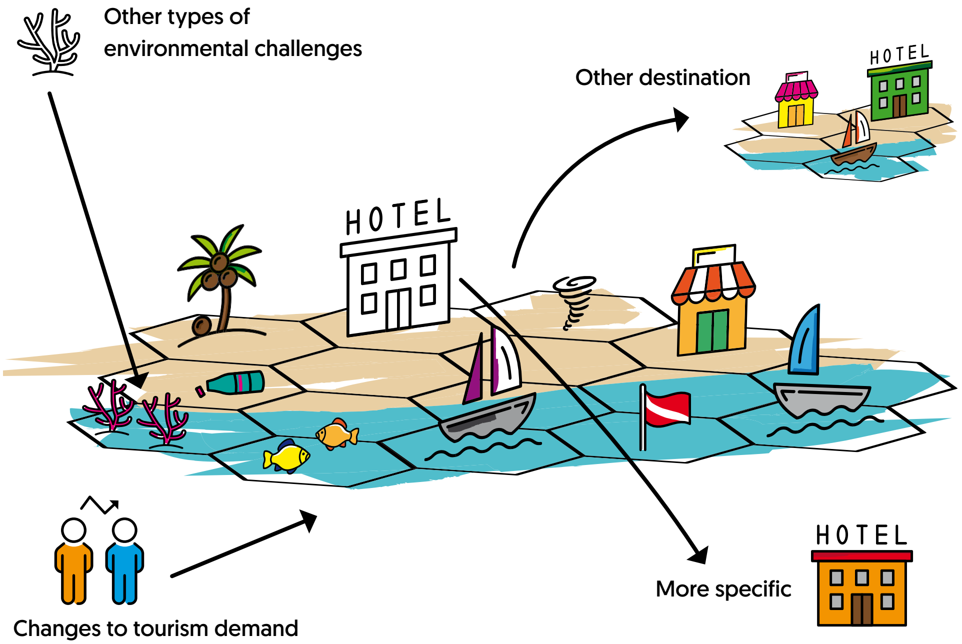


Interactions among factors that impact operator numbers



Factors leading to situations we want to avoid (e.g. loss of operators, deterioration of the environment)

Potential model extensions



Abstract

Coastal tourism destinations face a range of climate-related changes. However, how to understand emerging changes and what to do about uncertainty are prevailing challenges. A dynamic vulnerability approach is a promising way to analyse future emerging socio-ecological vulnerabilities. This research presents an innovative example of coupling the human-environment system in the agent-based model *Coasting* and focuses on Curaçao's coastal tourism. We observe how operator numbers and environmental attractiveness, proxies for socio-ecological vulnerabilities, change over time. Global sensitivity analysis shows which main interacting features influence socio-ecological vulnerabilities. Moreover, scenario discovery helps explore the main factors contributing to vulnerabilities we want to avoid. The model's findings provide key insights on which factors tourism destinations need to focus to prevent socio-ecological vulnerabilities.

Prepared for submission:

Jillian Student, Mark Kramer, Patrick Steinmann (for review) Simulating emerging coastal tourism vulnerabilities: an agent-based modelling approach.

6.1. Introduction

Coastal tourism is exposed to a wide range of climate-related drivers of change, including sea-level rise, ocean acidification, coral bleaching, increased frequency of storms, and drought (Hall 2018; Nurse et al. 2014; Rhiney 2015; Scott, Simpson et al. 2012). The Caribbean is a region that is both highly exposed to these climate-related drivers and dependent on coastal tourism for employment and GDP (e.g. Cambers 2009; Hall 2018; WTTC (World Travel & Tourism Council) 2018). However, the rates and types of change vary among these islands. The IPCC has high confidence that "small islands do not have uniform climate risk profiles", that both physical (environmental) and human attributes and responses contribute to the diversity of climate change impacts and recognise that this diversity of response "has not always been adequately integrated in adaptation planning" (Nurse et al. 2014 p. 1616). This diversity breeds uncertainty about the types of vulnerabilities a coastal destination is exposed to. It also requires translating climate change issues to the context of a tourism destination, which is lacking in the literature (Rhiney 2015). Moreover, environmental changes evolve over time and occupy different spatial areas within the destination, which create further uncertainties of who and what will become vulnerable under what conditions. To deal with this complexity and uncertainty (Chapter 2; Baggio 2008), we apply a dynamic approach to analyse these emerging vulnerabilities in a coastal destination and consider adaptation strategies (Chapter 3 & 4).

A dynamic vulnerability approach includes five principles for conceptualising emerging vulnerabilities in a coastal system: agency, heterogeneity, feedbacks, uncertainty, and iteration; it also puts forward five methodological tools for implementing the approach (Chapter 4). Many coastal destinations are vulnerable to climate change. However, as previously indicated, context is important for understanding emerging vulnerabilities. As a result, we focus this analysis of dynamic vulnerability on the coastal tourism destination of Curaçao, which is considered a vulnerability hotspot in the region (Rhiney 2015; UNWTO-UNEP-WMO 2008). Moreover, Curaçao is also a small island developing state (SID). SIDs are particularly vulnerable to climate change and noted to have limited capacities, resources, and alternatives (Nurse et al. 2014). Curaçao has been an independent state within the Kingdom of the Netherlands since 2010 and there is limited data and research related to climate change and tourism. Curaçao's tourism masterplan for 2015-2020 does not include environmental challenges nor climate change (CTB (Curaçao Tourist Board) 2015). Thus, although it is known that Curaçao is dependent on tourism in a region vulnerable to climate change, climate change is not directly considered for coastal tourism planning. As such, this research can contribute to improving understanding at the destination level in a geographical region where there is a prevailing gap (Becken 2013a). As mentioned above, there are many potential environmental threats identified for Curaçao and the Caribbean region. However, proactive, rather than reactive, responses to these challenges require new tools to explore the future (e.g. Chapters 3 & 4; Cinner et al. 2018; Rhiney 2015). A virtual laboratory can help us test multiple future vulnerability outcomes in the coastal destination of Curaçao, improve our understanding of emerging socio-ecological vulnerabilities, and contribute to improving adaptation strategies. Student et al. (Chapter 4) propose computational modelling, and specifically agent-based modelling (ABM), as part of a dynamic vulnerability approach to experiment with human and environmental heterogeneities, different levels of uncertainty, and test implications of different socio-ecological feedbacks in a virtual lab.

ABM is a promising method for multiple reasons. Baggio (2008) reasons that interactions, feedbacks, and iterations contribute to tourism system complexity. However, Bramwell et al. (2017) surmise that the methodological tools applied to tourism sustainability research have been limited thus far and call for a more diverse range of methodologies. The tourism field has traditionally employed linear causality modelling techniques, which are insufficient for capturing system complexity (Baggio 2008). Amelung et al. (Chapter 2) call for more exploratory and transdisciplinary methods "rather than disciplinary and predictive tools" to analyse changes in the system. ABM is comprised of three main elements: agents (e.g. humans), relationships (or interactions), and the environment (Macal & North 2010); it is a form of computational modelling that integrates agents with the environmental system in a simulated spatial and temporal setting. Moreover, ABM is a recognised tool for studying dynamic socio-ecological systems (Lippe et al. 2019). Recent applications of ABM in tourism include: the dynamics of changing destination choice preference (Alvarez & Brida 2019), crisis management in China (Zhai et al. 2019), and the growth of Airbnb and rental housing regulations (Vinogradov et al. 2020). Some researchers recommend agent-based modelling (ABM) as part of an interactive process to facilitate better system understanding (Chapters 2 & 4; Le Page et al. 2017; Nicholls et al. 2017; Ruankaew et al. 2010). ABM permits modelling from bottom-up including the heterogeneities of different actors and the environment (Chapter 4) in complex systems (Macal & North 2010) to investigate how destination level vulnerabilities emerge.

As there is little known about the multiple factors affecting socio-ecological vulnerabilities in Curaçao, we want to be able to explore the interactions among people and their environment under varying conditions using ABM. Turner et al. (2003) identifies two types of environmental change: slow emerging stressors and quick onset shocks. These challenges affect stakeholders and the coastal system differently. Tourism operators are identified as being more vulnerable than tourists as they have limited capacities, fewer alternatives (Kaján & Saarinen 2013; UNEP-UNWTO-WMO 2007), and are directly connected to the destination and the emerging environmental challenges. The term *tourism operator* refers to the people operating coastal tourism related businesses, not to be confused with tour operators, which offer package tours to tourists. As such, we study their interactions with emerging change. Moreover, adaptation is "not an isolated phenomenon; the process requires cooperation at social, political and spatial levels" (Csete & Szécsi 2015 p. 480). Collaborative action is considered important on small island developing states; the IPCC (2014 p. 106) state that "community-based adaptation has been shown to generate larger benefits when delivered in conjunction with other development activities". Thus, we want to know more about individual and collaborative actions in a dynamic system and consider the trade-off of looking after one's own resources and working on issues that are larger than individual abilities. Interactions among heterogeneous operators and the environment under climate change conditions lead to deep uncertainties. There are many challenges that destinations could work on. However, limits on time and capacity necessitate insights on what are the main factors decision-makers need to concentrate on in order to avoid an undesirable future situation. As such, we explore these uncertainties in our agent-based model using techniques to provide key insights for decision-makers on areas to focus on in consideration of limited capacities.

This research explores which human and environmental interactions lead to the emergence of social and ecological vulnerabilities in the coastal destination of Curaçao and uses innovative analyses to better understand emerging socio-ecological vulnerabilities and potential adaptation strategies. This study offers three types of dynamic analyses to better capture these emerging vulnerabilities: vulnerability over time; main contributing and interacting factors that affect human and environmental vulnerabilities; and an analysis of the most influential factors leading to situations we want to avoid.

6.2. Methodology

6.2.1. *Coasting* agent-based modelling

The following sections explain the main features related to the human-environmental interactions in the agent-based model. More details about model specifics required to replicate the model are available in the ODD+D section of the annex, which is based on Müller et al. (2013), an extension of the ODD proposed by Grimm et al. (2010). The ODD+D is more explicit in its representation of the human dimension within ABM.

The *Coasting* model, used to study emerging socio-ecological vulnerabilities in Curaçao, is based on a dynamic vulnerability approach developed on Barbados and Curaçao (Chapter 4). The *Coasting* model was developed in a way that it can be instantiated for other coastal destinations. This particular model instance focuses on the coastal destination of Curaçao and simulates 30 years from the present date. The five principles of a dynamic vulnerability approach inform the set-up of the key human and environmental features, and socio-ecological interactions of the model; Table 6.1 shows how the model applies this conceptual lens. The *Coasting* model mimics the human and environmental features of the *Coasting* simulation game; many of the input parameters in the agent-based model are similar to the game (see Chapters 4 & 5).

Table 6.1. Principles of a dynamic vulnerability approach present in the *Coasting* ABM

Agency	- Decide how to distribute personal resources based on weight preference, where to operate based on geospatial type preferences and in some cases, presence of environmental resources. - Environmental resources (coral reef, mangroves, sea turtles, reef fish) can reproduce, deteriorate and sea turtle and reef fish may move to other locations - Decision whether or not to act: if act, whether to collaborate or act individually - Decision to move to another location (for the mobile operators)
Heterogeneity	- Tourism operators: five operator types (hotels, beach, dive, boat, and nearshore), needed resource inputs required by type, mobility (mobile vs immobile), individually different input strategies (preferences), different input strategy for when they have sufficient resources and insufficient resources - Environmental resources: varying health levels, abundance, location, mobility (mobile vs immobile) - Environment: different types resources (sand, nearshore, deep sea, coral reefs, sea turtles, reef fish), geospatial type (e.g. coast, nearshore beach, nearshore waters inland), level of pollution, environmental degradation, biodiversity - Runs: Input parameters can be modified (see Annex 5)
Feedback	- Tourism operators: pollution limits returns, spending more on tourism increases profits, spending on environment can reduce pollution; if tourism product spending is not balanced with environment pollution increases - SLR: decreases land area, bankrupts land-based businesses and associated water-based business if they become inundated - Sudden events: create environmental degradation - Pollution and environmental degradation decrease health
Uncertainty	- Tourism operators: will personal expenditures generate enough returns, will individual contributions help the environment - Collaboration: will others be willing to collaborate, will they be willing to invest enough - Pollution: where will it disperse to, will action alleviate it - Sudden event: where it will occur in the system, will it go away naturally, will actions reduce the environmental degradation caused - Environmental actions to SLR: will action be sufficient to deal with SLR
Iteration	- Multiple runs with different settings - Within each run, every time step builds on the context of the previous round, operators' capacities, and environmental health - Explores a period representative of 30 years - ABM elements were adapted so that the model can be alerted to look at a different location and operator set-up - Modified to specify operator or environmental resource behaviour from simulation sessions

6.3. Main features of the *Coasting* model

As we are assessing dynamic socio-ecological vulnerability, we focus on outputs related to tourism operators and the environment. The main output of socio-economic vulnerabilities is the number of tourism operators with enough resources to maintain their businesses. Each simulation session starts with 75 operators and no new operators are added during simulation runs. Bankruptcy indicates that insufficient resources are available for sustainable tourism operations. The number of tourism operators still in business indicate the level of socio-economic vulnerability.

Table 6.2. Main parameters considered as part of the analysis

Parameter name in *Coasting*	Explanation
Tourism-returns	Tourism returns, >=3 sustainable ratio Ratio of tourism revenue earned compared to inputs in tourism product
Revenue-limited?	Boolean, if true, limits the amounts operators can earn to consider capacity and infrastructure limitations; if false, ratio tourism-returns remains consistent
Seed-for-random	For reproducibility of stochastic aspects of the model (during initialisation and further development of the run)
Pollution-threshold	The amount of pollution that accumulates before an operator observes (lower number indicates higher sensitivity)
Cost-pollution	Cost to remove pollution from the environment
Pollution-change	The amount (rate) of pollution added or removed from the system from operator actions
Linear-SLR?	Boolean, if true, linear SLR assumes same continued rate; if false, slowly increases the rate of SLR
SLR-increase	The amount of sea-level rise per year ranging from none to 50m
Min-acceptable-elevation-above-SL	Minimum elevation difference between sea level and land-based operators' infrastructure that operators find acceptable
Increased-elevation	The increased coastal elevation through operator interventions on SLR
Geospatial-weight	Geospatial influence, how much the geospatial type (nearshore waters, coastline (beach, shore), nearshore beach) contributes to environmental attractiveness, the coastline has the largest value
Biodiversity-weight	Biodiversity influence, how much biodiversity contributes to environmental attractiveness
Pollution-weight	Pollution influence, how much anthropogenic pollution detracts from environmental attractiveness
Environmental-degradation-weight	Environmental degradation influence, how much anthropogenic pollution detracts from environmental attractiveness

The main output indicating changes to environmental vulnerability is environmental attractiveness. Environmental attractiveness is found in the literature as an important proxy for vulnerability. For example, Santos-Lacueva et al. (2017 p. 11) "define a destination's vulnerability to climate change as being a reduction in its attractiveness caused by climate change". Similarly, Hopkins et al. (2013 p. 449) state that "how climate change might affect demand and perceived attractiveness of destinations relative to their competitors" is used in tourism studies to determine relative vulnerability. Along with an average environmental attractiveness for the coastal destination, the model separates environmental attractiveness into three sub-categories: coastal (land and water in immediate contact), beach (land immediately connected to the initial coastal area), and nearshore (water area that is near to the coast and not considered deep sea). In the model, environmental attractiveness is made up of a base increased by geospatial type and biodiversity, and lowered by pollution and environmental degradation. As it is unknown how much these four factors determine environmental attractiveness, the weights of these four factors are varied. Table 6.2 displays the main parameters relevant to the analysis results.

The main steps of the model are the following: (1) the environment changes, (2) operators plan how to distribute their resources over their operational budget,(3) an environmental event may occur, (4) operators decide whether they want to collaborate on it, (5) if not, they decide whether they want to act alone, (6) the environment responds, (7) the operators then collect their revenue from tourism minus any penalties for delays on maintenance, (8) pollution level is updated, (9) mobile water-based operator move, (10) operators without enough earnings go bankrupt, (11) environmental resources (fish, turtles, reef, mangroves) update their health and if mobile, can move to another location. Figure 6.1 shows the main human and environmental features included in *Coasting*.

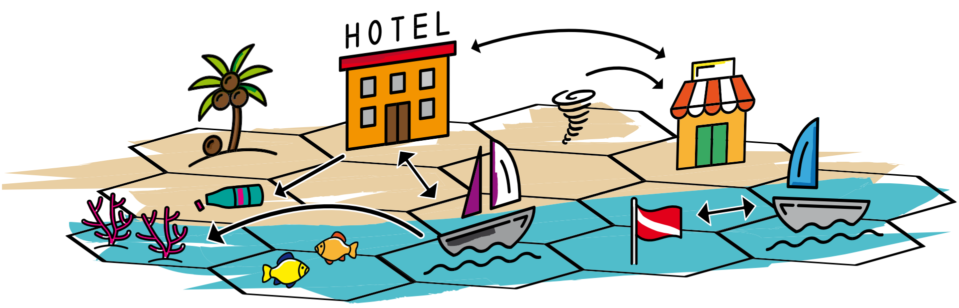


Figure 6.1. *Coasting* model features: tourism operators (e.g. hotels, beach vendors, boat and dive operators), interaction between operators, different coastal features (e.g. coral reef, beach, fish, nearshore waters), effects of tourism on the environment (e.g. pollution, stress on reef), effects of the environment on tourism (e.g. storms and decreasing beach (right))

6.3.1. Human (agent) inputs included in *Coasting*

The simulated tourism operators differ in their mobility, their resource input requirements, and their resource allocation preferences (in both situations of excess and limited resources). There are four main allocations for their business: maintenance (upkeep of their infrastructure and tools), the tourism product (bringing in and catering to tourists), short-term environmental actions (e.g. beach clean-up, educating on reef safe), and savings. These categories are based on earlier results of the dynamic vulnerability approach: as identified in interviews, verified in simulation guided-interviews, and experimented with in the simulation sessions (Chapters 4 & 5).

In ABM, entities can be considered "agents" if they express some form of agency—the ability to act independently (e.g. Macal & North 2010). In *Coasting,* tourism operators are the human agents and environmental features of mangroves, fish, coral reef, and sea turtles are considered environmental agents. In the model, the simulated tourism operators have preferences of location (e.g. dive operators prefer coral reef areas with fish and/or sea turtles) and resource allocation (how to distribute their resources among four input categories (maintenance, tourism product, environment, and savings)), and interact with changes to the system. Our model explores how different tourism operator preferences for location and resource allocation interact spatially and temporally.

In response to environmental changes (detailed in the following section) in the model, tourism operators can first choose to collaborate; if the problem is not addressed, they may act individually. The corresponding model outputs of numbers of actions are registered separately for collaborative and individual actions. Two alternative options are doing nothing and, for mobile operators, moving away. The environmental features in *Coasting* have the following characteristics: some have mobility (fish and sea turtles), their health is affected by pollution and environmental degradation, they have a sensitivity to pollution and degradation, and they can multiply or die. These environmental resources contribute to biodiversity, influence some operators' (dive and boat operators) location selection, and contribute to environmental attractiveness.

Tourism operators interact directly with each other through collaborations. Tourism operators' networks are expressed in links between operators. Links are established, either through model initialisation or as a result of collaborating on an environment. Links are held by each operator of all of the other operators they have established. Links have strength; the strength can be positive (good past collaborations) and negative (unsuccessful or unhelpful past collaborations). The strength enables the simulated operators to remember whether and to what extent other operators in their network have helped them on previous environmental challenges. Links become more positive if others helped and more negative when collaborations fall through or other operators free-rides.

6.3.2. Environmental features included in *Coasting*

The spatial coastal environment is characterised by key geospatial types (beach, coastline, nearshore waters, deep sea, inland), elevation, pollution level, and environmental degradation. Elevation is important when considering SLR and the dispersion of pollution (downhill on land, mixed along the coastline, and dispersed in nearshore waters). For example, pollution is a proxy for anthropogenic waste that includes chemical and physical waste. Pollution level is calculated based on a balance between investments in tourism and environment. If they are in balance, no pollution is emitted. If there is more focus on the tourism product, then pollution is generated. If there are relatively more investments in the environmental, pollution levels in a space may be lowered. Environmental degradation relates to the damage caused to locations by climate change.

6.3.3. Environmental change inputs included in the *Coasting* model

Three types of environmental changes are included in this version of the *Coasting* model: locally derived pollution; sea-level rise (SLR); and unknown sudden events. Local contribution to environmental change is in the form of (increasing) pollution levels that follow an imbalance between their allocations in the tourism product and environment. Two climate change related events mimic climate change stressors and shocks: SLR is a slow emerging stressor, and unknown sudden events are the shocks. To explore the emergence of vulnerabilities in relation to SLR, the modelled system is exposed to different rates of sea-level rise, different minimum acceptable height above sea level for land-based infrastructure, the cost of intervening SLR, and the amount of elevation gained by an intervention. Table 6.2 provides further explanation of these input parameters. The unknown sudden events represent the new emerging challenges that tourism destinations are confronted with and stem from field observations. Sudden events can proxy the negative effects of heavy storms, coral bleaching events, inundations of sargassum seaweed, and outbreaks of diseases such as Chikungunya and Zika. Sudden events have an interval of occurrence, percentage chance of parts of the coastal space being affected, the degree of environmental degradation caused by an event, duration before they may naturally go away, costs for trying to remove the problem, and operators have a threshold for noticing environmental degradation caused by sudden event.

6.3.4. Data generation

Global sensitivity analysis results are obtained using software packages developed by Herman and Usher (2017). Scenario discovery results are generated using the Exploratory Modelling and Analysis Workbench Kwakkel (2017) as well as software from Jaxa-Rozen and Kwakkel (2018).

Global sensitivity analysis

Global sensitivity analysis is used to test the uncertainty of the model outputs (67) to measured model inputs (34). The global sensitivity analysis results are derived from 700,000 runs using the Saltelli sampling method.

Scenario discovery

For exploring future scenarios of socio-ecological vulnerability, we use scenario discovery. Scenario discovery is a general analytic method for identifying decision-relevant or insightful scenarios in the outputs of complex system models (Lempert et al. 2006). It is based on the idea that the narratives used for scenario-based planning should not be specified in advance, but emerge from the complex interactions within the studied system (Bryant & Lempert 2010). Scenario discovery can be seen as a computational back casting, the inverse of sensitivity analysis, and is a complementary model analysis technique. For this research it is useful because we do not have to pre-define the ranges of SLR in combination of sudden events in advance, but can see how different values of these environmental factors mixed with other parameters lead to situations we want to avoid, i.e. socio-ecological vulnerabilities. In scenario discovery, we set criteria that indicate whether a run describes an acceptable future or an unacceptable one. In this case, do operator numbers decline below an acceptable threshold and/or does the environmental decline beyond an acceptable threshold? Exactly what constitutes an unacceptable number of bankrupt operators or level of degradation by attractiveness varies from destination to destination, but extreme losses to the tourism sector or environment can be considered undesirable and for Curaçao we look at extreme losses to both. From this, we can assess the parameters that are most influential in creating the unacceptable futures.

In practice, scenario discovery is a three-step process, comprising generation of data (model set-up and runs), identification of outcomes of interest (in this case operator numbers and environmental attractiveness), and induction of input parameter rules (determining thresholds for number of operator lost and percentage of environmental decrease) (Lempert et al. 2006). In the first step, a large ensemble of computational experiments is performed on a simulation model by sampling from the input parameter space. In the second step, the decision-relevant or interesting experiment outcomes are identified, often based on a failure threshold—futures that should be avoided. In the third step, the region of the input parameter space which generates the outcomes of interest is identified using a rule induction algorithm (Lempert et al. 2008). The identified region of the input parameter space is highly predictive for the outcomes of interest. In other words, it shows under which input conditions a system failure is likely, i.e. unacceptable decrease in operator numbers and/or environmental attractiveness decrease.

We performed 4000 simulation experiments, with 30 replications each (120,000 runs). Each experiment was performed with a unique set of input parameter values, while the replications of each experiment differed only in the random seed. We computed the mean across the 30 replications for each experiment to eliminate stochastic influence. Scenario discovery looks at how the dynamics of the system contribute to unacceptable futures and is analysed at a particular future moment in simulated time. For *Coasting,* the end of simulated time (30 years) was selected.

6.3.5. Experimental set-up

The main objective of this particular model instance simulating Curaçao is to analyse socio-ecological vulnerabilities. The main outputs that are explored in the results sections are operator numbers (by type), number of individual and collaborative actions over the simulation, and changes to average environmental attractiveness (see Table 6.3).

Vulnerability over time

Figures 6.2 and 6.3 use kernel density to indicate how operator numbers and environmental attractiveness change over time. Kernel density estimates are statistically inferred estimations of the probability distribution curve—the shape—of some underlying data. They are the continuous equivalent of discrete histograms. In both figures, we plotted kernel density estimates at every time step for 4000 runs of *Coasting,* with the probability density function being represented by the color gradient: bright yellow indicates a large amount of data points (i.e. many of the simulation runs have roughly this value at this time step), dark blue the opposite. Plotting kernel density estimates over time can be useful for identifying overall trends across many simulation runs.

Table 6.3. Main outputs of interest for *Coasting* simulation of Curaçao

Output	Model name	Description
Socio-economic vulnerabilities	m-all-ops m-hotelops m-beachops m-boatops m-diveops m-waterop	Number of [...] all operators, hotels operators, beach operators, dive operators, boat operators, nearshore operators (NSOs)
Action outputs	Number of individual actions Number of collaborative actions	Total number of actions up to the point of analysis
Ecological vulnerabilities	m-av-now-attr-beach m-av-now-attr-coast m-av-now-attr-nearshore m-av-now-attr-area	Average per type [...] Beach attractiveness Coastal attractiveness Nearshore attractiveness Overall environmental attractiveness

Interacting factors affecting vulnerabilities

The circle plots in section 6.4.2 show how strongly model outcomes depend on parameter values of individual parameters and combinations of parameters. In their paper on PyNetlogo, Jaxa-Rozen and Kwakkel (2018) introduced these plots and we use their Python code for generating them. The underlying values are obtained using SAlib (Herman & Usher 2017). The inner (black) circles indicate the sensitivity of an outcome to an individual parameter (S1). The outer (white) circles indicate the sensitivity of an outcome to a parameter in conjunction with all other parameters (ST). The connecting lines indicate the sensitivity of an outcome to the combination of two parameters (S2).

All sizes of lines and circles are relative: the larger the circle or thicker the line, the larger the sensitivity. For each of the three circle plot sets, we take the top four most sensitive parameters for each output (e.g. each of the operator number types). This resulted in six unique input parameters. Then, we show the same six parameters in all sub-figures of one figure to enable comparison among social vulnerabilities, environmental actions, and ecological vulnerabilities. To look at social vulnerabilities, we look at the sensitivities of operator numbers (Figure 6.4). As both individual and collaborative action is required to deal with environmental challenges, Figure 6.5 indicates which factors influence operators' environmental actions. To study ecological vulnerabilities, we look at the average attractiveness for the three main coastal areas: beach, coastal, and nearshore waters as well as the overall average for the destination (Figure 6.6).

Scenario discovery

We identified two distinct system failures which should be avoided, which are indicative of socio-economic and ecological vulnerability. The first scenario, *Economic Failure,* is characterised by the bankruptcy of 75% or more of the businesses in the model. The second scenario, *Ecological*

Failure, is characterised by a decrease in environmental attractiveness by 25% or more (which is large considering the calculation of environmental attractiveness, please see section A5.2 of Annex 5). We also considered a third scenario, *Combined Failure,* which is defined as the intersection of the two first scenarios: a future in which both the economy collapses and the environment degrades unacceptably (75% business loss and 25% environmental deterioration).

We use the Patient Rule Induction Method (PRIM) (Friedman & Fisher 1999; Kwakkel 2017) to find our scenario regions in the input space. PRIM tries to fit an orthogonal box around the region of the input space in which inputs generating undesirable outputs lie. This box can then be considered a very simple surrogate model, and its dimensions indicate under which input conditions an undesirable output is likely to develop. The fitting of this box is governed by three distinct parameters. Coverage represents how many of the decision-relevant (i.e. unacceptable) futures are included in a PRIM box. This attribute should be maximised to reduce false negatives (decision-relevant input parameter sets outside the box). Density captures the ratio of decision-relevant to -irrelevant futures in the boxes, which should also be maximised to avoid false positives (decision-irrelevant inputs inside the box). Interpretability covers to what dimensions the many input parameters dimensions the box has been restricted in size, i.e. the more parameter dimension, the more influencing input parameters the output has. To ensure the induced box is analytically tractable and useful, this value should be minimised.

Scenario discovery is heavily dependent on how the outcomes of interest are specified as that is the starting point for assessing whether or not a run meets the criteria. Both *Economic* and *Ecological Failures* outcomes are extreme. The reason for this that is that they both describe a future that we absolutely do not want to have. At the same time, fewer runs will meet the unacceptable future thresholds, likely reducing the number of dimensions required to demarcate the region of the input space generating unacceptable outputs.

6.4. Results

The following three sections show: which main vulnerability patterns for operators and the environment are observed over time (6.4.1); the interactions among factors affecting vulnerabilities (6.4.2); and scenario discovery of the main factors contributing to a vulnerability at the end of 30 simulated years (6.4.3).

6.4.1. Operator and environmental vulnerability over time

The following figures give an indication of how operator numbers and environmental attractiveness change over time. Figure 6.2 shows the probabilities over time for operator numbers over the simulated time of 30 year. It further indicates different levels of operator success when exposed to the same wide range of environmental and social input parameters. For example, the wide yellow band across the y-axis for m-beachops (beach operators) over the first 10-years indicate a wide range of possible beach operator numbers (high sensitivity to input parameters), but a tendency to values closer to 10 (darker yellow). Thereafter and until the end of simulated time, there is a smaller range of beach operator numbers (more blue areas), a tipping point (two yellow areas), and a tendency towards less beach operators (values closer to 0). Hotel operator numbers stay largely consistent and close to the initial numbers up until the last 10 years when another

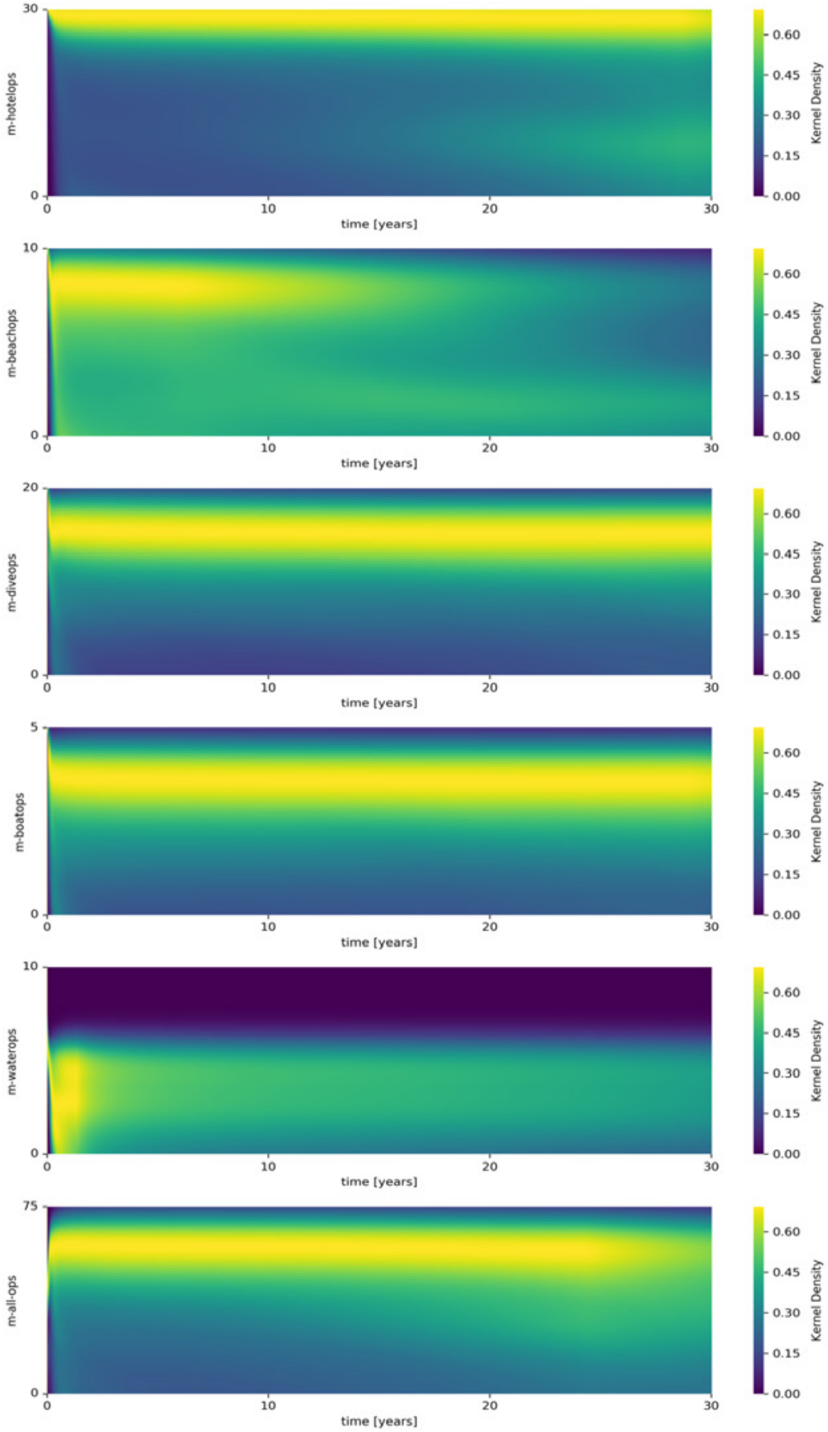


Figure 6.2 Kernel density of operator numbers over simulated time (30 years) for 4000 runs. The number on the y-axis indicates the max amount recorded in any of the runs. For every point in time on the x-axis, the colour gradient can be used to determine the density of model outputs occurring at a particular y-value

potential state of lower numbers is indicated. Surprisingly, dive operator numbers and range remain fairly consistent. Boat operators show a slight downward trend, but are largely consistent. Nearshore operators show a high tendency towards bankruptcy over the short-term. The general trend for all operator numbers is a decrease, but the there is less consistency and certainty.

For environmental attractiveness (Figure 6.3), the wide spread kernel density of potential attractiveness values indicates response to the wide-range of socio-ecological parameter combinations. In other words, the environmental attractiveness of different parts of the system (beach, coastal, nearshore areas) is highly dependent on the input parameters.

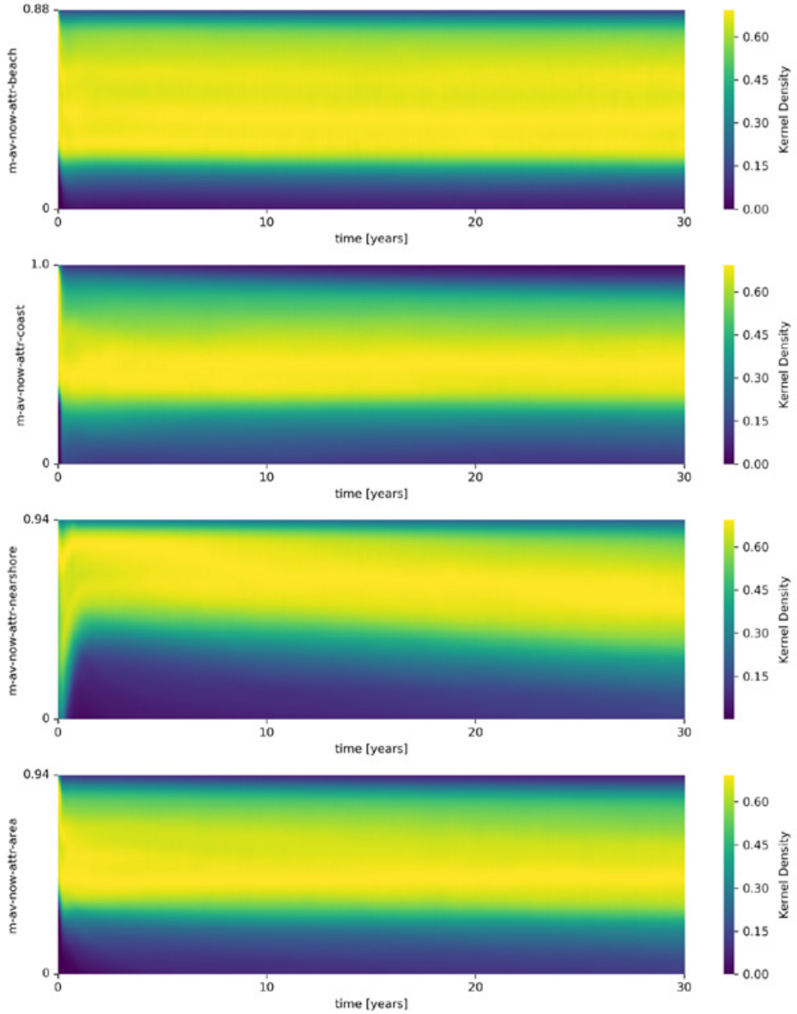


Figure 6.3. Kernel density of environmental attractiveness over simulated time (30 years) for 4000 runs. The number on the y-axis indicates the max amount recorded in any of the runs (range 0:1)

6.4.2. Interactions among factors leading to different levels of environmental and operator success

The previous section gave a global indication of how operator numbers and environmental attractiveness responded to all of the parameter combinations during the runs. But it does not indicate the main parameters that influence operator numbers and environmental attractiveness within the runs, nor does it show which of these input parameters interact with others. It also does not give us an indication of which conditions (input parameters) induce operators to act (output). Figure 6.4. indicates the influence of the most important parameters on different operator numbers. For example, the largest direct influence (S1) on beach operator numbers are tourism returns, rate of SLR, and the minimum acceptable elevation of their infrastructure above sea level. Along with direct influences, interactions (S2) between tourism returns and SLR, tourism returns and minimum acceptable elevation, and to a lesser extent tourism and stochasticity (seed-for-random) affect beach operator numbers. Stochasticity on its own does not exert much influence, however in combination with other parameters it does exert influence on operator numbers (ST). For all five operator types, tourism returns are the main influence on operator numbers. However, the input parameter (tourism returns) interacts differently with other parameters. For example, for land-based operators, i.e. hotel and beach operators, as well as nearshore operators, their sensitivity to rising sea levels (minimum acceptable elevation above sea level) has a relatively strong interaction with tourism returns.

As actions, both individual and collective, are required to deal with environmental challenges, Figure 6.5 indicates which factors influence their numbers. Surprisingly, the parameter tourism-returns (which contributes to the amount of available resources) is a more influential determinant of collaborative action while for individual action, the pollution-threshold (the amount of pollution necessary to consider action) is more influential. Moreover, for individual action, there is less interaction among the factors, while for collaborative actions and the main factor of tourism-returns, we see more influence of other factors for generating collaborative actions.

As the weights determining environmental attractiveness are one of the tested parameters, we observe in Figure 6.6 how the weights play a large role in determining the overall attractiveness, with geospatial weight (i.e. nearshore waters, coastline, nearshore beach) consistently being the most important parameter. The parameter is static throughout the simulation except when beach becomes water or beach is heightened to prevent loss of beach. Beach attractiveness, where immobile land-based tourism occur, has second order sensitivities to pollution factors (threshold, weight, and change) as well as tourism returns. This show operators' activities have a strong influence on beach attractiveness.

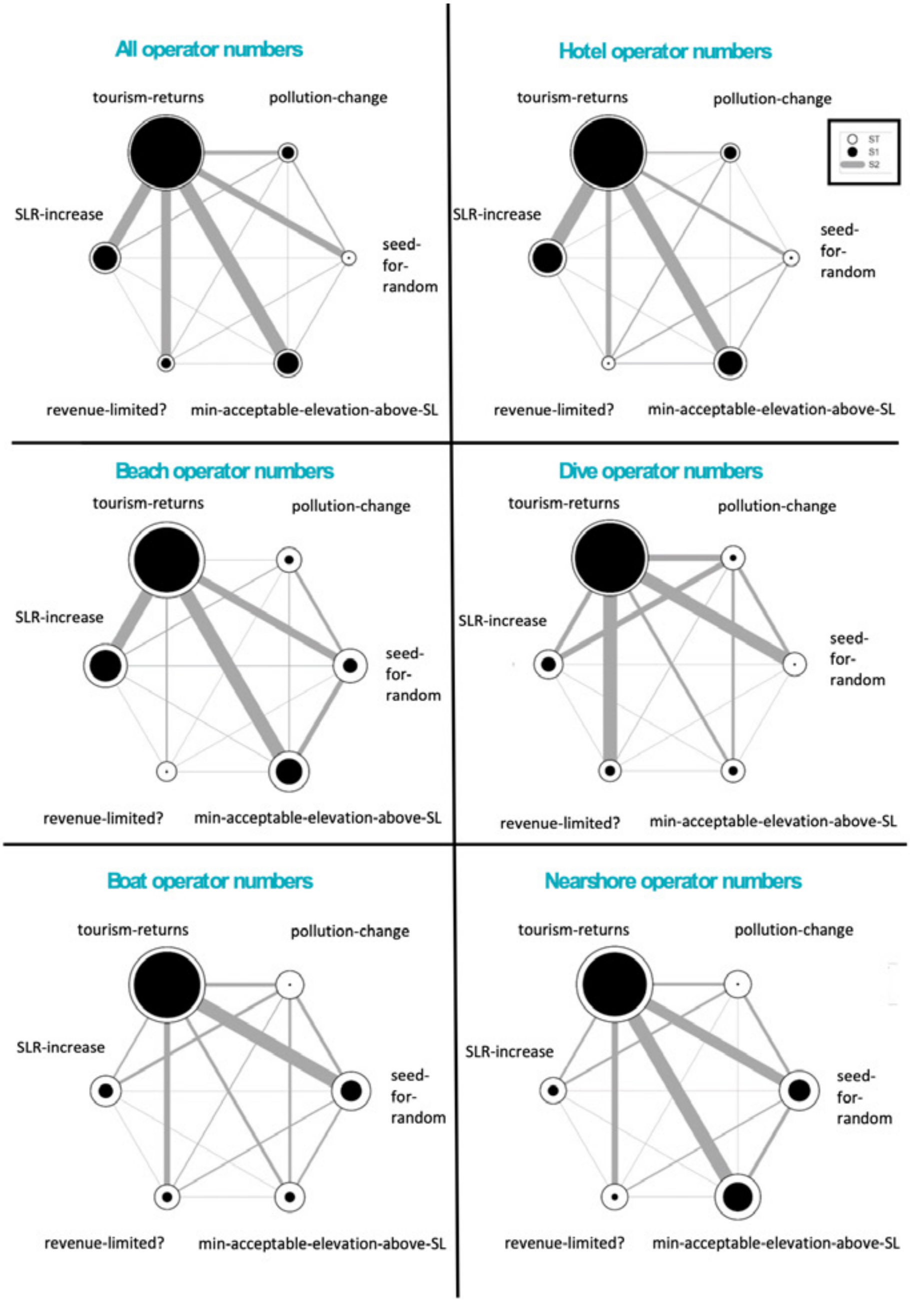


Figure 6.4. Key interacting parameters that lead to changes in operator numbers ST=total sensitivity, S1=1st order, S2=2nd order (interactions among parameters leading to output); size indicates relative influence on operator type numbers

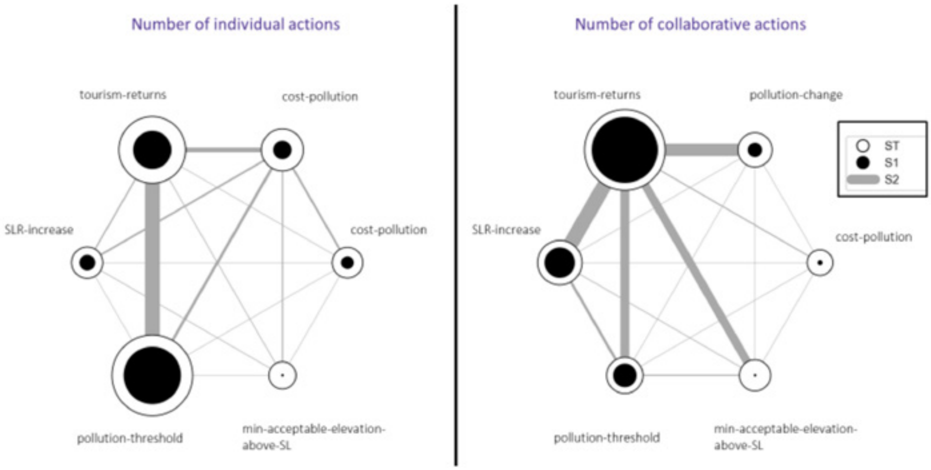


Figure 6.5. Key interacting parameters that lead to changes in actions taken and collaborations (output); ST=total sensitivity, S1=1st order, S2=2nd order (interactions among parameters leading to output)

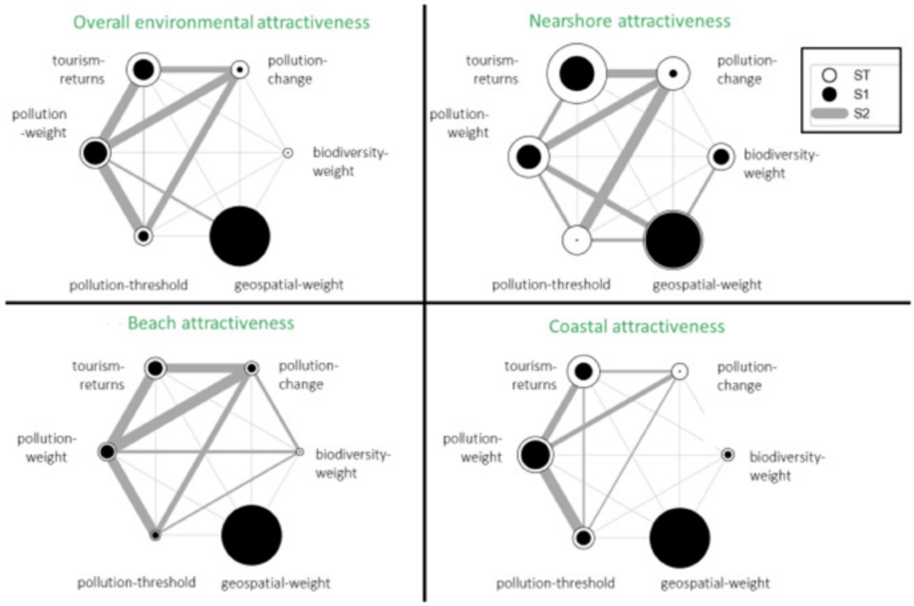


Figure 6.6. Key interacting parameters that lead to changes in environmental attractiveness (output) ST=total sensitivity, S1=1st order, S2=2nd order (interactions among parameters leading to output)

6.4.3. Scenario discovery

Many experimental runs resulted in ecological, economic, or combined failures. Figure 6.7 indicates the number of unacceptable outcomes that occurred. In dark blue, the number of purely economic failures is given—the majority of businesses go bankrupt, but the environment does not significantly degrade. In green, the purely ecological failures are shown—most businesses survive, but the environmental attractiveness degrades unacceptably. Turquoise represents both combined (ecological and economic) failures. It is evident that both ecological and economic failure can occur independently of each other. However, the fact that there is an overlap indicates there are some interactions and dependencies between the two failure modes under certain conditions. Scenario discovery can help identify under which conditions these combined failures may occur.

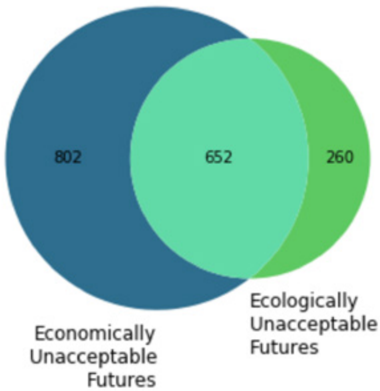


Figure 6.7. Venn diagram of unacceptable economic and ecological futures (from 4000 experiments)

Economic failure

Economic failure of the system is largely driven by low returns from tourism—it is the dominant input parameter in all three identified PRIM boxes constituting the scenario region of the input space (see Annex A5.4). In particular, almost 90% of all experiments which exhibited a collapse of the economic sector had a tourism return value of ~3.3 or lower (i.e. that high returns are necessary for economic success, see Table 6.2). Secondary predictors are acceptable sea-level rise, the existence of a revenue limit, pollution change, the cost of pollution, and absolute sea-level rise (please see the section A5.4 of Annex 5).

Ecological failure

Ecological failure is largely driven by the actors' pollution behaviour and perception, which are governed by the parameters pollution threshold and pollution weight. Pollution weight is the dominant parameter for this scenario region consisting of two boxes. Secondary predictors were tourism returns, acceptable elevation above sea level, and absolute sea-level rise (please see the section A5.4 of Annex 5).

Combined failure

For the scenario of combined economic and ecological failure, three parameters exert the strongest influence on this outcome: pollution change, pollution weight, and tourism returns (Figure 6.8). The red box of the scenario region indicates the parameter settings where there is the highest prevalence of runs that indicate an unacceptable future. For example, in the top-right plot, the PRIM box indicates a high failure rate (yellow circles representing runs) when pollution-

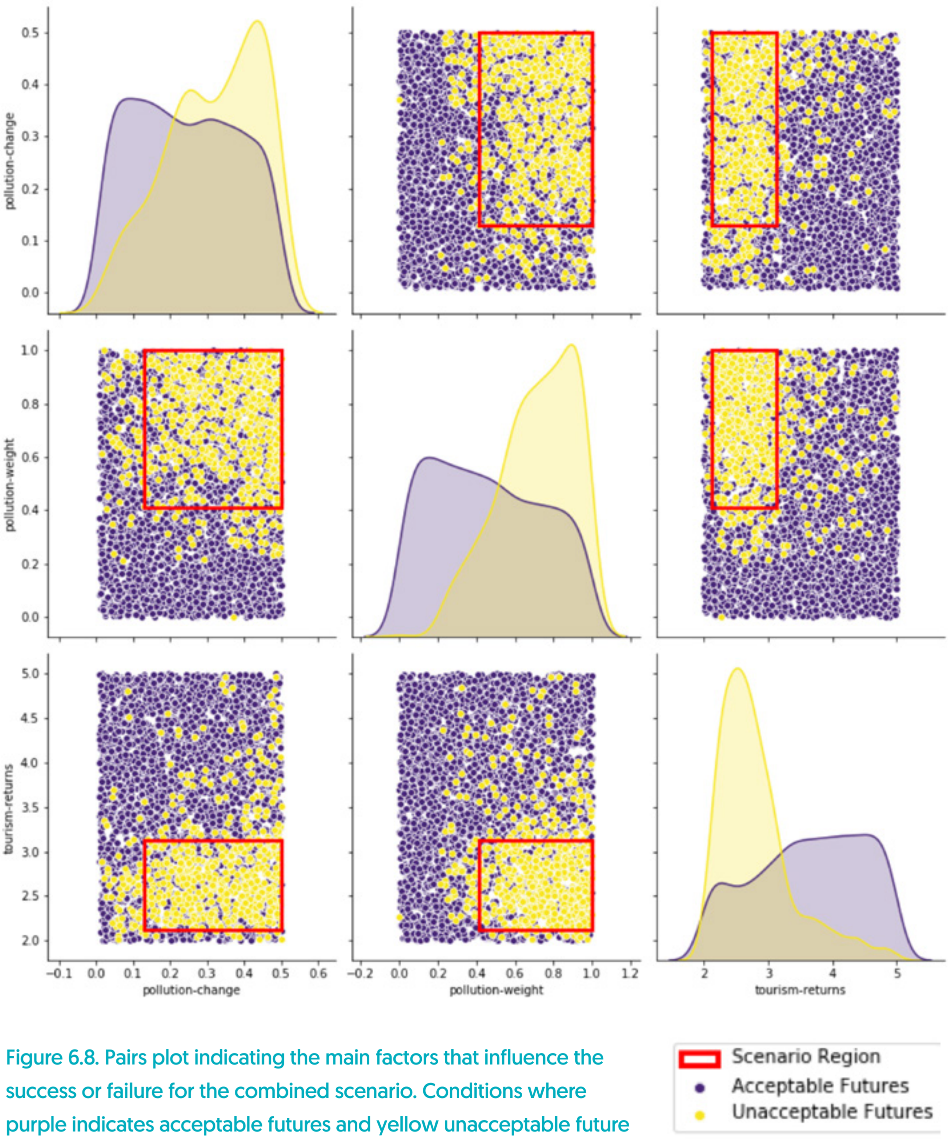


Figure 6.8. Pairs plot indicating the main factors that influence the success or failure for the combined scenario. Conditions where purple indicates acceptable futures and yellow unacceptable future (threshold is 25% ecological loss and 75% economic loss). Kernel density estimates of the two output classes are on the diagonal

change is > 0.1 and tourism-returns are < 3. Outside of this box, many runs indicate desirable outcomes (purple); however, there are clusters of yellow when tourism-returns is < 3 and for pollution-change >0.4 showing undesirable outcomes. The histograms in the diagonal indicate the acceptable and unacceptable futures for every value of the parameter (x-axis). As this scenario is a combination of the first two (economic and ecological failures), the further predictors are the same as in those.

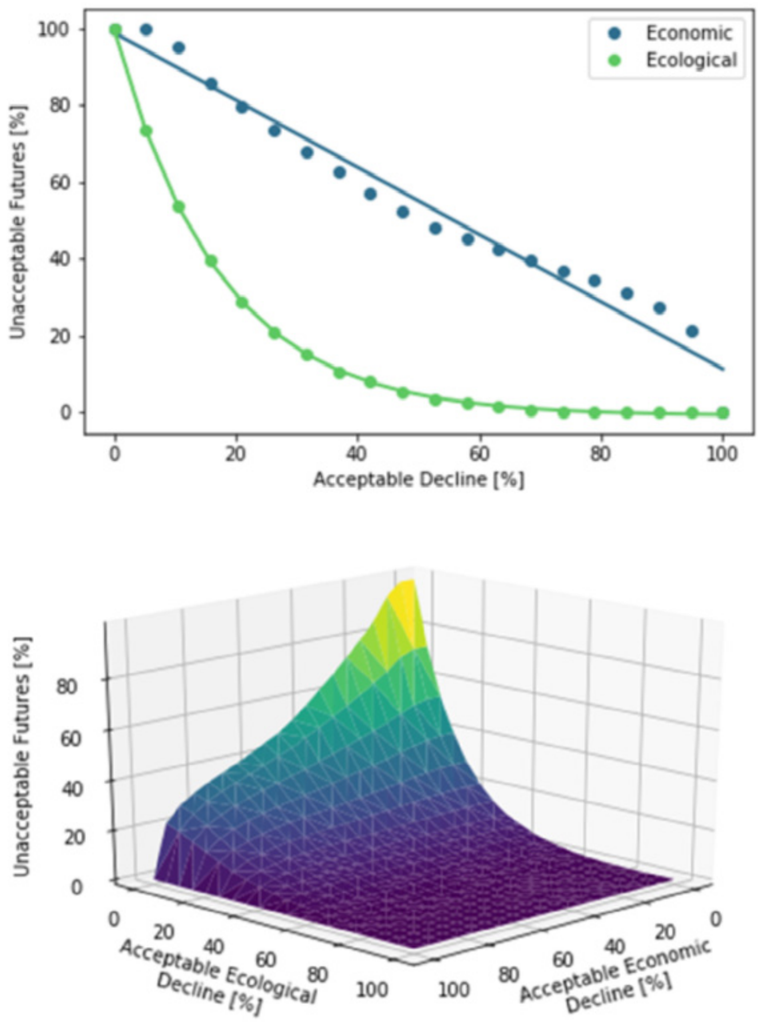


Figure 6.9. Top: Regression of acceptable economic and ecological failures percentage of unacceptable futures over the total runs; Bottom: 3D depiction of the nexus of acceptable ecological and economic decline and the % of unacceptable failures recorded over the total runs (4000 runs with 30 repetitions)

We then evaluated the sensitivity of unacceptable future scenarios to their chosen thresholds. In Figure 6.9 we show the number of outcomes of interest—experiments in which the unacceptable threshold is reached—over possible threshold values. It is apparent that while the economic failure scenario is linearly dependent on its threshold value, the ecological failure scenario is nonlinearly dependent. We underline this claim by showing regressions for the two series (Figure 6.9 top). While the economic failures are well-matched by a linear regression, an exponential regression is a much better fit for the ecological failures. We find that these trends hold true for the combined scenario, where high failure counts are driven largely by a low acceptable ecological failure threshold (e.g. <20%) (Figure 6.9 bottom)—the response surface is more sensitive to changes along the ecological decline axis than the economic decline axis.

6.5. Discussion

The *Coasting* model integrating human-environmental interactions is the first attempt known to the author of modelling the coastal tourism system, including both locally induced environmental problems as well as global challenges. The dynamic analysis of vulnerability is also new for tourism-climate studies. This study developed an agent-based model to research the emergence of socio-ecological vulnerabilities and is instantiated for Curaçao, which responds to Amelung et al.'s (Chapter 2) call for more transdisciplinary and exploratory tools, and multiple researchers call for destination level approaches to improving our understanding of emerging vulnerabilities and potential adaptation strategies (e.g. Cinner et al. 2018; Nurse et al. 2014; Rhiney 2015). It helped identify some of the dynamic mechanisms related to coastal destination vulnerability in Curaçao. This helps address the prominent climate change challenge of relating "physical impacts and changes in the environment with their human implications such as socioeconomic impacts or human responses" (Pons et al. 2012 p. 199) at a the destination level and highlights the utility of ABM for tourism planning and management (Nicholls et al. 2017). The *Coasting* model is part of a dynamic vulnerability approach and helps analyse complex effects in the socio-ecological tourism system from the ground up, including unexpected interactions between the social and ecological components.

Tourism returns is the most predictive parameter for success according to the different analyses of vulnerabilities. In the presented model of Curaçao, economic failure is largely driven by low tourism returns. This does not bode well for real tourism-based economies, where the "race to the bottom" on tourism returns is evident in price dumping on flights and accommodation fees, high competition among islands, and tax incentives to attract foreign tourism companies. In our model, there appears to be a sharp transition for tourism returns (around tourism-returns = 3). This indicates there may be a tipping point regarding the health of the tourism sector. In the model set-up, tourism-returns= 3 is considered a sustainable rate under normal conditions. This sensitivity and potential tipping point indicate that there is not much room for operators to adapt to impending combinations of environmental change. This finding is important for decision-makers in Curaçao as it indicates their positioning of Curaçao in the market and accepting lower returns from tourism can lead to both economic and ecological decline. Figure 6.5 provided insights on what key factors influence individual and collaborative actions. Individual action depends on when (at what level of pollution) people notice change; this is more influential than how much it costs or what rate it increases at. Thus, heightening operators' sensitivity to pollution (making pollution unacceptable) may help initiate more environmental actions. For collaborative action, the model indicates that having enough resources is a precursor to collaborating in conjunction with other environmental thresholds and change rates. This indicates that islands need to consider both the ecological problem as well as operators' capacities to promote collaborative actions.

Ecological failure is largely driven by the rate of pollution change. How much pollution determines environmental attractiveness (pollution-weight), and lower tourism returns; however, no significant tipping point can be identified. That pollution change rate and pollution weight are important, gives both hope and a warning. This finding indicates that actions to lower and prevent locally induced waste are significant influences on ecological success (i.e. limited environmental vulnerability). In other words, local actions matter. At the same time, if the island does not address locally-induced pollution it makes chances of ecological and economic vulnerabilities significantly higher, especially when other parameters can also lower operator capacities. It is surprising that the parameters of sudden events did not have a significant influence on economic nor ecological failure. This could be due to the larger role of pollution and sea-level rise; or possibly, their designed influence on the system was too conservative. This simulation indicates that the ongoing challenges of generating and dealing with waste along with SLR have larger influences on the emergence of vulnerabilities than the sudden extreme events that receive much media coverage. To sum up, although Curaçao is facing global climate, the model indicates that local actions to limit pollution are critical for limiting both socio-ecological vulnerabilities.

Specification of failure (or success) criteria in nonlinear systems is not trivial (Figure 6.9). While we had originally identified two distinct failure scenarios for scenario discovery, we later found that they had highly dissimilar sensitivities to their chosen threshold values. This highlights how different success or failure metrics in complex systems cannot be treated identically.

Moreover, this research is an important point of departure for future research on emerging vulnerabilities in coastal tourism. While this model does indicate important patterns leading to socio-ecological vulnerabilities, this model should not be confused for being predictive in nature. Rather, *Coasting* is an exploration of potential vulnerabilities under known and anticipated environmental change. Researchers (e.g. Le Page & Perrotton 2018) advocate for starting simple and adding complexity to the model in layers as different parts of the base are better understood. Necessarily, the *Coasting* model is a simplification of the system (e.g. Turner et al. 2003), but it has been designed in a way that it is a promising means for improved understanding of emerging vulnerabilities.

Future versions of this model can go in many directions: looking at different case study areas, further specifying model mechanisms (for humans, the environment, and/or the environmental challenges), including global and tourism demand scenarios, and including more types of environmental challenges. Figure 6.10 indicates opportunities for further applications of the model. We see that many island destinations such as Curaçao are vulnerable (Hall 2018; Rhiney 2015). One of the low hanging fruits for *Coasting* is changing the initialisation of environmental space and tourism operator numbers to proxy other coastal destination to explore what kind of vulnerabilities emerge in that destination. A second opportunity is to further specify different mechanisms and inputs. Some simplification is common when simulating complex systems (Rouan et al. 2010; Turner et al. 2003). Behavioural

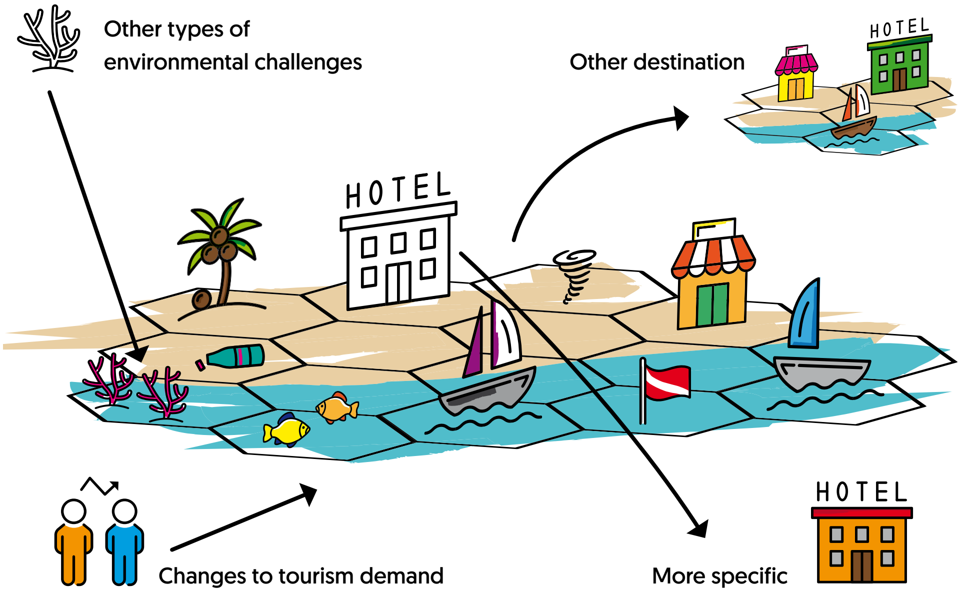


Figure 6.10. Potential expansions of the *Coasting* model

rules were necessarily simplified for the process of modelling. This model does operationalise how different peoples' individual preferences for inputs in their own businesses and emerging relationships that either foster collaboration or limit it, affects vulnerability; this is instead of assuming an ideal situation where everyone is willing, knows how to act, and that the endeavours to do so are successful. This reflects the limited willingness of (local) respondents to contribute extra reserves to deal with environmental change (Cumberbatch et al. 2018).

In future editions of this model, nuances of behavioural rules can be added or simplified based on theoretical musings and/or empirical data. This especially applies to the individual trade-offs on where to expend resources, which were based on observations during the simulation sessions. However, as there was no clear indication of how individuals dealt with trade-offs, preferences were randomly attributed to simulated operators during model initialisation. The environmental resources (e.g. coral reefs, fish) could be specified per species and better reflect known mobility patterns. For environmental challenges, this version of the model took a conservative view of SLR. Future versions could experiment with more variations of increased rates and include feedbacks of coral reef health on increased erosion (Cambers 2009). Specifying waste/pollution types and their dispersion could enrich knowledge of containing specific waste streams, especially as the results of the scenario show that the rate of pollution change has a high impact on socio-ecological vulnerability. Another potential expansion is that this model could include more specific types of environmental pressures, e.g. coral bleaching events, sargassum seaweed inundation, and storms of varying severity.

A final way to expand this model, is to further explore the influence of changing tourism demand. This model focuses on coastal tourism operators in Curaçao. However, the mechanism tourism returns proved an important indicator of operator success. The assumption of this model instance is that tourism demand is inelastic, but is mediated by impacts of maintenance delays, pollution, environmental degradation and environmental attractiveness, which is recognised as having potential impact on visitor preference/arrival numbers (e.g. Cumberbatch et al. 2018; Hopkins 2015; Santos-Lacueva et al. 2017). Thus, the modelled potential returns are dependent on the local environmental conditions and maintenance delays, but not on changing international arrival scenarios. Future versions can consider changes to this ratio over time or among operators to reflect uncertainty to tourism arrivals (Cumberbatch et al. 2018; Gössling et al. 2012), tourism numbers affected by weather data information (Matthews et al. 2019), or tourist destination preference (Alvarez & Brida 2019).

6.6. Conclusion

This research makes two significant contributions for dynamic vulnerability assessments, tourism research, and climate change studies: the flexible simulation of a coastal tourism destination and the novel analysis techniques applied to analyse deep uncertainty. In this paper, emerging vulnerabilities to tourism operators and the coastal environment of Curaçao were explored. The most prominent parameters increasing vulnerabilities were low tourism returns, increasing pollution levels, and how much pollution levels lower environmental attractiveness. Tourism returns and increasing pollution levels are factors that Curaçao can consider in its adaptation strategies. However, neither the computer simulation nor the challenges of climate change are limited to the Curaçao destination. Thus, the ability to adjust the set-up mechanisms to those that simulate other destinations or other changes to other key parameters are available for users. This type of modelling does not predict which type of future is more likely, but it does indicate what the patterns mean for emerging vulnerability and adaptation.

In addition to the model, the innovative mode of analysis is a contribution to dynamic vulnerability assessments and future-looking scenarios under conditions of deep uncertainty for tourism in general. The time scale helps us look at different trends for operator numbers over time and reveals how different operators are affected differently by the same coastal system features i.e. input parameters. We were also able to see which parameters interact that influence socio-ecological vulnerabilities as well as individual and collaborative action. The analysis of scenarios through scenario discovery enables us to consider what kind of future we want as a basis for scenario analysis and determining decision-relevant factors to act on. This is useful because of prevailing complexity and uncertainty in tourism destinations, we do not know in advance which factors will have the largest influence on vulnerabilities we wish to avoid and impede sustainability goals.

Recently, climate change has been described in more black and white terms: either we maintain emissions at a level below the 1.5°C target or we do not, and face the consequences. Instead of focusing on different rates of SLR that may lead to vulnerabilities at a destination level, scenario discovery flips the question around and asks if we want to meet our 1.5°C target, what are the main factors that determine our ability to meet our target and how much of the success or failure can be clearly attributed to that parameter or interactions with other parameters. This provides decision makers as well as researchers with a better idea of where to focus their efforts. As such, scenario discovery can be applied more broadly to tourism and climate research.

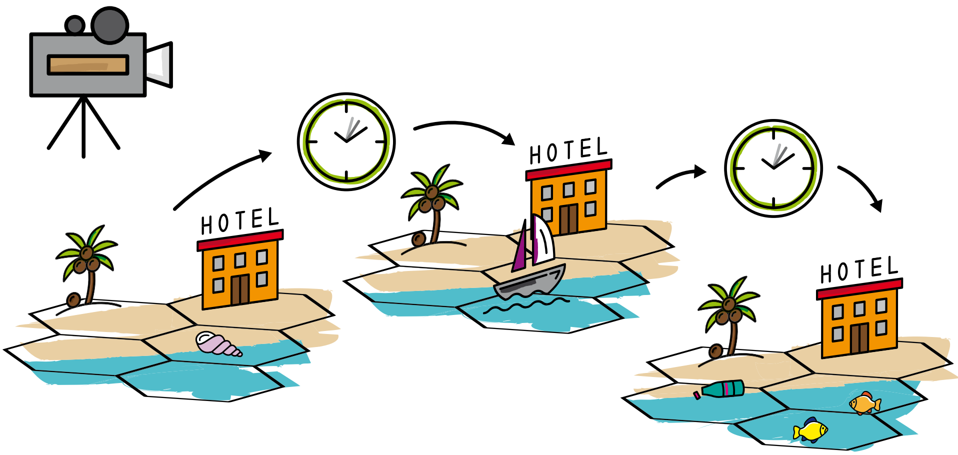
CONCLUSION

7

CONCLUSION

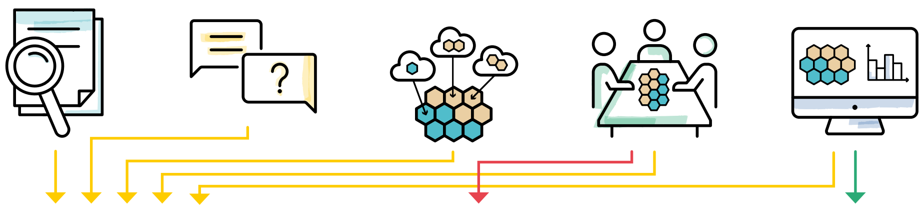
How can dynamic vulnerability be operationalised to inform adaptation strategies for coastal tourism?

Conceptualised a dynamic vulnerability approach for coastal tourism destinations considering interactions of a socio-ecological system



HUMAN AGENCY | HETEROGENEITY | FEEDBACKS | UNCERTAINTY | ITERATION

Operationalised approach with five methodological tools

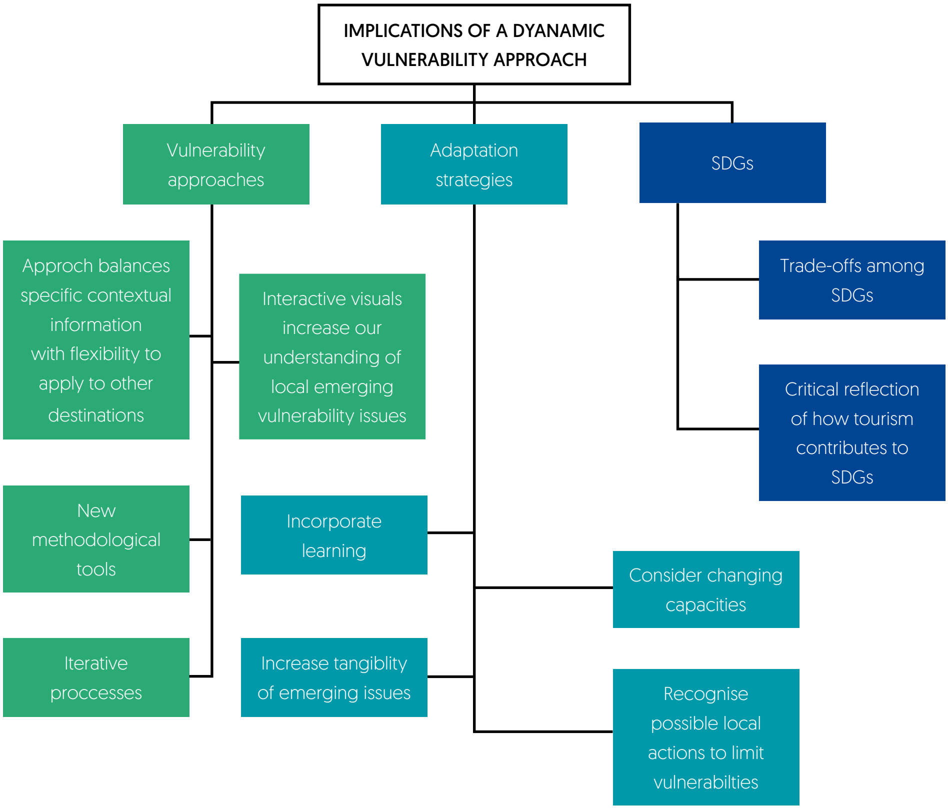


Provided illustration of the emerging dynamics of sea-level rise

Improved understanding of how humans interact with the coastal system under conditions of change in Curaçao

Simulated results of emerging socio-ecological vulnerabilities

Enhanced vulnerability understanding and adaptation strategies



Future avenues of research

7.1. Introduction

Coastal tourism destinations, such as those found in the Caribbean islands, are vulnerable to climate change. Attention to climate change for this type of tourism destination has thus far been limited. Vulnerability assessments are available, but they take a static perspective while vulnerability is dynamic. This research's goal was to better capture the emerging vulnerabilities to enhance adaptation strategies. This requires improving our understanding of system dynamics, investigate how this dynamic understanding of vulnerabilities influences adaptation. The overarching research question guiding this work is:

How can dynamic vulnerability be operationalised to inform adaptation strategies for coastal tourism?

Not only does this research expand on the ongoing academic discussions of vulnerability as a dynamic phenomenon (Chapters 2-4), but it takes steps to operationalise these principles, agency, heterogeneity, feedbacks, uncertainty, and iteration as part of a dynamic vulnerability approach (Chapters 4-6), and illustrates the new insights we can gain from taking a dynamic perspective (Chapters 4-6). The operationalisation and dynamic analyses are important distinctions from previous research. While previous research indicated that vulnerability is dynamic, how to operationalise vulnerabilities was not clearly set-out. Metaphorically speaking, this research helps to change our conceptual lens from a static snapshot to a motion picture capturing emerging socio-ecological vulnerabilities. The chapters of this dissertation address the critical knowledge gap for science of matching a dynamic problem with a dynamic approach. Moreover, through the iterative interactions with stakeholders, the research provides insights to the persisting challenge of global awareness of climate change and local inaction in vulnerable areas such as small islands. As context is important to understanding vulnerabilities and devising adaptive actions (e.g. Rhiney 2015), two separate islands from the Caribbean were selected to develop the dynamic vulnerability approach and improve our understanding of emerging vulnerabilities in these coastal tourism destinations: Barbados and Curaçao. This chapter presents the learnings for these particular cases in section 7.2 and reflects on the the methods applied in the dynamic vulnerability approach in section 7.3. The wider implications for vulnerability approaches, adaptation strategies, and coastal tourism's role in the Sustainable Development Goals are discussed in section 7.4. The chapter concludes with future avenues of research in section 7.5.

7.2. General discussion of the main thesis findings

As explained in Chapter 1, the overarching research question can be divided into three (sub-) research questions: how to conceptualise dynamic vulnerability, how to operationalise a dynamic vulnerability approach, and what are the implications of this approach on vulnerability assessments and adaptation strategies. Figure 7.1 depicts these research questions and the insights provided per chapter. Taken together, these insights provide the answers to the research questions. They will be further specified in the following sections.

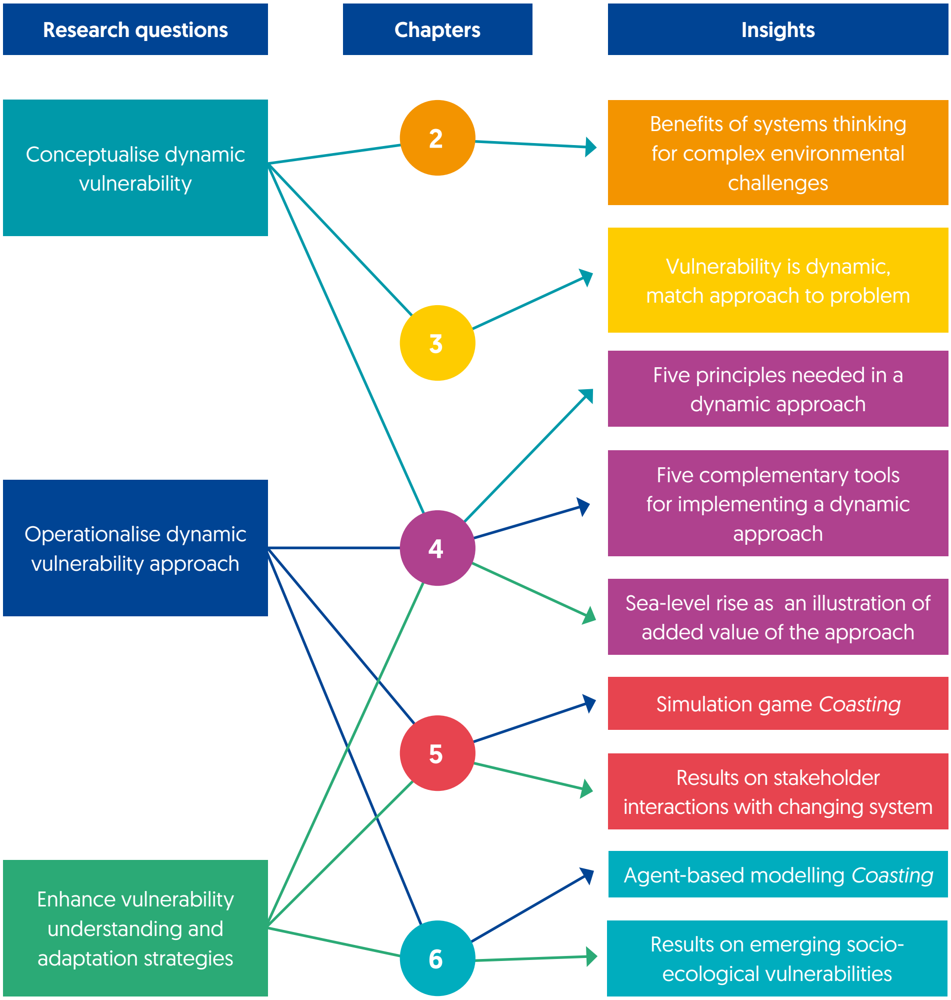


Figure 7.1. Research questions and main insights per chapter

7.2.1. Conceptualising dynamic vulnerability

This thesis provides multiple ways of answering the first research question:

How can we can conceptualise dynamic vulnerabilities in a coastal tourism context?

This research demonstrates that including interactions among humans, and between humans and their environment, is critical for conceptualising vulnerability in a coastal tourism context. Furthermore, this thesis provides ample evidence that we are not facing only one problem and one solution because we are dealing with a complex socio-ecological system. This research specifically illustrates the diversity of climate change-related challenges that are faced by coastal tourism destinations and how local actions interact with these globally induced challenges. The thesis shows the added valuse of systems thinking as a means to take these interactions into account and explicitly address the complexity involved. Importantly, the thesis indicates five principles of a dynamic conceptual lens to help us look at vulnerabilities as part of an ongoing process, which as mentioned in section 1.4, are unclear in the prevailing definitions of vulnerability.

Systems thinking helps to address the inherent systems complexities of tourism when studying environmental challenges (Chapter 2). Chapter 3 takes the conceptualisation of dynamic vulnerability as a starting point and examines the current available vulnerability frameworks and the limitations of static approaches. Static approaches suggest that by categorising the problems in a destination, we know enough about the problems to create solutions to the problems. Overlooking the consequences of interactions and future uncertainty are critical weaknesses of snapshot vulnerability assessments. These deterministic environmental risk/hazard approaches often lead to technical solutions (Füssel 2007), which give the impression of "certainty" (e.g. Stirling 2010). However, the future is characterised by uncertainty as a result of ongoing interactions, which makes it difficult to know how to act and whether our actions will lead to the desired results. The findings concur with Nurse et al. (2014 p. 1644) who state that "uncertainty in the [climate] projections is not a sufficiently valid reason to postpone adaptation planning in small islands". In other words, we cannot allow the persistence of uncertainty stop us from working on vulnerability issues. The five main principles of a dynamic vulnerability lens are agency, heterogeneity, feedbacks, uncertainty, and iteration (Chapter 4). Furthermore, the results indicate that in addition to these principles, interactive involvement with stakeholders is key to gaining insights on the coastal system, emerging challenges, and potential responses. The complexity of the issues and the legion of potential solutions (Santos-Lacueva et al. 2019) indicates the need to include stakeholders. There will be winners and losers, trade-offs are necessary and as such stakeholder buy-in is important to encourage actions being fulfilled.

7.2.2. Operationalising a dynamic vulnerability approach

This research offers a dynamic vulnerability approach as a means to answering the research question:

How can we operationalise dynamic vulnerability?

The insights on conceptualisation of vulnerability, described above, are well in line with existing several other dynamic conceptualisations of vulnerability in literature (Adger 2006; Moreno & Becken 2009; Smit & Wandel 2006; Turner et al. 2003). However, in much of this literature, how to actually go about a dynamic approach is missing. The development of a practical approach is one of the key contributions of this thesis. Along with literature review, interviews, and simulation development, this research presents concrete procedures of simulation gaming and computer modelling to operationalise a dynamic system. To this end, the serious game and computer model *Coasting* were developed in the context of this research project. Parts of the dynamic approach are interactive with stakeholders so that we can better incorporate stakeholders' perceptions and interactions while also providing co-learning opportunities. The *Coasting* serious game played by local stakeholders and agent-based computer model explore how a diversity of changes lead to human and environment related vulnerabilities.

System-thinking and a dynamic conceptualisation of vulnerability require new tools. In this thesis, we move from purely conceptual to practical ideas of how to operationalise a dynamic vulnerability approach (especially in Chapter 4). The five principles mentioned in the previous section are captured through five complementary methodological tools: desktop research, interviews, simulation development, simulation sessions, and computational modelling. These tools help explore interactions in a dynamic system and uncover emerging socio-ecological vulnerabilities. Simulation-guided interviews improve system understanding during interviews and introduce stakeholders to other interactive methods (e.g. Chapter 4). Simulation development, simulation-guided interviews, simulation sessions, and computational modelling help make these interactions and consequences more tangible for both researchers and stakeholders.

Chapter 5 delve deeper into the operationalising of simulation sessions, combining systems thinking and engaging people in the interactions in the coastal system to understand emerging vulnerabilities in nine simulation session in Curaçao. This dynamic setting requires different means to observing the dynamic process and discussing experiential learning. These observation tools (input forms, recording, observation protocols, and debriefings) are explained to show how we can analyse a dynamic interactive setting. Operationalisation of the *Coasting* agent-based model in the context of Curaçao looked at how the coastal tourism destination changes over space and time. The locally induced environmental pressure of pollution is combined with the slowly evolving change of sea-level rise and the unexpected challenge of quick onset events. The time frame of 30 years that Chapter 6 investigates is longer than the initially proposed time frame of 20 years, and this enabled exploration of potential long-term effects of sea-level rise (SLR). The *Coasting* computer simulation improved our understanding of socio-ecological vulnerabilities by applying innovative analytical tools, in particular global sensitivity analysis and scenario discovery (a computational means of back casting) for the purpose of better understanding changes to socio-ecological vulnerabilities over time, the influence of interactions among different parts of the system on emerging vulnerabilities, and the main system features that contribute to socio-ecological vulnerabilities we wish to avoid (Chapter 6). In sum, the answer to this research question consists of the concrete set of tools presented (methodological, observational, computational, and analytical).

7.2.3. Enhancing vulnerability understanding and adaptation strategies

The final research question examines the added value of a dynamic vulnerability approach over a static one:

What are the implications of this approach on vulnerability assessments and adaptation strategies?

Although it intuitively makes sense to match the scientific process (dynamic approach) to the type of problem (dynamic vulnerability), it is a valid question to assess the added value of the extra effort of including interactions and transdisciplinary research as it is more time consuming, involves system integration, necessitates experiencing and experimenting, and requires a dynamic setting to engage with stakeholders. One significant result from the dynamic approach is that it illustrates the gross overestimation of human capacity suggested by static vulnerability assessments. The findings make clear that a static assessment tends to underestimate the challenges of dealing with multiple environmental challenges and overemphasise the success of existing adaption strategies. This research has demonstrated that trade-offs, experiencing multiple environmental events, dealing with uncertainty, feedbacks, different and sometimes competing strategies, limit both participants and simulated operators' abilities to cope with environmental change. This suggests more limits to capacities in real life as there are even more trade-offs, uncertainties, feedbacks, and human-interactions than can be included in this study.

An illustration of the approach in Chapter 4 shows how the seemingly straight-forward climate-related challenge of sea-level rise (SLR) and the tourism destinations interact. Instead of using a static snapshot lens, the dynamic motion picture illustrates three main findings. First, there is a mismatch between the scientific urgency of sea-level rise and the urgency felt by other stakeholders. Second, tourism operators in a destination have different capacities and willingness to respond as they may not be directly affected or are mobile within the destination. These capacities change over time. For example, the simulation games showed that limited capacities emerged from expenditures in previous rounds, trade-offs to deal with other challenges or focus on own operations, and growing uncertainties of whether actions would fully address the problem. Third, the illustration in Chapter 4 shows many unintended consequences of the adaptation strategies of sea walls, setting back beach infrastructure, beach nourishment, and nature based-solutions. A static approach assumes similar capacities and ignores the consequence of the interventions which the illustration shows can result in inaction, resistance, and new challenges emerging in different parts of the coastal system.

In Chapter 6, we experiment and explore how humans interact with their coastal system, and how these interactions result in emerging socio-ecological vulnerabilities using the tool of simulation sessions. The simulation sessions analysed how stakeholders' willingness to act and/or collaborate changes over time based on their varying personal capacities and accumulated experiencing. The results suggested a difference of visibility of environmental challenges. For example, Curaçao is already experiencing drought, but drought events in the simulation did not generate much response nor reflection from participants, while new unknown events and loss of coastline did generate concern among participants. The simulation sessions further demonstrated the challenges of participants to deal with uncertainty. The unknown events, though they generate a reactionary response, did not necessarily incite action as participants were more concerned with knowing exactly what the event is and whether or not their resource investments will reach the desired result (it going away). In such cases, a pro-active participant or leader, as well as a general willingness to collaborate and sufficient capacity to act were necessary for participants to take action on unknown events.

This research's computational modelling also shows the results of emerging socio-ecological vulnerabilities. We explored how individual tourism operators' actions can lead to system-level socio-ecological vulnerabilities in conditions of emerging climate change (Chapter 6). The results indicate heterogeneous rates of emergence of socio-ecological vulnerabilities over time. For example, the loss of nearshore water operator numbers can occur rapidly, whereas there is a slower rate of decrease for beach operators under the same range of system conditions. Moreover, we can see that although different factors play an important role in sociological and ecological factors, there is a lot of crossover, i.e. input factors that lead to an undesirable ecological future (output) also lead to an undesirable sociological future. The simulation model also indicates that the decisions to act alone or to collaborate are dependent on different factors: for acting alone, lower thresholds (higher sensitivity) to increasing pollution levels incited action and were mitigated in systems where sufficient resources were available for tourism operators whereas for collaboration, sufficient or surplus resources were most indicative of collaborative actions and this interacted with multiple other factor (e.g. rate of sea-level rise, rate of pollution entering the systems, the minimum acceptable elevation above sea level for land-based operators and lower thresholds to increasing pollution levels). One of the determining factors for socio-ecological vulnerabilities are tourism revenue generated. The scenario findings suggest three decision-relevant factors that should be focused on, if Curaçao is to avoid losses to the tourism sector and the environment: tourism returns, pollution change (the rate that pollution is created through tourism), and pollution weight (how much pollution affects environmental attractiveness). This is surprising as one would expect global environmental pressures (SLR, sudden events) to have the strongest influence on socio-ecological vulnerabilities. This finding suggests the importance of local adaptation strategies (e.g. limiting pollution) in Curaçao to reduce the influence of global environmental pressures on Curaçao's coastal system.

7.3. Reflection on the methodologies of a dynamic vulnerability approach

The dynamic vulnerability approach includes new methodological tools to complement more traditional techniques of desktop research and semi-structured interviews. Techniques particularly useful for system integration and experiencing and experimenting with dynamic vulnerability are simulation-guided interviews, simulation development, simulation sessions, and computational modelling.

7.3.1. Reflection on methodological choices and process

Admittedly, many system heterogeneities were not incorporated; system aspects needed to be simplified to make this research feasible. For the human part of the system, the operator types were grouped into four types for the simulation game and five types for the computer simulation. Mobility, capacities, resources used, and location of activities were used to define categories. In reality, there are many more heterogeneities that could be considered to form even more groups. For example, the category *nearshore operators* represents many types of small operators (see Annex 1); but for some nearshore operators, wind is important and for others, proximity to a hotel or beach vendor is. Participants were able to consider wind and proximity to others in the game; but they were not directly benefitted or categorised by them. In the model, wind was not included.

For the environment, simplification was also necessary. The spatial setting had a few defining geospatial features (e.g. beach, nearshore waters, deep sea) and resources (mangroves, coral, fish, and sea turtles). Further specification is possible in the future. Nonetheless, these are the main environmental features identified by the literature and stakeholders for the coastal destinations researched.

For climate change, a limited range of types could be incorporated. In the game, participants were exposed to a maximum of five of the six external challenges and pollution was an aggregation of locally-induced environmental challenges. In the computer simulation, two types of climate change-related events are focused on: gradually occurring and anticipated sea-level rise and sudden-onset unknown events. In reality, there are more types of locally- and globally-induced challenges than covered in the game and model. However, the environmental challenges included do illustrate different ways in which the destination can be affected by climate change. Moreover, the inclusion of unknown events tries to incorporates some of the general implications of other types of climate change events on coastal destinations.

The complementary methodological toolbox offered by this approach helps fill in the short-comings of the individual tools. Desktop research and interviews are easier to do, but provide limited information on how vulnerabilities emerge. However, simulations may not be accessible for all stakeholders, so using interviews or simulation-guided interview sessions are alternatives. Interviews, simulation development, and simulation sessions are dependent on the time that participants are willing to volunteer whereas computer simulations such as agent-based modelling can require less ongoing interaction with stakeholders, but more technical skills (Johnson et al. 2016). Whereas the simulation sessions are limited in the number of participants, and the number of rounds that could be played, the agent-based model is limited in how precisely it could represent people as well as the number and type of emerging environmental issues. However, as computer simulations include many runs, they make it easier to identify vulnerability patterns that are not limited to a particular participant group. As such, using multiple methodological tools helped provide a more holistic understanding of vulnerability.

7.3.2. Main challenges and limitations

Despite the advances these methods make, it is important to reflect on challenges of implementation and their limitations. For starters, the dynamic approach is based on systems thinking to include interactions between people and the environment and among stakeholders. However, choices of what to include in the system is challenging, i.e. human and environmental features, and interactions. Stirling (2010) argues that interactive modelling is a means to consider the conditional and pluralistic nature of knowledge. As such, we require multiple perspectives to have pluralist understanding and it is not always easy to include stakeholders (Chapters 4 & 5). To help ensure this, the companion modelling approach suggests stakeholders should be involved early in the process and that they should be included in problem definition so that the relevant problem(s) is/are identified and to aid in scoping (e.g. Étienne 2014). An initial literature review indicated the high vulnerability of the tourism supply side and in particular SIDs in the Caribbean. In this research, local stakeholders, were contacted early in the research to scope the system.

A model may appear to give more specific quantitative results than simulation guided-interviews and simulation sessions. While the quantitative results of the agent-based model are appealing, it is important not to forget local people in understanding emerging vulnerabilities (e.g. Cinner et al. 2018; Pyke et al. 2018; Solinska-Nowak et al. 2018). People are a critical part of the analysis of vulnerability; they provide context and they also need to act on the results at some point. Locals are the individuals who are affecting and affected by change. If we want to consider effective and relevant adaptive policy, it is not enough to know emerging patterns, we also need to know how people respond to these patterns. Moreover, their insights were critical in developing the *Coasting* model.

On the one hand, as researchers, we want to include as much of the complexity as possible and avoid simplification. One the other hand, we face practical limitations. Just like any lens, our dynamic conceptual lens cannot capture everything. The ARDI framework (actors, resources, dynamics, and interactions) informed the interview questions to help ensure that many of the important system features were identified (Étienne et al. 2011). Simplification was necessary to make the game playable and the model understandable. Although the dynamic approach does not capture all of the details of a snapshot, a dynamic motion picture helps us to focus on main changing forces instead of getting lost in details and giving overconfidence that we see the whole picture (e.g. Stirling 2010). With further applications of this approach, we can continue to improve the quality of our lens (the dynamic vulnerability approach) and decrease the graininess of the image of our motion picture (assessment). As much as possible, this research's application of the approach endeavoured to keep the main sources of complexity and uncertainty included. However, with improved systems understanding and future iterations, more and different complexities and uncertainties can be included while less relevant ones can be simplified or removed.

Another limitation is that power differences among destination stakeholders are not explicitly studied, but were observed during site visits, simulation sessions, and mentioned in interviews with stakeholders. Power differences among operators are represented somewhat through the different capacities and collaborations (both in the simulation sessions and in the computer simulation). But we need to keep in mind that although there is the intent to include agency and heterogeneities, system features such as power are simplified.

A further challenge is a dynamic analysis of the results. This is more easily accomplished in the simulation sessions as the researcher can observe the progression of changes throughout the rounds. Nonetheless, how to portray and describe dynamic results is difficult in typical 2D representations of articles and books. Over 700,000 model runs for global sensitivity and 120,000 model runs for scenario discovery were performed to generate results for the *Coasting* model. Although computational modelling enables an experimental setting where you can perform many more runs, with more variations, and over a longer time period than simulation sessions, for the most part, you still have to define a moment of analysis. This means that you are assessing the results of interactions up to a particular time step. In the case of this study, the end of the simulated period (30 years) was selected and as such, the focus was on long-term results. However, it is easy to imagine that results for 10 years could be different, especially as many of the consequences of SLR will be realised later. A follow-up of this research is to look at sensitivities at multiple moments of the simulated time and examine how they shift over time, especially when considering the near future (0-5 years) and the longer term of 15-30 years.

7.4. Implications of a dynamic vulnerability approach

Along with providing insights in the context of the two cases studies, this study has wider relevance in relation to other vulnerability approaches, adaptation strategies, and the Sustainable Development (SDGs).

7.4.1. Implications for vulnerability approaches

First, this research responds to the call for more research of vulnerability issues on coastal tourism (e.g. Becken 2013a) and SIDs (Kuruppu & Willie 2015; Nurse et al. 2014). This study is part of a small but growing body of research taking a systems approach in this context among which Calgaro et al. (2014) in Thailand, Loehr (2019) in Vanuatu, and Filimonau and De Coteau (2019) in Grenada. This is important for improving adaptation strategies in coastal destinations and give new methodological tools for these contexts as well as other destinations. The dynamic vulnerability approach is flexible to many contexts and helps address the need for more than generalised understanding of "the potential impacts on small islands and their adaptive capacity" (Nurse et al. 2014 p. 1618; Rhiney 2015). Importantly, this approach views vulnerability as both a state and a process (e.g. Rhiney 2015) so that we can look at processes of emerging vulnerabilities as well as their outcomes. Moreover, the bottom-up nature of the approach helps assess who can be vulnerable in what ways, and how they affect and are affected by change when looking at system level vulnerabilities. Bramwell et al.'s (2017) review of the past 25 years of tourism sustainability research finds that the methods used in the field are too narrow and limited. The methodological tools presented in this approach are a new way forward for transdisciplinary science for impact, which arguably vulnerability-related studies are. Through interactions with local stakeholders it enables the process and the results to better reflect the local context as well as better understanding of limited and changing capacities for dealing with emerging environmental challenges.

This study attempted to find the balance between (1) expediting the assessment process by reapplying similar tourism stakeholders (tourism operators), coastal features (e.g. nearshore waters, coral reef), environmental challenges (e.g. SLR) as a starting point for other destinations while (2) recognising the heterogeneities within and among tourism destinations. Critically, this approach does not suggest that the problems and solutions for one island will be the same for another. What it does do is take the information from one area and see to what extent the information can be adjusted and applied to a new study. This corresponds to the idea that "lessons learned from adaptation and mitigation experiences in one island may offer some guidance to other small island states, though there is low confidence in the success of wholesale transfer of adaptation and mitigation options when the local lenses through which they are viewed differ from one island state to the next, give the diverse cultural, socioeconomic, ecological[,] and political values" (Nurse et al. 2014 p. 1616).

One of the important and novel contribution of this research is the visualisation of potential emerging vulnerabilities, particularly with simulation-guided interviews, the simulation sessions, and the computational modelling. The interactive visuals enable stakeholders to comment more specifically on features of their coastal system during simulation-guided interviews. The interactive visualisations of the simulation sessions create a setting where stakeholders can experience changes to their coastal system with others. Furthermore, it provides stakeholders the opportunity to discuss their shared experiences with the other participants. The computational model's interface provides a simplified visual of the human and environmental spatial features of a coastal tourism destination changing over time in response to different input parameters. The results further visualise how vulnerabilities emerge over time, how system features interact to create socio-ecological vulnerabilities, and which parameters exert the largest influence over socio-ecological vulnerabilities that destinations would prefer to avoid. Together, these visualisations are a means to relate intangible ideas of global climate change to coastal destination for both stakeholders as well as researchers.

7.4.2. Implications for adaptation strategies

Emerging socio-ecological vulnerability challenges clouded by uncertainty necessitate more flexible types of adaptive measures as we do not know in advance which adaptation strategies will be the most effective. Biesbroek et al. (2013 p. 1128) note that adaptation studies are in their infancy, and conclude that future research needs to "change from the inventory questions of 'if' and 'which' barriers to adaptation exist towards more analytical questions as to 'why' and 'how' these barriers emerge". How and why barriers to adaptation emerge necessitate a dynamic construct. As such, this research contributes to a more meaningful discussion of what anthropogenic barriers mean for emerging vulnerabilities. The implications of this research are that our adaptation strategies need to consider the consequences to tourism operators' capacities, that we need to pay attention to what problems are visible to stakeholders (e.g. drought), and that we should not underestimate the potential for islands to have adaptation strategies that can limit harm to the environment (computational model findings).Although coastal destinations face pressure from global issues, this research indicates that we should not forget about what can be done to limit locally derived stressors. Both the simulation sessions and ABM findings indicate that the inability to deal with emerging pollution limited capacity to deal with new challenges (game), and was a main indicator of the coastal systems reaching an undesirable level of socio-ecological vulnerability for Curaçao (computational model). In other words, the findings suggest that in order to counteract global change, the island destination needs to be able to deal with local changes.

This approach informs adaptation strategies for coastal tourism in relation to work by Cinner et al. (2018); they identify five key domains for building adaptive capacity: "(1) the assets that people can draw upon in times of need; (2) the flexibility to change strategies; (3) the ability to organi[s]e and act collectively; (4) learning to recogni[s]e and respond to change; and (5) the agency to determine whether to change or not"(2018 p. 117). This research makes contributions to each of these domains. First, changes and limits to assets, referred to as resources in the text, are included and assessed throughout the research. Moreover, resources are identified as key factors to collaboration on environmental issues (Chapter 6). Second, the simulation sessions provide the opportunity to experience and change strategies at the same time that other participants are. The model enables study of flexibility of choice by simulating operators that have different preferences for resource allocation, location, and action on environmental change. The results of this approach strongly suggest the need for flexible approaches to better address unintended feedbacks, iteration, and changing capacities. This is in line with Brown et al.'s (2012) and Csete and Szécsi's (2015) suggestions for flexible adaptive approaches. Third, both in the *Coasting* simulation sessions and the agent-based model opportunities to collaborate are assessed. Collaboration in the simulations was sensitive to previous actions of others, individual capacities, and whether or not they believed their collaborative actions would succeed (Chapter 5). In the *Coasting* model, collaboration was sensitive to tourism revenue and thereby their individual resource capacities (Chapter 6). Fourth, through participation in the simulation sessions and discussions during the debriefings, stakeholders have the opportunity to act and reflect on experiential learning. Fifth, the simulation sessions enable participants to determine and react to the changing conditions and the computational simulation simulates how agency of individual operation decisions in combinations with opportunities to act alone or collaboratively relate to emerging socio-ecological vulnerabilities.

Although the dynamic vulnerability approach does offer suggestions for adaptation strategies, it does not provide definitive answers on how to stop coastal tourism destinations from becoming vulnerable. This research supports the call for adaptation strategies to move beyond pure technical solutions, which often succeed simplified assessments (e.g. Nicholls et al. 2017; Rhiney 2015) and involve stakeholders (e.g. Cinner et al. 2018; Solinska-Nowak et al. 2018). In recognition of the ongoing uncertainty, Stirling (2010 p. 1029) recommends resisting the pressure to over-simplify: "Expert advice is often thought most useful to policy when it is presented as a single 'definitive' interpretation. Even when experts acknowledge uncertainty, they tend to do so in ways that reduce unknowns to measurable 'risk'. In this way, policy-makers are encouraged to pursue (and claim) 'science-based' decisions". We want to give simple answers to destinations, but we need to recognise the complex nature of change. Nonetheless, this approach helps identify barriers for dealing with the disconnect between awareness of climate change and action (Bruno Soares et al. 2018; Filimonau & De Coteau 2019). For example, Chapter 5 highlighted the trade-offs that individuals have limited personal resources but also need to respond to multiple emerging environmental challenges.

The increased pressure tourism operators are encountering limits their capacity to deal with more future challenges. As shown above, this has negative implications on the environment, requiring new adaptation strategies. For addressing future uncertainty related to climate change, Vervoort and Gupta (2018 p. 105) encourage reflection on how researchers conceptualise the future: "is the future predictable and controllable? Or wholly unpredictable? Or uncertain but navigable?". This research suggests that due to the complexity of the tourism system, uncertainty will persist as sub-elements constantly change. However, the dynamic approach analyses potential futures because we still want to do something about the negative repercussions of emerging vulnerabilities even if we do not know precisely how the future will look nor what is the best adaptation strategy. The implication of this, is that we look to potential futures and try to analyse uncertainties with stakeholders so that we can co-create a better understanding of our system and a more desirable future.

7.4.3. Sustainable Development Goals

The Sustainable Development Goals (SDGs) set a path for future global sustainability and "[t]ourism industries play a vital role in all 17 SDGs" (UNDP-UNWTO 2017 p. 49). Of the countries that submitted their national voluntary reviews to the UN, two thirds cited tourism as important for reaching the SDGs, and of those responents, two thirds are considered developing countries. Cleary, tourism is considered an important opportunity for sustainable development for developing countries. Nurse et al. (2014 p. 1640) cite a growing support in the literature to combine climate change planning with development plans. This research's findings suggest that we need a more critical look at tourism's development role in the SDGs. Tourism is considered a potential revenue stream, especially when traditional environmental resources are depleted. However, Chapter 5 and 6 show the dependence of tourism on the local ecology for generating revenue. So, although tourism may be a means of generating foreign receipts and employment, this research indicates that changes to operators' capacities, i.e. resources, comes at a cost to environmental well-being. Thus, the consequences of tourism operators' individual trade-offs need to be considered when people are put under increasing pressure.

The SDGs aim for tourism development to be sustainable. Many developing countries cited SDG 8 of decent work and economic growth and SDG 12 of responsible consumption and production as the SDGs role for tourism development; the focus on other goals such as no poverty, equity, environmental sustainability, and climate action goals were less represented in how they related the SDGs to tourism development (UNDP-UNWTO 2017 p. 25). This already indicates that there is more focus on economic goals than ecological ones for 'sustainable' tourism development. Furthermore, the more countries that are dependent on tourism, the more competition there will be among destinations for tourists. Competition among islands for tourists in the Caribbean is already high. This creates the potential for the focus of tourism operators and destination managers to shift the focus from the environment, to attracting tourists. This trade-off was analysed in this research (Chapters 5 & 6) and is difficult to avoid when people's livelihoods are at stake. Thus, simplistic aspirations for sustainable coastal tourism in developing countries are counterproductive. Van Soest et al. (2019) reason that in order to achieve the SDGs, we need to consider how the SDGs interrelate with each other and use simulations that look at human-environmental interactions to better inform decision-makers of the trade-offs among the goals. This research highlights the complexities of interactions within a destination and under conditions of climate change. Adding further complexity to the trade-offs among SDG goals does not make tourism a simple solution to development issues, especially in coastal areas.

7.5. Future avenues of research

This research presents version 1.0 of a dynamic vulnerability approach. As such, much can be improved by the iterative process in terms of the analysis, results as well as the process itself. Moreover, the approach and its tools can be applied to analyse emerging vulnerabilities in other (coastal) destinations.

First, we can apply the approach (principles and methodological tools) as well as the prepared tools (simulation-guided interviews set-up, *Coasting* simulation sessions, and *Coasting* model) for other (coastal) destinations. Although they share some similarities, the emerging socio-ecological vulnerabilities in Barbados and Curaçao are distinct from those emerging on other coastal destinations (Rhiney 2015). The simulation-guided interviews and *Coasting* simulation sessions (Chapters 3 & 6) can be used in their current forms to scope the environmental and tourism issues relevant to other (Caribbean) coastal destinations. Through this process, they can then be adapted to better represent the local context, provide insights on how stakeholders interact with their system there, and identify emerging vulnerabilities in that context. For the *Coasting* model (Chapters 4 & 6), the model initialisation of the number and type of operators as well as the environmental coastal context can be changed to better reflect those of the studied coastal destination.

The visualisation and experiential learnings are critical contributions of the simulation sessions to researchers and stakeholders (discussed in Chapters 4 and 5). Only some stakeholders on two destinations were reached within the context of this research. This research can be expanded so that more people receive the opportunity to experience and reflect on potential emerging vulnerabilities in their own local setting, and see how changes can emerge. With increased stakeholder and decision-maker support, we can shift the focus from the first companion modelling goal of improving system understanding to the second goal of improving and implementing more informed adaptive decisions strategies. Moreover, there are opportunities in the future to allow participants to play the game a second time to have an experiential reflection of how they think they would or could do things differently as opposed to a stated reflection of how they would do things differently during the debriefing.

As indicated in chapter 6, there are many directions that the foundational *Coasting* model can go. Mechanisms can be further specified to represent social theories or social and/or empirical findings. Through tools of global sensitivity analysis and scenario discovery, decision-makers can identify futures that they want to avoid or achieve and learn about what are the features that assist or undermine those goals. Global sensitivity analysis and scenario discovery are particularly useful in the complex system of tourism destinations. Global sensitivity enables us to look not only at how individual variables influence certain outcomes, but also how multiple variables interacts to influence socio-ecological vulnerabilities.

In traditional scenario testing, as in any experiment, one needs to isolate the variable that one wants to test, to find out how changes to that variable (e.g. sea-level rise) affect a particular observable outcome (tourism operator numbers i.e. socio-vulnerability). However, in a complex socio-ecological system such as coastal destinations, there are many interacting variables of interest. So, the first challenge is that you may want to know how changes to multiple variables affect tourism numbers, e.g. how changes to SLR rates and tourism revenue affect the number of tourism operators. This requires many more tests than if one just analyses different rates of SLR. Moreover, if you want to look at different rates of SLR, sudden events, and tourism revenue, there are exponentially more runs to look at to determine which combinations lead to the desired output. The second challenge is equally important in scenario analysis. Namely, it is difficult to determine if the settings of the set parameters are correct. So, while we, as researchers, may be focusing on how SLR affects operator numbers, the setting for pollution entering the environment may be set at a level that more heavily influences operator numbers.

Alternatively, we can focus on the outcomes (e.g. avoiding loss of tourism and degradation of the environment) instead of individual input parameters (e.g. rate of SLR) for scenario testing. In this realm, scenario discovery is an exciting way forward for analysing emerging challenges in (tourism) systems. This is because instead of focusing on whether the input parameters are set at the right value, the focus is on a decision-relevant outcome. In other words, we start with our future goal in mind and then based on that find the system features that are the most influential on getting to that outcome. As such, scenario discovery allows system features, or input parameters, over a wide range of values for all parameters. This type of computational analysis is more in line with the deep uncertainty in tourism destinations and can help us critically reflect on what vulnerabilities we want to avoid rather than focusing on if a specific parameter is set right. As such, these tools can be applied to different island context and consider different goals (e.g. very little coastal environmental decline allowed and only 10% loss of dive operators). Moreover, global sensitivity analysis and scenario discovery can be applied to a range of human-environmental challenges and is certainly not limited to tourism.

Although there are many exciting opportunities to expand the approach and utilise the methodological tools, the original case study destinations should not be forgotten. Vulnerabilities will continue to emerge and human and environmental capacities will continue to change. Thus, Barbados and Curaçao should be revisited. Moreover, while the process on Curaçao benefitted from Barbados, especially with the use of simulation-guided interviews, because Barbados was part of the initials process, Barbados has not experienced the same level of experiencing and experimenting as Curaçao. Continuation of research on these islands is the best way to prevent the insights from becoming static.

The unfortunate reality of dynamic vulnerability in a complex system is that we will never be finished. This makes the often-quoted academic phrase “more research is required” superfluous. However, the need for iteration does not have to be a “the glass is half empty” situation, rather a reminder that there is more to fill and that we do not have time for complacency. The approach, the developed tools, and the contextual insights of emerging vulnerabilities in Barbados and Curaçao, are outcomes of iterations that did not exist before the start of the research. As such, this research contributes to the conceptualisation, operationalisation, and insights of dynamic vulnerabilities in (coastal) tourism destinations and provides the groundwork for future vulnerability research.

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ANNEXES

ANNEX 1. STAKEHOLDER INFORMATION

Table A1.1. Stakeholder overview

Location	Sakeholder type	Number of interviews	Revisited interview-ees	Interviewees who participated in 2017 simulations	Participants in 2017 simulations who were not interviewed
Barbados 2015	Tourism operators	39			
	Local (research) experts	5			
	Government officials	13			
	NGO representatives and tourism-related parties	5			
	Total	**62**			
Barbados 2016	Tourism operators	14	5		
	Local (research) experts	2	2		
	Government officials	3	1		
	NGO representatives and tourism-related parties	0			
	Total	**19**	**8**		
Curaçao 2016	Tourism operators	20		2	
	Local (research) experts	2			
	Government officials	5			
	NGO representatives and tourism-related parties	7		1	
	Total	**34**		**3**	
Curaçao 2017	Tourism operators	5		1	7
	Local (research) experts	0			
	Government officials	3		2	10*
	NGO representatives and tourism-related parties	2		1**	3**, 2*** 14****
	Total	**10**		**4**	**36**

* One government official was interviewed after participating in the simulation

** Identify as NGOs first, but also as tourism operators

*** Identify as NGOs

**** Local stakeholders in services related to coastal tourism or affected by tourism in Curaçao

Table A1.2. Stakeholder categories

Core stakeholders: tourism operators	
Hotels	All beach hotel type and sizess
Beach vendors	Beach cafes, bars, and restaurants; beach entertainment, beach activities, beach chair renters
Dive operators*	Dive operators offering shore diving and boat diving
Boat operators*	Catamarans, day trip boat excursions
Nearshore operators	Glass bottom boat operators, surf shops, kayaking, snorkelling, stand up paddling related activities, wind surfing, jet skis, banana boat operators
Secondary stakeholders	
Local experts	Marine biology (including fisheries, sea turtles, and coral reefs), coastal governance, marine policy and management, conservation, and tourism
Government officials	Tourism, spatial and land-use planning, infrastructure, coastal planning, environmental protection, public health, fisheries, environmental clean-up, environmental policy, law
NGO representatives and tourism-related parties	Nature education, species conservation, clean-up, waste management, environment protection and conservation, insurance providers, financial services, tourism operator interest groups

* In the simulation sessions, these have the same operational inputs, in the computational model these two types are separate entities and have the same operational budgets, but boat operators can be active in more locations than dive operators

ANNEX 2. DETAILS OF *COASTING* GAME DESCRIPTION

A2.1. Geospatial set-up for *Coasting* game in Curaçao

The board is made up of 5 rows with 5 hexagon tiles per row. Starting from the top, the second and fourth rows have tiles split in two so that the game boarder is consistent. Figure 5.1 visually depicts the *Coasting* game.

The firsts row is a boundary and represents the inland and land-based operators (hoteliers and beach vendors) are not permitted to build here.

The second row is coastal area approximately 250m from the coastline. Hotels and beach vendors based here are more protected from activities along the coastline. However, they are farther away from the beach. Operators who build there can potentially be blocked by operators who choose to build between them and the water (row 3).

The third row represents the coast. Tiles are half water, half-land. This is prime beachfront area and the first row for land-based operators. It is also where water-based operators (dive/boat operators and nearshore water operators) can act.

The fourth row is nearshore water. Reef is placed on three of the four whole tiles and one of the half tiles. One sea turtle is place and four fish are put on reef. This area is attractive for dive operators.

The fifth row is dark blue and depicts the deep sea. Water-based activities do not occur here.
Wind direction faces to the left and towards the shore and helps water-based operators who are dependent on wind determine more appropriate locations.

In the case of three participants simulating 6 operators instead of 8, one column is removed. This is to ensure that there is enough interaction and potential competition for space.

A2.2. Set-up explanation

The coastal setting is described: coastline, nearshore, deep sea, inland, mangroves, fish, coral reef, and sea turtles. No pollution or environmental challenges are present in the beginning. Pollution is an aggregation of locally-induced environmental problems. Mangroves are described, participants could decide to plant more mangroves if they inquire, but this option is actively presented to participants.

The four operator types are explained: two are land-based (hotels and beach vendors) and two are water-based (dive/boat operators and nearshore operators). Land-based operators cannot change location after set-up. Maximum two land-based operators may be located on a whole tile and one may be located on a half tile. Water-based operators' location on the board indicates the location of their water activities, not their land-based infrastructure. There is no limit to the number of operators on a water tile. Proximity to land-based operators is not specifically beneficial in the game although many participants prefer to operate close to land-based operators. Dive/boat operators have two markers to represent their two preferred locations as their businesses are typically larger than nearshore operators and have a couple of preferred spots in real life.

Tokens represent operators' resources of time, energy, expertise, and financial capacity. They require a certain amount of resources for sustainable operations (see Table A2.1 and A2.2). The three operational inputs (maintenance, tourism product, environment) and recommended amounts for each type are explained. Participants are informed that they do not have to do more maintenance than stated, but they need to make sure that invest the recommended amount. Participants are told that they may invest more or less in the tourism product and environment, but the recommended amounts are as stated on their operational input forms. Dive/boat operators specify whether they are a dive operator or a boat operator and nearshore operators decide which type they represent (e.g. surf school, jet skis, kayaks). Their type motivates their location choice. Dive operators, in particular prefer coral reef, fish, and/or sea turtles.

Table A2.1. Example of operational input forms

What is your actual role in tourism (tourism operator, NGO, government)?

How do you want to achieve sustainable tourism operations in this simulation?

HOTEL							
Maintenance 4		**Tourism product 5**		**Environment 2**		**Returns**	**Comments**
(Round 1)							
(Round 2)							
(Round 3)							
(Round 4)							
(Round 5)							
(...)							
(...)							

Table A2.2.Relative recommended operational inputs for each of the three categories and the amount each operator starts with

Operator type	Maintenance per round	Tourism product per round	Environment per round	Starting available resources (capacity)
Hotels	4	5	2	12
Beach vendors	1	2	1	6
Dive operators/boat operators*	2	2	1	6
Nearshore operators*	1	1	0	3

* Type is specified by participant

The game play is described and the goal of the simulation is to sustainably operate their business in the coastal tourism setting. Participants may decide themselves what they consider to be sustainable. Then, participants choose their initial locations, starting with hotels, then beach vendors, dive/boat operators, and lastly nearshore water operators.

Participants are asked to describe their real-life roles in relation to tourism and their initial strategy for sustainable operations. If there are less than eight participants, some participants are allocated two roles, usually one land-based and one water-based. They are reminded that they need to think of their two business as separate entities. Ideally, there are at least four participants, but a last-minute cancellation resulting in three can make the game still playable by removing one beach operator and one nearshore operator and updating the geospatial set-up.

A2.3. Game play

The sequence of the game is illustrated in Figure 5.2. First, participants determine how they will allocate their resources in their operational budget. Table A2.1 provides an example of an operational input form and A2.2 shows the recommend amounts of inputs for each operator type.

Then, the dice is rolled and one of the six challenges in Table A2.3 occurs. When relevant, severity and location is determined by further rolling of the dice. The options and consequences are shared with participants and they decide how to respond. Their response may require them to change their initial operational inputs to allocate tokens elsewhere.

Depending on the actions and participants' responses (did they act on the environmental issue, did it go away), the environmental setting is updated. Operators then collect revenues based on their operational inputs, their location, and the surrounding environmental conditions, see Table A2.4.

Operators generate pollution by not investing in the environment or investing more in the tourism product, but the same amount or less in the environment. Pollution is represented by

Table A2.3. Six possible challenges faced during simulation sessions

Challenges	Environmental changes	Stated options	Long-term effects
More effort required to attract same number of tourists		-Participants can increase their inputs in tourism product to attract more tourists, if not ratio of tourism returns are lowered from 3:1 to 2:1	
Coral bleaching	-Severity determined by dice -Bleached coral replaces healthy coral. -Fish and sea turtles may move to other tiles	-Water-based operators may move away	-Bleaching may eventually go away in successive rounds -Continued pollution can add stress and prolong bleaching -Dive and boat operators returns can decrease if located on bleached reer
Drought	-Three pollution units introduced inland proxy-ing extra water extraction and potential salt water intrusion	-Participants are required to give one token to deal with drought	
Erosion	-Proxy of sea-level rise -Coastline changes based on randomly drawn ero-sion tiles -Erosion tiles have alternate coastlines, some with more water and less beach, others with more beach -Coast tiles with mangrove are unaffected	-Operators can pay 3 tokens for beach nourishment, this action restores a coastline tile to the original state, but generate pollution units on the reef	-In successive rounds, the coastline may go back to the original coastline -Land-based operators on erosion tiles with less beach lose one token of income
Storm surge, tropical storm (120> wind > 63km/h), or hurricane (wind > 120)	-Severity determined by dice, coral can be dam-aged, existing pollution moved around -In the case of a hur-ricane, pollution can be introduced -Opportunity to discuss actions in preparation of storm	-Storm surge: cost 1 token for repair -Tropical storms: 2 tokens for repair and 3 for hotels -hurricane: 2 tokens and ratio of tourism returns is lowered from 3:1 to 2:1	
Unknown event	-Red marker coordinates determined by dice, deptics environmental degradation -Participants can describe potential environment or tourism-related challenges	-Do nothing, it may go away, stay the same, or spreads to other tiles (33% chance of each) -If operators can pay 5 tokens, have a 50% chance it will go away and 50% chance it will stay the same -Water-based operators can move away	-If remains, lose 2 tokens revenue if on same tile as operator, lose 1 token if it is on neighbouring tile -In successive rounds, participants can decide to do nothing or pay 5 tokens to deal with the unknown event, whcih affects whether it goes away, stays the same, or spreads

Table A2.4. Factors influencing operator revenue

Inputs in tourism product	Inputs in other categories	Location effects
-Typically a 3:1 ratio of what operators invest in the tourism product -If operators invest 2 tokens more than recommended amount for tourism product, surplus tourism product investments decrease to 2:1 ratio	-If the operator invests more in environment twice, receives bonus of 1-2 tokens -If operators get behind on maintenance, delayed impact on income, 1st year no impact; if in the following year invest less in than recommended amount in maintenance, 1 token deducted if land-based or nearshore operator, 2 tokens if water dive/boat operator	-Earn 1 less token if land-based operator is not located on the coastline -If land-based operator is located on a tile where the beach shrinks, 1 token is deducted -If pollution is located on tile, 1 token is deducted - If no fish, sea turtles or coral for dive/boats operators two markers, 1 token deducted -If uknown event located on tile, income is decreased by 1-2 tokens; if it is on a neighbouring tile, income is decresaed by 1

black markers. Once generated, pollution can disperse from inland towards the sea. When in the sea, it can follow the wind direction or disperse randomly. Pollution in coastal waters can wash up onshore or from the beach pollution can enter the sea. The game master places the black markers, but does not describe what it is until a participant asks. Only when a participant asks, does the game host describe how to remove pollution: a token *may* remove a unit of pollution. Participants can try to remove pollution individually or collectively and determine which units of pollution in the system they would like to work on. Pollution may be removed or dispersed by game master. Usually, the first unit is removed. Pollution on land is more often removed (66% chance), while pollution in the water has a higher chance of being dispersed. This represents the increased effort of removing pollution once released in the environment (instead of prevention) and the increased effort fo removing pollution in the sea over the land.

The mobile environmental resources of fish and sea turtles may change location. Multiple water-based operators on one tile can cause breakage to coral, especially when environment inputs are less than recommended levels.

The final step in the round is the opportunity for mobile operators to change location if they would like a more ideal spot for their activities. A short summary of what has happened in the round is provided by the game master and then the following round is started with the participants filling in their operational input forms. The game ends after approximately one hour and a half and is followed by a debriefing discussion planned for at least thirty minutes.

In some cases, the effects on income have to modified by the game master as operators can go bankrupt quickly depending on their initial strategy and the environmental challenge they face.

ANNEX 3. OBSERVATION PROTOCOL *COASTING* SESSIONS

General summary of session
Major events, statements, or developments

Simulation session details
Language:
Number of players:
Number of rounds:
Codes and abbreviations used:

Set-up notes
Location chosen, comments made on location selection

First round
Time noted of when these steps start

1^{st} round - Filling forms for personal expenditures in
1^{st} round - environmental change
1^{st} round payment step

Tourism operator	Inputs and changes made to inputs

1st round- summary

Second round

.....

Third round

.....

Fourth round

.....

Fifth round

Debriefing notes

....

Collaboration

Under what situation do participants work together [increasing pollution, sudden event, lack of income]?

____

____

____

Who suggests they work together? [indicate which colour]

O Hotel _______ O Beach vendor _______ O N.S.Watersports _______ O Dive shop/Boat _______

O Hotel _______ O Beach vendor _______ O N.S.Watersports _______ O Dive shop/Boat _______

Who works together [what alliance are formed]? [use pen to show links]

What do they do together? ____

To what extent do they share information?

O Very much	O Moderately	O A little	O A little	O Moderately	O Very much	O Hard to say
No, actors refuse to share information			Yes, actors share information			

Are there exceptions? ____

____

How would you evaluate group level interactions?

O Very much	O Moderately	O A little	O A little	O Moderately	O Very much	O Hard to say
Compete or have conflicts			Cooperate			

If they do not work together,
....who does not want to work together?

O Hotel _______ O Beach vendor _______ O N.S.Watersports _______ O Dive shop/Boat _______

O Hotel _______ O Beach vendor _______ O N.S.Watersports _______ O Dive shop/Boat _______

....what is the explanation given (e.g. trust, not in their interest, financial, risks, future, personal)?

____

____

Environment

Which players express concern about which resources (e.g. dive operator and less coral reef)? (indicate which colour)

Operator	Round(s)	Resource
Hotel ____________________		
Hotel ____________________		
Beach vendor ____________		
Beach vendor ____________		
Dive shop/Boat ___________		
Dive shop/Boat ___________		
N.S. Watersports __________		
N.S. Watersports __________		

When (at what moments in the simulation) do individuals do more for the environment (see challenge, other people say something about the environment, see growing pollution)?

Operator	Round(s)	Action (number actions if occur in multiple rounds)
Hotel ____________________		
Hotel ____________________		
Beach vendor ____________		
Beach vendor ____________		
Dive shop/Boat ___________		
Dive shop/Boat ___________		
N.S. Watersports __________		
N.S. Watersports __________		

Personal Resources

When participants do not have enough money, to pay the basic sustainable amount for their business, where do they make cuts (maintenance, tourism, environment)? What reasons do they give (i.e. what are their main considerations)?

Operator	Round(s)	1	2	3	4	5	6	7	Reason
Hotel ________	M								
	T								
	E								
Hotel ________	M								
	T								
	E								
Beach vendor ________	M								
	T								
	E								
Beach vendor ________	M								
	T								
	E								
Dive/Boat ________	M								
	T								
	E								
Dive/Boat ________	M								
	T								
	E								
N.S. Watersports ________	M								
	T								
	E								
N.S. Watersports ________	M								
	T								
	E								

ANNEX 4. QUESTIONS ASKED DURING DEBRIEFING

Guiding debriefing questions

- How do you feel about what happened during the simulation?
- What were key moments in this process?
- What were the main trade-offs?
- In what ways does do events in the simulation connect to reality?
- What did you learn from your role?
- What were the obstacles in operating in this (Curaçao's) coastal setting?
- What are some opportunities to changing or preventing certain outcomes?

ANNEX 5. *COASTING* SIMULATION ODD+D AND SCENARIO DISCOVERY

A5.1. Introduction

The model is made as part of a dynamic vulnerability approach (Chapter 4). The model endeavours to understand emerging vulnerabilities that tourism operators encounter; tourism operators are considered the most vulnerable of the coastal tourism sector as tourists have a higher adaptive capacity due to their ability to choose alternate locations, activities, timing (e.g. Kaján & Saarinen 2013; Moreno & Becken 2009; UNWTO-UNEP-WMO 2008). This section describes the *Coasting* simulation using the ODD+D in section A5.2., it then gives details about the global sensitivity analysis A5.3., and scenario discovery A5.4.

A5.2. *Coasting* ODD+D

This section describes the *Coasting* simulation. The simulation was developed in NetLogo 6.0.4. The ODD follows the format of Grimm et al. (2010) and Müller et al. (2013).

A5.2.1 Overview

Purpose

The intended audience is researchers and interested coastal tourism stakeholders. The general purpose is to explore what emergent patterns of socio-ecological vulnerability occur in coastal tourism settings. It also gives the opportunity to visualise different types of environmental change in the coast for stakeholders. This particular version of the model explores how vulnerabilities emerge over time when unknown events (a proxy for many types of quick onset events), slowly developing sea-level rise (SLR), and locally-induced vulnerabilities (aggregated as pollution). The model also shows the interactions between tourism operators and their coastal environment.
Several indicators are available to measure the emergence of socio-ecological vulnerability. The proxy for human vulnerability is the inability to survive as a business (having no reserves and going bankrupt), as well as not having enough reserves for the recommended needed inputs for a sustainable business. Environmental vulnerability is measured by changes to environmental attractiveness of different spatial locations. It is divided into three regions, coastal (immediate land and water space), beach (inland location near coast), and nearshore (waters located near the coastline). Environmental attractiveness is made up of geospatial type, biodiversity, pollution level, and environmental degradation. Geospatial type and biodiversity contribute to patch attractiveness whilst pollution levels and environmental degradation lower patch attractiveness.

Entities, state variables, and scales

The focus is on the tourism operators (supply side) as they have been identified as the most vulnerable (e.g. Kaján & Saarinen 2013; Moreno & Becken 2009; UNWTO-UNEP-WMO 2008). In general, operators want to have a sustainable business, this can mean financially sustainable and/or environmentally sustainable. The agents are divided into five main coastal tourism operator types: hoteliers, beach vendors, nearshore operators (NSOs), dive operators, and catamaran/

boat operators. They seek to operate using certain environmental resources (e.g. beach, coral reef) under preferred environmental conditions (e.g. lack of pollution). Land-based operators are fixed to a certain location whereas water-based operators are mobile. Operators' resources are a combination of the time, energy, expertise and finances that they put into their business. Different types of operators have similar input categories, but different input requirements for sustainable operations, different mobility, different patch attribute preference. Operator attributes are described in tables A5.1. and A5.2. In this version of the model, we do not model tourists as such, but rather their influence on the system. Tourists main influence is income (tourism-returns) mediated by operators' inputs into the tourism product, and tourists' contribution to pollution. In the model, environmental resources are also considered agents; there are the following types: fish, sea turtles, coral reef, and mangroves. The former two are mobile while the latter are immobile. The model parameters and the ranges in which they were tested are in table A5.3.

Table A5.1. State variables

Variable	Static or dynamic	Range	Default	Function
tourism-operator	Static	0:1	Both	0= natural resource 1= tourism operator Differentiates natural resources from tourism operators
5 operator types	Static	1-5	5	Agent type: Hoteliers, beach operators, dive operators, boat operators, nearshore operators (NSOs)
mobility	Static	0:1	Both	0= immobile 1=mobile Land-based operators, coral, and mangroves have a fixed location (0), water-based operators, sea turtles, and fish are mobile (1)
resources	Dynamic	0:X		How many resources an operator has (proxy for time, experience, money). X=No upward limit, but there is a likelihood that it will not rise beyond a certain level because of costs -when operator has 0 resources, the operator will go bankrupt
input types	Static	4	4	Maintenance (Looking after infrastructure and resources) Tourism product (marketing and effort placed when tourists are there) Environment (Short-term activities) Saving (Non-spending)
needed-maintenance	Static*	1:4*		Depends on operator type needed inputs in for maintenance, *only changes with SLR

Variable	Static or dynamic	Range	Default	Function
needed-tourism	Static	1:5		Depends on operator type how much operator puts in for their tourism
needed-environment	Static	0:2		Depends on operator type how much operator puts in for environment
needed-saving	Static	0:1		Depends on operator type how much is allocated to be saved
alloc-maintenance	Dynamic	0:		Depends on operator type how much operator puts in for maintenance
alloc-tourism	Dynamic	0:		Depends on operator type how much operator puts in for their tourism
alloc-environment	Dynamic	0:		Depends on operator type how much operator puts in for environment
alloc-saving	Dynamic	0:		Depends on operator type how much is allocated to be saved
wght-pos-maintenance	Static	1:3		If sufficient resources, determines preference for distribution above default distribution
wght-pos-tourism	Static	1:3		If sufficient resources, determines preference for distribution above default distribution
wght-pos-tourism	Static	1:3		
wght-pos-environment	Static	1:3		
wght-pos-saving	Static	1:3		
wght-neg-maintenance	Static	1:3		If insufficient resources, determines where resources will be cut
wght-neg-tourism	Static	1:3		
wght-neg-environment	Static	1:3		
wght-neg-saving	Static	1:3		
default-maintenance	Static	n-m+ -1:1		Individual preference for minimum, depends on operator type needed-maintenance - 1 + random 3 Refer to Table A5.2.

Variable	Static or dynamic	Range	Default	Function
default-tourism	Static	n-t + -1:1		Refer to Table A5.2
default-environment	Static	n-e + -1:1		Refer to Table A5.2
default-saving	Static	n-s + 0:1		Refer to Table A5.2
max-maintenance	Static/ Dynamic*	0:6*		Depends on operator type and SLR Max-maintenance can increases needed-maintenance + 2
max-tourism	Static	0:10		Depends on operator type needed-tourism + 5
max-environment	Static	0:5		Depends on operator type needed-environment + 3
max-saving	Static	0:5		Depends on operator type needed-saving + 5
my-patch-affected?	Dynamic	Y/N		Determines whether the immediate location of the operator is affected
willingness	Dynamic	0:1		Willingness of operator to collaborate or act on environmental challenge
proposed-contribution	Dynamic	0:X		Amount of resources operator willing to contribute to problem
contribution	Dynamic	0:X		Amount of resources operator actually contributing to problem
max-possible-contribution	Dynamic	0:X		Limit of amount that operator can feasibly contribute
base	Static	Location		Water-based operators have a base on land. If this space gets inundated; they go out of business
my-sites	Dynamic	Location		Memory of locations where water-based operators have previously operated
links	Dynamic			Links directed at other operators to keep memory of how helpful the other operator was during past collaborations
strength	Dynamic	-1:1		Property of links, closer to 1, more successful past collaborations; closer to -1, more unsuccessful past collaborations or free-riding

Variable	Static or dynamic	Range	Default	Function
health	Dynamic	0:1		Health of environmental resources; if health is >.95 reproduce; if <.25 chance of death
patch-attractiveness	Dynamic	0:1		How attractive the environmental space is 0= completely unattractive 1= absolutely attractive
geospatial-type	Static*	0:1		Land, water type [inland, coast, nearshore waters deep sea] *only changes when sea-level is above elevation of land
elevation	Static*	-50:5		Elevation of environmental space [negative for underwater +0 for above land *only changes with SLR
temp-pollution-level	Dynamic	0:1		Temporary variable for pollution dispersion
pollution-level	Dynamic	0:1		0= no pollution; 1= completely polluted
enviro-degradation	Dynamic	0:1		Degradation caused to the environment though sudden event 0= no degradation 1= completely degraded

Table A5.2. Operator and environmental resource attributes

	4 input categories	Needed mainte-nance	Needed Tourism product	Needed environ-ment	Needed savings	Mobile	Environ-mental space preference
Hoteliers	Yes	4*	5	2	0	No	Near beach, good sand
Beach vendors	Yes	1*	2	1	0	No	Near beach, good sand
NSOs	Yes	1*	1	0	0	Yes	Coastal waters
Dive operators	Yes	2*	2	1	0	Yes	Nearshore waters, reef, fish, sea turtles
Boat operators	Yes	2*	2	1	0	Yes	
	4 input categories	**Abundance per environmental space**		**Health**		**Mobile**	**Space preference**
Mangroves	N/A	0-1, but can increase more if reproduce		0:1		No	Beach
Coral reefs	N/A	0-3, but can increase more if reproduce		0:1		No	Nearshore waters without pollution and environmental degradation
Reef fish	N/A	0-1, but can increase more if reproduce		0:1		Yes	Nearshore waters, abundant reef, pollution and environmental degradation < marine sensitivity
Sea turtles	N/A	0-1, but can increase more if reproduce		0:1		Yes	Same as reef fish

Table A5.3. Model parameters

Parameter	Parameter range	Parameter type
tourism returns	2, 5	float
revenue-limited?	0, 1	Boolean
enviro-degradation-income-penalty	0, 5	integer
maintenance-penalty	0, 3	float
pollution-penalty	0, 10	float
neighbor-pollution-penalty	0, 5	float
neighbor-pollution-threshold	4, 8	integer
link-chance	0, 10	float
links-to-my-base?	0, 1	Boolean
negative-association	0.01, 0.25	float
positive-association	0.01, 0.20	float
geospatial-weight	0.0, 0.5	float
biodiversity-weight	0.0, 0.5	float
pollution-weight	0, 1	float
enviro-degradation-weight	0.0, 1.0	float
marine-life-sensitivity	0.10, 0.50	float
pollution-change	0.01, 0.50	float
pollution-diffusion-rate	0.01, 0.25	float
pollution-clean-up	0.01, 0.10	float
pollution-threshold	0.0, 0.5	float
cost-pollution	1, 20	integer
SLR-increase	0, 50	float
linear-SLR?	0, 1	Boolean
min-acceptable-elevation-above-SL	0.20, 1.00	float
increased-elevation	0.2, 1.0	float
erosion-loss	0.00, 0.25	float
cost-SLR	5, 50	integer
sudden-event-interval	35, 350	integer
patches-affected-sudden-event	0, 10	float
enviro-deg-from-sudden-event	0.0, 1.0	float
acceptable-enviro-degradation	0.00, 0.50	float
cost-extreme-event	5, 50	integer
sudden-event-persistence	1, 10	integer
seed-for-random	-2**31, 2**31-1	integer

Each individual space (patches in Netlogo) represent parts of the coastal system. They spatial scale is approximate and represents 40-60m X 40-60 m. Simple spatial representation of the main coastal features (deep sea, shallow nearshore waters, coastal waters, coastal beach, prime nearshore land, nearshore land, subprime nearshore land, farther prime nearshore land, inland).

Each time step tick represents a little over a week. The time step represents the average time a tourist stays in the area (CTB 2018). For this reason, we choose 30-time steps per year. The simulation runs for approximately 30 years of simulated time and data is recorded at time 0, 10 years (350 time steps), 20 years (700), and 30 years (1050).

Process overview and scheduling

Set-up

The environmental spatial setting is read from file. The five operator types are then set up. First, the hotels and then the beach vendors select space on land, preferably close to shore. Then the water-based operators are randomly assigned a land base, which they may share with a land-based operator. Then links are set up among operators. Links may be set up based on which operators (both land and water-based) are located at the same location (base) or a chance that they are set up with an operator in an neighbouring area. Mobile operators are then given the opportunity to select a place in the sea and environmental resources' health in initiated.

At each time step

Please see Figure A5.1. for information regarding the main process.

A5.2.2. Design concepts

Theoretical and empirical background

The operators are modelled based on information acquired during literature review, (simulation-guided) interviews, simulation development, and serious games sessions. The level of aggregation depended on the means of access: literature data is typically at the destination (national level) or regional level; interviews (typically one on one, but on a few occasions with as many as five participants; focus group outputs (3 and 4 participants per session); and small group settings (3-8 participants) for simulation sessions. All tourism operators have the same main input categories: maintenance, tourism product (marketing plus providing the tourism experience), and short-term environment (e.g. cleaning the beach, educating tourists not to damage coral). Operators need to look after their operational infrastructure (maintenance), otherwise they will eventually lose money (delayed effect), if they do not focus on tourists, then they will not be able to attract people to their business, if they do not look after their environmental situation, it will (slowly) get polluted. If they put more emphasis on their tourism product this will have a negative impact on their environmental situation unless they also invest more in their environmental surroundings. In the game, in general, people did not need to do more than the required amount for maintenance, but are penalised in the following steps when they do not keep it up. If they do not look after the environment it will degrade, if they put more into it, it is either compensation for more tourism activities or is a potential future investment in the environment.

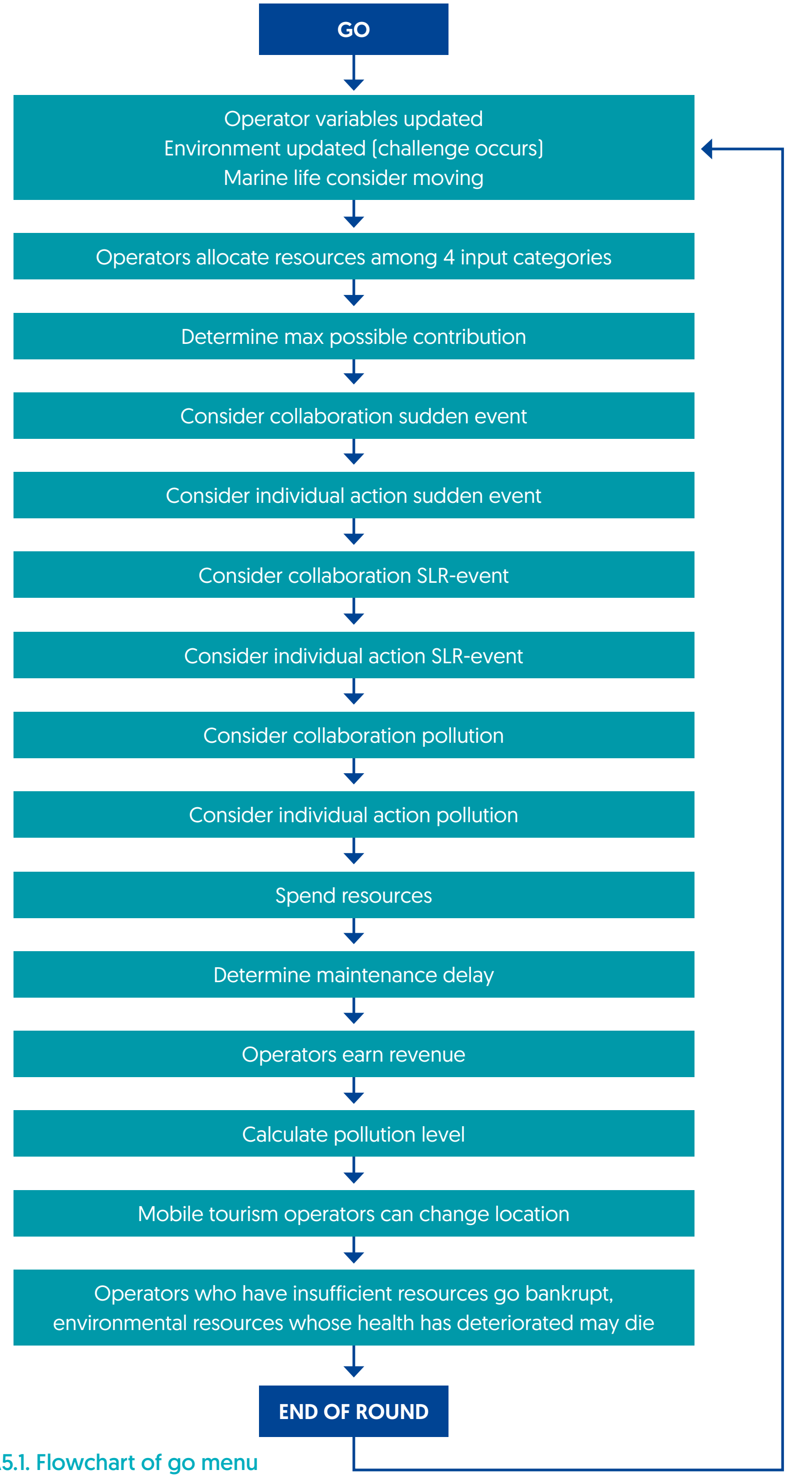

Figure A5.1. Flowchart of go menu

The simulated operators are exposed to different types of environmental events. The model focuses on the locally induced pollution as well as globally driven change manifested at the destination: gradual onset through SLR and sudden events that can be a proxy for immediate events such as hurricanes, coral bleaching event and other unknown and uncertain events. Pollution results from insufficient environmental expenditures and changes the pollution level. Pollution can disperse to adjoining areas. Sudden events, i.e. uncertain and new events, can emerge in different spatial areas and their cause is unspecified. In the model those situated immediately where this event occurs, are negatively affected, those in the perimeter are somewhat affected, those farther away are removed are unaffected unless the problem grows. Sudden events have a random chance of affecting a certain number of environmental areas. It has an amount of environmental degradation associated with it (severity) and this negatively affects environmental attractiveness. Sudden events also has a natural duration that can vary, which determines how low before it might go away if no one takes action. SLR occurs at set rate per year, unless nonlinear SLR-rate is selected, then sea-level's rate increases. The loss of land can become more extreme through erosion (amount is static throughout simulation). All of the environmental problems have an associated cost of dealing with them. For SLR, the intervention increases the elevation of the area by a set amount; it also changes the geospatial-type to a less attractive one than coastal land, contributes pollution of 0.30 to neighbouring coastal areas, and increases the cost of maintenance per round by 2 for land-based operators whose area is affected by the SLR-intervention, and by 1 for water-based operators who have their base on that space.

Environmental attractiveness is made up of geospatial type, biodiversity, absence of pollution and lack of environmental degradation, This is in line with the potential implications of resource degradation effect on tourism (e.g. Cumberbatch et al. 2018; Hopkins et al. 2013).

Individual decision-making

Simulated and real tourism operators work with imperfect knowledge and individual weight preferences. Simulated operators use the weight preference for deciding on whether to collaborate, act alone or do nothing. They use individual weight preferences for making input decisions and for reallocating resources when they have decided to contribute. They also use imperfect knowledge when deciding initial location and for mobile operators, when they decide to move.

The general goal of the operators is to survive as a business in the coastal tourism setting. This means to have more than or enough resources to meet the needed resource requirements to operate and not going out of business. This involves weighing of their individual expenditures (inputs), responding to what others are doing, and monitoring how their surrounding environment in changing.

Two levels of decision-making are included, individual decision-making for personal resource allocation, location, movement (if mobile), willingness to act alone, and willingness to collaborate. The second level is if multiple individuals are willing to collaborate, how much they will contribute to work on the problem together. Table A5.4. highlights the factors affecting their willingness.

Operators adapt their behaviour to both endogenous (network links to others, resource availability, action decisions) and exogenous variables (pollution levels, sea level rise, sudden events).The amount of available resources modify their resource allocation, willingness to act, the reallocation of resources if they have decided to act and have not exceeded the max possible contribution. Links affect willingness to act (see Table A5.4.). In response to environmental threats, operators can do the following: collaborate, individually act, move away (if they are mobile), or do nothing. The operators make decisions during the following go procedures: allocate-resources, determine-max-possible-contribution, consider-collaboration [to a certain event], consider-individual-action [to a certain event] , mobile-operators-move, and check-economic-viability. During each time step they have an opportunity to decide on their resource allocation and whether and how to respond to events. However, events (pollution, sea level rise, and sudden events) play out on different temporal scales and will only trigger consideration when the patch reaches a specified level for perceiving them. This can result in multiple events occurring at the same time or in succession. Social norms play a role through the links, but culture is not explicitly modelled. Spatial aspects play a role in whether or not an operator considers collaborating or acting individually in response to environmental change (see table Table A5.4.). They are more likely to act if their neighbouring area/environment is affected and most likely if their own space is affected.

Uncertainty is included in operators' decision rules. For deciding whether or not to collaborate or act alone, a number of factors create a higher probability of them acting (see table Table A5.4.on willingness to act). They do not know whether others will collaborate, if they will contribute and if so, how much. Moreover, actions do not mean that the expressed result is reached. All of the pollution may not go away, the sudden event might persist, SLR may continue pass the new elevation created to mitigate SLR.

Environmental resources also make simple decisions. If their marine sensitivity has been triggered (global parameter), mobile environmental resources will decide every time step whether or not they will move to another location within their geospatial context (nearshore waters). Their preference is to go to another site with a reef, if there is no reef, to spot in the water with lower pollution and degradation than their current location. Mobile environmental resources do not know for sure if the new location will be better than their current location nor the best possible location. Environmental resource numbers can increase (they reproduce) when their health gets to .95. Environmental resources can also die if there is too much pollution or degradation and their health gets below .25.

Table A5.4. Factors contributing to willingness to act in response to environmental threats

		Willingness to collaborate			Willingness to act alone	
		My patch is affected	Neighbouring patch affected	Not affected	My patch is affected	Neighbouring patch affected
Base amount		0.4	0.2	0	0.5	0.2
Added if mobile operator's base affected		0.2	0.2	0.20	0.20	0.20
Added if not mobile	Not able to move	+0.2	+0.2	0	+.2	+.2
One of these is have links	Positive links	+0.3	+0.3	+0.3	–	–
	Neutral	+.25	0.20	Chance +0.15 else 0	–	–
	Negative links	+0.25	+0.10	0	–	–
Range		0.4:0.9	0.2:0.7	0:0.3	0.5:0.7	0.2:0.4

Learning

Learning is limited. Operators respond to a build-up of pollution, environmental degradation, and/or increased sea level, which may trigger individual actions or collaborative responses to environmental change. When operators go from a state of sufficient resources to limited resources, they use a different set of preferences to determine for which categories they will lower their allocations.

Mobile operators and environmental resources [turtles and fish] can move to areas of less pollution and more [other] environmental resources. Collective learning only occurs in terms of adding links and changes to existing links. Operators modify their directed links to other operators based on whether or not collaborations were successful and whether the other operator contributed to that collaboration. This modifies who they are willing to work with in the future.

Individual sensing

The costs for cognition and gathering information are not explicitly included in the model.

Operators

Operators can sense the presence of others during initialisation. They sense geospatial type and the presence of certain environmental resources. They sense pollution, SLR, and sudden events over a threshold as well as other's willingness to collaborate and contribute to acting on environmental threats. They directly sense threats what affect their immediate space, a neighbouring space, or in the case of mobile operators, their base. Indirectly they sense affected areas through their established links. They also sense whether or not their collaborative efforts were successful in addressing the threat. They sense whether or not they have enough resources and adapt their allocation according to their weight preference. Mobile operators sense locations with potentially better environmental conditions (environmental attractiveness) in the same geospatial type (less pollution and environmental degradation and in some cases larger presence of environmental resources); they can misjudge what a better location is for their tourism activities. Directed links to other operators provides information on whether or not past interactions have been overall positive or negative (strength).

Environmental resources

Environmental resources sense pollution and environmental degradation over a threshold (slider marine-sensitivity) and sense places with potentially better environmental conditions. They can be mistaken in their selection of a better location. Location are the mechanisms by which environmental resources obtain information.

Individual prediction

The default weights for inputs is part of the internal prediction of how much resources they should invest in the four inputs. Moreover, based on their weight preferences, operators predict what outcome will give them a sustainable income. Their individual defaults and inputs may be incorrect; they can be either detrimental to their business short-term (tourism-product) or long-term (maintenance, savings) and/or detrimental to the environment. They also predict that by taking some action either alone or in collaboration that they will improved environmental conditions. In the case of collaboration, they may anticipate that the parties willing to collaborate are also willing to contribute. Their actions may not give them the environmental results they want, and others may not be willing to contribute resources for dealing with the environmental threat.

Mobile operators and environmental resources predict that a new location is better (in terms of potential revenue or less detrimental to health). They may not always be correct, it can be negatively affected to environmental changes or others' actions.

Interaction

Interactions among operators, environmental resources, and the environment are both direct and indirect.

Operators to operators

Operators compete for space, in the set-up. It is "first come first serve", the location of one land-based operator prevents another land-based operator from using that location.

Can collaborate on environmental issues. They can negatively or positively affect pollution levels of an area, which influences the income generated. Acting on environmental threats, whether individually or collectively, can improve environmental conditions and thereby improve operators' revenue potential. Links are how operators record information on past (attempted) collaborations. Directed links with positive strength increase the willingness to collaborate on events of those linked to the affected operator(s), negative links, lower the chance of willingness to collaboration. When collaborations are successful (enough resources are allocated to deal with the issue),

positive, when they are not successful, the directed links become more negative (the amount depends on how much was contributed by the other operator compared to the individual's own contribution)
Interactions depend on location, links, available resources, and willingness to collaborate.
Apart from the initialisation of links, the structure of the network is emergent.

Operators to the environmental resources
The operators can cause pollution to exist and persist as well as environmental degradation to persist in the areas, this affects the health of environmental resource. This interaction depends on the location of the environmental threat and the actions of the operators.

Operators to the environment
The operators can cause pollution to exist and persist, as well as allow environmental degradation to persist in a space. They can change the geospatial type of beach areas that will potentially become lower than sea level. This depends on the operators' inputs as well as the actions on environmental threats.

Environmental resources to environment
Mangroves can help prevent beach geospatial type from turning into to water (.20 cm extra elevation possible). In good health, environmental resource numbers can grow and spread to new areas. This depends on the sea level and sea level rise.

Environment to operators
Pollution and environmental degradation (can) negatively affect revenues and is dependent on the location.

Collectives
Collectives are represented by links and by a willingness to act during the collaboration step.
Individuals belong to different networks which are captured in directed links. Links have the characteristic strength, which can note a neutral association as well different degrees of negative or positive association (-1:1). In response to environmental threats, temporary collectives are formed that may or may not invest resources together to deal with the environmental threat.
The links may be initialised at the beginning: all of the operators on the same space, or through a probability of creating a link with an operator in a neighbouring area. The rest of the directed links and responses to environmental threats emerge during the simulation.

Heterogeneity

The agents and environment exhibit heterogeneity, including: state variables, processes, and decision-making differ among agents.

Operators

- Tourism operator vary in type (five types). The types they vary in required input levels for maintenance, tourism product (marketing and tourism experience) and short-term environmental efforts, the location and environmental preferences are different, mobility is also a heterogeneous. Water operators are mobile while land-operators are fixed to a specific location.
- The number of each type of operators in heterogeneous and relates to the context of the coastal setting that it is portraying.
- Preferences for how to distribute resources when resources exceed or are lower than input requirements vary per operator, but fall within the same range.
- The individual preference for the minimal amount to put towards each category is different but falls within the same range for each of the five operator types.
- Willingness to collaborate is different and depends on the extent to which the operator is affected and the positive strength of the operator's network. The starting links among the same type of operators starts slightly negative as they are potential competitors while the links between different types starts off neutral.
- Mobile operators consider their base as an affected patch when environmental threats occur, immobile operators do not have this. Mobile operators consider moving to another location if their preferences are not being met.

Environmental resources

- The environmental resources are heterogeneous in terms of location, mobility, and abundance.

Environmental features

- Environmental areas (patches in Netlogo) have different environmental attractiveness, geospatial type (e.g. land, beach area, coast water, shallow water, deep sea).For more information please see the section input data (Tables A5.1-A5.3). They have different elevation. After initialisation, environmental areas have different levels of pollution, environmental degradation. This initialisation of the coastal setting can be set in multiple ways to mimic coastal features of different coastal islands.

Stochasticity

Location

The operators have a preferred location type determined by their geospatial type preference and environmental resource features. However, the initialisation of the set-up is randomly selected among the available places in the coastal setting. For mobile operators and mobile marine life, if they decide to move, they choose one of the areas that has coral reef and/fish. The elevation of each patch type (except for the bordering types inland and deep sea) are partially randomly determined within a range. To improve visibility, the position of tourism operators and environmental resources on a location is slightly randomly offset

Collaboration

Key factors (whether they are affected, whether others in their network are affected) increase the probability that they will collaborate

Link set-up

If a probability determines that a link will be initialised with another operator whose operations or base (for mobile operators). It is more likely that mobile operators will choose a location where a beach café or hotel is located.

Operator resource input

Individual default is randomly determined and is -1, 0, 1 more than the recommended amount for each weight category except for default savings which is either 0 or 1. Weight preferences for resource inputs for sufficient and insufficient resources are 1 + random 3 (weight they place= 1, 2, or 3). For each type of operator recommended levels for each type of input, the minimum input (in cases of sufficient resources) and maximum input are set as well as the. However, the weight preferences for maintenance, tourism product, environment and savings are random and vary between the following ranges (see table below) and are distinct for the situation of having sufficient resources and insufficient resources. Moreover, the actual distribution of resources over these categories are more likely according to preference

Diffusion of pollution

The movement of pollution is stochastic but follows paths: on land, the tendency is to go downhill, on the coast beach and immediate surround water, in the water it disperses to adjoining patches following the dispersion rates.

Draw-weighted

Though the preferences are fixed, there is chance of one of the input categories being selected more up until either the max-amount per input category is reached or the total number of resources has been allocated (especially relevant in the case of insufficient resources).
When operators decide to act on event and needs to reallocate their resources based on their positive weights and element of chance (preferences indicate the likelihood of putting their resources, whereas the chance to allocate differently).

Chance-number

- Element of chance of whether environmental degradation will get worse by spreading to another patch, stay the same, or improve (go away)
- Element of chance of whether mobile environmental resources will moved to another patch if a threshold of pollution and environmental degradation is met.
  When operators invest (input) more in environment, they have a 50% chance that they will remove some pollution.
- If environmental health of environmental resources goes below .25, they have a 50% chance that they will die.
- If environmental health of environmental resources is higher than .95, they have a 1% chance that they will regenerate a new resource (e.g. more coral growth, increase in fish numbers.

- For collaboration, if operators are not directly (affects their immediate space) or indirectly (a surrounding area) affected by an environmental threat (pollution, SLR, sudden event), there is a 50% chance that they will express some willingness to collaborate. If the accumulated willingness is greater than a chance number, the tourism operators are in principle willing to collaborate on an issue at that current moment.
- For acting alone, if the accumulated willingness is greater than a chance number, the tourism operator is in principle willing to act on a particular issue at that current moment.
- For sudden event occurrence, each space has a chance (based on the probability) of it being affected by a sudden event.
- For acting on pollution event, a portion of pollution is removed if the chance number is less than the difficulty-to-remove (pollution in the water is more difficult to remove).
- For acting on a sudden event, there is a 50% chance that the environmental degradation will go away and 50% that it will persist.

Observation
Data for the following outputs is collected at different time steps equivalent to 10 year (time step 350, 700, and 1050) for global sensitivity analysis and at each time step for scenario discovery..
The key results emerging from the runs are in Table A5.5. They focus on operators' and ecological indicators of socio-ecological vulnerabilities.

Environmental quality/Environment vulnerability indicators
Average patch attractiveness

- Beach patch attractiveness, current and cumulative average
- Coast patch attractiveness, current and cumulative average
- Nearshore (water) patch attractiveness, current and cumulative average
- Overall patch attractiveness, current and cumulative average
- Average pollution level
- Number of fish, coral, mangroves, and sea turtles

Operator vulnerability indicators, number of

- Operators with sufficient resources per agent type, and overall average
- Operators with insufficient resources per agent type, and overall average
- Operators in business (not bankrupt) per agent type, and overall average
- Operators who have gone bankrupt per agent type, and overall average
- Operators with delayed maintenance per agent type, and overall average
- Operators businesses lost due to SLR

Duration operator vulnerability indicators, average time of

- Operators with sufficient resources per agent type, and overall average
- Operators with insufficient resources per agent type, and overall average

Actions taken to reduce environmental vulnerabilities vulnerability, number of

- Individual actions
- Collaborative actions
- Links (negative, positive, neutral, total)

Table A5.5 Output parameters for global sensitivity

Number of operators	Operators with sufficient revenue for operations	Operators short on revenue	Operators who have declared bankruptcy
m-hotelops	m-hotelops-enough	m-hotelops-short	m-hotelops-bankrupted
m-beachops	m-beachops-enough	m-beachops-short	m-beachops-bankrupted
m-diveops	m-diveops-enough	m-diveops-short	m-diveops-bankrupted
m-boatops	m-boatops-enough	m-boatops-short	m-boatops-bankrupted
m-waterops	m-waterops-enough	m-waterops-short	m-waterops-bankrupted
m-all-ops	m-all-ops-enough	m-all-ops-short	m-all-ops-bankrupted

Number of operators with delayed maintenance	Average time with sufficient resources	Average time short on reserves
m-hotelops-delayed-maint	m-hotelops-av-time-enough	m-hotelops-av-time-short
m-beachops-delayed-maint	m-beachops-av-time-enough	m-beachops-av-time-short
m-diveops-delayed-maint	m-diveops-av-time-enough	m-diveops-av-time-short
m-boatops-delayed-maint	m-boatops-av-time-enough	m-boatops-av-time-short
m-waterops-delayed-maint	m-waterops-av-time-enough	m-waterops-av-time-short
m-all-ops-delayed-maint	m-all-ops-av-time-enough	m-all-ops-av-time-short

Lost operators due to SLR	Number of environmental resources	Number of links	Number of environmental actions
lost-ops-due-to-SLR-land-based	m-corals	m-total-links	total-num-collaborations
lost-ops-due-to-SLR-water-based	m-fishes	m-neutral-links	total-num-indiv-actions
	m-seaturtles	m-positive-links	
	m-mangroves	m-negative-links	

Current environmental attractiveness	Cumulative average environmental attractiveness	Average pollution levels
m-av-now-attr-beach	m-av-av-attr-beach	m-av-pollution-beach
m-av-now-attr-coast	m-av-av-attr-coast	m-av-pollution-coast
m-av-now-attr-nearshore	m-av-av-attr-nearshore	m-av-pollution-nearshore
m-av-now-attr-area	m-av-av-attr-area	m-av-pollution-area

A5.2.3. Details

Implementation Details

The model was implemented in NetLogo 6.0.4. At initialisation, the model reads some data from file. The model and the input file used for all experiments can be found at https://harmoniqua.wur.nl/CoastingModel. For experimentation with many sets of parameters, one of the authors created a Java program that reads each parameter set from file, executes the model, and writes the corresponding simulation results to one or more other files. This program was used instead of NetLogo's BehaviorSpace for more specific control of parameter settings. Parameter sets for sensitivity analysis were generated by Python code using SALib (Herman & Usher 2017).

Initialisation

The initial state of the model is based on the input file for the geospatial set-up and environmental resources for the coastal setting, in this case Curaçao. Hotels select first and chose a location based on geospatial type. The area closest to the waterfront is considered prime location. Other areas are located farther away from the beach and access to the beach can be blocked/limited by another operator located on the waterfront. Land-based operators do not share the same space (patch in Netlogo terms) with another hotel or beach operator. There is a difference between good beach, i.e. a sandy beach, and less desirable beach, i.e. a rocky beach. Then, from the remaining locations, beach operators chose a location on one of the geospatial locations in the 1st two "rows" inland. First row is prime, the 2nd is farther away and can be blocked by another operator.
The initialisation of the spatial area of the coastal system is always the same (except for some variation in elevation). The same number of each type of operator is the same in all runs.
Their individual weight preferences, their location, and initial links are randomly determined. Links initialisation are modified by the input parameters (chance of neighbouring links) and (connection to other operators on the same space).

The initial values are based on data, but are not exact representations.
Text code file determines the original island set-up with a six-digit codes: xxyyzz for each of the patches represented in the island. The code can be expanded to allow for more variable features.

Submodels

Submodels were designed based on the empirical work in Barbados and Curaçao. Where possible they closely follow the mechanisms presented in the simulation game *Coasting*. Below are examples of some of the main submodels.

Updating the environment

This process consists of four steps: diffusing pollution, processing any SLR, processing sudden events and their effects, updating attractiveness of patches (i.e. environmental units).
Diffusion of pollution is controlled by parameter pollution-diffusion-rate. All updates of the pollution properties of patches are processed simultaneously, technically by taking a copy before further processing. On land, pollution disperses to neighbouring patches with the same or lower elevation; pollution will never move up-hill. At the coast line, the fraction of pollution that corresponds to the diffusion rate moves to a neighbouring patch at the coast line. At sea, pollution disperses to all neighbouring patches except land patches that are at least one metre above sea level.

Table A5.6. Initialisation environmental space input data

first two digits (xx) stands for land water feature	99 inland 75 beach250 meter away; poor sand quality 70 beach250 meter away; good sand quality 66 one removed from beachfront; poor sand quality 65 beachfront; poor sand quality 61 one removed from beachfront; good sand quality 60 beachfront; good sand quality 50 coastline (first 30 meters) inside high water mark 40 water edge of coastline 25 turbid nearshore water; not currently used 20 nearshore 00 deep sea
second two digits (yy) denotes natural features:	80 mangroves 33 sea turtles present, fish present and high coral cover/abundance 32 sea turtles present, fish present and medium coral cover/abundance 31 sea turtles present, fish present and low coral cover/abundance 30 turtles and fish, no coral cover 23 sea turtles present and high coral cover/abundance 22 sea turtles present and medium coral cover/abundance 21 sea turtles present and low coral cover/abundance 20 sea turtles present 13 fish present and High coral cover/abundance 12 fish present and Medium coral cover/abundance 11 fish present and Low coral cover/abundance 10 fish present
Third two digits	Not used in this version.

At each time step, the model computes the current sea level from SLR parameters. Then all land patches that border on the sea are inspected for erosion. If a patch has an elevation smaller that of the current sea level plus erosion loss (parameter erosion-loss), that land area (patch) becomes sea. When mangroves are present on the patch, the patch is protected somewhat from erosion. Therefore, where mangroves are present, 0.2 metre is added to the elevation before deciding if the land has to become sea. When land turns into sea, all operators that are located on that patch (or have their base there, in case of mobile operators) go out of business.

Sudden events take place at a fixed interval set by a parameter (sudden-event-interval). Another parameter (patches-affected-sudden-event) gives the chance (as a percentage) for each individual patch that environmental degradation due to the sudden event occurs on the patch. Environmental degradation lasts for at most sudden-event-persistence (another parameter) time steps. If the environmental degradation has not been resolved by collective or individual actions before that time, it will be removed after so many time steps after its occurrence. In case the patch is affected by another sudden event in between, time restarts counting. Environmental degradation has a 2/3 chance each time step of spreading to one of the neighbouring patches. Finally, There

is a 1/3 chance each time step that environmental degradation disappear autonomously.
After processing diffusion of pollution, SLR, and sudden events, the model recomputes the environmental attractiveness of all patches. The attractiveness is given by:

Att = 0.5 + Wgeo * Geo + Wbio * Bio – Wpol * Pol – Wenv * Env

The resulting attractiveness is limited to the range [0, 1]. In this formula, Wgeo, Wbio, Wpol, and Wenv are weighing parameters for the perceived values of geo-spatial type (Geo), biodiversity (Bio), pollution level (Pol) and environmental degradation (Env). The values of Pol and Env are the corresponding patch properties, where Pol is restricted to maximally 1. For Geo and Bio, the model uses lookup tables (see Table A5.7)

Table A5.7. Geospatial value and biodiversity values

geo-spatial type	Geo		sea life present	biodiversity value
inland	0.0		fish, sea turtles, and abundant corals	1.0
prime beach near shore	0.8		fish and abundant corals	0.85
prime beach far from shore	0.2		sea turtles and abundant corals	0.9
prime beach other	0.6		abundant corals	0.7
sub-par beach near shore	0.55		fish, sea turtles, and some corals	0.85
sub-par beach far from shore	0.15		fish and some corals	0.75
sub-par beach other	0.35		sea turtles and some corals	0.8
Beach	1.0		some corals	0.3
coast	1.0		fish and sea turtles	0.6
elevated beach	0.75		fish	0.3
water near shore	0.75		sea turtles	0.5
deep sea	0.0		none	0

Movement of marine life
Marine life select another nearshore water area when their sensitivity threshold has been met.

Resource allocation
Each operator has individual preferences for allocating resources to four possible action types: maintenance, tourism (advertisement, personnel, etc.), environment (cleaning), saving for later

times. For each action type, the operator has a default allocation, a maximum allocation, a weight for increasing if budget allows, and a weight for decreasing if there is too little budget. Each operator also has needed amounts for these action types, which depend on their operator type. The amount for needed maintenance will be increased when the operator elevates some ground to counter-act SLR. At the start of each time step, each operator individually determines allocations for the four types of actions. First they set the allocations to their respective (individual) default allocations, Then, while they have budget left and some allocation is below the (individual) maximum allocation, they add one to one of the four actions with relative chances defined by the (individual) weights for increasing. Then, while allocations exceed budget and some allocation is above zero, they subtract one from one of the four actions with relative chances defined by the (individual) weights for decreasing.

Actions (collaborative and individual)

Before considering any actions, collaborative as well as individual actions, each operator determines how much resources they want to spend on actions. This depends on their reserves, defined as their resources minus allocations for maintenance, tourism, and environment (this explicitly excludes allocations for savings). When reserves are larger than 3, the maximum contribution is equal to the reserves. After all operators have determined their maximum contributions, they consider the following actions: for each patch, operators address the effects of sudden events by collaborative action; then for each patch, operators address the effects of sudden events, as far as still there, by individual action; then for each patch, operators address the effects of SLR by collaborative action; then for each patch, operators address the effects of SLR, as far as still there, by individual action; then for each patch, operators address pollution by collaborative action; finally, for each patch, operators address pollution by individual action. Each of these actions follows the same pattern.

A5.3. Global sensitivity analysis

For Sobol global sensitivity analysis, n(2p+2) with n=1000 is advisable, p being the number of sampled uncertainties; in this case p=34 (Jaxa-Rozen & Kwakkel 2018). We were not satisfied with 70,000 runs and ended up performing 700,000 runs.

A5.4. Scenario discovery

Scenario discovery for the *Coasting* model seeks to identify the conditions, or ranges of input parameters, under which unacceptable outcomes may occur. The acceptability of outcomes is captured in two basic scenarios, Ecological Failure comprising a 25% drop in environmental (area) attractiveness, and Economic Failure comprising a 75% drop in number of businesses in operation. The declines of the scenario conditions are assessed by comparing the values of the state variables m-av-now-attr-area (for Ecological Failure) and m-all-ops (for Economic Failure) at time steps 0 and 1050. We also evaluated a third scenario, Combined Failure, which is when both previously described failures occur.

We used the Exploratory Modelling & Analysis Workbench (Kwakkel 2017) and PyNetLogo (Jaxa-Rozen & Kwakkel 2018) to perform 4000 simulation experiments on the *Coasting* model. The experiments differed by their input parameter sets, which we sampled using the Latin Hypercube method implemented in SALib [Herman & Usher 2017]. We replicated each experiment 30 times, and then calculated the means across those replications. This was necessary as ABMs are stochastically influenced, and therefore a single replication might not be indicative of a parameter set's effects.

In scenario discovery, a number of analyst decisions must be made regarding trade-offs between coverage and density of the proposed scenario regions. When in doubt, we opted for coverage [more false negatives] rather than density [more false negatives]. In the following tables and figures, we provide the relevant parameter ranges for each scenario and region. We also show pairs plots of the relevant input parameter dimensions for each region. For information regarding economic failure, please see Table A5.8. For information regarding ecological failure, please see Table A5.9. The pairs plot for Combined Failure is found in section 6.4.3. Table A5.10 shows the coverage and density for the pairs plot for Combined failure.

Table A5.8 Prim box information for economic failure

Prim box			Input parameters [default range]					
Number	Coverage	Density	tourism-returns *[2, 5]*	min-acceptable-elevation-above-SL *[0.2, 1]*	revenue-limited? *{False, True}*	pollution-change *[0.01, 0.5]*	cost-pollution *[1, 20]*	SLR-increase *[0, 50]*
1	54 %	98 %	[2, 2.6]	[0.24, 1]				
2	23 %	78 %	[2, 3.2]		{True}			
3	16 %	33 %	[2, 4.4]			[0.13, 0.5]	[5.5, 20]	[16, 50]

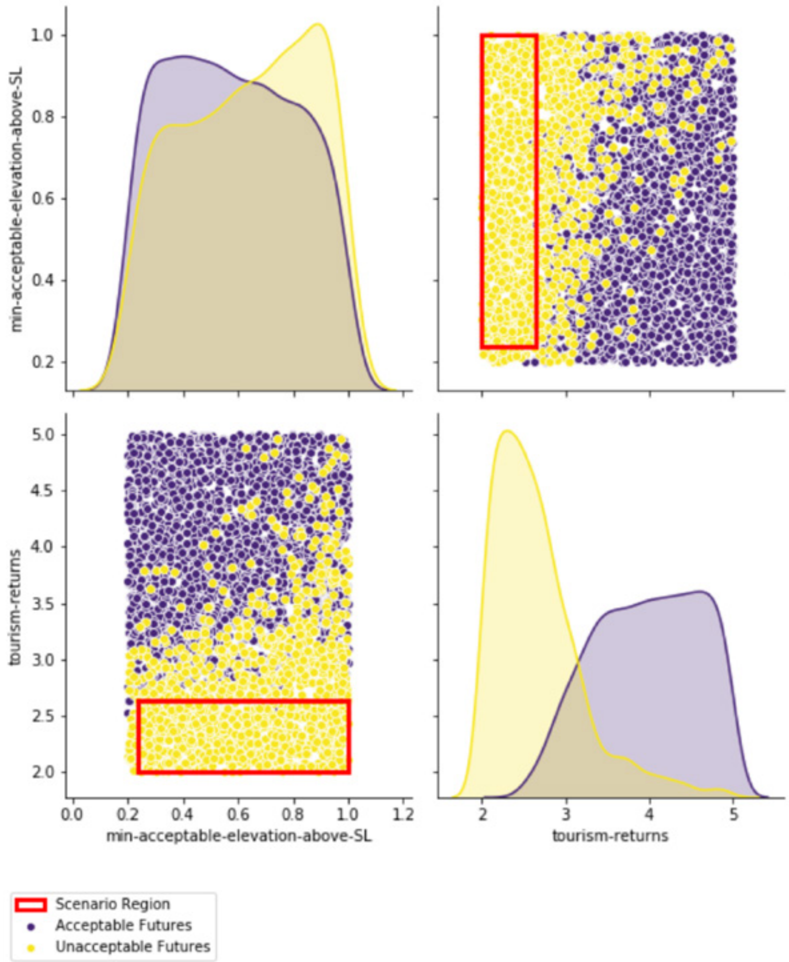

Figure A5.2 Economic failures Prim box 1

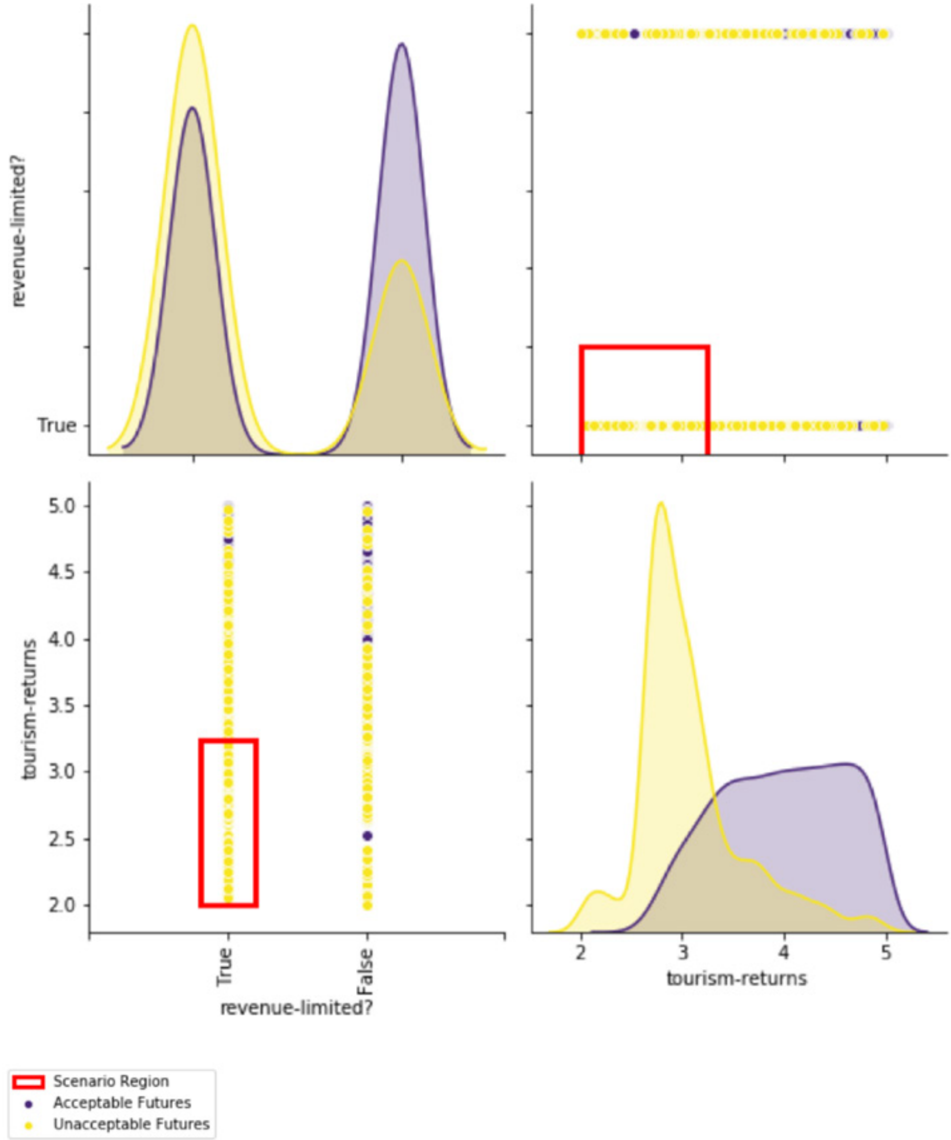

Figure A5.3. Economic failures Prim box 2

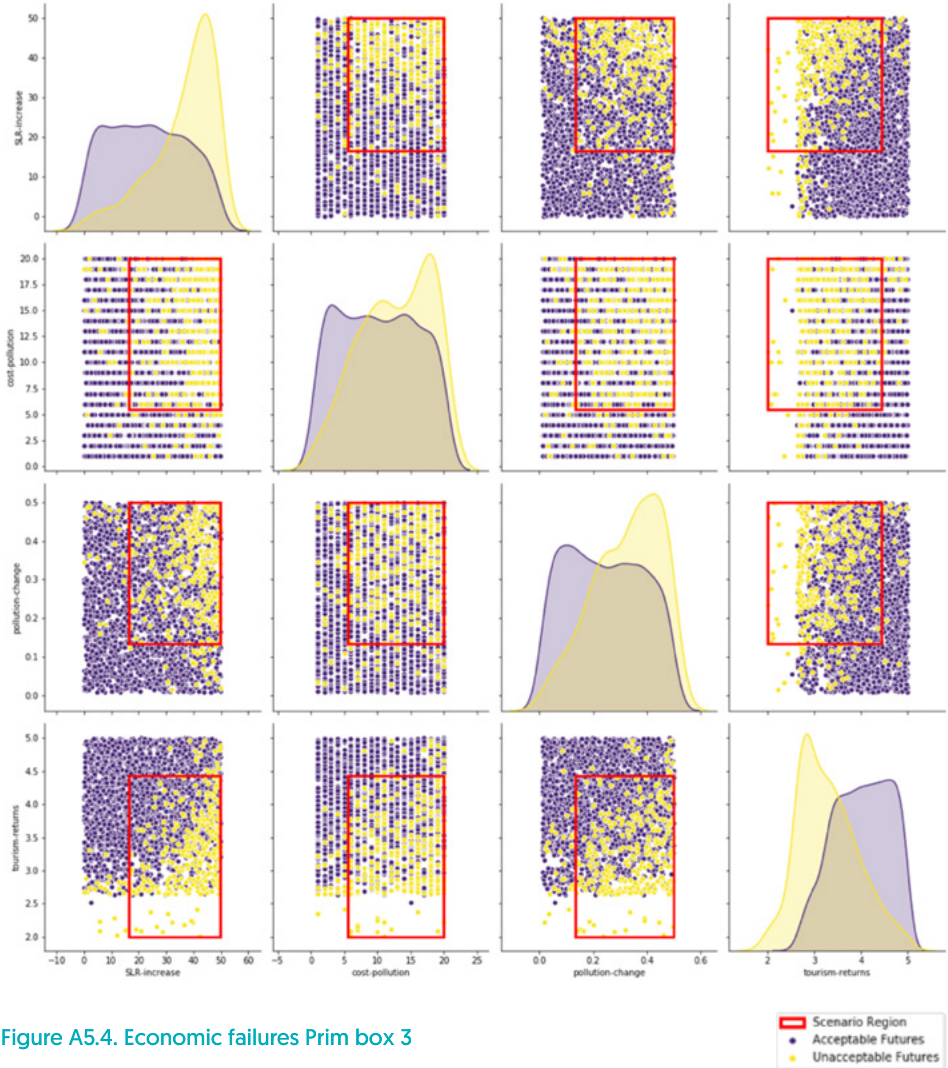

Figure A5.4. Economic failures Prim box 3

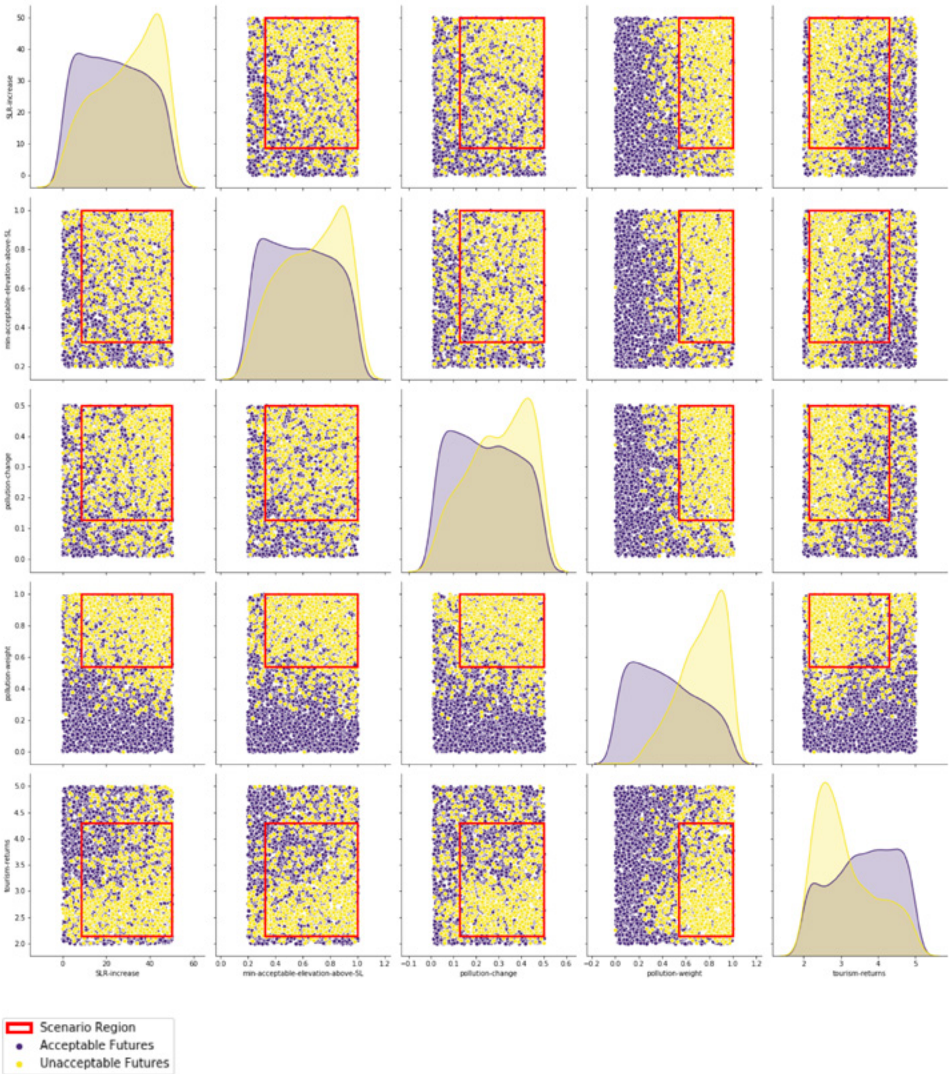

Figure A5.5. Ecological failures Prim box 1; y-axis (T-B) & x-axis (L-R): SLR-increase, min-acceptable-elevation-above-SL, pollution-change, pollution-weight, tourism-returns

Table A5.9. Prim box information for ecological failure

Prim box			Input parameters [Default range]					
Number	Coverage	Density	SLR-increase *[0, 50]*	min-acceptable-elevation-above-SL *[0.2, 1]*	pollution-change *[0.01, 0.5]*	pollution-weight *[0, 1]*	tourism-returns *[2, 5]*	geospatial-weight *[0, 0.5]*
1	50%	63%	[8.6, 50]	[0.33, 1]	[0.13, 0.5]	[0.54, 1]	[2.1, 4.3]	
2	43%	24%				[0.38, 1]		[0.00012, 0.47]

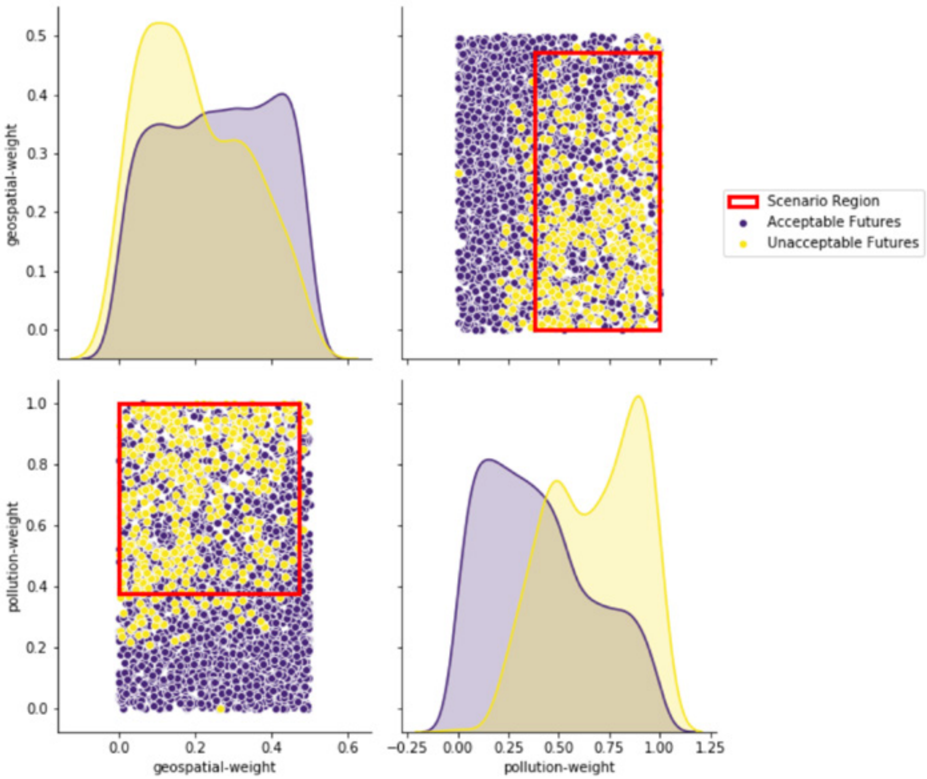

Figure A5.6 Ecological failures Prim box 2

Table A5.10 Prim box information for combined failure

Prim box			Input parameter [Default range]		
Number	Coverage	Density	pollution-change [0.01, 0.5]	pollution-weight [0, 1]	SLR-increase [0, 50]
1	62%	69%	[0.13, 0.5]	[0.41, 1]	[2.1, 3.1]

SUMMARY

SUMMARY

Scholarship on tourism and its relationship with climate change is not new. However, we are still struggling with how to make tourism sustainable in the context of emerging climate change and vulnerability issues. In coastal areas and ski destinations, we are already experiencing some of the initial effects of climate change on tourism. While both are problematic, ski tourism has received more attention. The environmental challenges in coastal destinations are complex and include: loss of land through erosion and sea-level rise; changing nature, frequency, and/or intensity of storms; ocean acidification; coral bleaching; drought; sea water intrusion; new movement of disease; and invasive species.

Moreover, the social consequences of climate change and coastal tourism are more urgent as coastal tourism affects some of the most vulnerable populations. Many small island developing states (SIDs) rely on coastal tourism for employment and GDP; their national economies are smaller and less diversified than many of the destinations where ski tourism occurs. At the same time, the sustainable development goals (SDGs) often recommend tourism as a key opportunity for development. However, the environmental resources that coastal tourism destinations depend on are recognised by the IPCC as being vulnerable to climate change. This complex relationship is understudied. Clearly, improving the sustainability of tourism in coastal destinations is not something we can ignore.

Existing static vulnerability assessments can offer detailed insights, but they miss a critical dimension: change. Ongoing interactions in a destination affect how vulnerabilities change over time. As such, current research offers little practical advice of how we can proceed. Our comprehension of who and what is vulnerable, and how that changes over time, is limited. This provides insufficient information on what vulnerabilities we can reduce and what adaptive measures we can/need to take in the face of change. To improve our understanding of emerging vulnerabilities and adaptation strategies, we need new means of studying the dynamic nature of vulnerability.

This thesis aims to contribute to this critical knowledge gap by understanding how we can conceptualise dynamic vulnerability, by taking into consideration human-environmental interactions and how they progress over space and time. Moreover, this study looks at what a dynamic understanding of vulnerability means for how we study vulnerability, and what new adaptation strategy insights come out of such an approach. As coastal tourism on SIDs is a pressing area where research is needed, two destinations in the Caribbean are the contextual focus to develop and assess the dynamic approach. Barbados is the first island of study and Curaçao the second. Both islands were visited twice and fieldwork on Barbados was completed before fieldwork on Curaçao began. As such, although Barbados was critical for developing the approach, the results of the process pertain more to Curaçao's context. The first three Chapters (2, 3, 4) lay the conceptual groundwork for vulnerability as a dynamic phenomenon. Chapters 4, 5, and 6 show how to operationalise a dynamic vulnerability approach, and what insights this approach yields on emerging vulnerabilities and what these mean for adaptation strategies.

Chapter 2 establishes the role of tourism in environmental challenges. It puts forward integrative systems thinking as a more appropriate framework for studying environmental-related challenges and deals with the inherent complexity of tourism as a unit of study. Integrative systems thinking is a better fit because it integrates humans with the environment and provides a more holistic understanding of environmental challenges instead of ignoring the interactions and treating them separately as many of the current tourism-environment studies do. Chapter 2 introduces two potential methodologies that can help capture human-environment interactions: agent-based modelling (ABM) and companion modelling. Chapter 3 builds on the idea of tourism as a complex system and introduces the notion that vulnerability is a dynamic phenomenon and as such, requires a dynamic approach to create more appropriate adaptive measures. Chapter 3 illustrates key limitations of current vulnerability assessments: top-down, static, and often fragmented analyses as well as ad hoc, short-term, and technologically focused adaptive measures. It is further argued that the supply-side of the tourism sector in (coastal) tourism destinations requires more focus because of the supply-side's limited adaptive capacity compared to that of tourists.

Chapter 4 focuses on how to do dynamic vulnerability assessments in a tourism context. Specifically, it looks at what researchers need to include so that their assessments capture complexity, interactions, and the perpetuation of change over space and time. Capturing dynamic systems complexity is important for improving adaptive capacity because while we aim to strengthen the social system in general terms, specific actions and especially their consequences are more difficult to fully comprehend from static vulnerability assessments. The principles of a dynamic approach—agency, heterogeneity, feedbacks, uncertainty, and iteration—are introduced and explained. These principles are coupled with practical methodological tools to show how researchers can use this conceptual lens to gain insights on emerging vulnerabilities. These methodological tools—desktop research, interviews, simulation development, simulation sessions, and computational modelling—are described. Three research steps—scoping (identifying important human-environment system features), system integration (bringing the system features together), and experiencing and experimenting (stakeholders and researchers exploring different emerging vulnerabilities in a dynamic simulated coastal system setting)—help structure how to order applying the methodological tools. To give an idea of how they can be exercised in practice, an illustration of how sea-level rise (one of the many climate-related changes) is analysed in the context of the two islands going through the three research steps. Simulation development, simulation sessions, and computational modelling are of particular value as they enable us to observe feedbacks over time and space. These visualisations serve to help tourism sector stakeholders rethink their individual and collective strategies to come up with actions/solutions. It also helps address the ongoing barrier between general climate change knowledge and local inaction.

The following two chapters delve into two of the tools of a dynamic vulnerability approach more deeply. In Chapter 5, the results of the simulation game *Coasting* played with local stakeholders in Curaçao are discussed and analysed. The focus is on the dynamic interaction of stakeholders with their coastal system, i.e. the tourism destination, under conditions of environmental change. The simulation integrates the coastal system with tourism operators in a game played over approximately five rounds. The tourism operators need to find ways to maintain their businesses while responding to changes to the environment and the actions of others. Experiencing and experimenting with this process is critical, because climate change is an abstract issue for many people, even when they are living in areas considered hotspots for environmental issues. The simulation provides a dynamic environment for stakeholders to experience environmental change, trade-offs, changing capacities, new environmental issues, and opportunities and barriers to (collaborative) actions.

In Chapter 6, computational modelling enables us to explore the main aspects of dynamic vulnerability over a longer time scale and many more simulated runs than the simulation sessions. The form of computational modelling used is agent-based modelling as it is a type of modelling known to capture individual human-environment interactions and explore how both the individual and system-levels are affected by ongoing change. Locally induced pollution is combined with scenarios of slowly developing sea-level rise and quick onset events. The simulated operators have to balance their individual operational plans with decisions of how to respond to the above mentioned environmental challenges and can either act alone, collaborate, move away, or do nothing. This simulation of the Curaçao coastal system is analysed to explore how socio-ecological vulnerabilities (involving operator numbers and environmental attractiveness) emerge over time, what are the main interacting factors that affect these emerging vulnerabilities, and what are the main influential factors that result in socio-ecological vulnerabilities that destinations want to avoid, including severe decline of operator numbers and environmental degradation.

Simulations models may generate exciting and clarifying (quantitative) results visualising socio-ecological vulnerabilities. While it may be tempting to forego the challenges of incorporating stakeholders to focus solely on computational modelling, a dynamic vulnerabilities approach recognises that stakeholder involvement is key for understanding the system and making sense of the results. Simulation sessions enable participants to explore emerging system dynamics while computer simulations explore the human-environmental system dynamics by varying different input settings. Stakeholder involvement may take more time and gives the researcher less control over the process and results, but human agency is one of the key challenges and opportunities of dealing with emerging vulnerabilities in coastal destinations. In order to overcome local inaction, stakeholder understanding of their system's vulnerabilities and willingness to act are key.

To conclude, this thesis provides a conceptual lens for capturing dynamic vulnerability to improve understanding of emerging vulnerabilities that affect (coastal) tourism destinations and what that means for adaptation strategies in Curaçao. For example, the approach shows that to encourage action, it is important to consider the trade-offs stakeholders experience and make emerging environmental challenges, such as drought, visible to stakeholders (chapter 5). The model illustrates the main factors contributing to actions under changing conditions as well as the main factors contributing to socio-ecological vulnerabilities (chapter 6). Some of the main factors—rate of pollution and tourism revenue—are things that Curaçao can incorporate in their destination management plan. Importantly, the approach, analysis, and results are not limited to the case study areas. They can be applied to other (coastal) destinations. As such, this dissertation offers a critical contribution to coastal tourism research, vulnerability studies, and adaptation governance to deal with the ongoing challenges of vulnerabilities that will not cease changing.

ABOUT THE AUTHOR

Jillian Student was born some time ago in the grandest of prairies in Alberta, Canada. Born a student, she naturally had an affinity for learning. She started her bachelor's degree in Grande Prairie and after taking time to live abroad, she finished her degree at Trent University in Canada and received the Governor's General silver medal for the highest cumulative average of any graduating student in 2009 at Trent University. With her bachelor's degree, she thought that she would find employment in the Netherlands after moving there at the end of 2009. However, at the height of the economic crisis, there were few jobs and lots of people looking for work. She also found out that her university bachelor's degree did not translate well into the Dutch job market. Motivated by her husband, she did a master's degree in Environmental Resource Management at the Vrije Universiteit where she accidentally discovered that she liked research and graduated cum laude. This led to the SENSE Honour's Programme, proposal writing, and a second master's degree in Environmental Sciences at Wageningen University (cum laude, "met lof"). This proposal was eventually funded by the NWO MAGW Talent search fund in 2014 and has provided Jillian with the opportunity to explore the environmental challenges faced by tourism destinations. In 2017, she was selected to be in the Young Scientists Summer Program with the RISK group at IIASA where she spent the summer amazed by PhDs from around the world. Jillian was invited to join the *Journal of Integrative Environmental Sciences* in 2018 as managing editor and has enjoyed her role in developing the journal with the Editors in Chief. After years of work, in 2019, she collected her thoughts into one document and submitted her PhD thesis. Now, in 2020, she starts a new chapter and looks forward to working on environmental challenges and how people can address them while contending with trade-offs and uncertainties.

PUBLICATION LIST

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Researching tourism, one may expect that this PhD was a holiday. Holidays come in many forms and may include the initial excitement, lost luggage, new places and cultures, closed attractions, amazing discoveries that were not in the guidebook, the FOMO while seeing social media of other people's great trips, incredible sunsets, swarms of mosquitos chasing you indoors, opportunities to meet fabulous people who make your journey better, getting lost, finding better places and alternatives, blocked credit cards, delays and cancelled flights, and once-in-a-lifetime opportunities. If that was what was meant by a holiday, then that sounds about right.

My PhD holiday, or journey, has been full of incredible highs and some very challenging lows. When I was younger, I did not think that a PhD was in the realm of possibilities. That my destination wedding with science is happening, is to the credit of many people. As such, I want to take the opportunity to thank a number of people who have contributed to my PhD journey.

Two conversations with Mathilde Molendijk made this whole journey possible: the first, at an intake for the Master's at the Vrije Universiteit where she convinced me that the Environmental Resource Management Master's was the right one for me, and the second, when she encouraged me to apply to the SENSE Honours Programme that offered the opportunity to 12 researchers in the Netherlands to write a PhD proposal. This opportunity introduced me to Wageningen and my supervisory team. My promotor Arthur, thank you for taking on my project and for always finding a way to get to the heart of the issue. My supervisors, Machiel and Bas, thank you for going through the many adventures that this PhD took us all on and making it possible by finding alternative funding. I appreciate the different perspectives that you provided on the topic while at the same time having a strong appreciation of each other's ideas. Machiel, thank you for helping me work out crazy ideas and Bas, thank you for your deep reflection on different research questions.

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Gert Jan Hofstede, thank you for the opportunity to join your team at NIAS, a research paradise, while I was waiting to hear about funding opportunities. The time there not only prepared me for my eventual PhD project, but I also got to lunch with such inspiring people and see what research could be like. The period also introduced me to the Pimpelmeisjes, Anne-Marie, Irene, Liesbeth, and Margriet, amazing women with whom discussions on societal challenges are accompanied with a good glass of wine or two.

I was lucky to be part of two research groups during my PhD—Environmental Policy (ENP) and Environmental Systems Analysis (ESA)—and was benefitted by even more expertise and PhD colleagues.

Thank you to all the staff at ENP who made ENP feel like home. Simon, thank you for promoting all of the visual communication at our group and for your advice at a critical moment in my PhD. Corry, I know that you do not like being the centre of attention, but you also know that I can't not thank you for all of your help navigating the web of university logistics and PhD life. I only hope that someday you will take that trip to Canada.

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Rik, thank you for all of your support during the SENSE Honours Programme and your continued help during my Master's and PhD. To all of the staff and PhDs at ESA, thank you for including me in the group even though I was not always able to be present over the years. You all made me feel very welcome.

Thanks to all of the ESA PhDs and Co. over the years including Adil, Alexander, Anna, Aritta, Clara, Confidence, Eka, Gabriela, Hidde, Ilan, Ingeborg, Jerry, Joyce, Julia, Lena, Lucie, Maddy, Maryna, María, Matthias, Mengru, Roy, Sarahi, Saritha, Shahid, and Siatwiinda. I really appreciate that you involved me in different activities. I loved the after-lunch coffee tradition and was always happy to join.

My research took place on two islands. I thank all of the people in Barbados and Curaçao who considered, participated in, or helped my research in some way. Without you, it would not have been possible. Judi and her team in Barbados helped identify potential stakeholders. Jules Vastert helped make life easier in Barbados and familiarised me the local context. In Curaçao, Filomeno Marchena introduced me to key people. Xiomar Pedro arranged for an open presentation at the University of Curaçao and introduce me to many contacts. And Paul Markus, thank you for welcoming me into your home, showing me around the island, and making my time in Curaçao so enjoyable.

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smart, but also kind and willing to collaborate in what could be such a competitive environment. The summer I spent with you at IIASA was a highlight of my PhD. A happy accident because of issues with accommodation resulted in the Simmering Seven, a group of people who could not be more different, but who have made me laugh more than I thought possible, who explored Vienna with me, and who continue to be such a great support. Francine, I was lucky to be able to continue to work and have fun adventures with you in Amsterdam after our summer in Vienna. Xiaogang, I am constantly in awe of all you do, and yet, you are also always ready to help or cheer on your friends. Radosti, thanks for your listening ear, encouragement, and sound advice.

Through my participation in SENSE, I got to be part of the SENSE matties and we continued our nice meet-ups over the years. I have also had the privilege to be part of a number of research networks. CAS-klein with Francine, Floor, Irene, Sjoukje, Mark, Gert Jan, Guus, and Yang where we discussed how to model complex-adaptive systems. The SMASH team (ABM meets tourism) where we worked on how agent-based modelling could contribute to tourism research. The ComMod group who supported each other's developments of serious games. I would also like to send a shout out to PhDs from other groups who I have collaborated with. Thank you.

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To all the people outside of my PhD bubble, thank you for reminding me of the other splendours in life. I appreciate all of the friends in the Netherlands and abroad who cheered me on throughout this journey. A special thanks to Grace, Jules, MJ, Julie, Yumi, Ellen, Christina, Javi, Susanne, Koen, Maarten, Saskia, Mariëlle, Kris, Hsiao Han, Natalie, Gido, Ingrid, John and Loek.

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Dad, thanks for the importance of seeking knowledge that you instilled in me. You were once scared that I would travel and not go to university. Now, I know you have been wondering if I will ever leave. The next chapter is open, but it may happen that just when I think I have gotten out, they might pull me back in. We'll see.

I have been fortunate to have someone support me at home. Being the partner of a PhD is sometimes difficult work with few rewards—the holiday equivalent of receiving one of those shirts "My wife did a PhD in Barbados and Curaçao and all I got was this stupid T-shirt". Rob, was the one who got me on the path to doing an PhD, but also got to witness all the ups and downs of this journey. Rob, lief, je bent altijd een grote steun voor vrouwen naar de top en zorgde ervoor dat ik verschillende kansen durfde aan te pakken. Woorden komen te kort. Samen, hebben wij het gedaan. Dankjewel lief.

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Socio-Economic and Natural Sciences of the Environment

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for specialised PhD training

The Netherlands research school for the
Socio-Economic and Natural Sciences of the Environment
(SENSE) declares that

Jillian Rose Student

born on 24 September 1983 in Grande Prairie (Alberta), Canada

has successfully fulfilled all requirements of the
educational PhD programme of SENSE.

Wageningen, 27 March 2020

The Chairman of the SENSE board

Prof. dr. Martin Wassen

the SENSE Director of Education

Dr. Ad van Dommelen

The SENSE Research School has been accredited by the Royal Netherlands Academy of Arts and Sciences (KNAW)

KONINKLIJKE NEDERLANDSE
AKADEMIE VAN WETENSCHAPPEN

The SENSE Research School declares that **Jillian Rose Student** has successfully fulfilled all requirements of the educational PhD programme of SENSE with a work load of 49.5 EC, including the following activities:

SENSE PhD Courses

- Environmental research in context (2015)
- Research in context activity: 'Co-organising international workshop programme and facilitating discussion and networking on "Agent-Based Modelling (ABM) meets Tourism" (Wageningen, 18-20 January 2016)'

Other PhD and Advanced MSc Courses

- Reviewing a scientific paper, Wageningen Graduate Schools (2016)
- Companion Modelling: Principles and applications with a special focus on facilitation, Wageningen Graduate School PE&RC (2014) and Sociology and political science of environmental transformations, Wageningen Graduate School WASS (2018)

External training

- Young Scientists Summer Program, International Institute for Applied Systems Analysis, Austria (2017)

Selection of Outreach activities

- Videos on 'ABM Meets Tourism' (2016), 'Complex Adaptive Systems'(2017) and 'A Dynamic Vulnerability Approach For Tourism Destinations' (2019)
- Coasting through environmental change? Serious games blog post (2017)

Selection of Management and Didactic Skills Training

- Guest lecturer in the BSc course 'Tourism systems analysis' (2016-2018) and the MSc courses 'Tourism and globalisation' (2016), 'Governance of tourism and natural resources' (2017) and 'Development of sustainable tourism' (2018)
- Workshop Simulation sessions and environmental challenges, Nanjing Agricultural University, Nanjing, China (2018)
- PhD representative on the ENP daily board (2015-2017)
- Managing editor of the Journal of Integrative Sciences (2018-present)

Selection of Oral Presentations

- *Vulnerability is dynamic! Conceptualising a dynamic approach to coastal tourism destinations' vulnerability*, World Symposium on Climate Change Adaptation, 2-4 September 2015, Manchester, United Kingdom
- *Challenges with modelling the coastal system*, ABM teaches tourism a lesson, 6-8 February 2018, Andorra

SENSE coordinator PhD education

Dr. ir. Peter Vermeulen

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PROPOSITIONS

1. Understanding interactions between people and their environment is essential for understanding how vulnerabilities emerge.
(this thesis)

2. Generalisations of vulnerability indicate a problem, but do not help us with looking for solutions.
(this thesis)

3. Research is like a drug, the key is to find out how to become a responsible user.

4. Climate change science is constant balance work between optimism and realism.

5. Ethics limit science, but are necessary for (scientific) survival.

6. Tourism is the ultimate double-edged sword.

7. OneWageningen and the location of the Leeuwenborch are incompatible.

8. Environmentally speaking, we are all downstream.

Propositions belonging to the thesis, entitled:

VULNERABILITY IS DYNAMIC

An interactive approach to enhance adaptation strategies to climate change for coastal tourism

Jillian Student

Wageningen, 27 March 2020