IVM Institute for Environmental Studies

Protecting Bonaire against Coastal Flooding

A participatory multi-criteria analysis of coastal adaptation options

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Contents

Summary

Coastal hazards pose a significant threat to small islands, especially in combination with Sea Level Rise (SLR). Currently, the small Caribbean island of Bonaire is poorly protected against coastal flooding and there is a lack of local knowledge on potential adaptation options and their benefits and trade-offs. This study aims to fill this gap by evaluating how different coastal adaptation options to protect Bonaire are valued, considering economic, social, environmental, and technical criteria. This is evaluated using a participatory Multi-Criteria Analysis (MCA) that includes key stakeholders through semi-structured interviews and the use of an online questionnaire. A wide variety of coastal adaptation options, ranging from grey infrastructure to softer Nature-based Solutions (NbS), is assessed based on an interdisciplinary set of 10 different criteria, providing a holistic view of the consequences of each option. The results show that NbS, especially mangrove restoration, and spatial zoning measures are overall perceived to be most beneficial. The least favourable adaptation strategies include the construction of any type of seawall and doing nothing. While an MCA does not lead to a final perfect solution, it does provide valuable comparative information about potential future adaptation strategies for Bonaire, which can be used to aid policy makers in the decision-making process. Moving forward, it is important to further strengthen the results of this study by conducting additional quantified analyses, including an evaluation of the spatial suitability of specific measures or combinations of measures. Moreover, to ensure public support for any final policy decisions, regardless of the specific measures that are selected, it is vital to keep involving and informing the local community of Bonaire.

1 Introduction

Small island communities globally are facing several risks due to climate change, driven by climatic drivers such as ocean acidification and increased air and sea surface temperatures (Nurse *et al.*, 2014). While small islands contribute minimally to global warming, emitting only a negligible amount of carbon when compared to global emissions, they are among the regions that are most vulnerable to climate change related risks. (Srinivasan, 2010). They are particularly susceptible to Sea Level Rise (SLR), as they have a relatively large low-lying coastal area (<10m): on average, 16% of their total land area, in comparison to 2% globally (McGranahan *et al.*, 2007; Nurse *et al.*, 2014; Srinivasan, 2010). In the coming decades, SLR is projected to significantly increase the flood hazard for coastal communities, resulting in a growing need for adequate coastal adaptation strategies (Vousdoukas *et al.*, 2018).

The intergovernmental Panel on Climate Change (IPCC) defines climate change adaptation as “the process of adjustment to actual or expected climate change and its effects” (Allen *et al.*, 2014). While it is clear that small islands will need to adapt to the increasing flood risk, it can be challenging for them to undertake adaptation efforts (Robinson, 2018). For Caribbean islands, adaptation is for example often limited by a lack of financial resources, especially after the recent pandemic hit their highly tourism-driven economies (Robinson, 2018; Thomas & Theokritoff, 2021). Other limiting factors that can play a role include a lack of data, resources, and knowledge about climate change and its effects (Robinson, 2018).

Although it was pointed out several years ago that the Netherlands has been taking insufficient action to protect the Dutch Caribbean against the impacts of climate change, like flood risk, the state of the protection of these islands has barely been changed since (Severijnse, 2021). Recently, Greenpeace Netherlands has again drawn attention to this issue, pointing out the vulnerability of Bonaire, a tropical island that is a part of the Caribbean Netherlands, to SLR (Greenpeace NL, 2022). Despite being a part of the Netherlands, one of the global forerunners in the field of coastal protection, there are major differences between Bonaire and the Netherlands regarding the current degree of protection. In the Netherlands, there are strict legal protection standards for large parts of the Netherlands varying from 1/250 inland to up to 1/30.000 per year (Kind, 2014). However, these protection standards have not been extended to the Caribbean counterparts of the Netherlands: large parts of Bonaire already flood under storm conditions with a 100-year return period (Figure 1).

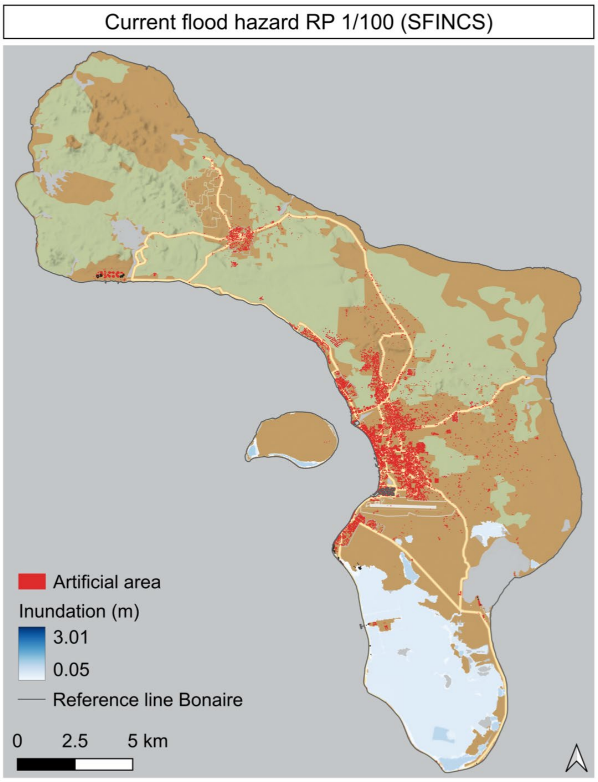

Figure 1 Current flood hazard of Bonaire during a 1/100 years storm, modelled using the dynamic SFINCS model (van Manen, 2022)

To achieve coastal adaptation against flood risk, many different types of measures can be used, including grey adaptation measures like sea dikes and softer, more eco-friendly options like Nature-based Solutions (NbS) (Hegde, 2010; Wong, 2018). But while it is clear that solutions are necessary and available, choosing adaptation strategies is a complex process that requires careful evaluation of many different factors, especially when resources are limited (Preston *et al.*, 2013). When adaptation is poorly planned, it can even be maladaptive, for example when it has high opportunity costs or when it creates a false sense of security (Barnett & O'Neill, 2010; Nunn *et al.*, 2021). Therefore, studies have stressed that for successful planning and implementation of adaptation measures it is vital to tailor adaptation strategies to local conditions and to involve local communities in a participatory manner (Filho *et al.*, 2021; Haque *et al.*, 2016; Wong, 2018).

Several studies have already evaluated coastal adaptation strategies, also focussing specifically on small islands and the Caribbean region (Baills *et al.*, 2020; Filho *et al.*, 2021; Klöck & Nunn, 2019). However, a local in-depth analysis, using a structured decision-making approach to evaluate different adaptation options has not yet been performed for Bonaire. As a first step towards realising improved coastal protection of Bonaire, this study will therefore investigate different coastal adaptation options for the island. The question that will be answered is:

"How can different adaptation measures that could potentially protect Bonaire against coastal flooding by 2050 be valued by key stakeholders, considering economic, social, environmental, and technical criteria?"

The method that will be used to answer this research question is a participatory Multi-Criteria Analysis (MCA). An MCA is a method that is widely applied in many similar policy decision-making contexts, for example by Baills *et al.* (2020), who performed a general assessment of coastal adaptation options, and by Alves *et al.* (2018), who use MCA to select urban flood measures. Banton *et al.* (2017) specifically recommend the use of an MCA to evaluate coastal protection strategies for the Caribbean. The participatory aspect of the MCA allows for the involvement of stakeholders in various stages of the analysis, which can increase the acceptance and legitimacy of the outcomes and help raise awareness about challenges and adaptation options (de Bruin *et al.*, 2009; Esmail & Geneletti, 2017; Haque *et al.*, 2016).

For the analysis, it is first determined which coastal adaptation measures could be suitable for Bonaire. The different options are then evaluated by several stakeholders, based on social, economic, environmental, and technical criteria. In addition, it is assessed how relatively important each of these criteria-groups is to the stakeholders. Amongst the included stakeholders are representatives of various local organisations, as well as of the local community, -businesses, and -government. The final result provides insights into the valuation of different adaptation options according to the stakeholders and subsequently into potentially suitable adaptation strategies for Bonaire moving forward.

2 Theoretical background

This chapter will first briefly discuss the suitability of the methodological approach taken within this study. Then a description of the local context and potential impacts of coastal flooding on Bonaire will be provided. The third part of the chapter will then describe the wide range of possible coastal adaptation measures for Bonaire, providing a categorisation that can be used to identify a suitable range of adaptation options to be included in the MCA.

2.1 Methodological framework

According to the United Nations Framework Convention on Climate Change, several assumptions can be made when evaluating climate adaptation measures (Haque, 2016):

- You need to take into account a wide range of criteria and indicators.
- It is often not possible to evaluate the costs of climate change in monetary values.
- There is often insufficient data for a Cost-Benefit Analysis (CBA) or cost-effectiveness analysis.
- The perspectives of locals need to be considered because they are the most affected.
- Adaptation responses that are assessed based on the participation of all relevant stakeholders in the decision-making process are most acceptable.

Because of these assumptions, the United Nations advocates MCA as the preferred method to assess adaptation options (Haque, 2016). MCA can be defined as *"any structured approach used to determine overall preferences among alternative options, where the options accomplish several objectives"* (Brooks *et al.*, 2009). It is a powerful decision-making tool for a systematic comparison of the benefits and trade-offs of different policy alternatives and it is especially useful when policy decisions involve several stakeholders with varying objectives, as the performance of alternatives on specific criteria can be combined with the preferences of stakeholders in a transparent manner (Esmail & Geneletti, 2017). Additionally, the measurement units do not necessarily have to be monetary values, which makes MCA more widely applicable than classic economic methods like a CBA (Haque *et al.*, 2016). Through the meaningful inclusion of key stakeholders, an MCA helps to integrate the preferences of the people that are most affected into the decision-making process (Gamper & Turcanu, 2007). By structuring how stakeholders value different adaptation options, using a wide range of assessment criteria, the final ranking of options that results from an MCA can provide valuable input for future discussions about coastal adaptation strategies for Bonaire (de Bruin *et al.*, 2009; Gamper & Turcanu, 2007).

2.2 Local context

This study focuses on Bonaire, a tropical island that is a part of the Caribbean Netherlands together with Saba and Sint Eustatius (BES islands). Like many Caribbean islands, Bonaire's capital and largest urban area Kralendijk are located right along the coast, where its inhabitants are highly exposed to coastal hazards (Figure 2). Between 2010 and 2022, the population of Bonaire has grown from 15.5 thousand to almost 23 thousand people (CBS, 2022). This growth was mainly attributable to migration and is expected to continue (CBS, 2020). Moreover, Bonaire has the ambition to increase stay-over tourism by 47% in the next 10 years (Croes *et al.*, 2017). Together, these socio-economic developments have been leading to urban sprawl along the coast.

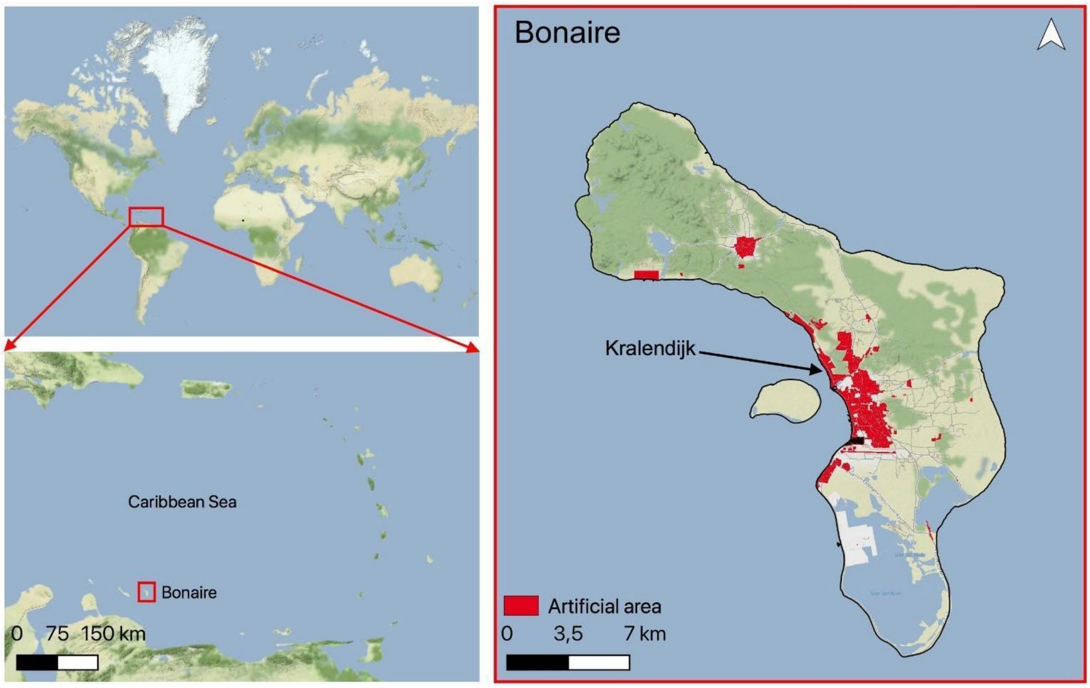

Figure 2 Reference map of the study area

It has been projected that flood hazards in Bonaire will increase in the coming decades, which, in addition to continued coastal developments, will result in elevated flood risk over time (van Manen, 2022). Aside from the risk of direct damage to houses and infrastructure, these developments also threaten Bonaire's cultural heritage and the health of its residents (Baertz, 2022; de Boer, 2022). Moreover, coastal flooding can negatively impact Bonaire's unique habitats, such as the saliñas, located in the vulnerable south part of Bonaire, that provide habitat to endangered species like flamingos (Debrot & Bugter, 2010). These negative effects can indirectly also affect the local residents of Bonaire, as many of them depend on nature-oriented tourism for their livelihoods (Schep *et al.*, 2013).

2.3 Categorisation of coastal adaptation measures

A classical classification of coastal adaptation options is the one described by the Coastal Zone Management subgroup of the IPCC in 1990, who defined three coastal adaptation categories: retreat, accommodate, and protect (Dronkers *et al.*, 1990). Mallette *et al.* (2021) define retreat strategies as those that reduce exposure by withdrawing people from high-risk areas. Protection measures are measures that reduce coastal risk, by reducing the hazard component of risk and measures that fall in the accommodate category reduce risk either through social mechanisms or physical adaptations (Mallette *et al.*, 2021). The section below will establish sub-categories for each class of adaptation measures, resulting in the final categorisation of coastal adaptation measures shown in Table 1.

Table 1 Categorisation of coastal adaptation measures

Category	Type of measure	Description	
Retreat	Managed retreat/ realignment	Actively moving out of hazard-prone areas, towards safer areas.	
	Development restrictions	Restrictions on new construction in hazard-prone coastal areas.	
Protect	Grey infrastructure	Physical, engineered structures, either onshore or foreshore.	Onshore examples: • Boardwalk • Revetments • Seawalls • Dikes/embankments/levees Foreshore examples: • Breakwaters • Groynes • Jetties
	Green infrastructure	NbS focused on the conservation, restoration, or creation of coastal ecosystems.	• Coral- and oyster reefs • Coastal wetlands: salt-marshes and mangroves • Seagrass- and kelp beds • Beaches • Sand dunes
	Hybrid infrastructure	Ecological enhancement of grey infrastructure, or the combination of grey and green measures.	Examples: • Ecologically enhanced seawall (eco-seawall) • Combination of a seawall with coastal vegetation
Accommodate	Property level strategies	Adaptations to buildings that either prevent flooding or minimise the impacts in case of flooding.	• Avoidance (elevated or floating houses) • Dry-proofing • Wet-proofing
	Compartmentalisation	A measure that reduces the exposed area by dividing an area into enclosed compartments.	
	Soft measures	Economic and/or social measures	• Early warning systems • Evacuation • Raising awareness • Insurance schemes • Accommodation shelters

2.4 Retreat

Retreat measures include managed retreat/realignment, which requires the active relocation of people, infrastructure, and buildings to safer regions and development restrictions that prevent construction in areas at risk of flooding (Lincke *et al.*, 2020; Mallette *et al.*, 2021). While not yet widely applied, retreat strategies are being implemented in an increasing number of places (Hino *et al.*, 2017; Lincke *et al.*, 2020). Many Caribbean islands, like Barbados and Cuba, have setback regulations in place, restricting built development near the shore (Mycoo, 2018; OLB, 2018). Bonaire's current spatial development plan, established in 2010, includes a setback zone of 15m from the high tide line, however, just like in many other Caribbean islands, these regulations are poorly enforced (Mycoo, 2018; Simpson, 2012).

2.4.1 Protect: grey infrastructure

Grey infrastructure, or hard coastal protection, is a group of artificially built physical measures that can be roughly divided into onshore and foreshore structures (Mallette *et al.*, 2021; Schoonees *et al.*, 2019).

Foreshore structures like breakwaters, groynes, and jetties can help to protect the coast against wave impact and erosion by reflecting and dissipating the energy of the waves (Schoonees *et al.*, 2019). Breakwaters are structures that are built parallel to the coast, while groynes and jetties are structures that start at the coastline and then extend seawards perpendicularly. A major disadvantage of using foreshore adaptation options is that they can significantly affect the erosion and sediment accretion on nearby shores (Schoonees *et al.*, 2019).

Onshore structures are measures like dikes, seawalls, and revetments that are built parallel to the shoreline (Schoonees *et al.*, 2019). The application of onshore grey infrastructure is one of the most commonly applied approaches to addressing coastal flooding (Griggs & Reguero, 2021). Examples of grey adaptation measures that can be found on Bonaire are shown in Figure 3. Seawalls and revetments are, respectively, vertical and sloped structures that protect the area behind them against flooding and wave impacts, for example in the case of storm surges and waves during a storm (Morris *et al.* 2018; Schoonees *et al.*, 2019). Seawalls have minimal spatial requirements, which makes them especially suitable for densely populated urban areas like Kralendijk (Schoonees *et al.*, 2019). Another example of onshore structures is dikes, also known as levees or embankments, which are structures with smoothed slopes on both sides that, similarly to seawalls and revetments, provide a high level of safety against coastal flooding (Schoonees *et al.*, 2019). Boulevards, like the one in Kralendijk (Figure 3.B), have the added benefit that they fulfil a recreational purpose.

Figure 3 *Example of grey coastal adaptation in Bonaire: A) traditional stone seawall, Boca Slagbaai, B) boulevard, Kralendijk, C) boulder revetment, Kralendijk D) smooth concrete revetment, Kralendijk (photos: author)*

2.4.2 Protect: green infrastructure

Because of the increased recognition of the need for sustainable development and minimisation of environmental impacts, there is a growing interest in protecting coastlines against coastal flooding through the restoration, conservation, and creation of coastal habitats (Morris *et al.*, 2017; Narayan *et al.*, 2016; Schoonees *et al.*, 2019). **Coastal habitats** like coral reefs, mangroves, salt-marshes, and seagrass beds can significantly reduce wave heights by dissipating wave energy (Narayan *et al.*, 2016). The potential for coastal protection depends on the environment that the habitat occurs in: mangroves and seagrasses for example generally occur in more sheltered environments than coral reefs, which means that they experience less powerful waves and thus have less wave-reducing potential (Narayan *et al.*, 2016). **Sediment-based** examples of green infrastructure include sediment-nourishment of beaches and the creation or restoration of sand dunes (Mallette *et al.*, 2021). Coastal ecosystems do not only have the potential to reduce flood risk, but they also deliver a wide range of Ecosystem Services (ESs), including habitat provision, recreational services, and sediment stabilisation (Narayan *et al.*, 2016). Some examples of green infrastructure in Bonaire are shown in Figure 4. Out of all the habitat types found in Bonaire, the ones that provide coastal protection include coral reefs, mangroves, beaches, and seagrass beds (Debrot *et al.*, 2018).

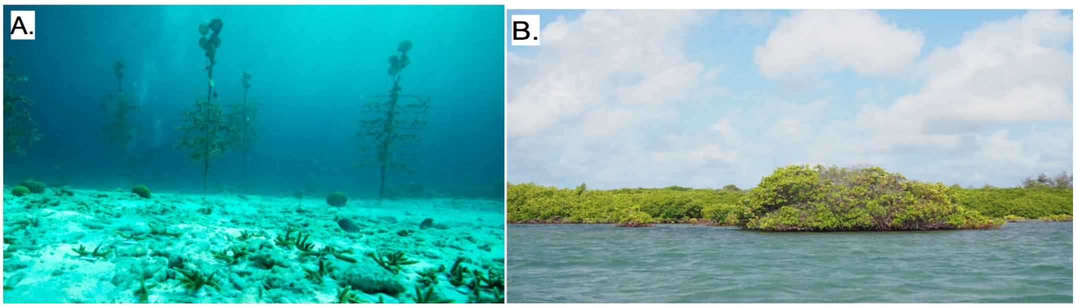

Figure 4 NbS on Bonaire: A) a coral nursery for reef restoration purposes (Erik Meesters, 2016) and B) mangrove forest in the Lac Bay (photo: author)

2.4.3 Protect: hybrid infrastructure

Hybrid infrastructure can either refer to the **combination of grey and green infrastructure**, or the ecological enhancement of grey solutions (Schoonees *et al.*, 2019). Recent studies have shown that hybrid strategies have the potential to outperform individual grey or green measures in terms of costs and benefits, making hybrid solutions not only a more sustainable solution than traditional grey coastal adaptation options but also potentially financially preferable (Du *et al.*, 2020; van Zelst *et al.*, 2021). Ecological enhancement of grey infrastructure, also referred to as **eco-engineering**, can create new ESs or help to restore and conserve existing ESs, mitigating the negative environmental impacts of grey infrastructure (Schoonees *et al.*, 2019).

2.4.4 Accommodate: property level adaptation

According to Proverbs & Lamond (2017) there are three strategies for flood protection at the property level. The first strategy, **avoidance**, includes building new properties in appropriate locations and designing buildings in a way that prevents water from reaching the property. Examples of this strategy are floating houseboats, commonly found in the Netherlands, and elevated houses, which are traditionally used in various SIDS, such as the Philippines, Belize, and the Cook Islands (Jamero *et al.*, 2017; Wong, 2018). In Bonaire's urban centre, many houses have a slightly elevated foundation (Figure 5.A), however, this is often done in the context of pluvial rather than coastal flooding. The second and third strategies are **dry-proofing**, where the aim is to keep water out of the property, and **wet-proofing**, which entails letting water enter the property and minimising potential impacts (Proverbs & Lamond, 2017). An example of a flood-proofed house in Bonaire is provided in Figure 5.B. Private implementation of building-level adaptation measures can be enforced by the local government or flood insurance agencies through the implementation of building regulations in high-risk flood zones (de Ruig *et al.*, 2020). Compared to other coastal adaptation measures, building-level adaptation measures are relatively cheap (de Ruig *et al.*, 2020).

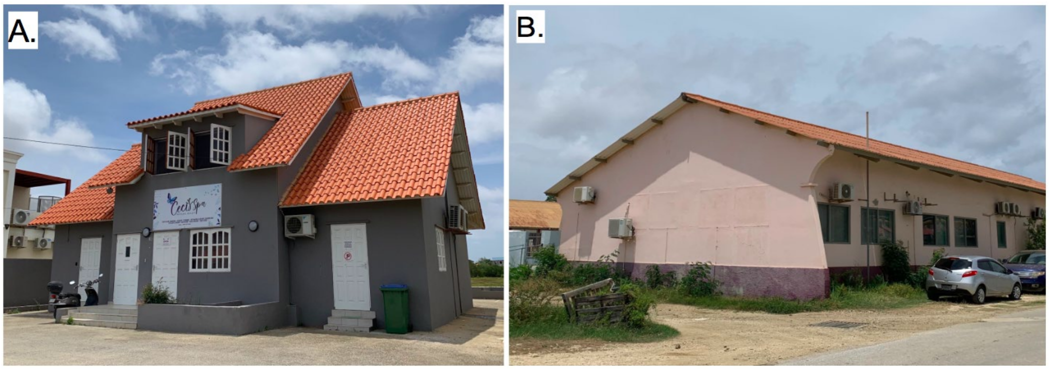

Figure 5 *Two applications of building-level protection measures found in Kralendijk: A) elevated building foundation and B) dry-proofing (photos: author)*

2.5 Accommodate: compartmentalisation

Compartmentalisation, which means to split up into smaller sections, is a measure that aims to reduce the inundated area during a flood by creating several enclosed compartments within an area (Klijn *et al.*, 2010). Compartmentalisation can also be used to slow down the floodwater or redirect it into less vulnerable areas (Klijn *et al.*, 2010). As the objective of this measure is to reduce flood risk by lowering the exposure and consequences, compartmentalisation is classified as an accommodation strategy (Koks *et al.*, 2014). Disadvantages of compartmentalisation are that risk can increase for compartments that do get flooded and that implementation and maintenance are very expensive (Klijn *et al.*, 2010). It is widely applied in the Netherlands by the division of large dike-ring areas into smaller sections (Klijn *et al.*, 2010). As compartmentalisation is considered to be a secondary line of defence rather than a primary defence, Koks *et al.* (2014) suggest that the first line of coastal defence should be strengthened before implementing a compartmentalisation strategy.

2.5.1 Accommodate: soft measures

This is a very broad class of coastal adaptation measures that for example includes **hazard preparedness measures**, such as evacuation plans, construction of emergency shelters, and the development of an early warning system (Banton *et al.*, 2017; Mallette *et al.*, 2017). Additionally, they can be **social measures** aimed at improving knowledge, education, and information (Baills *et al.*, 2020). Soft measures can also be financial measures, like insurance schemes and financial incentives to adapt (Mallette *et al.*, 2017). While they, by themselves, provide insufficient protection from the effects of climate change, they are suitable to complement adaptation plans (Baills *et al.*, 2020). They are robust, easily reversible, and no-regret, which means that they also provide benefits irrespective of climate change (Baills *et al.*, 2020). One example of a soft measure on Bonaire is the early warning system that is in place: the KNMI provides a warning in the case of extreme weather events (KNMI, n.d.).

3 Methodology

This study will evaluate how potential coastal adaptation options for Bonaire are valued, using a participatory MCA that takes into account economic, social, environmental, and technical criteria, considering a time period spanning now until 2050. The research phases, as well as methodological steps used for the participatory MCA in this study, outlined in Figure 6, are based on the generalised MCA phases and steps as defined by Esmail & Geneletti (2017).

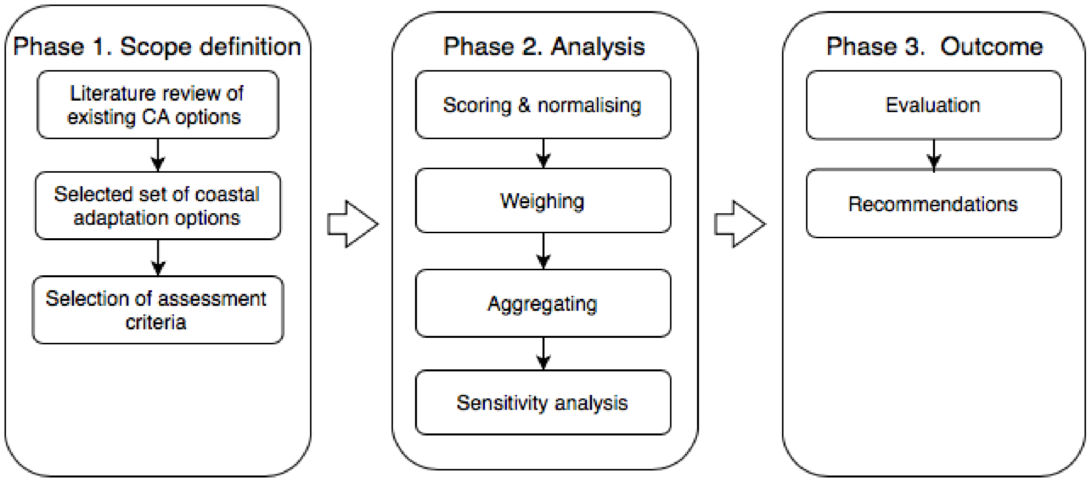

Figure 6 An overview of the MCA's steps (adapted from Esmail & Geneletti, 2017)

3.1 Phase 1: scope definition

In this section, the selection of potentially suitable coastal adaptation options will be discussed, after which the selection of assessment criteria to meaningfully compare these options will be elaborated upon. Together, the selection of options and assessment criteria defines the scope of the MCA.

3.1.1 Selection of suitable adaptation options

Using the classification of adaptation options that resulted from the literature review (Table 1), a selection was made of the alternative adaptation strategies for Bonaire that would be reviewed in the MCA (Table 2). This was done based on the expert judgement of the author and internal consultations with the project's partners.[1] It was made sure that a wide range of strategies was considered, since it is important to have a representative set of alternatives that includes relevant options for the different stakeholders (Janssen *et al.*, 2014). A detailed description of each of the selected alternatives can be found in the appendix, in section A.1. The different scenarios are compared to a do-nothing scenario. It is important to note that the adaptation

[1] A representative of Wolfs company and daily supervisor Timothy van Tiggeloven (Vrije Universiteit Amsterdam).

scenarios are not spatially explicit, since the goal of this study is to provide general recommendations on suitable coastal adaptation strategies, rather than to deliver recommendations on locations that would be suitable for the implementation of specific measures.

Table 2 An overview of the selected coastal adaptation options

Type	Adaptation strategy	Description
Retreat	Managed realignment: setback zone	The implementation of a horizontal setback zone within which future development is restricted and from which current residents will be actively relocated through a buy-out program.
	Construction restrictions	The implementation of construction restrictions that limit future development along the coast, extending the current restrictions (15m from the high water tide) further inland.
Protect	Grey: seawall	The construction of onshore grey adaptation in the form of a seawall.
	Green: mangroves	Restoration of mangrove area and replantation of mangroves to create new mangrove areas along the coast. Hereafter referred to as mangrove restoration.
	Green: coral reefs	Restoring the coral reefs either using natural or artificial reef restoration methods.
	Hybrid: eco-seawall	The construction of a seawall, enhanced with ecological features like eco-engineered tiles.
Accommodate	Building-level adaptation: dry-proofing	A set of measures that prevent water from entering the house, like flood-shields and a waterproof coating.
/	Do nothing	Reference scenario of not undertaking any action to protect Bonaire against coastal flooding.

The final set of options was validated by a regional coastal adaptation expert (F1) who confirmed that the chosen options were representative of the different directions that can be pursued in terms of adaptation strategies. One comment that he provided was that combined adaptation solutions are a common strategy in the Caribbean region. However, since the focus of this study was on the evaluation of individual measures, this alternative has not been taken into account. Soft adaptation measures, although being relevant additions to an adaptation plan, have also not been taken into account in the MCA because of their complementary nature.

3.1.2 Selection of assessment criteria

Several steps were taken in the process of selecting the MCA's assessment criteria. First, an overview was made of all MCA criteria used in 11 different scientific papers and policy reports about MCAs regarding (coastal) adaptation options. In addition, 4 more criteria were created based on the strategic policy goals for Bonaire outlined in the Plan for Land and Water (AFN *et al.*, 2020). The resulting list, containing 107 criteria, was then simplified by merging similar criteria, to reduce overlap. Ultimately, 10 final assessment criteria, clustered into four main categories, were selected from this overview. Similarly to the selection of coastal adaptation options, the criteria were selected based on the expert judgement of the author and internal consultation with the project's partners[2]. An overview of the selected criteria can be seen in Table 3. The inclusion of environmental, social, and economic criteria ensures that all three dimensions of sustainable development are addressed in the study (Figure 7).

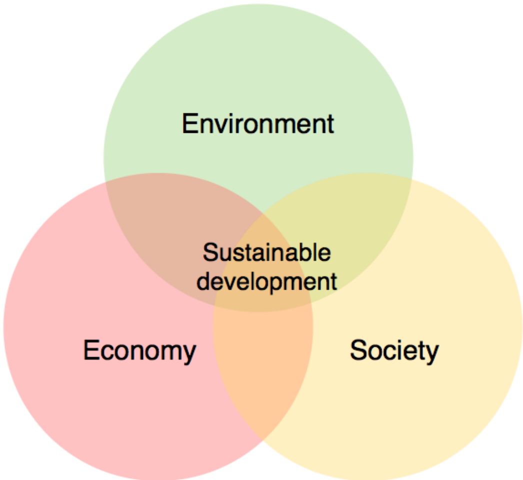

Figure 7 The three dimensions of sustainable development: society, environment, and economy (Mensah, 2019; Purvis et al., 2019)

The social criteria encompass the social acceptability of a measure, as well as how it would affect the typical characteristic appearance of Bonaire The environmental criteria include the direct and indirect effects on nature. In the economic criteria, the effect on the local economy is included, as well as a measure's costs and benefits in terms of damage reduction. Lastly, the technical criteria consider whether many other measures would be needed to successfully implement a measure and how well it can deal with the uncertainties of climate change.

A number of the final criteria are based on strategic policy goals for Bonaire (ANF *et al.*, 2020). Aligning the criteria with local policy goals aligns the outcomes of the MCA with objectives that are pursued by the local government, potentially enhancing political support for the results. **Erosion** is based on strategic policy target 1.1: *"Controlling erosion and runoff"*. The **effect on coral reefs** reflects strategic policy goal 1: *"Reversing the trend of coral reef degradation to create healthy, resilient, and restored coral reefs,*

[2] A representative of Wolfscompany and daily supervisor Timothy van Tiggeloven (Vrije Universiteit Amsterdam).

ensuring well-being in the Caribbean Netherlands". Inclusion of the **effect on other habitats** can be related to strategic policy target 2: *"Restore and conserve the unique habitats and species in the Caribbean Netherlands for current and future generations"*.

Table 3 An overview of the assessment criteria used in the MCA, grouped per category

Category	Criterion	Description	References
Social	Acceptability	The societal acceptance of the measure: whether people would support the implementation of a measure.	Banton *et al.* (2017), Bhave *et al.* (2014), Mamo *et al.* (2022), and Haque (2016)
	Effect on characteristic appearance	The measure's aesthetics and whether it would affect the typical local landscape of Bonaire.	Banton *et al.* (2017), Mamo *et al.* (2022), and Mallette *et al.* (2021)
Environmental	Erosion	How the measure would affect erosion on Bonaire.	ANF *et al.* (2020)
	Effect on coral reefs	How the measure would affect the coral reef habitat of Bonaire.	ANF *et al.* (2020), Banton *et al.* (2017), Bhave *et al.* (2014), Haque (2016), and Raucher *et al.* (2013)
	Effect on other habitats	How the measure would affect other habitats on Bonaire.	ANF *et al.* (2020), Banton *et al.* (2017), Bhave *et al.* (2014), Haque (2016), and Raucher *et al.* (2013)
Economic	Costs	The costs of implementation and maintenance of the measure. It is assumed that costs are borne by the government.	Baills *et al.* (2020), Bhave *et al.* (2014), Haque (2016), and Raucher *et al.* (2013)
	Effectiveness	How effective the measure would reduce damages from coastal flooding.	Banton *et al.* (2017), Bruin *et al.* (2009), and Porthin *et al.* (2013)
	Effect on economy	What the effect would be of the measure on the economy of Bonaire (tourism, employment, local businesses).	Banton *et al.* (2017), Bhave *et al.* (2014), and Haque (2016)
Technical	Robustness	Whether the measure would be capable of being effective in the long term and under various scenarios of climate change.	Baills *et al.* (2020), Banton *et al.* (2017), and Hallegatte (2009).
	Self-sufficiency	If the measure would require the implementation of other measures in order to be implemented effectively.	Baills *et al.* (2020)

3.2 Phase 2: analysis

This section discusses the second phase of the MCA, the analysis, which is the phase in which all adaptation options are compared using the selected set of assessment criteria. Since the participatory aspect of the MCA takes place in this phase, through the collection of stakeholder scores and weights, this section will start with an explanation of the data collection process and stakeholder involvement. Afterwards, each of the research steps involved in the analysis will be shortly discussed.

3.2.1 Data collection and stakeholder involvement

To evaluate adaptation measures holistically it is important to take into account the views of various types of stakeholders. The final stakeholder selection includes representatives of various local organisations, as well as of the local community, -businesses, and -government. In addition, a regional coastal adaptation expert and several flood risk experts from the Vrije Universiteit were consulted. Hence, the range of stakeholders covers the cultural, environmental, economic, and technical dimensions of the study.

The stakeholders were contacted using a purposeful sampling method, performed in collaboration with the project's partners[3]. The stakeholder list was complemented using snowball sampling, by asking interviewees if they had any suggestions on additional relevant stakeholders. In total, 18 semi-structured interviews were conducted, 17 of which were transcribed using either Otter.ai (English) or Word (Dutch). After the transcription, they were manually checked by the author. For the one interview that did not have an audio recording available, notes were made by the author. All interviews were conducted with informed consent, in line with the regulations of the ethics regulations of the Faculty of Science of the Vrije Universiteit (VU Faculty of Science, 2018). Table 4 shows an overview of all conducted interviews. A more elaborate overview of the stakeholders can be found in the appendix (Table A.1). In addition to the interviews, 4 stakeholders filled out an online questionnaire.

The stakeholders were provided to score the adaptation options on varying criteria. Which criteria a stakeholder was asked to provide information on was determined based on the author's expert option. Unfortunately, the lack of local flood risk or adaptation experts does mean that for some criteria no local knowledge could be included.

[3] Representatives of Wolfscompany and Greenpeace.

Table 4 Overview of the conducted interviews

Organisation	Short description	Group	Reference
FuHiKuBo	Culture expert (focus intangible)	Culture	C1
/	Local	Culture	C2
/	Historian, local	Culture	C3
Mangrove Maniacs	Mangrove expert	Nature	M1
[Anonymous]	Reef expert	Nature	R1
STCB	Sea turtle expert	Nature	S1
[Anonymous, nature consultancy]	Nature expert (focus terrestrial)	Nature	N1
Bonbèrdè	Nature expert (focus terrestrial)	Nature	N2
STINAPA	Nature expert (focus marine)	Nature	N3
CURO, Wannadive Grand Windsock	Economic expert (focus diving industry)	Economic	E1
Chogogo Dive & Beach Resort	Resort manager	Economic	E2
BBE	Economic expert (focus businesses)	Economic	E3
Delfins	Economic expert (focus tourism), resort manager	Economic	E4
Smith Warner International	Caribbean coastal adaptation expert	Flood risk	F1
WNF, Piskabon	Economic expert (focus fishing industry)	Other	O1
OLB	Policy maker, direction of spatial development	Other	O2
Fundashon Mariadal	Operations manager Fundashon Mariadal, local, former politician	Other	O3
Steenbouwadvies	Construction expert	Other	O4

3.2.2 Scoring and normalising

Scoring the adaptation options based on the criteria was performed qualitatively by the experts and stakeholders. A discrete scoring scale was applied, with scores ranging from 0-4 or 0-5, depending on the criterion. All criteria were scored so that the desired output is always the highest score and the least desired output is the lowest score. The averages of the stakeholder scores were normalised, using a linear scaling method, which assumes that for each criterion the minimum score is 0 and the maximum score is 1.

For the reference scenario, doing nothing, scores were pre-assigned by the author, based on the scoring process for the other scenarios. For most of the criteria, the reference scenario was assigned a neutral score of 3, indicating that the other measures can be either better or worse. For the costs and self-sufficiency, the reference scenario was assigned a maximum score of 5 and 4, respectively, reflecting that doing nothing does not cost anything and also does not require any additional measures. It was assumed that all adaptation options were either equally or more effective and robust than doing nothing, hence the reference scenario was assigned a minimal score of 1 for these criteria. An overview of the range of possible scores for each criterion, as well as the score that has been assigned to the reference scenario, can be seen in Table 5.

Table 5 An overview of the range of possible scores per criterion, as well as the score that has been assigned to the reference scenario

Criterion	Scale	Attributes	Pre-assigned score reference scenario
Acceptability	1-5	Very low - very high	3
Effect on characteristic appearance	1-5	Very negative - very positive	3
Erosion	1-5	Much worse - much better	3
Effect on coral reefs	1-5	Very negative - very positive	3
Effect on other habitats	1-5	Very negative - very positive	3
Costs	1-5	Very expensive - very cheap	5
Effectiveness	1-4	Equally effective - much more effective	1
Effect on economy	1-5	Very negative - very positive	3
Robustness	1-4	Equally robust - much more robust	1
Self-sufficiency	1-4	Not self-sufficient - very self-sufficient	4

3.2.3 Weighing

To simplify the stakeholder interactions, stakeholders were only asked to weigh the overarching categories, rather than specific criteria. The weights indicate how relatively important a specific category of assessment criteria is to an individual stakeholder, in making adaptation decisions (Esmail & Geneletti, 2017). The stakeholders were asked to assign each of the categories a percentage between 0 - 100%, taking into consideration that the total weight of all categories should add up to 100%. Within a criterion group, all criteria were assigned equal weights. Since the weighing specifically addresses which things should be taken into account when deciding on adaptation policies for Bonaire, the decision was made to only collect weights from local stakeholders.

3.2.4 Aggregating

To aggregate the scores with the average stakeholder weights, weighted linear combination was used. Out of different aggregation methods, this is the simplest and potentially most widely applied method (Zucaro *et al.*, 2021). The normalised scores for each criterion were multiplied by the relative weight of that criterion, after which all criteria scores were added up for each adaptation option to obtain a final ranking.

3.2.5 Sensitivity analysis

As only local stakeholders were asked to weigh the relative importance of the assessment criteria, not all stakeholder types are equally represented. Of the 16 stakeholders that provided their weights, 40% are categorised as nature, 26.7% as economic, 20.0% as culture, and 13.3% as other. Since no local flood risk expert is present on Bonaire, this category of stakeholders could not be represented in the weighing. The lack of flood risk experts, as well as the disproportionally large number of nature experts, could cause bias in the weighing process. Therefore, a sensitivity analysis was done that investigates how robust the final results are under the application of different weights. Running a sensitivity analysis addresses the uncertainties involved in the weighing process and is a way to incorporate a large range of stakeholder preferences into the analysis (Haque *et al.*, 2016).

4 Results

The results chapter will summarise the outcomes of the analysis, the second phase of the MCA. First, an overview of the normalised stakeholder scores and stakeholder weights is provided. Then, the final MCA scores, obtained by aggregating the scores and weights, are presented and discussed. Lastly, this chapter contains a sensitivity analysis that tests the robustness of the final results.

4.1 Scores

Most of the scores were provided by stakeholders during the interviews. In some cases where a score was not provided by the stakeholder explicitly, a score was constructed by the author based on interview quotes (Table C.1). When a range of scores was provided by a stakeholder, the highest and lowest score of this range were added as two separate score entries. Because of the lack of a local flood risk or adaptation expert, it was not possible to assign self-sufficiency scores to some adaptation options. Hence, the decision was made to assign predefined scores to all adaptation options, except for the NbS. All of these scenarios were assumed to be fully self-sufficient, as they, unlike NbS, do not strongly depend on the quality of the environment to be effective.

An overview of all individual stakeholder scores per criteria, colour coded by stakeholder type, can be found in the appendix, in Figure C.1-3. The individual scores were averaged and normalised to obtain the scores that are shown in Table 6 below. The raw average scores can also be found in the appendix, in Table C.2. An elaborate description of the reasoning behind the scores will be given in section 5.3, where the weighted scores and final ranking are presented.

Table 6 Summary of the normalised scores. The colour indicates whether the score is good (green, > 0.67), reasonable (yellow, > 0.33 and ≤ 0.67), or bad (red, ≤ 0.33)

Criterion	Do nothing	Seawall	Eco-seawall	Coral reef restoration	Mangrove restoration	Dry-proofing	Setback zone	Construction restrictions
Acceptability	0.18	0.39	0.50	0.89	0.94	0.63	0.52	0.82
Effect on characteristic appearance	0.50	0.06	0.31	0.88	0.75	0.38	0.94	0.75
Erosion	0.50	0.50	0.63	0.60	0.85	0.50	0.56	0.63
Effect on coral reefs	0.50	0.13	0.33	0.83	0.83	0.50	0.83	0.83
Effect on other habitats	0.50	0.40	0.40	0.70	0.95	0.50	0.80	0.75
Costs	1.00	0.13	0.08	0.50	0.56	0.57	0.44	0.67
Effectiveness	0.00	0.71	0.62	0.48	0.63	0.67	0.94	0.78
Effect on economy	0.5	0.45	0.75	0.88	0.83	0.50	0.38	0.80
Robustness	0.00	0.60	0.67	0.44	0.76	0.67	0.80	0.73
Self-sufficiency	1.00	1.00	1.00	0.00	0.50	1.00	1.00	1.00

4.2 Weights

Out of all 22 stakeholders that were contacted, 16 provided their weights (Table A.1). The averages of all stakeholder weights have been shown in Table 7. Although the weighted importance of the criteria categories varies a lot per stakeholder, the results clearly show that the environmental effects of a measure are deemed most important by stakeholders: the environmental category is given over a third of the weight (37%). One of the reasons that is mentioned for the high valuation of this category is that a healthy environment also results in other socio-economic benefits for the island (M1, E1). Because there are only two criteria in the social category, the individual social criteria get a relatively high weight in comparison to the other criteria, despite the social category receiving only an average weight (25%). Opinions about the importance of the social criteria differ. Some stakeholders argue that people will simply have to adjust when they do not agree with the decisions that are being made (N2), while other stakeholders stress the fact that Bonairians are very proud people and that their opinion needs to be included (C1). The least importance is attributed to the technical aspect of the measures: the technical category received a weight of only 18%. Some stakeholders did indicate that it is important to consider whether a project will be successful, especially since Bonaire has had many failed projects in the past (C1, E1). In general, many of the stakeholders stressed that it is important to create a balance between all the different factors (C1, E1, E3, O2-3).

Table 7 Average stakeholder weights

Category	Weight per category	Criterion	Weight per criterion
Social	0.25	Acceptability	0.13
		Effect on characteristic appearance	0.13
Environmental	0.37	Erosion	0.12
		Effect on coral reefs	0.12
		Effect on other habitats	0.12
Economic	0.20	Costs	0.07
		Effectiveness	0.07
		Effect on economy	0.07
Technical	0.18	Robustness	0.09
		Self-sufficiency	0.09

An overview of the mean weights per stakeholder group, in comparison to the average weights, is shown in Table 8. A more detailed version of this table that includes the scores per criterion can be found in the appendix (Table C.3). The weights per stakeholder group look quite similar to the average weights, with both the nature and economic stakeholders attributing high importance to the environmental criteria and reasonable importance to the other three criteria groups. Economic stakeholders do attribute a significantly higher weight to the social criteria and a slightly lower weight to the technical criteria than the other stakeholder groups. Finally, the other stakeholders both opt for absolute balance, attributing equal scores to all categories.

Table 8 Mean weights per stakeholder group, in comparison to the average weights. The colour indicates the perceived importance of the category, ranging from high (green, > 0.30), reasonable (yellow, > 0.15 and ≤ 0.30), to low (red, ≤ 0.15)

Stakeholder type	Environmental criteria	Economic criteria	Social criteria	Technical criteria
All	0.37	0.20	0.25	0.18
Nature	0.45	0.19	0.19	0.17
Economic	0.32	0.16	0.38	0.15
Culture	0.35	0.25	0.22	0.18
Other	0.25	0.25	0.25	0.25

4.3 Final scores

The final scores per adaptation option, resulting from the aggregation, can be seen in Figure 8. Since the environmental criteria received a high weight from the stakeholders, the scores for these criteria have a relatively more pronounced effect on the final outcome of the MCA than the scores for the other criteria.

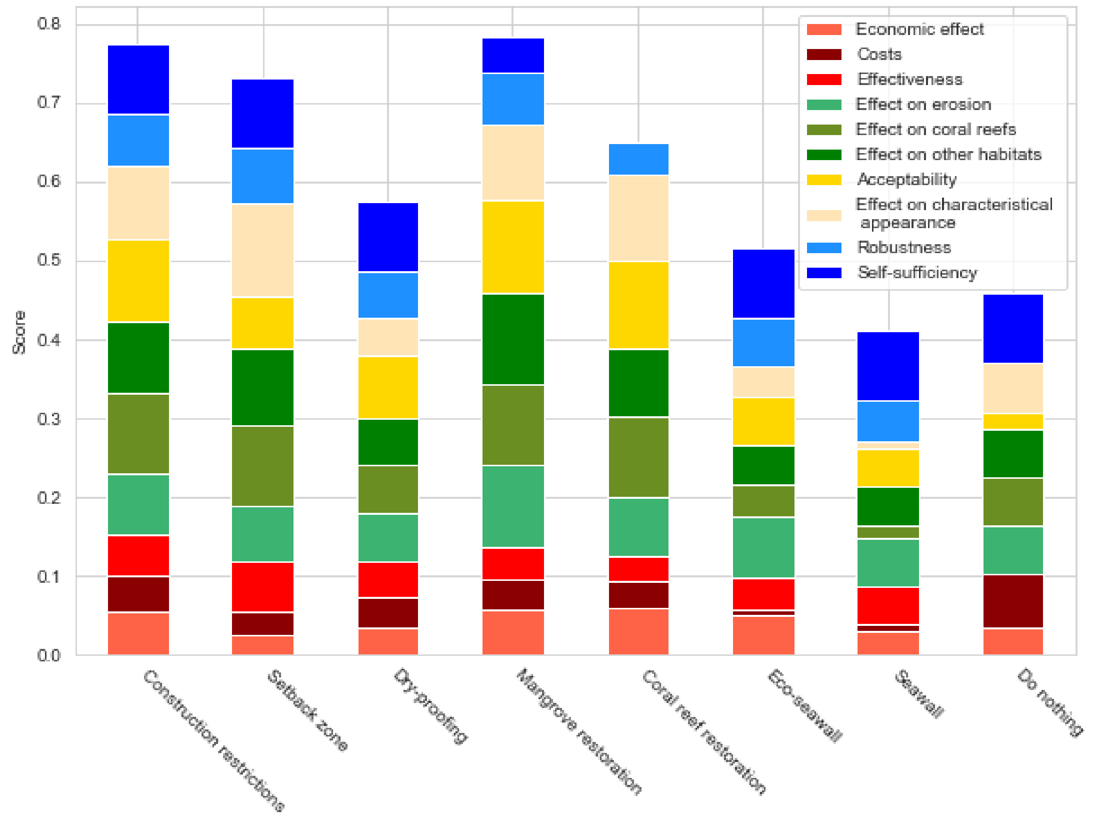

Figure 8 Overview the final MCA scores per adaptation option. The colour shows which part of the score comes from the technical (blue), social (yellow), environmental (green), and economic (red) criteria

Combining all the weighted scores per adaptation option results in a final ranking of the measures (Table 8). Mangrove restoration and construction restrictions are the two measures that score highest. Both types of seawalls, as well as doing nothing end up at the lower end of the spectrum. Dry-proofing and coral reef restoration both receive an average score, ending up in the middle of the final ranking. The rest of this section will describe the reasoning behind the final scores for each measure.

Table 9 Final ranking and total scores of the assessed coastal adaptation options

Rank	Measure	Total score
1	Mangrove restoration	0.784
2	Construction restrictions	0.774
3	Setback zone	0.732
4	Coral reef restoration	0.649
5	Dry-proofing	0.576
6	Eco-seawall	0.515
7	Do nothing	0.460
8	Seawall	0.412

4.3.1 Do nothing

The do-nothing scenario has previously discussed predefined scores for all criteria except for the acceptability criterion. In terms of acceptability, not all stakeholders are unanimous: the individual scores range from 1 to 5. Table 10 shows some arguments that are made to support either taking or not taking any action against coastal flooding. However, the majority of the stakeholders scored the acceptability of doing nothing either low or very low, resulting in doing nothing getting the overall lowest acceptability score of all adaptation measures.

Table 10 A selection of stakeholder quotes related to the acceptability of doing nothing

Stakeholder	Quotes
C2	“There are always people that cannot deal with that or who do not want that. They say *no nothing will change, nothing will happen*, but you have to do something.. You cannot just wait around.”
E1	“It is very desirable to take action against flooding, also from the sea, but are our concerns about that justified? I think that rainwater is a bigger problem. I am not convinced that SLR will be significant in the tropics within the next three to four generations and once you start you never stop, you will be fighting permanently. Look at the Deltawerken.”
E3	“It is not desirable that no plans are being made.”
E4	“If it happens, then it just happens. Then it is done and we will simply rebuild. It is possible, because we have our own construction company. Taking measures against that [coastal flooding].. It would be nearly impossible to do something here like a seawall and those solutions would be so expensive and ugly. In my opinion, those would never happen. The choice is either you invest now or you will rebuild and then I say let's just rebuild.”

4.3.2 Seawall

A seawall is the measure with the overall lowest score of all the adaptation options. It has a significantly negative effect on the characteristic appearance of Bonaire and also scores relatively low on acceptability. While stakeholders agree on the negative effect on Bonaire’s appearance, the acceptability of a seawall receives scores between 1 and 4. From the interviews, it is clear that the acceptability of a seawall is highly dependent on how and where the seawall will be implemented. If it is nice looking, like the one in Slagbaai (Figure 3.A) or the Malécon in Cuba, and properly executed, that is considered a pro in terms of acceptability (C2, E3, N1). Multiple stakeholders stress that a wall should not be built so high that it blocks the ocean views (C2-3, E2). The accessibility of the ocean is also an important factor: structures can for example restrict the accessibility of sandy beaches for recreational purposes and for fishermen it is important that they are able to easily access the sea with their boats (C1, C3, E3, R1). The location is also mentioned: a seawall is often deemed appropriate for Kralendijk, but not for the natural areas (C2, E1, N2, O1). Stakeholder O2 notes that a seawall would not be desirable at all, as pieces can break off during a storm, which can then cause damage to the reefs and also increase damage onshore. This was later confirmed by expert F1.

The total sum of technical scores of a seawall is similar to that of many of the other adaptation options. A seawall is deemed relatively robust, although one flood risk expert does note that implementing a seawall can cause a technological lock-in, reducing future flexibility (F4). Moreover, a seawall is assumed to be self-sufficient, as there are already several ones constructed on the island. It is, however, because of poor local rainwater management, important to construct seawalls so that water can flow out from under them (e.g. by creating small holes) in the case of heavy rains (O2). While a seawall is one of the most effective measures, it is also the second most expensive. A seawall also scores poorly in terms of total environmental effects, with a total score that is the lowest of all adaptation options. Some exemplary quotes on the environmental effects of a seawall can be found in Table 11.

Table 11 A selection of stakeholder quotes related to the environmental effects of seawalls

Stakeholder	Quotes
N1	"If you're blocking the waves that normally pass by.. If they're blocked you get more concentrated wave energy in the shallow areas and all these shallow corals, the ones they do in restoration, they are going to break apart."
N3	"You cannot build along the coastline without impacting the reefs. That's.. We would like that, but it is just not possible. The main problems are physical damage and physical degradation of the reef during the construction process." "What the effect would be depends on where you will do it. You see, in all of those places that already have coastal development, there all of the [shallow] reef is already gone anyways, so there it won't affect the reefs, but in places where there is nothing yet -and then I'm mainly referring to the north of the island- if you are going to build something there then it will definitely have a negative effect on the reef that you have there."
R1	"That will depend on the material and the way they are built, the construction process of it. I'm sure there will be a way to do it in a clean way, but if it is not done in the proper way then it kills it [the corals] all. And we see it with the construction that has been going on in Bonaire."
S1	"This scenario would affect the turtles through the effect on the reefs, loss of nesting area, and disorientation of turtles because of the light pollution [during the construction process]. So it would affect both the population living here, as well as the population that comes here to nest. It actually affects everyone in terms of sea turtles."

4.3.3 Eco-seawall

An eco-seawall scores similar to a traditional seawall in terms of erosion, effect on other habitats, costs, effectiveness, robustness, acceptability, and self-sufficiency. The opinions of stakeholders on the acceptability of an eco-seawall vary even more than for the traditional seawall, with scores ranging from 1 to 5. Some stakeholders indicate that the ecological enhancements would not change their opinion about having a seawall (C1, E4, O3). The aesthetics of an eco-seawall improved the acceptability for many stakeholders (C2, C3, N1) and decreased it for stakeholder S1. Policy representative O2 brought up one problematic aspect of this measure: current regulations do not allow the construction of any type of structure within 2m from the high tide line, meaning that an eco-seawall as proposed is not permitted. The reasoning behind this is again the fear of pieces breaking off, causing damage to the reef or onshore.

One of the major differences that can be observed in comparison to a traditional seawall is the effect on the characteristic appearance, which is less negative for an eco-seawall. Since each of the individual social criteria have a relatively large weight, this has a significant effect on the final score of the eco-seawall. The less negative effect results from an eco-seawall being a more nature-oriented measure (C1, C3). Another criterion on which an eco-seawall scores higher than a normal seawall is the economic effect. One of the reasons that is provided for this is that an eco-seawall would fit better with Bonaire's Blue Destination vision (E3). A final interesting difference that is observed between the two is the effect on coral reefs, which is less negative for eco-seawalls, although nature experts do not agree on this (Table 12).

Table 12 A selection of stakeholder quotes related to the effect of eco-seawalls on coral reefs

Stakeholder	Quotes
N1	"My feeling [is that] all will get filled with algae pretty fast and then coral cannot grow on it. It is more about the wave energy than about corals growing on that wall."
N3	"Our tidal range is very small, but yeah then it is mainly about habitat for sea urchins and small crabs, maybe algae, not necessarily corals because those don't grow in the intertidal zone that much."
R1	"This definitely provides substrate where to outplant corals. I wouldn't do it for ecological restoration for now in Bonaire. Meaning that I think we still have enough reef that instead of putting an artificial structure, we should try to keep wildlife as it is and protect it."

4.3.4 Mangrove restoration

Mangrove restoration is the measure with the overall best score. The fact that mangroves provide the most environmental benefits of all measures significantly contributes to its high total score. Some quotes on the environmental effects of mangroves can be found in Table 13. These environmental benefits also lead to various economic benefits. The mangrove's contribution to a healthy fish population benefits the fishermen (M1, O1) and nature restoration efforts provide a good marketing narrative for the tourism industry (E1). While mangroves also provide an opportunity for activities like kayak tours, there is limited opportunity to expand these (E1-4, M1).

Mangroves benefit the characteristic appearance because Bonaire used to have mangroves in many more locations (M1, O3) and through their importance to the fishermen, who are an important part of Bonaire's culture (C1, N1, O1, O3). Moreover, mangroves were originally used for the construction of houses (C1), but general knowledge on such past social and cultural functions of natural elements is gradually disappearing on Bonaire (O1). With all of these benefits, it is not surprising that mangrove restoration is the most accepted of all adaptation options.

Stakeholders stress that mangroves can be very effective in terms of coastal protection, but that mangrove restoration is only possible in certain areas (N1, M1). Additionally, along the south coast, the strip of mangroves is very narrow, which limits its effectiveness (M1). The areas where they are already restoring mangroves, along the south coast and in the Lac Bay, are the only areas in Bonaire that are suitable for mangroves (M1). For successful mangrove restoration, it is important to take an integral approach, also addressing the major pressures that mangroves are currently experiencing: Sargassum and erosion (N1-2, M1).

Table 13 A selection of stakeholder quotes related to the environmental effects of mangrove restoration

Stakeholder	Quotes
N1	"Some species of bats, they feed on the insects you find in the mangroves" "Well the mangroves are super important for the fauna, especially for the birds, everybody knows. I mean, but also for the bats. But also there is a lot of bird life in the mangroves."
N3	"From what I know it is positive. Mangroves are a nursery for many different species of fish that move to the reefs afterwards, but they also have sort of a barrier function, retaining all of the silt and sediment that comes from the land, so that it does not end up on your reef right away."
S1	"Well mangroves play an important role for the sea turtles, for example as a habitat, water purification, retaining the area, so as to prevent it from being eroded.

4.3.5 Coral reef restoration

Similar to mangroves restoration, coral reef restoration scores high in terms of social and environmental benefits. Healthy reefs can provide important habitat, for example for sea turtles, and can also benefit other habitats like mangroves and seagrasses (N1, S1). However, there is some debate about whether or not coral reefs can be restored (Table 14). In some places, targeted restoration of shallow reefs works well, however, it can be questioned if the entire reef can be significantly improved in a short amount of time (N3, R1). In terms of method, stakeholders unanimously disapprove of the use of reef balls (E1, N3, R1, S1). As is exemplified by the few that they have on Bonaire, nothing grows on them (N1, N3, R1). While they can form a barrier that dissipates some wave energy, this would require a lot of them and it would come with the risk of them breaking apart and destroying the reef during a storm (N1, R1).

Like mangrove restoration, coral reef restoration is highly accepted and has very positive effects on the economy and characteristic appearance of Bonaire. The reefs are Bonaire's major selling point for tourism and play an important role in the diving sector (E1-4, R1). Additionally, reef restoration benefits the fishing industry (C1, O3). Similarly to mangroves, the awareness of past cultural usages of corals, for example for the construction of houses, is slowly fading (O1).

The major reason that coral reef restoration does not end up high in the final ranking is its low robustness and self-sufficiency. Several local pressures would need to be addressed to successfully restore corals, including Sargassum, wastewater, tourism, erosion, and coastal development (N1-3, R1, S1). In addition, there are pressures like ocean warming, SLR, ocean acidification, and coral diseases, which cannot be solved on a local level (N1, N3).

Table 14 A selection of stakeholder quotes on the effect of coral reef restoration on coral reefs

Stakeholder	Quotes
N1	“Let me start by the beginning by saying that I don't believe in coral reef restoration. It works at a certain level, as in it is one of those feeling good things, like we feel we are restoring. But I don’t think you can restore a coral reef. Once it is gone it is gone.” I don’t think it will have a significant impact. Because between here and 2050, I think there is going to be at least three or four big storms that will wipe everything out.”
N3	“If someone will do it [coral reef restoration] and they are not doing it in the right way.. Francesca [Reef Restoration Bonaire] is doing it in the right way, she has a plan and they track which genotypes are outplanted in which locations. Because if you don’t do coral reef restoration in the right way you can also damage the reef even further.”
R1	“If you do coral reef restoration for coastal protection it would absolutely benefit the biodiversity of the reef and the ecosystem of the reef. But the strategy will be different, you know. You would use fast growing corals, and robust, and you are not focusing for example on genetic diversity and reproduction, because you don't care particularly.. When you're creating a wall you don't care particularly about having this coral reproduce or a lot of genetic diversity. You care about corals growing fast and being sturdy and they can be all the same as long as they protect from waves.”

4.3.6 Dry-proofing

Dry-proofing does not end up very high in the final ranking, which is mainly caused by the fact that it scores neutral in terms of its environmental effects and effect on the economy. It will also not significantly impact Bonaire’s appearance. The acceptability of this measure widely varies among stakeholders: scores range from 1 to 5. Table 15 provides some quotes from stakeholders on the acceptability of dry-proofing. The hospital is currently in the process of installing flood shields, but mainly because of pluvial flooding (O3).

The effectiveness and feasibility of dry-proofing have been questioned by stakeholders. While dry-proofing prevents water from entering a house or monument, it does not necessarily help against wave energy, while the main damage on Bonaire during a storm is caused by high energy waves (E4, O2). Also, the problem is considered to be too wide-scale to be fixed effectively on the scale of individual houses (F1).

Table 15 A selection of stakeholder quotes related to the acceptability of dry-proofing

Stakeholder	Quotes
C1	"I think people would be very happy with that because not just on Bonaire, everyone in the world when it becomes personal if you can say you can protect yourself, your own house." "I think that, like, when it comes to safeguarding yourself, your own family, that is accepted and welcomed."
E1	"Eventually in terms of acceptance you'd almost say no, because if people that live along the coast can protect themselves against the impacts from the sea that might make it more attractive to actually build along the coast, in contrast to when it becomes a bit dangerous and when it is impossible to insure, then you'd rather not do it." "For important buildings like a hospital or the fire station, then it would be okay of course."
N1	"I'm okay with that for the people that don't have the resources to buy a house somewhere else and move."
N2	"I think it would be a waste of money."

4.3.7 Setback zone

Implementation of a setback zone ends up in the middle of the ranking. It can potentially reduce erosion, especially if a vegetation buffer is created (N1, S1), provide extra space for coastal vegetation (M1, N2), and reduce the pressure of coastal development on the beaches (S1). Aside from these environmental benefits, it has a positive effect on Bonaire's appearance. Along the coast are mainly expensive villas and hotels, which are not considered to be a part of the Bonairian culture (C1, O3). Getting rid of some of these would restore the accessibility to the ocean, which is very important to many locals (C1, C3). A setback zone would affect Bonaire economically in various ways (Table 16).

One of the most problematic aspects of this adaptation option is that it is economically not at all feasible to buy all coastal properties, especially considering the current house prices (C2, O2). Additionally, resort owners indicate that it would be economically impossible for them to move, considering the investments that they have made (E2, E4) and resorts would have to be offered an equally good alternative as well as proper compensation, including compensation for lost future earnings (E3). Implementing it only for residential houses would be more manageable (E3). Acceptability can also become a problem for this measure, with its scores being highly variable, ranging from 1 to 5. Multiple stakeholders note that many people would strongly oppose this measure (C1-2, E2, E4, O3, R1).

Table 16 A selection of stakeholder quotes related to the economic effects of a setback zone.

Stakeholder	Quotes
E1	"It is somewhat extreme, but still it would be good for the diving industry. The reason for that is that there is an increasing number of places in which you used to be able to dive from the shore that you currently cannot reach anymore." "A hotel by the sea is easier to sell than a hotel that's behind the airport."
E3	"It depends on the type of tourist that you want to attract as an island. See, the type, the mass tourists that we have now.. They want to be by the sea, simple as that. The diving tourists that we had and have, yeah they want to be near the sea because they dive in it, but I don't think that it would be a major problem for them to walk or drive a few metres further to go to the pier."
E4	"If you take away all the resorts here by the water and you place them further inland then people will go and find another place where it is possible to sit by the water. Why would you otherwise have an island? It is for the water. This scenario would be a death blow to the tourist industry".

4.3.8 Construction restrictions

Construction restrictions is the second-highest scoring measure. The main reason that this measure ends up significantly higher in the ranking than a setback zone is a difference in acceptability, costs, and economic effect. Generally, it is considered to be beneficial to the economy if there is no more construction along the coastline (Table 17). Compared to the setback zone, there is much less variation in the acceptability of construction restrictions, with the majority of the stakeholders ranking its acceptability either high or very high. One of the reasons that is mentioned is that not building along the shore would prevent the problem altogether (C2, N1, O2, O3, R1). Stakeholders do note that the areas in which construction is allowed are already fully built, so not much more construction would be possible, because of the protected nature areas (C1, E2, O2). However, in the past, it has occurred that buildings were constructed in areas that were supposed to be protected nature areas (M1, N1, O2).

Table 17 A selection of stakeholder quotes related to the economic effect of construction restrictions

Stakeholder	Quotes
E2	"We already feel like there is relatively little beach area on Bonaire, because it has been washed away in some locations, so we think such a solution would only be beneficial to Bonaire."
E3	"I think we need to stop that [coastal development]. I also don't think it will have a significant economic effect. I think it would be better to look at what you already have and to adapt that based on where you want to go, using the space that is left for.. Yeah for more nature and culture related activities. Especially when you talk about high end tourism, then you don't need extra hotel rooms."
E4	"If Bonaire does not want to end up in the pit of Curaçao and Aruba, you'll have to be somewhat exclusive, which means keeping some open space. I think if you think collectively about how you want to market this, you can say *oh we're so pretty and nice and beautiful*, but if you then only have crowded resorts along the entire road then you have mass tourism and that's not what we want."

4.4 Sensitivity analysis

The sensitivity analysis consists of two parts: the first half of the runs consist of the stakeholder weights separated per stakeholder group and the second half consists of artificially assigned weights that reflect a strong focus on each of the criteria groups (Table 18). The criteria within each category are again assigned equal weights. After the weights are re-assigned, the aggregating step of the analysis is repeated to obtain a new ranking for each sensitivity run.

Table 18 Weights applied in each sensitivity run

Type of sensitivity analysis	Sensitivity run	Environmental criteria	Economic criteria	Social criteria	Technical criteria
Weights per stakeholder group	Nature stakeholders	0.45	0.19	0.19	0.17
	Economic stakeholders	0.32	0.16	0.38	0.15
	Culture stakeholders	0.35	0.25	0.22	0.18
	Other stakeholders	0.25	0.25	0.25	0.25
Artificially assigned weights	Environmental focus	0.50	0.17	0.17	0.17
	Economic focus	0.17	0.50	0.17	0.17
	Societal focus	0.17	0.17	0.50	0.17
	Technical focus	0.17	0.17	0.17	0.50

The rankings resulting from the different sensitivity runs can be seen in Figure 9. The results are robust with a wide range of stakeholder preferences and also with adopting a different focus. In the majority of the runs, only the top two measures in the ranking switch places. The only focus that does lead to significant changes in the ranking is the adoption of a technical focus, which results in a significantly lower ranking of the NbS.

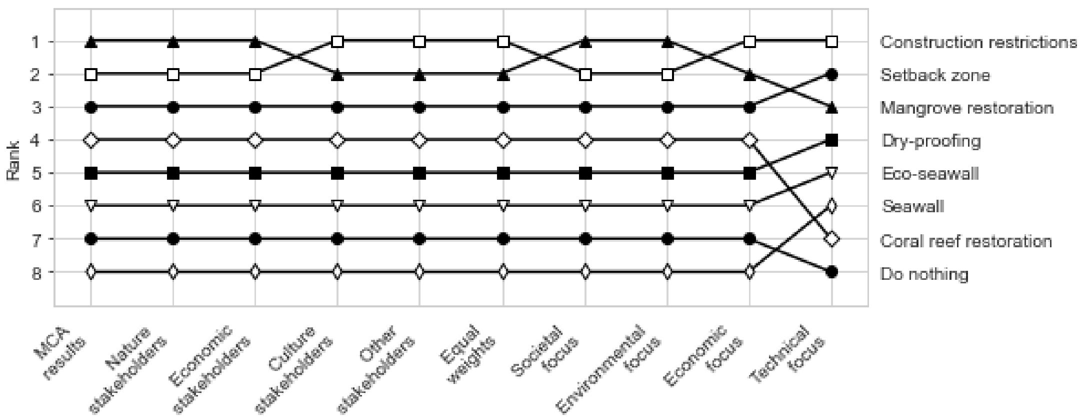

Figure 9 Results from the sensitivity analysis

5 Discussion

Within this section, some interesting findings resulting from the data will be discussed and compared to the broader scientific literature. Additionally, this section will explain the limitations of the research and how future research could build upon the results of this study. Finally, the chapter contains some general policy recommendations.

5.1 Comparison of results

From the findings, it can be extracted that the NbS, especially mangrove restoration, and both spatial zoning measures received relatively high overall scores, while the construction of any type of seawall, as well as doing nothing, ended up at the lower end of the ranking. That NbS solutions score significantly better than grey infrastructure, when you take a holistic approach, is in line with findings from studies that were conducted in other locations. Raucher *et al.* (2013) for example find that while grey infrastructure is more effective, green infrastructure generally is the best option because it has fewer externalities and more additional benefits. The current study shows similar results, with a seawall scoring highest in terms of effectiveness and the NbS scoring significantly higher in terms of additional benefits, such as environmental benefits and a positive effect on the economy and the characteristic appearance of Bonaire. However, there is a likelihood that these measures will not always be effective. While a comparison to a generalised study like the one of Raucher *et al.* (2013) is possible, it is difficult to compare the results of the current study to spatially explicit studies done in other locations, as the results can vary significantly based on local conditions and as different analyses compare a locally relevant set of coastal adaptation options. Sauvé *et al.* (2022) for example showed that, for Canada, NbS were ranked highest in the three of their study sites that had a low sandy coast, while a rock armour and seawall were ranked highest in another one of their study sites, which had a cliff coast, exemplifying that results can be highly variable even within one country.

In terms of weights, stakeholders especially attribute high importance to the environmental effect of measures and the least importance to the technical aspect. The sensitivity analysis does show that when the technical criteria are attributed higher importance, the NbS end up significantly lower in the ranking, which can be explained by the low self-sufficiency of both of these measures. It is in line with expectations that nature is considered to be very important, as Bonaire has a history of extensive nature protection schemes. They were for example the first Caribbean island to ban spearfishing and Bonaire established its entire coastline as a Marine Protected Area over 40 years ago (Steneck *et al.*, 2019). Moreover, several wetlands are protected under the Ramsar convention (Debrot *et al.*, 2018).

The results of the flood risk assessment in our study indicate that some residential areas can already be prone to flooding in the case of high tide events that occur with a frequency of 1/100 years. Compared to most areas in the European part of the Netherlands, such a probability does not result in flooding. Despite the low preferences for hard infrastructure options, such as seawalls, it might still be necessary to implement these measures to protect the people of Bonaire against the effects of climate change.

5.2 Subjectivity of MCA

An MCA does not provide a final perfect solution, but should rather be considered an exploratory comparison of options that provides valuable information about the trade-offs that are involved with the selection of an adaptation option, which can be used to aid policy makers in the decision-making process (Alves *et al.*, 2018; Gamper & Turcanu, 2007). It is important to note that the MCA depends on stakeholder scores and weights, which means that the final results can be influenced by subjective choices and assumptions made by the stakeholders (Zucaro *et al.*, 2021).

One example of this is the weighing process. Since weights were assigned only to the main categories of criteria, it was necessary to assume equal weights for all criteria within one category. This might lead to somewhat simplified results, as it is not necessarily the case that all criteria within one category are equally important to a stakeholder. The weighing process also proved to be prone to insufficient understanding of the criteria within one category. Stakeholder E1 for example indicated that he deemed the technical criteria to be important because it was important to him that measures actually work, thus referring to their effectiveness. However, the effectiveness criterion is included in the economic, in the form of risk-reducing benefits, rather than in the technical category. A way to reduce this ambiguity is by scoring the individual criteria, rather than criteria groups. Additionally, the sensitivity analysis addresses some of the uncertainties in the weighing process (Haque *et al.*, 2016). How uncertainties derived from subjectivity in the scoring process of some criteria can be addressed will be discussed in the next section.

5.3 More quantification required

The costs and effectiveness have, within this study, only been evaluated qualitatively. Thus, to arrive at a final policy decision, these aspects of the adaptation options should be assessed in further detail. Ideally, a CBA should be performed for each adaptation option under consideration (de Bruin *et al.*, 2009).

The resulting effectiveness of NbS, relative to each other, for example, does not align with findings by previous studies. Research by Narayan *et al.* (2016) shows that mangroves are, in general, only half as effective as coral reefs in terms of wave reduction because of their sheltered environment. However, the results of the current analysis indicate that mangrove restoration is potentially more effective than coral reef restoration for Bonaire. While it is clear from previous studies, such as the study by Menéndez *et al.* (2018), that mangroves can potentially play an important role in the coastal protection of islands, it can be questioned if mangrove restoration for Bonaire can indeed be as effective as suggested by the results. Especially since stakeholders noted that its effectiveness is limited by the fact that mangroves only grow in specific locations. This aligns with the data of Ocean Wealth mapping tool, which indicates that a maximum of 12% of the total mangrove area on Bonaire can be restored, but that this will result in zero extra people protected (Nature Conservancy, 2016).

Costs were also not included quantitatively within the analysis, as obtaining specific cost information was very challenging for some measures. An important example is coral reef restoration, for which it was indicated that the costs would be significantly different for restoration with the purpose of coastal protection rather than ecological purposes (R1). As the current cost information would not adequately transfer to the cost information required for this study, a cost specification was not provided (R1). One measure for which the costs could be exceptionally problematic, as was discussed in the results section, is the setback zone. This measure also exemplifies why further quantification is required, as the extremely negative notions given by local stakeholders on the affordability of this measure do not align with its final score for this criterion, which is relatively average.

To obtain conclusive results about these matters, it is vital that more detailed cost and effectiveness information is acquired, to improve the rough estimates that were provided within this study. This is especially important since these approximations were mainly done by flood risk experts with no knowledge of local factors in Bonaire, like labour costs and the coastal geomorphology. Du *et al.* (2020) exemplify a suitable methodology: they apply an integrated modelling approach to provide a comparative CBA of coastal adaptation options for Shanghai. A similar approach should be considered to strengthen the MCAs results of this study.

5.4 Looking beyond coastal flood risk

Aside from increased coastal protection, there are several other things that Bonaire needs to address going forward. These include the several pressures that, according to stakeholders, are vital to address to successfully implement NbS in Bonaire. As previously mentioned, stakeholders have identified Sargassum and erosion as the two major pressures that would need to be addressed for successful mangrove restoration. Both problems are currently already being included in Bonaire's policy plans (ANF *et al.*, 2020).

Sargassum is a specific type of algae that washes ashore, and it has become increasingly problematic for Bonaire. It has been a problem on Bonaire since 2015 and it is still poorly controlled (M1). N3 noted that this is likely because of climate change and while recent studies have also identified this as a potential main cause, it could also be enhanced to drivers that are unrelated to climate change, like wastewater runoff from an increasing number of tourists (Debrot *et al.*, 2018). Currently, there is still insufficient research to establish the exact cause of the worsening Sargassum problems.

Erosion has also been identified as a major pressure on mangroves and coral reefs. On Bonaire erosion is worsened by free-ranging grazers, mainly goats and donkeys, who affect the natural vegetation, reducing its capacity to retain water (N3). To reduce erosion, this is one of the main things that should be addressed according to the stakeholders (M1, N1-3, S1). Dealing with uncontrolled grazing is also one of the management recommendations provided by Debrot *et al.* (2018) to improve the quality of the reefs and mangroves on Bonaire. An additional cause of the erosion problems is the state of Bonaire's road network. Because most of Bonaire's roads are dirt roads, a lot of sediment ends up in the marine park when it rains (N3). In line with the results of this study, Bonaire's policy plans to address erosion problems on the island include fencing-in livestock, as well as the development of rainwater retention plans (ANF *et al.*, 2020).

Rainwater management is also relevant irrespective of the problems with erosion, as many stakeholders describe rain as one of Bonaire's most pressing issues (C2, E1, O3-4).

It is therefore recommended that future studies address pluvial flooding in addition to coastal flooding, especially since rainfall extremes in the Caribbean are expected to become more intense (Taylor *et al.*, 2020).

5.5 Combining adaptation strategies

In addition to individual adaptation options, future research should investigate the potential of hybrid adaptation solutions, consisting of combinations of measures in one location. As was briefly discussed in the methodology section, combined adaptation measures were considered an important adaptation strategy for Caribbean islands by regional expert F1. He indicated that specifically the combination of hard adaptation options, like seawalls, with mangroves is a common strategy in the Caribbean that should be considered for Bonaire as well. The relevance of hybrid adaptation solutions is underscored by recent literature, such as the study by van Zelst *et al.* (2021), which showed that a hybrid solution in which coastal vegetation is combined with levees can be a more sustainable and financially preferable option, or the study by Du *et al.* (2020), who concluded that hybrid strategies result in lower residual risk and higher cost-benefit ratio than individual measures for Shanghai.

Despite the choice of an individual solution or combination of measures, it also emerges from the interviews that it is unlikely that one uniform solution will fit all locations, because of the variable character of Bonaire's coastline (N1). Therefore, implementing different solutions in different locations, based on the local characteristics of the coastline, should be considered moving forward. A suitable method to further investigate this matter is an MCA on a site-by-site basis, such as done by Preston *et al.* (2013) for coastal adaptation measures in Australia or by Sauvé *et al.* (2022) for coastal defence measures in Canada.

5.6 Involvement of the local community

Since a lack of public support can cause significant barriers to the actual implementation of coastal adaptation strategies, it is important to consider the acceptability of adaptation options and how it can be enhanced (Mallette *et al.*, 2021). Generally, hard adaptation options are most frequently preferred by stakeholders (Mallette *et al.*, 2021). For Bonaire, this is not the case: in the current study, the seawall was one of the least accepted measures. A potential explanation for this is the fact that the public increasingly recognises that hard measures can be maladaptive (Mallette *et al.*, 2021). According to Mallette *et al.* (2021), retreat options are, on average, the least preferred measures. While it is not one of the lowest scoring measures for Bonaire in terms of acceptability, it did become clear from the interviews that the implementation of a setback zone could lead to strong public resistance. Despite the potential issues with public acceptance, retreat options might be necessary when there are no other reasonable alternatives available, for example when protection is becoming too expensive (Griggs & Reguero, 2021, Mallette *et al.*, 201). The scientific literature suggests that for some coastal communities, especially in the context of small islands, relocation will eventually become inevitable (Mycoo, 2018; Nunn *et al.*, 2021).

While it is evident that nature is important to Bonairians, looking at the high weight that the environmental criteria received and the high acceptability of the NbS, it does emerge from the interviews that there is an insufficient understanding amongst the local community about the functions of natural systems. People acknowledge their importance, but do not truly understand how they work, what their functions are, and why they need to be protected (O1). The communication about these topics, in the way that it is currently being done, only reaches a specific audience and not the general population of Bonaire (O1). However, proper environmental education is important to increase the capacity of the local community to deal with environmental problems and to enhance the conservation of natural systems (Ardoin *et al.*, 2020).

A potentially related finding is that despite the fact that multiple stakeholders indicate that Bonairians do not worry about climate change (C2-3, O3), doing nothing is the lowest scoring measure in terms of acceptability. Since research has shown that climate change education increases climate change perception, a potential explanation for this discrepancy could be the selection of stakeholders, which mainly consist of experts who are generally well-educated (Ranney & Velautham, 2021). Future research should therefore investigate the link between the acceptability of coastal adaptation measures and the stakeholder's educational level, using a stakeholder selection that accurately represents the general Bonairian population. This could provide insights into the relevance of education for the acceptability of future decisions on adaptation strategies.

The importance of education and involvement of the local community for the social acceptability of policy decisions, regardless of the specific measure that will be implemented, was also apparent from the interviews. Stakeholder C2 indicated that it could, for example, be helpful to include the Bonairian youth, by explaining climate change and potential adaptation options in schools and making students interact with the topic for example by writing an essay. Additionally, the acceptability of policy decisions can be increased by discussing them on well-known talk shows, for example on the radio, or by writing about them in the local newspaper (C2).

In conclusion, there is an opportunity for Bonaire to invest in improving education for sustainable development and general knowledge on climate change-related topics. Doing this would also contribute to the achievement of SDG target 4.7, part of SDG goal 4: "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all." (UN, 2018).

6 Conclusion

The question that has been evaluated within this study is how different adaptation measures that could potentially protect Bonaire against coastal flooding can be valued by key stakeholders, taking into account economic, social, environmental, and technical criteria. Ultimately, seven different adaptation options, ranging from hard coastal adaptation options to softer NbS, were compared against a do-nothing scenario using an interdisciplinary set of 10 different criteria, providing a holistic overview of the benefits and trade-offs of each measure.

Mangrove restoration received an overall score of 0.784, followed by both spatial zoning measures: construction restrictions (0.774) and the implementation of a setback zone (0.732). The other NbS, coral reef restoration, also ends up in the higher half of the ranking, with a final value of 0.649. For these measures, according to stakeholders, benefits are maximised and potential trade-offs are minimised. The environmental effects are considered the most important category of assessment criteria according to the stakeholders, with an average weighted importance of 37%.

The scenarios that receive the lowest overall scores from the stakeholders include the construction of a seawall (0.412) or eco-seawall (0.515), as well as doing nothing (0.460). These measures are thus considered as the overall least favourable adaptation options for Bonaire by the stakeholders. Significant trade-offs of the construction of an (eco-)seawall include potentially detrimental effects to nature and high costs. Although Bonairians are, generally, not very worried about climate change, the low acceptability of doing nothing shows that it is clear that something needs to change and that adaptation efforts need to be made.

While mangrove restoration appears to be the best adaptation option based on this study, it is important to realise that this measure also comes with several trade-offs, such as the fact that several other local issues will have to be solved to make it a viable option. Additionally, its potential benefits in terms of risk reduction are still poorly defined. Moving forward, there is a need for **follow-up research to provide quantitative data** to support the findings of this study and to **explore additional options** that go beyond generalised individual adaptation solutions, including a spatial assessment and adaptation options to pluvial flooding. Moreover, to ensure societal support for any policy-measures, policy-makers should **ensure proper involvement and environmental education of the Bonairian population.**

The results from this study do not yet provide a finalised solution to the problem of coastal flooding on Bonaire. However, its results will aid policy makers moving forward in the decision-making process and form the basis for additional research. In addition to the policy-guidance this study provides for Bonaire, this study also offers a useful methodological framework that can be used in locations with similar characteristics, like the other BES islands, for additional research. This would require stakeholder consultations, to adjust or validate the relevance of any local factors that have been considered within this study, such as the inclusion of local policy targets.

The qualitative exploratory comparison of coastal adaptation options that has been delivered by this study can thus be considered as the first step in improving the coastal protection of Bonaire, eventually raising the island's protection standards to levels that are equivalent to those that are applied for the rest of the Netherlands, and that of other at-risk coastal communities.

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Annex A Description of coastal adaptation scenarios

A.1 Retreat: managed realignment & construction restrictions

Two retreat strategies have been selected. The first strategy is managed realignment through the implementation of a horizontal setback zone within which future development is restricted and from which current residents will be actively relocated through a buy-out program. A schematic representation of this strategy is provided in Figure A.1. This strategy corresponds to practices that are already being implemented globally, such as the US Hazard Mitigation Grant Program and the UK Coastal Change Pathfinder Programme (Hino *et al.*, 2017; Lincke *et al.*, 2020). While relevant for the practical implementation of a managed retreat strategy, providing recommendations about suitable areas to relocate to is beyond the scope of the current study.

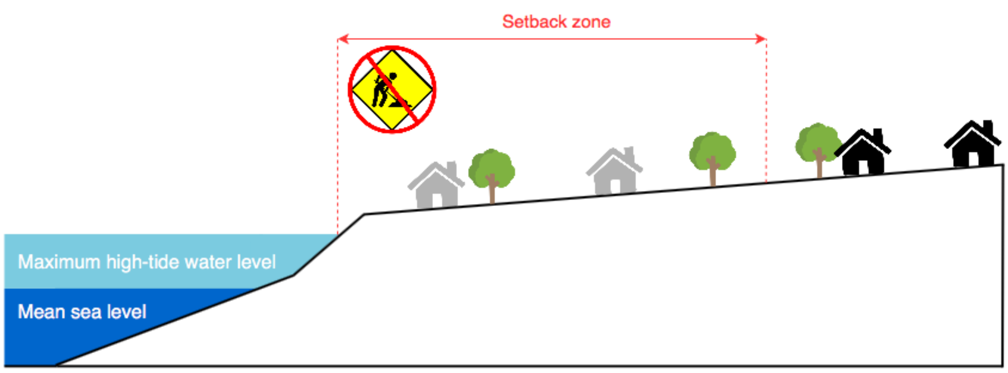

Figure A.1 Schematic representation of managed realignment through the implementation of a horizontal setback zone (adapted from Lincke et al., 2020)

The second retreat strategy is the implementation of construction restrictions that limit future development along the coast. As previously mentioned, Bonaire already legally restricts new development within 15m of the high tide line (OLB, 2018). Implementation of this second adaptation strategy would mean extending this zone further inland. A schematic representation of this strategy is provided in Figure A.2.

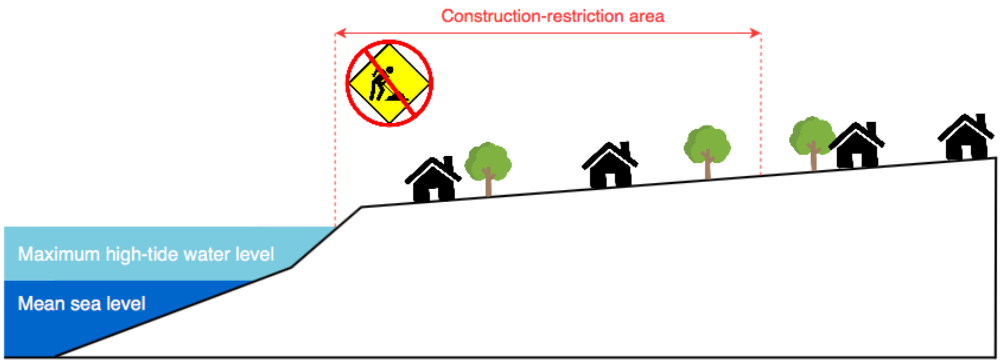

Figure A.2 Schematic representation of construction limits along the coast (adapted from Lincke et al., 2020)

Of the two strategies, managed realignment is more extreme, meaning that it is likely to be more difficult to implement and that it will get less support from residents, however, its potential benefits in terms of avoided damage outweigh those of construction restrictions (Lincke *et al.*, 2020; Mallette *et al.*, 2021). For that reason, both strategies have been included in the analysis. The zone distance for setback regulations implemented in Caribbean islands varies a lot. Fish *et al.* (2008), who evaluated the adopted zone distances for 33 Caribbean islands, reported setback zones ranging from 10 to 81m. A specific zone distance for the managed realignment or construction restrictions will not be considered for evaluation within this study, since this is highly location-specific and would require additional research that is beyond the scope of this thesis.

A.2 Seawall

A seawall has been selected as a potentially appropriate coastal adaptation option for Bonaire, since they only require minimal space, making them well-suited to protect coastal urban areas like Kralendijk (Schoonees *et al.*, 2019). Moreover, an onshore structure was selected rather than an offshore structure because foreshore structures merely reduce wave energy, while onshore structures also protect against flooding and storm surges (Schoonees *et al.*, 2019).

A.3 NbS: mangroves & coral reefs

The green infrastructure strategies that were selected for this study include coral reef restoration and mangrove restoration and replantation. Figure A.3 shows the Reef Health Index (RHI) values of coral reefs on the Leeward side of Bonaire. Research has shown that healthier reefs provide more coastal protection than degraded reefs (Harris *et al.*, 2016). As is shown in Figure A.3, a significant part of Bonaire's shallow reefs is currently significantly deteriorated. Therefore, it is deemed potentially beneficial for the coastal protection of Bonaire to actively pursue reef restoration, specifically for coastal protection purposes. The reef restoration scenario will consider both natural reef restoration as well as the use of artificial restoration, which is for example done by using concrete reef balls (Hegde, 2010). The latter is a commonly applied method in Caribbean small islands, implemented in for example in Mauritius and the Dominican Republic (Hegde, 2010; Wong, 2018). Mangrove restoration has also been included, as mangroves can be found in the Lac Bay as well as along the vulnerable south-coast of Bonaire, in comparison to seagrass beds, which are only found in the Lac Bay (Debrot *et al.*, 2018). A recent study by Menéndez *et al.* (2018), carried out in the context of the Philippines, showed that mangroves can potentially play an important role in flood risk reduction on small islands.

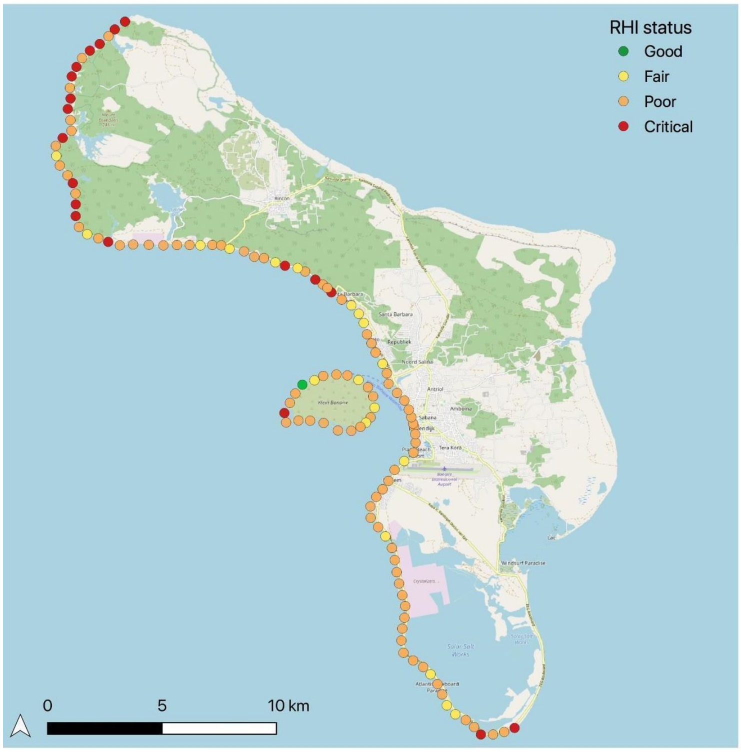

Figure A.3 *This figure shows RHI values for 2017, indicated per site, for the shallow reefs (5m) at the Leeward side of Bonaire. None of the shallow reef locations have an RHI value that corresponds to very good (Meesters, 2020)*

A.4 Eco-seawall

The selected hybrid solution is the use of an eco-seawall (Figure A.4). Building eco-engineered seawalls can be done without negatively affecting the level of protection offered, while potentially delivering ecological benefits (Schoonees *et al.*, 2019). Research has shown that using eco-engineered tiles can result in increased habitat complexity when added to conventional seawalls, effectively contributing to marine biodiversity (Bradford *et al.*, 2020). This hybrid option has been chosen over a combination of measures as the focus of this study is on the evaluation of individual measures.

Figure A.4 An example of a 3D printed eco-seawall in Sydney (Living Seawalls, 2021)

A.5 Dry-proofing

The selected property level adaptation option is dry-proofing houses along the coastline. As dry-proofing strategies aim to prevent floodwaters from coming into the building, dry-proofing strategies entail a combination of measures that account for water entering the house through doors or other openings, through walls, and via the sewage system (FEMA, 2014). Generally, this includes the deployment of removable door shields and airbrick covers, the retrofitting of houses with waterproof coatings, and the installation of backflow valves in the sewer lines and drains (FEMA, 2014). An overview of a typical dry-proof scenario can be seen in Figure A.5. Dry-proofing measures can be affordable adaptation options that can also be installed by residents themselves. It is not recommended to dry-proof homes above a 1m elevation, as houses can collapse under the pressure of the water surrounding their walls (de Moel *et al.*, 2013). The measure thus protects against shallower floods but also buys time for the relocation of valuable belongings upstairs in the case of a more severe flood (Bowker, 2007). In line with the approach taken by de Moel *et al.* (2013) and Lasage *et al.* (2013), this study assumes dry-proofing up to a height of 1m.

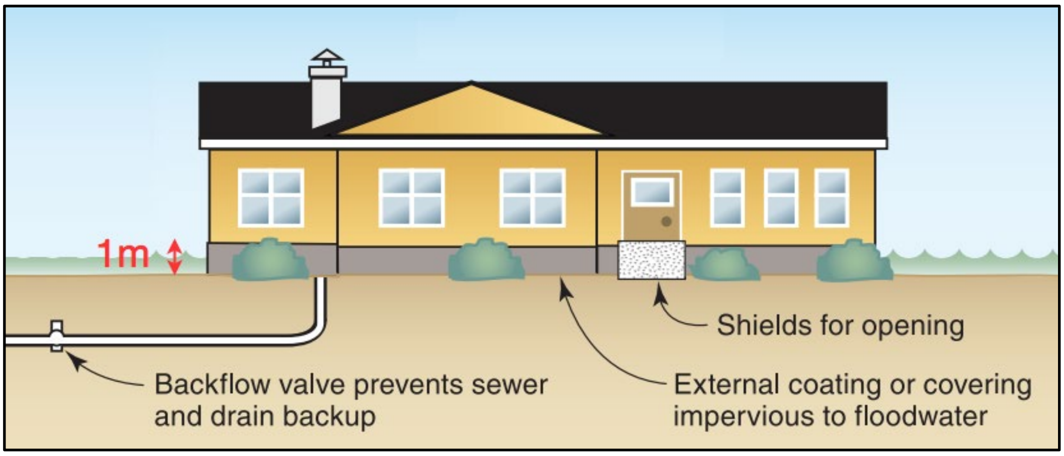

Figure A.5 Schematic representation of a dry-proofing scenario. Adapted from FEMA (2014)

Annex B Stakeholder involvement

Table B.1 Elaborate overview of conducted interviews. All interviews were conducted in 2022

Name	Organisation	Elaborate description	Date	Weights provided?	Language
Emma Pratt	Fundashon Históriko Kultural Boneriano (FuHiKuBo)	Project leader at FuHiKuBo, an organisation focused on intangible cultural heritage on Bonaire	18-Apr	Yes	ENG
Serapio Pop	/	Local, former director of the Scholengemeenschap Bonaire, former board member of the Movementu di Pueblo Bonariano	09-May	Yes	NL
Arthur Sealy	/	Historian, local	11-May	Yes	ENG
Sabine Engel	Mangrove Maniacs	Owner of Mangrove Maniacs, marine biologist	28-Apr	Yes	NL
[Anonymous]	[Anonymous]	Reef expert	16-May	Yes	ENG
Kaj Schut	Sea Turtle Conservation Bonaire (STCB)	Manager at STCB	20-Apr	Yes	NL
[Anonymous]	[Anonymous, nature consultancy]	Nature expert	21-Apr	Yes	ENG
Quirijn Coolen	Bonbèrdè	Director of Bonbèrdè, a nature consultancy company. He has a background in forestry and conservation management	19-Apr	Yes	NL
Roxanne-Liana Francisca	Stichting Nationale Parken Bonaire (STINAPA)	Marine biologist at STINAPA	25-Apr	Yes	NL
Bart Snelder	Council of Underwater Resort Operators (CURO), Wannadive Grand Windsock	Director of CURO(diving association) and owner and founder of Wannadive Grand Windsock (dive school)	05-May	Yes	NL
Leon Schellevis	Chogogo Dive & Beach Resort	Manager of Chogogo Beach Resort	04-May	Yes	NL

Name	Organisation	Elaborate description	Date	Weights provided?	Language
Anja Romeijnders	Bonaire Business and Employers (BBE)	Board member at BBE	10-May	Yes	NL
David Rietveld	Delfins Beach Resort	General manager of Delfins Beach Resort, former board member of Bonaire Hotel and Tourism Association (BONHATA)	06-May	Yes	NL
David Smith	Smith Warner International	Managing director at Smith Warner International: an engineering-, construction-, and management company working on coastal adaptation in the Caribbean.	16-May	No	ENG
Stacey Mac Donald	Wereld Natuur Fonds (WNF), Piskabon	Project advisor of WNF and founder of Piskabon, the local fisheries association on Bonaire	23-May	Yes	ENG
Frank van Slobbe	Openbaar Lichaam Bonaire (OLB)	Policy advisor of environment and nature at the direction of spatial development of the OLB	10-May	Yes	NL
Burney el Hague	Fundashon Mariadal	Operations manager at Fundashon Mariadal, a healthcare institute in Bonaire. He is also a local, former politician, and the host of a talk show on general and sustainable development (LIVE99.9FM)	29-Apr	No	ENG
Jimmy Meijer	Steenbouwadvies	Director of Steenbouwadvies, a construction company on Bonaire	04-May	Yes	NL

Annex C Scoring of criteria

Table C.1 Overview of the scores that were constructed for individual stakeholders based on quotes

Stakeholder	Scenario	Criterion	Score	Quotes
N3	Coral reef restoration	Economic effect	4	"Ja ik weet niet, qua werkgelegenheid, op de manier hoe het nu wordt gedaan zou ik zeggen nee, omdat het voornamelijk door stagiaires gedaan wordt. Niet echt werkgelegenheid verschaffend. Ik weet wel dat ze ook met andere dive shops samenwerken en die kunnen dan ook die pakketten verkopen, dus ik denk wel dat het een positieve impact heeft op de economie door, meer geïnteresseerden laten we zeggen, die dan voor dat soort.. Misschien kiezen mensen voor een dive extra om dan de coral restoration dive te kunnen doen." "Als het koraal beter zou worden van de restauratie, dan zou dat een positieve impact hebben op de economie en de mensen. Mijn vraag is of dat echt waar is, dat het koraal beter wordt van de restauratie."
M1	Mangrove restoration	Self-sufficiency	2	"Sargassum en dat is.. Ja daar hebben ze nog geen grip op. Dat verbetert wel elk jaar, maar dat is gewoon nog heel moeilijk en dus in dit hele zuidelijk gebied komen mangroves voor, meer binnen maar ook vooral langs de kust. En heb je hier Lagun, daar komen of ja komen ook, of kwamen, mangroves voor. Die staan door Sargassum heel erg onder druk en daar doen ze nu nog niks aan en dat is heel jammer, daar zie je gewoon alles doodgaan." "Als we die lading modder eruit hebben, dan heeft het veel meer zin om dat te herstellen." "En de drie grootste bedreigingen voor mangroves zijn inderdaad die hydrologische connectiviteit, verhoogde erosie en sinds kort ook Sargassum, sinds 2015. Dus die hydrologische connectiviteit pakken we aan. Erosie zijn we ook mee bezig. Dat doen we ten noorden van Lac en de catchment area. Daar zijn al twee gebieden die omheind zijn en waar geen grazers meer kunnen komen. En het ene gebied is 32 hectare en dat van een private stichting. De andere gebied is bijna 7 hectare en van de Bonaire overheid en, dat hebben we in 2019 omheind en we zijn nu pas begonnen te planten. Wat we daar nog moeten doen is dammetjes aanleggen, zodat het oppervlaktewater er niet zo doorheen stroomt en alle modder meeneemt, want met herplanten heb je wel succes, dus dat je op de grond vasthoudt, maar dat duurt gewoon.. dat heeft de tijd nodig."
		Effectiveness	2	M1: "Maar we moeten echt nog kijken van.. het is maar een hele smalle strook, dat zie je wel. Sommige stukken zijn iets breder, maar andere stukken zijn heel smal. Er zijn gegevens over, dus je dat zou je gewoon kunnen extrapoleren, maar het is natuurlijk maar vrij beperkt. Ik heb ook gevraagd wanneer wat de laatste keer was dat er een storm kwam en wat het effect was en dat was 1999 en toen, in dat gebied, dus hier langs de zuidkust in een gedeelte is een heel strand weggeslagen en in dit gedeelte is hoofdzakelijk de schade die er was dat er stenen en materiaal dat langs de kust lag, dat dat op de weg lag en meer naar binnen. Dus de schade was relatief beperkt, maar.." Onderzoeker: "Maar je weet niet zo goed wat de rol is die de mangroves daar..?" M1: "Nou die kunnen dat allemaal tegenhouden tot op een bepaalde hoogte."

Stakeholder	Scenario	Criterion	Score	Quotes
O3	Seawall	Acceptability	1 to 5	Researcher: "So if we would put a wall or make like a Boulevard in more places, do you think people would accept that?" O3: "No, they won't. They will be.. they will be very negative about it. They won't accept it in the sense of.. they won't tell you that yeah we are so pleased that you're coming and setting up a wall. But at the end, I mean, if it is for their protection, they will have to accept it. It is, like, more an imposed acceptation that you will have." Researcher: "But you would find it a good idea? Would you be positive when they would say we put a high wall?" O3: "Yeah, it is for protection and actually, if we did not build this close to the, to the ocean.." Researcher: "The problem would not be there." O3: "Exactly." Researcher: "Why do you think other people would be negative?" O3: "People are more used to what they are used to. They are used to that view and that sight. They won't be positive about changes."
	Dry-proofing	Effect on characteristic appearance	2	"It will change, but this is less of an impact and it is more acceptable compared to the walls. It is not neutral, it is slightly not positive. I wouldn't call it negative, but not positive."
	Construction restrictions	Acceptability	1 to 5	Researcher: "And then the last one is only limiting future construction. Would people be less negative about that?" O3: "Depends on which people you see, you're already.. people made already cost with locations near the shore. They bought land, or they have a long lease that they paid for years. They pay money to the government and things like that, so.. and they will influence the rest." "I'm positive. Once again, but people need to move away from the shore. They don't believe it. But really, they have to get away from the shore. They're crazy building things on the shore." O3: "You see, maybe you haven't experienced it yet, but I have been in politics, I can assure you, it is very strange. But you never have rich people, people will interest, fighting anything. Have you ever seen in The Hague or Amsterdam, any rich people walking into any manifestation? I never saw anybody with money walking in.. Always you know, poor people will be at a manifestation and you always ask yourself, how can the poor people, what do.. you don't even have properties? So in my time as a politician, I made this island financially sound again, it is one of my major achievements on the island. And people recognize that too. And every time I was imposing things, people paying back etc, poor people have manifestation. I just asked them and I said, *"do you have that?" "No. Yeah, but you're killing people.." "Killing who? I'm killing rich people? That never pay taxes? So you pay taxes every day." "Oh." "Yeah, you pay taxes every day. You pay taxes buying stuff, you pay taxes in your loan, loan taxes and salary taxes imposed on your on your salary, but they are not paying anything."* Not that people believe me, I'm not socialist. I'm not communist. I'm not nothing. I'm a calculist. I just calculate. You need to pay your taxes and if you don't pay them, then I will make you pay, period." Researcher: "But they're still negative about this, even though they don't have any..?" O3: "Still. I'm telling you. The people that have the interest, the influence, the other people they have no interest at all to be negative about it to go against it. [Funny voice] *"They are taking away our rights"*. And then they don't even have a place along the shore." Researcher: "Okay, so do you think it would be equally negative as the setback zone or maybe less negative?" O3: "In the sense of how they experience it?" Researcher: "Yeah. Equally negative?" O3: "Yeah."

Stakeholder	Scenario	Criterion	Score	Quotes
N1	Seawall	Effect on coral reefs	2	Researcher: “Do you think if you would build something like this sort or the coastal construction, do you think it affects the reefs somehow?” ... N1: “like a wall behind the sand? Or a wall where?” Researcher: “Would it matter for the effect on the corals?"”... N1: “In the shallow areas, yes, in the deep areas, no.” Researcher: “Because what would the effect in the shallow areas be?” N1: “Because if you're blocking the waves that normally pass by, if they're blocked then you get more wave energy concentrated in the shallow areas and all these shallow corals, the ones that they do in restoration, they are going to break apart.”
	Eco-seawall	Effect on coral reefs	2	
	Coral reef restoration	Effectiveness	1	Researcher: “The effectiveness of corals in general in protecting the coast against storms?” N1: “So the coral for Bonaire, I actually think is neutral. If you restore the corals it is not that much more effective.” Researcher: “Corals, would that be effective? If it would be everywhere, the corals?” N1: “Yeah, but that's utopic, they will not be. Not in 50 years, or even 100.”
	Mangrove restoration	Effectiveness	2	N1: “If you do the mangroves it is more effective, but of course only in the mangrove area, which is not a lot of the island.” Researcher: “So in terms of damage reduction during a storm?” N1: “Yeah if we're looking at the entire Bonaire coast. Yeah, the mangroves are a very small [part].” Researcher: “Is there some place that really depends on the mangroves to be protected?” N1: “Yeah the Lac Basin” ... Researcher: “So if you would restore there it would be..” N1: “Effective only there, yeah. It is not a lot of effect for the island”
		Effect on coral reefs	4	“All these mangrove roots that's where there is like a nursery for the fish that then go back to the reef when they grow so yes, having more mangrove is good for the fish that also are out on the reef. But if that is good for the corals themselves? The hardstone corals, no I doubt it very much.”
	Dry-proofing	Acceptability	4	“I'm okay with that for the people that don't have the resources to buy a house somewhere else and move.”
	Setback zone	Effect on coral reefs	4	Researcher: “And then the last two, so the limiting the construction or taking away the construction? Do you think those would have positive effects on other ecosystems?” N1: “On the, yeah on the reef, which is basically also depending when they're located in the mangroves too and in the seagrass, depending on location.” [Because of deterioration of the watershed] N1: “Well, the problem is that construction guidelines that have been around I believe, since the 70s, or the 80s, are never respected. So every construction site that you go, hardly any, I mean I'm talking probably less than 5%, they actually clean construction. You can see s**t being blown on the reef, from plastics, from water with cement. The construction itself is so terribly regulated. And the guy's [that are] building, of course, the easiest is not to be careful and the cheapest, you just you know, whatever. So then yeah, coastal development is terrible.” Researcher: “So yeah, taking the houses away doesn't necessarily have a positive effect but not building new stuff would have?” N1: “Yeah. Not that it has a positive effect. It takes away that negative effect.”
		Effect on other habitats	4	
	Construction restrictions	Effect on other habitats	4	

Stakeholder	Scenario	Criterion	Score	Quotes
S1	Do nothing	Acceptability	2	“Geen actie is ook niet wenselijk, want als we het gewoon door laten gaan zoals het nu gaat .. We hebben natuurlijk heel veel kustbebouwing en dergelijke en als we dat gewoon door laten gaan dan is dat zeker niet wenselijk. Dus de huidige situatie is wat mij betreft onwenselijk om die gewoon door te zetten. Met betrekking tot zeeschildpadden, wanneer je niks doet en de zeespiegel blijft stijgen dat betekent dat er minder nestgebied beschikbaar zal zijn want de standen verdwijnen dus dat onwenselijk. Dus in dat opzicht is het wel wenselijk om iets te doen, maar dan eerder de oorzaak aanpakken dan op zoek te gaan naar oplossingen.” “Geen actie is ook niet wenselijk nee, want als je nu ziet hoe het gaat, waarbij de kust volgebouwd wordt, waarbij we steeds meer last zullen krijgen van storm, van zeespiegelstijging, waarbij een deel van het eiland van water zal lopen, dat is uiteraard ook niet wenselijk vanuit zeeschildpadden oogpunt. Vooral omdat je dan nestgebied niet ziet verdwijnen.” Researcher: “Maar er zijn dingen die je nog minder wenselijk vindt op de lijst toch?” S1: “Nou dat denk ik wel.”
C3	Coral reef restoration	Acceptability	4	Researcher: “And then, coral reef restoration. Corals, they break the waves. Therefore it can help with protecting Bonaire. Do you think people accept this?” C3: “Yes, because there is a, from STINAPA, they are now growing reefs, yeah.”
	Dry-proofing	Acceptability	5	Researcher: “Do you think people would accept a measure like this? To protect their house if it is along the shore?” C3: “Yes, yes. But who is going to pay? (laughing). But yes they will accept. It is about protection. They won't hesitate with those things.”
	Setback zone	Acceptability	2 to 5	C3: “The local people will say, five. But they will say four or three because they say *"we have to stay here, we can protect ourselves"*.” Researcher: “So maybe they would even be negative towards it?” C3: “The richest will be negative.”
E2	Coral reef restoration	Acceptability	5	Researcher: “Dus de acceptatie is sowieso hoog als jullie het gaan doen?” E2: “Ja, ja absoluut, ja, want op Curaçao hebben we al een duikschool, daar doen we dit ook.”
C2	Do nothing	Acceptability	1	“Er zijn altijd mensen die daar niet tegen kunnen of dat niet willen. Die zeggen nee er verandert niks, er gebeurt niks, maar je moet iets doen, je kunt niet zeggen van ik wacht af.” “Er moet iets gebeuren.”

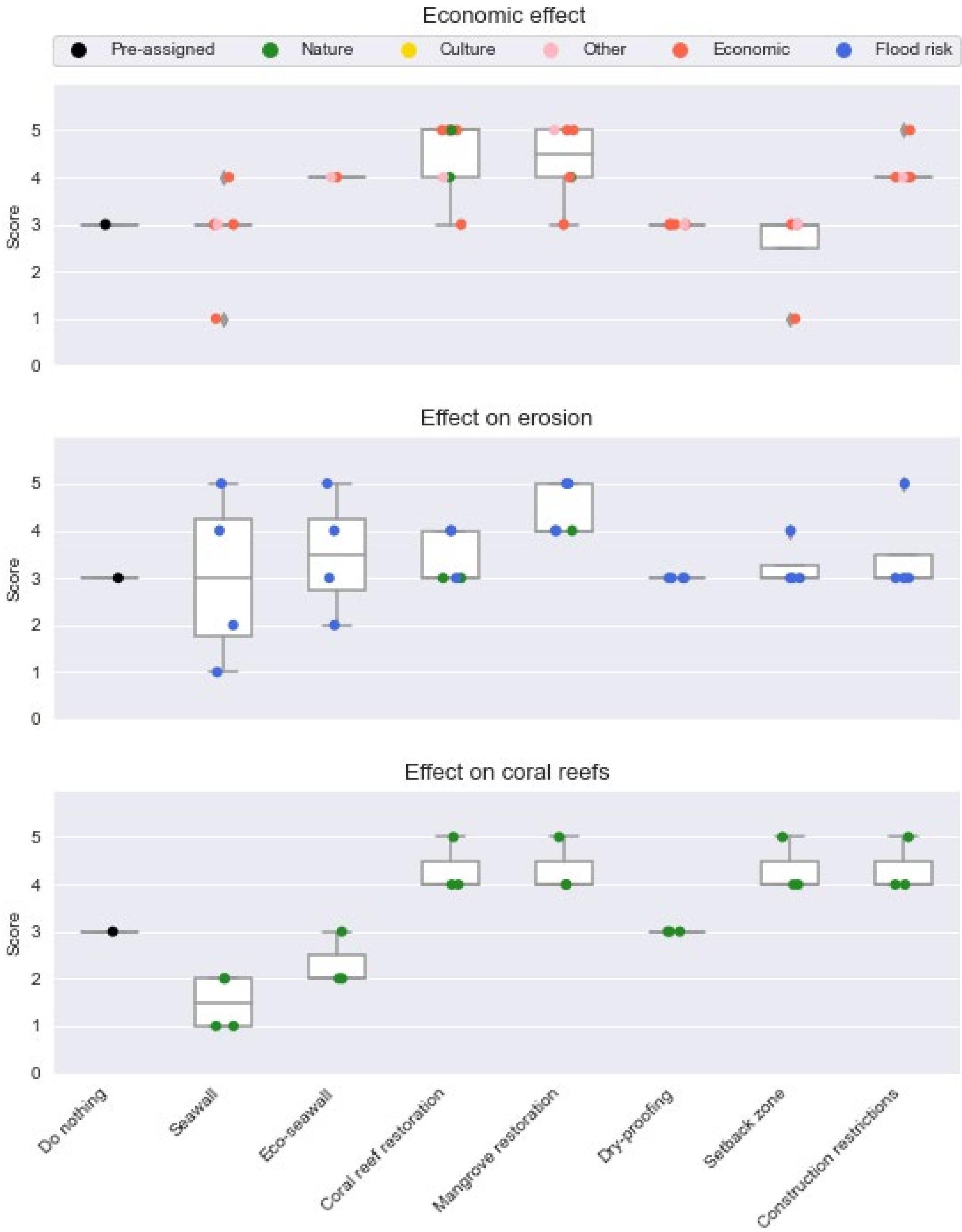

Figure C.1 Part 1 of the overview of the final scores provided for the criteria with scores ranging from 1 to 5, colour coded by stakeholder type

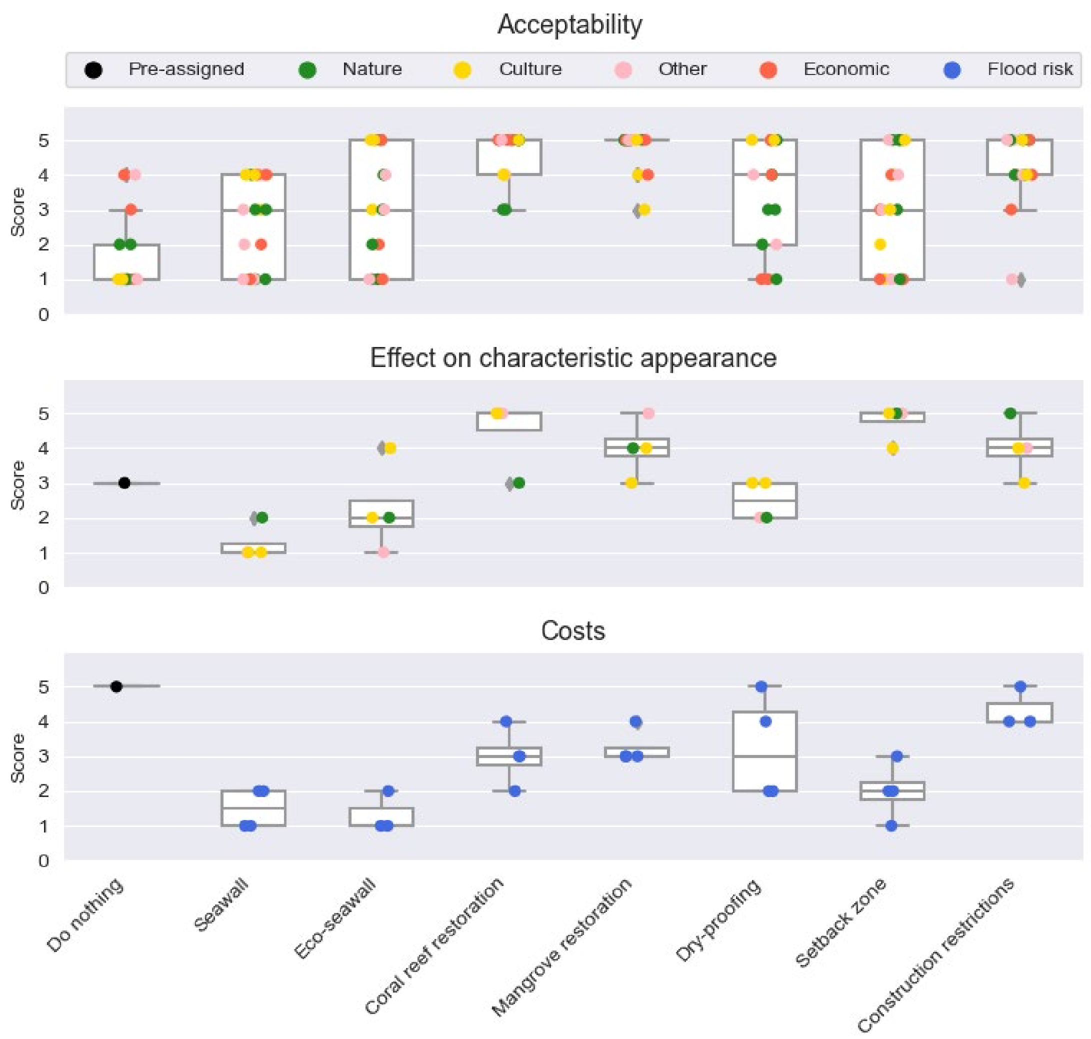

Figure C.2 Part 2 of the overview of the final scores provided for the criteria with scores ranging from 1 to 5, colour coded by stakeholder type

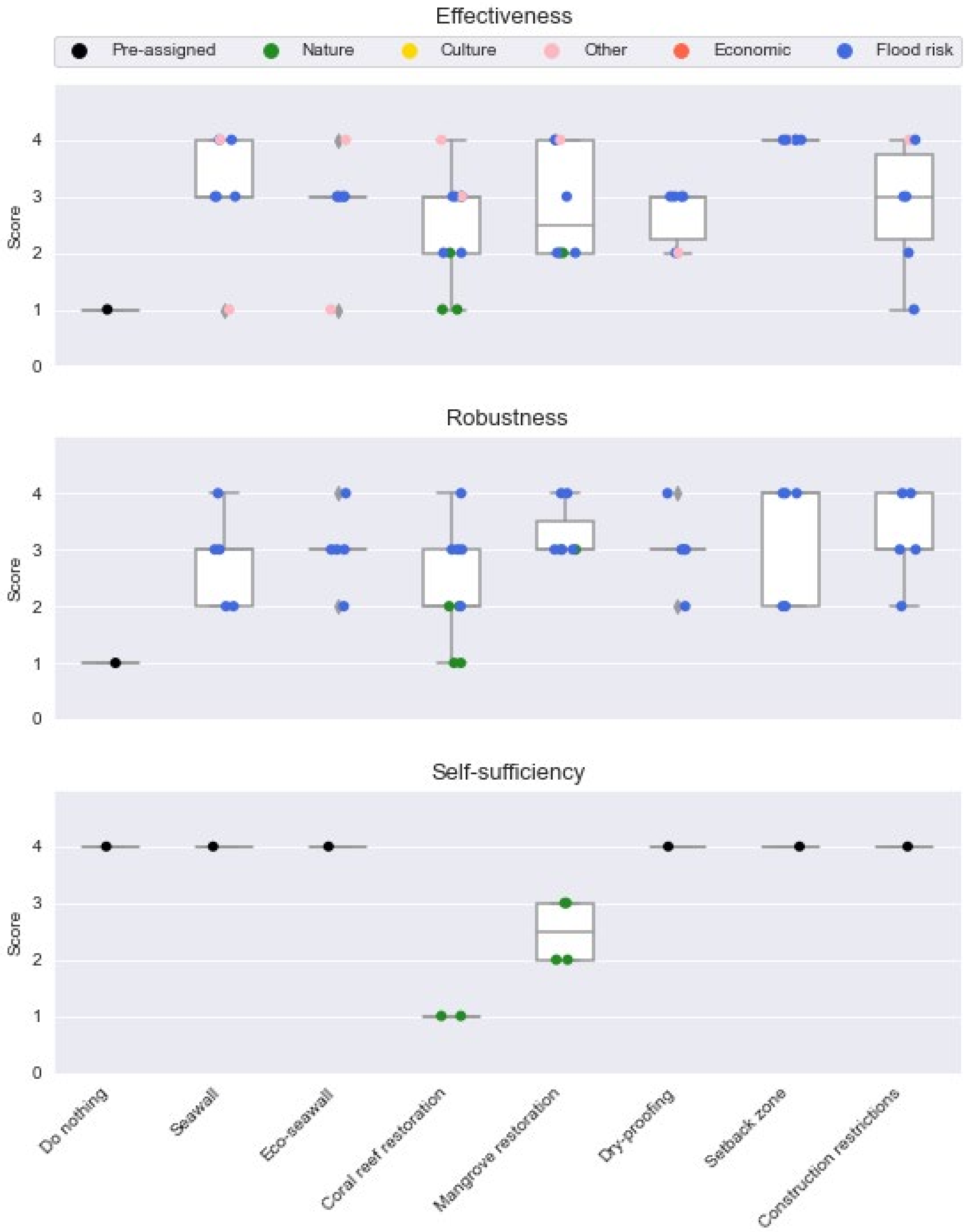

Figure C.3 Overview of the final scores provided for the criteria with scores ranging from 1 to 4, colour coded by stakeholder type

Table C.2 Summary of the raw average scores

Criterion	Do nothing	Seawall	Eco-seawall	Coral reef restoration	Mangrove restoration	Dry-proofing	Setback zone	Construction restrictions
Acceptability	1.71	2.56	3.00	4.56	4.75	3.53	3.10	4.29
Effect on characteristic appearance	3.00	1.25	2.25	4.50	4.00	2.50	4.75	4.00
Erosion	3.00	3.00	3.50	3.40	4.40	3.00	3.25	3.50
Effect on coral reefs	3.00	1.50	2.33	4.33	4.33	3.00	4.33	4.33
Effect on other habitats	3.00	2.60	2.60	3.80	4.80	3.00	4.20	4.00
Costs	5.00	1.50	1.33	3.00	3.25	3.25	2.75	3.67
Effectiveness	1.00	3.14	2.86	2.45	2.88	3.00	3.83	3.33
Effect on economy	3.00	2.80	4.00	4.50	4.33	3.00	2.50	4.20
Robustness	1.00	2.80	3.00	2.33	3.29	3.00	3.40	3.20
Self-sufficiency	4.00	4.00	4.00	1.00	2.50	4.00	4.00	4.00

Table C.3 Detailed version of the average weights per stakeholder group in comparison to the average weights. The colour indicates the perceived importance of the category, ranging from high (green, > 0.30), reasonable (yellow, > 0.15 and ≤ 0.30), to low (red, ≤ 0.15)

Category	Criterion	Weights									
		All stakeholders		Nature stakeholders		Economic stakeholders		Culture stakeholders		Other stakeholders	
Social	Acceptability	0.25	0.13	0.19	0.09	0.38	0.19	0.22	0.11	0.25	0.13
	Effect on characteristic appearance		0.13		0.09		0.19		0.11		0.13
Environmental	Erosion	0.37	0.12	0.45	0.15	0.32	0.11	0.35	0.12	0.25	0.08
	Effect on coral reefs		0.12		0.15		0.11		0.12		0.08
	Effect on other habitats		0.12		0.15		0.11		0.12		0.08
Economic	Costs	0.20	0.07	0.19	0.06	0.16	0.05	0.25	0.08	0.25	0.08
	Effectiveness		0.07		0.06		0.05		0.08		0.08
	Effect on economy		0.07		0.06		0.05		0.08		0.08
Technical	Robustness	0.18	0.09	0.17	0.08	0.15	0.08	0.18	0.09	0.25	0.13
	Self-sufficiency		0.09		0.08		0.08		0.09		0.13