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Regeneration at the Coast: Benefits beyond Blue Carbon

A New Framework for Impact Assessment of Mangrove Restoration

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Regeneration at the Coast: Benefits beyond Blue Carbon

A New Framework for Impact Assessment of Mangrove Restoration

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MANGROVE MANIACS
LAC RESTORATION PROJECT

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Cover Image: One of the channels cleared and maintained by Mangrove Maniacs in Lac, Bonaire. (H. Smulders, 17-08-2020)

Content

Acknowledgements 1
List of Abbreviations 2
Summary 3
1. Introduction 4
1.1. Multipotent Natural Climate Solutions 4
1.2. Mangrove Restoration as an Example 5
1.3. A New Approach for Impact Assessment 5
1.4. The Purpose of this Research 6
2. Theoretical Framework 8
2.1. Solutions and Services from Nature 8
2.2. The Importance of Mangroves 8
2.3. Restoration and Conservation 9
2.4. Mangrove Restoration Potential 10
2.5. Impact Assessment of Mangrove Restoration 10
2.6. Downscaling the Doughnut 12
2.7. SJOS and Effective Implementation 12
2.8. SJOS and Community Perception 13
2.9. Conceptual Framework for Mangrove Restoration Impact Assessment 13
3. Methods 15
3.1. General Research Framework 15
3.2. Development of the ISJOS framework 15
3.2.1. Interview Set-up 16
3.2.2. Interview Analysis 17
3.2.3. Identification of Indicators for the ISJOS Impact Dimensions 18
3.3. Development of Indicators for Effective Implementation 19
3.4. Case Study 19
3.4.1. Dialogue with OLB and STINAPA Bonaire 19
3.4.2. Assessment of ISJOS Indicators 20
3.4.3. Assessment of Effective Implementation Indicators 22
3.4.4. Community Perception study 22
4. Results 24
4.1. The ISJOS Framework 24
4.1.1. Overview of Interview Results 24
4.1.2. Dimensions of the ISJOS Framework 24
4.1.3. Indicators of the ISJOS Framework 30
4.2. Effective Implementation Indicators for Mangrove Restoration 40
4.2.1. Internal Factors 40
4.3.2. External Factors 41
4.3.3. Indicators for Effective Implementation 43
4.3. Case Study 44

4.3.1. Background 44
4.3.2. Dialogue with OLB and STINAPA Bonaire 46
4.3.3. Sustainability Impact of Mangrove Maniacs 48
4.3.4. Effective Implementation score for Mangrove Maniacs 49
4.3.5. Perceived Impact by the People of Bonaire 50
5. Discussion 56
5.1. Methodological caveats 56
5.1.1. Limitations of the development of the ISJOS framework 56
5.1.2. Limitations of the development of effective implementation indicators 57
5.1.3. Limitations of the assessment of Mangrove Maniacs 57
5.1.4. Limitations of the community perception study 58
5.2. Implications of Results 58
5.2.1 Findings from the ISJOS framework for mangrove restoration 59
5.2.2. Findings from effective implementation indicators in mangrove restoration 62
5.2.3. Findings from the assessment of Mangrove Maniacs 63
5.3. Mangrove Restoration Potential in a Broader Context 66
5.3.1. Taking mangrove restoration from potential to scale: financing beyond blue carbon 66
5.3.2. The importance of regeneration at the coast in changing times 67
6. Conclusion 69
6.1. A novel impact assessment of mangrove restoration 69
6.2. Challenges and facilitating conditions in mangrove restoration 69
6.3. Lessons learned from the work of Mangrove Maniacs 70
6.4. Recommendations 70
Appendix 1: Expert Interview Framework 72
Appendix 2: Interview Coding Schemes 73
Appendix 3: Literature Review on Impact Indicators 77
Appendix 4: Community Perception Surveys 79
Appendix 5: Expert Interview Results 81
Appendix 6: Outcomes of Dialogue Session with OLB and STINAPA 86
References 87

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Thyrza Zoons, 11th of February 2022



List of Abbreviations

Abbreviation	Definition	Page
CB	Citizens of Bonaire	23
CDR	Carbon Dioxide Removal	32
CO_2	Carbon Dioxide	4
DE	Doughnut Economy	11
EC	Ecological Ceiling	11
ES	Ecosystem Service	5
IAM	Integrated Assessment Model	4
IPCC	Intergovernmental Panel on Climate Change	4
ISJOS	Impact on the Safe and Just Operating Space	14
MM	Mangrove Maniacs	20
NbS	Nature-based Solution	8
NCS	Natural Climate Solution	8
NDC	Nationally Determined Contribution	32
NGO	Non-Governmental Organisations	6
NTFPs	Non-Timber Forest Products	29
ROB	Ruimtelijk Ontwikkelingsplan Bonaire (*Spatial Development Plan Bonaire*)	47
RSJOS	Regional Safe and Just Operating Space	12
SDGs	Sustainable Development Goals	4
SF	Social Foundation	11
SJOS	Safe and Just Operating Space	11
SWI	Salt Water Intrusion	29
TEEB	The Economics of Ecosystems & Biodiversity	8

Summary

To close carbon emission gaps and achieve the Paris Climate Agreement, mangrove restoration has emerged as a potential solution. These forests are known for their exceptional carbon sequestration rates, but the attention for mangrove restoration and similar climate solutions in the marine and coastal environment is limited as compared to their terrestrial counterparts. By broadening our scope from a sole focus on the climate mitigation potential of these aptly coined 'blue carbon' solutions, towards the appreciation of their full range of benefits, the case for marine nature regeneration becomes more compelling.

In this thesis, I developed a new impact assessment framework for mangrove restoration, that includes indicators for sustainability impact as well as indicators for effective implementation. The framework is based on the concept of a Safe and Just Operating Space and is the first to translate this concept to the intervention level. Based on expert interviews and literature review, it explicitly considers the impact of the natural system as well as the impact arising from human interference. Altogether, 30 impact dimensions have been identified, underpinning the fact that benefits of mangrove restoration go far beyond its climate mitigation potential alone. This is complemented by an overview of challenges and facilitating conditions that typically influence the implementation success of mangrove restoration efforts.

The feasibility of local application of these frameworks is assessed through a case study on mangrove restoration on Bonaire. A selection of impact dimensions in this context is discussed, but data required for quantification was lacking. The case study score on indicators for effective implementation left only three indicators with considerable space for improvement. Mangrove restoration as performed on Bonaire may therefore provide useful lessons for efforts elsewhere. An additional community perception study suggested a difference in apprehension of mangrove ecosystem services between different demographic groups that exist on the island. It also showed how active engagement with restoration improved people's understanding of the value of mangrove forest.

The 'Impact on Safe and Just Operating Space' framework and the associated indicators for effective implementation presented here, provide a novel, more all-encompassing approach for impact assessment of mangrove restoration and may well be applied to other nature-based solutions. This thesis manifests a trans-disciplinary perspective on the meaning of sustainability impact, engaging both field practitioners, various stakeholders, and the local community. Further research should provide a quantitative analysis of mangrove restoration potential on a local scale, including counteracting disservices.

1. Introduction

As one of the most productive ecosystems on earth, mangrove forests are able to sequester grand amounts of carbon from the atmosphere. This feature has resulted in an increasing interest in the conservation and restoration of mangroves and other types of coastal wetlands as a climate mitigation strategy. Indeed, more than 840 Gt additional CO_2 has remained in the atmosphere since the post-Industrial Era (le Quéré et al., 2014). A systematic review of solutions to remove this 'excess' carbon dioxide from the atmosphere is published in 'Drawdown' (Hawken, 2017), listing a hundred promising innovations for either carbon sequestration or emission avoidance, including coastal wetlands. Each solution is presented as a business case, indicating their corresponding investment costs, net savings, and projected atmospheric CO_2 reduction potential by 2050. This approach taps into the global carbon market, allowing states and enterprises to buy or receive emission allowances from one another.

The monetization of coastal wetland carbon sequestration potential does however not account for the broad range of co-benefits, which would build an even stronger case for nature regeneration and help avoid perversely designed restoration efforts (Lewis III, 2005). Thus, the question remains as to how the impact of coastal wetland restoration can be best assessed in a more holistic and comprehensive manner. This thesis considers mangrove restoration as the most thoroughly studied and widely employed intervention in this field. Before elaborating on its benefits beyond climate mitigation, one first ought to understand the basic principles of carbon sequestration in natural systems.

1.1. Multipotent Natural Climate Solutions

The vast amount of naturally stored carbon in land and water ecosystems is a major contribution to the earth's carbon stock. Note here that not all natural sequestered carbon contributes to climate mitigation, since sequestered carbon dioxide is also partially released again in natural metabolic processes, such as respiration and oxidation. Only the share of sequestered carbon that is transformed into biomass results in a long-term carbon sink, required for climate mitigation.

Interventions that consist of active protection and restoration of the biosphere for the purpose of preserving these natural carbon sinks, are referred to as Natural Climate Solutions (NCS) (Griscom et al., 2017). The highest carbon sequestration rates are found in coastal wetlands, more specifically salt marshes, mangrove forests and seagrass meadows, which add up to 284-750 t CO_2 y^{-1} globally (Howard et al., 2017; Mcleod et al., 2011). Despite this potential, recognition of NCSs in the marine and coastal environment is limited in the 'Drawdown' publication and are far less represented in climate policy as compared to terrestrial systems.

In a special report by the Intergovernmental Panel on Climate Change (IPCC) on mitigation pathways, none of the analyzed Integrated Assessment Models (IAMs) – coupled climate-economy models that project the interaction between humans and nature – had incorporated the potential of carbon stored in the coastal and marine environment (Rogelj et al., 2018), also referred to as 'blue carbon' (Lovelock & Duarte, 2019). Incorporating deployment of marine and coastal NCSs in these models would provide policy makers with an indication of their usefulness in achieving climate targets and other sustainability goals.

Besides, for NCSs in general, it goes that their carbon sequestration potential alone does not capture the full range of benefits they generate. A more accurate valuation can be obtained by accounting for their multifunctionality towards other sustainability aspects alike (Kabisch et al., 2016), such as defined by the Sustainable Development Goals (SDGs) of the United Nations that include social, economic, and environmental dimensions of sustainability (United Nations General Assembly, 2015). With this approach, NCSs often prove as viable and even more cost-effective alternatives to engineered or 'grey'

solutions (Calliari, Staccione, & Mysiak, 2019; Seddon et al., 2020), which underpins their feasibility for investment and scaling.

1.2. Mangrove Restoration as an Example

The limited representation of marine and coastal NCSs and the services they deliver may form an underexposed opportunity to increase carbon sequestration capacity, while simultaneously addressing other sustainability challenges. An adequate impact assessment is required to reveal this broader potential, but existing frameworks used to assess NCSs impact fail to capture the full potential of solutions in coastal wetlands (C. J. Brown et al., 2021). This can be explained by limited data availability, difficulties in quantifying socio-ecological indicators for these systems and the immature understanding of interconnectivity between the different types of coastal wetlands.

Since mangrove forests and their services are better described in academic literature as compared to salt marshes and seagrass meadows (Macreadie et al., 2019), the scope of this research is limited to mangrove restoration as a NCS. Mangrove ecosystems are, however, closely interconnected with the latter two marine ecosystems that are often found in close proximity to mangrove habitat and are both known to have similarly high carbon sequestration rates (Himes-Cornell, Pendleton, & Atiyah, 2018a). Even though interaction between these different types of coastal wetlands is vital to their combined impact on humans, climate and biodiversity, assessment of NCSs concerning salt marshes and seagrass meadows is not included here. The methods applied in this research may serve as a starting point for a more integrated framework that is suitable for interventions that concern various types of coastal wetlands.

1.3. A New Approach for Impact Assessment

The rapid degradation of mangrove forests globally (Goldberg, Lagomasino, Thomas, & Fatoyinbo, 2020) and their potential to contribute to sustainability objectives related to climate (Taillardat, Friess, & Lupascu, 2018; Zeng, Friess, Sarira, Siman, & Koh, 2021), biodiversity (Aburto-Oropeza et al., 2008) and socio-economic interest (Hochard, Hamilton, & Barbier, 2019), creates a strong incentive to restore degraded mangroves. Insights in the outcomes of mangrove restoration can be obtained through a variety of approaches: ranging from 1) ecosystem assessments that identify the ecosystem services (ESs) provided by mangrove forests (Mukherjee et al., 2014), 2) economic valuations that aim to capture the economic benefits of mangrove forests in monetary value (Mohammad Mahfuzur Rahman & Mahmud, 2018) and 3) impact assessments that evaluate environmental, social and economic outcomes of mangrove restoration as a human endeavor (Viswanathan, 2016). Here, it is important to differentiate between mangrove forests as a natural system and the intervention of mangrove restoration as a human-nature interaction.

For the purpose of analyzing the impact of mangrove restoration, a sole ecosystem level approach is per definition not sufficient, since it neglects the socio-economic impacts that follow from processes inherent to the way an NCS intervention is set up, such as community engagement and education. Economic studies that have made an effort to monetize the services provided by mangroves showed these can not be fully expressed in monetary value (Mukherjee et al., 2014). Also, the economic value of natural mangrove forests is estimated to be higher than restored mangrove forests (Su, Friess, & Gasparatos, 2021), but this conclusion negates the urgency of enhancing carbon sequestration through nature regeneration alongside conservation efforts.

Despite providing insightful information, the first two approaches fail to capture a holistic picture. Impact assessments on the other hand, are better suited to assess the intervention of restoration and also allow for intangible outcomes that can not be monetized. A recent meta-analysis of impact

assessments of mangrove restoration efforts analyzed 188 studies, listing 26 relevant benefits of mangrove restoration (Su et al., 2021). However, no socio-economic indicators were included in this analysis as data availability on these services was too little to assess. This indicates that more analysis efforts should go into the socio-economic outcomes of mangrove restoration, alongside the environmental outcomes.

Furthermore, mangrove restoration is not an anthropogenic intervention in vacuum, but its impact and effectiveness are submitted to external stressors, such as the influx of sargassum seaweed (Chávez et al., 2020) and marine aquaculture (Ahmed & Glaser, 2016). Similar to these external factors on higher scales, there may also be internal factors on the project scale, concerning the restoration practice itself, that determine its success. Assessing the exposure to these challenges or the availability of solutions to deal with them, contributes to the overall understanding of the effective implementation of a mangrove restoration effort, in addition to its sustainability potential. Conversely, the sustainability impact as measured through indicators, may be well different from the perceived impacts amongst the community. Specific consideration of these perceived impacts are valuable in improving community engagement and support, which are inherent to a restoration effort's longevity and social sustainability.

1.4. The Purpose of this Research

This research aims to identify and apply a framework of indicators for mangrove restoration to understand the sustainability impact and conditions for effective implementation of this multipotent NCS. The local application of the framework is studied through a case study on a mangrove restoration project on Bonaire, 'Mangrove Maniacs', which entails discussion of some framework indicators in a local context and a complementary community perception survey (see Methods). The following research questions guide the development and application of the framework:

1. What indicators describe sustainability impact of mangrove restoration?
    a. How does mangrove restoration impact the planetary boundaries?
    b. How does mangrove restoration impact human needs and interests?
2. What factors influence effective implementation of mangrove restoration?
    a. What are the internal challenges and facilitating conditions for mangrove restoration?
    b. What are the external challenges and facilitating conditions for mangrove restoration?
3. What is the actual and perceived impact of mangrove restoration on Bonaire?
    a. How does mangrove restoration on Bonaire score on both previously developed indicator frameworks?
    b. How are the impacts from mangrove restoration on Bonaire perceived by its residents?

Where the first and second research questions are concerned with the identification of indicators, the third research question seeks to provide an example of how these framework indicators are used. Results that follow from each of these research questions, directly address various societal interests and academic knowledge gaps. Firstly, the framework and corresponding indicators on sustainability impact that will be developed, can be used by policy makers, NGOs and investors that seek better understanding of the potential benefits and disservices concerning mangrove restoration. The framework may also serve as an inspiration for a similar tool for other (coastal) NCSs. Secondly, an overview of challenges and facilitating conditions in mangrove restoration informs field practitioners on the boundary conditions that should be in place in order to realize the aforementioned

sustainability impacts. Thirdly, the application of these sustainability and effective implementation indicators on the work of Mangrove Maniacs as a mangrove restoration project in Bonaire provides detailed insights in its 'on the ground' impact in a specific geographic context. This information may help the project to strategically present their efforts and outcomes to various stakeholders, e.g. in fundraising and collaboration. Additionally, a community perception survey complements these insights to facilitate further improvement in communication and education efforts on project activities.

2. Theoretical Framework

2.1. Solutions and Services from Nature

Before we proceed to define what Natural Climate Solutions (NCSs) encompass, we first consider the umbrella term 'nature-based solutions' (NbSs). Even though the terminological discussion on NbS has not reached consensus yet (Calliari et al., 2019), the use of it in the academic realm builds on a conceptualization by the IUCN (Cohen-Shacham, Walters, Janzen, & Maginnis, 2016) and the European Commission (European Commission, 2015). The essence of NbSs is in working with nature to tackle a wide variety of societal problems, which often share common drivers (Seddon et al., 2020). These solutions can range from nature preservation, to the integration of nature in human engineering and the translation of ecosystem functioning to anthropogenic systems, such as regenerative agriculture.

Regardless of their type of intervention, NbSs address multiple societal needs simultaneously, as a result of the natural range of services provided by an ecosystem. The latter is referred to as 'ecosystem services' (ESs) and consist of direct and indirect contributions of ecosystems to human well-being. Conceptualized by the Economic of Ecosystems & Biodiversity (TEEB), these services entail provisioning services (e.g. food and water), regulating services (e.g. climate regulation and water purification), habitat services (e.g. nurseries and genetic diversity) and cultural services (e.g. aesthetics and opportunities for tourism) (Kumar, 2012). An example of a NbS are 'vertical farms' in urban areas that not only serve as a food production system, but also serve as an aesthetic amenity in urbanized areas and have a cooling effect on the built environment (Kalantari, Tahir, Joni, & Fatemi, 2018).

As a result of this multifunctionality, NbSs have gained increased recognition as an integrated approach to realize the SDGs. Nota bene, the benefits of NbS are therefore assessed through an anthropocentric philosophy and ignores any intrinsic values nature may have (Nesshöver et al., 2017). The latter is neither included in the scope of this study. Other aspects of NbSs mentioned in literature are opportunities for participatory processes within the intervention (Pauleit, Zölch, Hansen, Randrup, & Konijnendijk van den Bosch, 2017) and the evidence-based, transdisciplinary knowledge required for effective implementation ("'Nature-Based Solutions' Is the Latest Green Jargon That Means More than You Might Think," 2017).

NCS are a subsection of NbS, to which all the above applies, but are distinguished in that these interventions have a specific purpose of reducing greenhouse gas levels and harnessing an ecosystem's potential as carbon sink. Note here, that this distinction is relevant in the discussion on climate mitigation solutions, but is not characteristic to the different functionalities of an NCS, as it may have a similarly wide range of benefits. That being said, NCSs have been recognized as helpful methods to reach the target under the Paris Agreement (Griscom et al., 2020). The maximum cost-effective potential of NCS for the purpose of carbon storage and avoidance of greenhouse gasses, is estimated to be 11.3 Gt of CO2 equivalent (GtCO2e) y^{-1}, which is a major contribution as compared to the current anthropogenic emission level of 42.1 GtCO2e y^{-1} (Friedlingstein et al., 2019) and counts for a >66% chance of limiting global warming to 2°C (Griscom et al., 2017). This calculation also includes coastal wetland restoration, but does not differentiate between different strategies therein, such as mangrove restoration. Another study estimated the mitigation potential for mangrove conservation to be 26.2 $MtCO_2e$ y^{-1} (Zeng et al., 2021), but the action of conservation is not one-on-one comparable with restoration, as will be explained below.

2.2. The Importance of Mangroves

Mangrove forests are found in coastal zones in the (sub)tropical and warm temperate regions and were estimated to cover approximately 137.000 km^2 in 2010 (Bunting et al., 2018). Anthropogenic

stressors, such as pollution (Maiti & Chowdhury, 2013), sea level rise (Saintilan et al., 2020), obstructed hydrology (Lewis et al., 2016) and deforestation (Thomas et al., 2017), pose threats of degradation and loss of these ecosystems (Islam & Bhuiyan, 2018). This is not surprising when considering that many coastal wetlands, including mangrove forests, are located in the world's most densely populated areas (Neumann, Vafeidis, Zimmermann, & Nicholls, 2015). People living in these regions, but also humanity as a whole, are however, reliant on the services that these ecosystems produce. The ESs of mangrove forests and their monetized value to humans, has been studied extensively and encompasses, but is not limited to, climate regulation through carbon storage (Taillardat et al., 2018), promotion of biodiversity through its nursery function (Carrasquilla-Henao & Juanes, 2017), coastal protection (Hochard et al., 2019) and opportunities for education and recreation (Spalding & Parrett, 2019). The combined value of and threats to mangrove ecosystems around the world creates a great incentive for their preservation. The potential for mangrove restoration might even be as big as 8000 km^2, referring to the surface area of already lost mangroves (Worthington, Spalding, Herr, Hingorani, & Landis, 2018). Another 1400 km^2 of degraded mangrove area could add to this potential.

2.3. Restoration and Conservation

It is important to distinguish the action of conservation from the action of restoration. Conservation is defined to be the active protection of healthy, well-functioning ecosystems from degradation threats. Restoration concerns ecosystems that have suffered degradation, but have the potential to be restored to productive, self-sustaining levels. The most commonly used definition of restoration is provided by the Society for Ecological Restoration (SER, 2004):

> *"Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed."*

In this study however, a more modern definition is adopted that captures both the ecological goals and social incentives (Martin, 2017):

> *"Ecological restoration is the process of assisting the recovery of a degraded, damaged, or destroyed ecosystem to reflect values regarded as inherent in the ecosystem and to provide goods and services that people value."*

Both conservation and restoration are relevant in the light of climate mitigation and other sustainability goals, but the scope of this research is limited to mangrove restoration as a NCS. The main reason for this approach lies in the difficulty of determining a reference point for mangrove conservation: calculating mitigation and other sustainability impacts for mangroves that 'might have been lost otherwise' tends to be biased towards scenarios that give the highest result (Gifford, 2020). The reference point for mangrove restoration however, can be determined more objectively with data on already lost and degraded mangrove forests. Another reason is the fact that restoration actively increases the amount of carbon sequestered in the soil and aboveground biomass, thereby removing it from the atmosphere and directly decreasing humanity's 'legacy load' of carbon dioxide. Furthermore, by adopting the definition for restoration as proposed by Martin (2017), one can consider a more comprehensive set of activities within mangrove restoration. Mangrove restoration might for example include the outplanting of seedlings (Kodikara, Mukherjee, Jayatissa, Dahdouh-Guebas, & Koedam, 2017), the maintenance of nurseries (Ravishankar & Ramasubramanian, 2004) and recovery of the hydrological regime (Jaramillo et al., 2018), but it might also entail the process of clarifying land ownership (Lovelock & Brown, 2019) and outreach and educational activities to engage the local community (Ellison, Felson, & Friess, 2020). Considering the full range of efforts and operations of a mangrove restoration enterprise is important in assessing its holistic impact.

2.4. Mangrove Restoration Potential

In a comprehensive model study of 6000 mangrove areas around the world and their respective restoration potential, Worthington and Spalding (2018) describe the benefits that mangrove restoration can yield globally. This includes a quantification of potential carbon sequestration, fish stock increases and the amount of people that profit from its coastal protection. The following paragraph describes this work in more detail, as it is considered a key paper in the relevant literature stream, and uses its findings to put the case study on Bonaire in the context of most recent quantification attempts for mangrove restoration impact.

An accompanying online tool, the "Mangrove Restoration Potential Map" (https://maps.oceanwealth.org/mangrove-restoration/), draws out a global extent of 6081 km^2 of lost mangroves between 1996 and 2016 and an extra 1389 km^2 of degraded mangroves in 2016, that drives the urge of restoration. The true potential however, depends on the 'restorability' or 'restoration potential score', which accounts for mangrove typology and environmental factors that influence effective implementation of efficiency. Mangrove typology has been classified into fringing (open coast), lagoonal, estuarine, and deltaic systems (also see Worthington et al., 2020). This distinction matters, as these systems thrive under very different ecological circumstances like salinity and freshwater inflow, and therefore have different levels of productivity. Environmental factors that determined the restorability factor include, for example, proximity to intact mangroves, permanent erosion, urbanization, time since loss, projected sea level rise and tidal range.

The projected global impact from restoring the lost mangrove areas in 2016, and the regional equivalents for Bonaire are presented in Table 1.

*Table 1 Mangrove restoration impact from a global projection, the impact share from Bonaire and earlier work on which model calculations are based (Worthington and Spalding, 2008). *It was not deemed legitimate to extrapolate coastal protection benefits to restorable areas from data available on current global benefits. ** This is the mean Restoration Potential Score of all mangrove areas assessed.*

	Based on	Global impact	Bonaire impact
Carbon	Hutchison, Manica, Swetnam, Balmford, & Spalding, 2014; Sanderman et al., 2018	1.34 Gt CO_2	29.7 kt CO_2
Fisheries (commercially viable fish and invertebrates)	Hutchison, Spalding, & Zu Ermgassen, 2014	63 trillion	5 million
Coastal Protection (people protected)	Losada et al., 2018	n.d.*	0
Restoration Potential (%)	Worthington & Spalding, 2008	60**	52

Boundary conditions that are stressed throughout the work of Worthington and Spalding (2008) are 1) the prioritization of conservation efforts in the first place, 2) a focus of restoration efforts in areas where mangroves have previously flourished, 3) the regard for social drivers that have disturbed the ecological balance originally and 4) community engagement and support to secure restoration impact in the future.

2.5. Impact Assessment of Mangrove Restoration

Since the impact of mangrove restoration goes far beyond its climate mitigation potential, or even fisheries enhancement and coastal protection value, it is important to account for all services that may arise from the ecosystem itself and the human intervention of restoration. Ecosystem assessments that identify and quantify the ESs from mangrove forests, such as the work of Worthington and Spalding (2008), do not allow for the latter, while the organized and often participative character of

NCSs may be significant in relation to sustainability goals such as social and gender equality (SDG 10 and 5) or just and inclusive communities (SDG 16). Moreover, the socio-ecological links that connect ecological processes to human needs and interest are difficult to translate into useful metrics (Ostrom, 2009) and therefore not yet sufficiently quantified for coastal wetlands (C. J. Brown et al., 2021). This is not to say however, that the valuation of ESs cannot be informative for an impact assessment. In fact, Schaubroek (2018) calls for an overarching sustainability assessment tool that also includes the explicit consideration of ESs.

To accommodate for the ways in which the endeavor of mangrove restoration benefits both social and ecological goals, a more holistic approach is required. The Doughnut Economics (DE) framework developed by Raworth (2017) provides a suitable basis, see Figure 1. The concept is in academic literature often referred to as the Safe and Just Operating Space (SJOS) and builds on the knowledge that sustainability is only possible within the biophysical limits of our planet– or the 'ecological ceiling', whilst accommodating for minimum social standards that are referred to as the 'social foundation'. The nine dimensions within the ecological ceiling (EC) are derived from the updated work of Earth system scientists on 'planetary boundaries' (Steffen et al., 2015). Transgressing the limits for these ecological dimensions means that we are overshooting the earth's carrying capacity. The dimensions within the social foundation (SF) are based on the international standards set for human rights under the 2030 Agenda for Sustainable Development (United Nations General Assembly, 2015), thereby demarcating the minimum thresholds for a dignified life that no-one should be deprived of. Any system or impact that remains between these two outer limits, the SJOS visualized as a 'doughnut', is considered to meet the needs and interest of the people involved within the means of our planet.

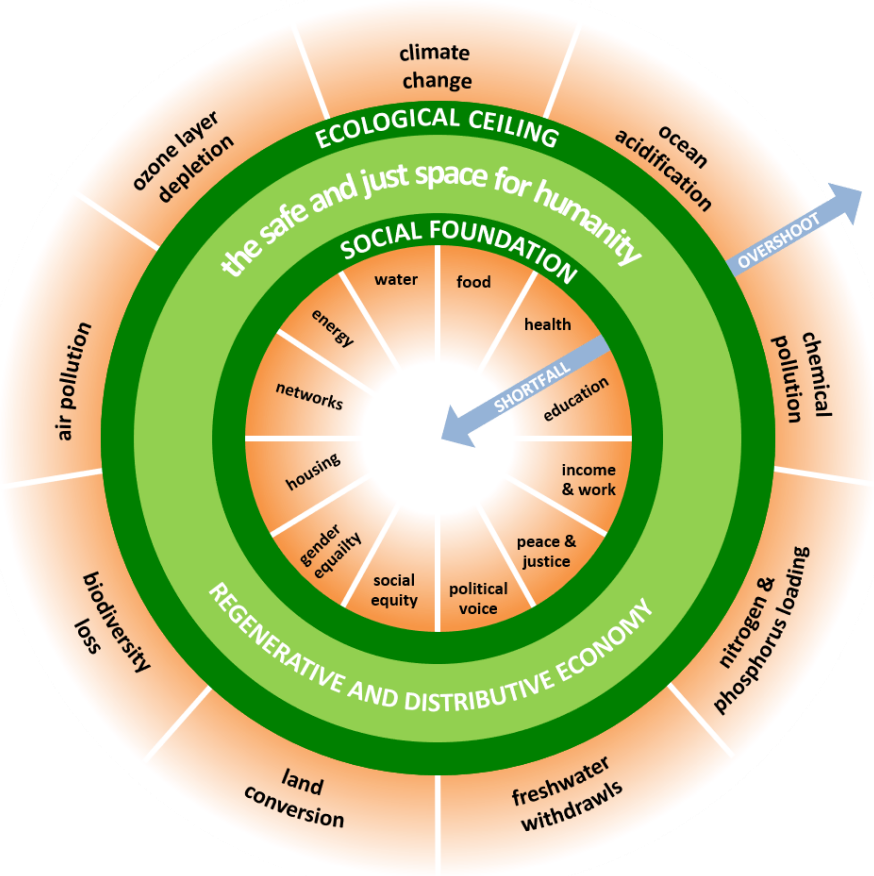

Figure 1 The conceptual model for Doughnut Economics (Raworth, 2017).

The visual framework has also proved very effective in communicating the complexity of sustainability to the broader public (Raworth, 2018) and has been embraced by the city of Amsterdam to shape its city-wide sustainability policy (Gemeente Amsterdam, 2020) with other cities following. Even though the framework has mostly been applied to the national (O'Neill, Fanning, Lamb, & Steinberger, 2018) and urban (Hoornweg, Hosseini, Kennedy, & Behdadi, 2016) context, and is well known for its global projection (Raworth, 2017), there is no application of the SJOS framework known to the organizational or intervention level, such as restoration efforts.

2.6. Downscaling the Doughnut

The first attempt to downscale the SJOS framework to the regional level, a Regional Safe and Just Operating Space (RSJOS), followed from the realization that most policy concerning sustainability issues is made on smaller scale (Dearing et al., 2014). It may therefore be more relevant to develop a SJOS on a regional level. There is a distinction between two different approaches in this regard: 1) a calculation of a region's relative share in and contribution to the global SJOS, and 2) the connection between relevant social well-being indicators on the regional level and the sustainable management of the relevant ecological indicators in the socio-ecological system (SES) concerned. The latter implies that both the SF and EC are qualified for the regional level and maybe different from the global SJOS framework as depicted in Figure 1. This is also the approach that is tested by Dearing and colleagues (2014). In later studies (J. Dearing et al., 2015; Hossain, Dearing, Eigenbrod, & Johnson, 2017), the necessity of long-term monitoring records and palaeoecological data for determining the ecological limits (Holocene values) was emphasized for the purpose of this approach. Since this requirement is unfeasible within the scope and time restraints of this thesis, the main focus here is on the first suggested approach, focusing on the contribution of a certain SES to the global SJOS.

A study on the SES of grasslands in Inner-Mongolia uses the RSJOS framework to quantify sustainability shifts after a change in local policy for grassland use (Fang, Wu, & He, 2021). The interlinkage between herder's wellbeing and different indicators for grassland state was assessed before and after the policy change, which is an example of the second approach mentioned before. Still however, the case for the Inner-Mongolian grassland has added interesting elements to the existing RSJOS literature by explicitly considering influences from outside the SES, being external systems – such as the local urban and mining system – and macro-conditions – such as climate change and human demography. As will become clear in Section 2.9., this extension of the RSJOS framework may prove very suitable for further downscaling the application of the SJOS framework to an intervention, such as restoration projects.

2.7. SJOS and Effective Implementation

When applying the SJOS framework to a planned or running project through the 'relative contribution' approach, we ask ourselves: '*How do(es) our project/organization/operations contribute to the social foundation and the ecological ceiling?*' So far, we have assumed this question to be sufficient in addressing sustainability impact. However, on the organizational level, local external systems and global macro-conditions influence the effective implementation of efforts. This influence may be positive (a *facilitating condition* to foster*)*, such as willingness in local politics, or negative (a *challenge* to overcome), such as limited management capacity.

Four major challenges concerning the effective implementation of coastal restoration have been identified to be related to 1) the restoration methodology, 2) climate change, 3) integration of social priorities and 4) perception of coastal restoration as a science-based tool (Abelson et al., 2020). The challenge of climate change can be directly linked to global macro-conditions. The third en fourth challenge can be linked to local external systems, as these provide the social support or opposition to restoration efforts. The challenges that may arise from the restoration methodology are not external,

but intrinsic to the restoration effort, therefore internal. The use of these three levels of challenges and facilitating conditions in mangrove restoration is further explained in section 2.8.

2.8. SJOS and Community Perception

The local community's perception of mangrove restoration is granted special attention in this thesis. As opposed to the aspects of sustainability impact or successful implementation, community perception does not illustrate what is *observable*, but what is *perceived*. To acquire suitable knowledge on these limitations, one ought to cross the traditional boundaries of academics, into the realm of society and its wide array of stakeholders. The added societal engagement that arises from doing so, results in 'transdisciplinary science'.

Where multidisciplinarity refers to the parallel application of different scientific fields, and interdisciplinarity refers to the integration of knowledge from these field, transdisciplinary science goes beyond the integration of disciplines and translates scientific knowledge into practical outcomes (Tress, Tress, & Fry, 2005). Here, not just the variety in academic perspectives is consulted, but also a similarly diverse range of perspectives from the live world and the societal values that exist therein. This has been a key point of attention in the methodology in this thesis, by involving on the ground practitioners and the surrounding community.

Transdisciplinary science operates in the interface between the academic realm that investigates sustainability issues and the societal realm that handles these issues (Pohl, Krütli, & Stauffacher, 2017). From this, it can be well understood that a transdisciplinary approach is very effective when studying the potential of nature-based or natural climate solutions, like mangrove restoration, since it inherently addresses the embedment of these solutions in a broader societal context (Wamsler et al., 2020). Acquiring data on the community perception of a mangrove restoration project can for example provide insights on the project's contribution to social capital and livelihood (Valenzuela, Yeo-Chang, Park, & Chun, 2020), which is represented by the 'social foundation' in the DE model. Including community perspectives can also expose challenges and opportunities that would not have been foreseen through a purely academic lens (Nguyen, van Tam, Quoi, & Parnell, 2016). Negative perceptions, or perceived 'ecosystem disservices' (D. Friess et al., 2021), of mangrove forests can for example include odour (Knight, Dale, Dwyer, & Marx, n.d.), a sense of danger (D. A. Friess, 2016) and the role of these ecosystems in pests and disease transmission (Claflin & Webb, 2016). The implications of both positive and negative perceptions of mangrove forests and restoration efforts related to them are essential in capturing the complexity of human interaction with mangrove ecosystems (Dahdouh-Guebas et al., 2020).

2.9. Conceptual Framework for Mangrove Restoration Impact Assessment

The conceptual framework used in this thesis builds on the original SJOS concept (Raworth, 2017), by adopting the SES framework developed by Fang and colleagues (2021) and extending it with the work done by Abelson and colleagues (2020), see Figure 2. Keeping with the aim to provide an improved impact assessment, we do not investigate the state of the system per se (*How far is it removed from the SJOS?*), but we want to increase our understanding of the intervention's Impact on the Safe and Just Operating Space (ISJOS) (*How does it contribute to the SJOS*?). Note the difference between SJOS and ISJOS.

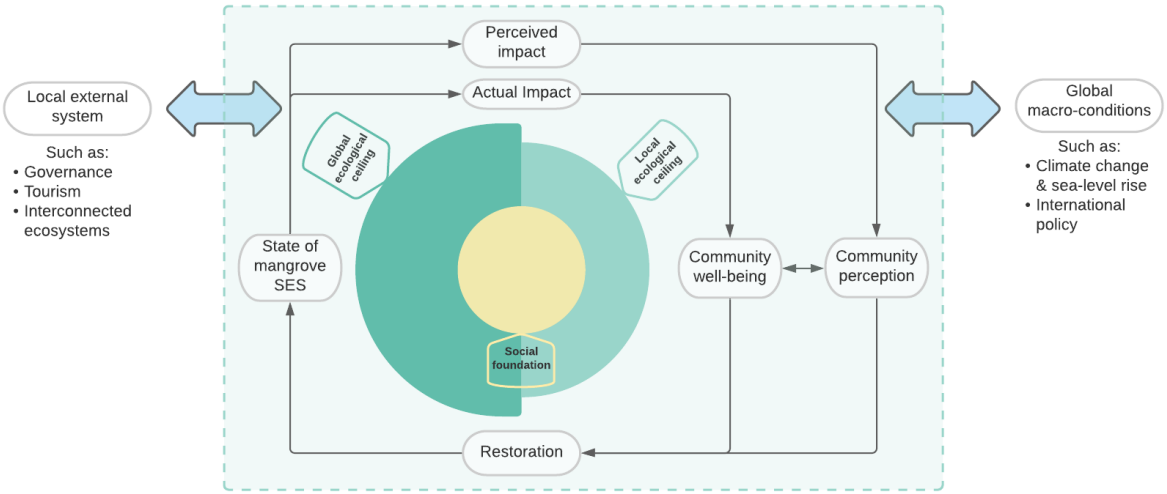

Figure 2 Conceptual framework for Impact Assessment of Mangrove Restoration

The impact from an intervention – in this case mangrove restoration, consists of what impact is observable (*Actual Impact*) and what impacts are perceived by the community (*Perceived Impact*). These impacts respectively affect *Community well-being* and *Community perception*, which have a reciprocal working as well. The combined community well-being and perception provides the incentives to either engage in or deter from restoration activities. The impact of restoration activities, through a change in SES state, can be measured and visualized in the SJOS framework. The doughnut then represents the organization's relative contribution to the local social foundation, the global ecological ceiling, and the local ecological ceiling. The scale distinction made between the latter two is presenting the scale differences between possible ecological ceiling dimensions that might be different for mangrove restoration. For example, the contribution of mangrove restoration to climate change would be protecting the global ecological ceiling. The contribution of mangrove restoration to sediment trapping would be protecting the local ecological ceiling. The restoration methodology, local external systems and global macro-conditions might pose certain challenges or facilitating conditions to the realization of restoration impact.

The dimensions of the SJOS or 'doughnut' for mangrove restoration, their respective indicators and the challenges and facilitating conditions arising from the restoration methodology, local external systems and global macro-conditions, are studied and defined in this research. The case study on Bonaire provides an example of a local application of this framework.

3. Methods

This chapter follows the three research questions defined in section 1.5. respectively, starting with an overview of the connection between them.

3.1. General Research Framework

The first stage of this research is dedicated to the development of indicators for sustainability impact (RQ1) and conditions for effective implementation (RQ2) of mangrove restoration. This is indicated in Figure 3 in blue and red respectively and will be further explained in the next paragraph. The steps in green and yellow comprise of an application of this framework on the case study in Bonaire (RQ3).

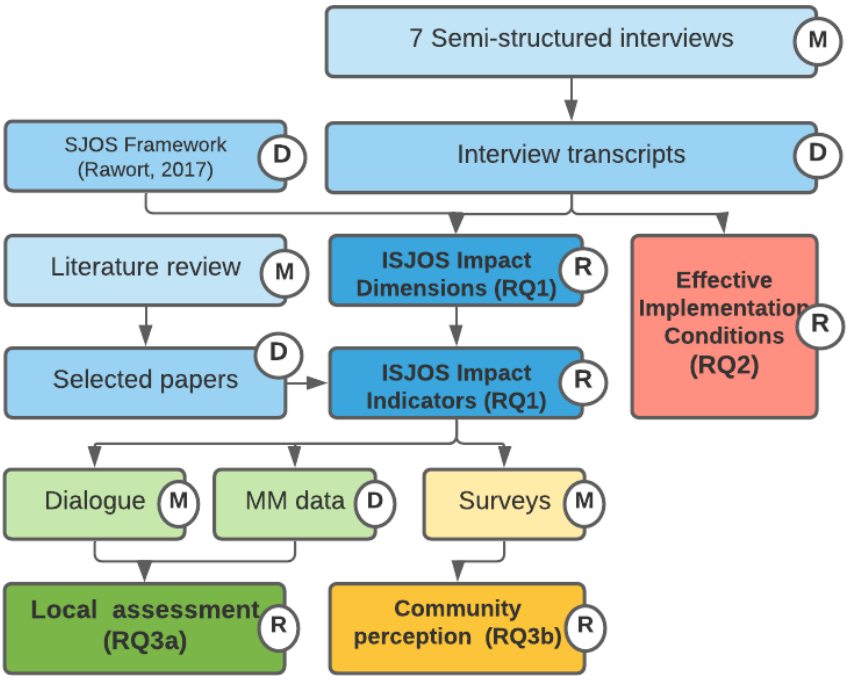

Figure 3 Research framework. M = methods. D = Data. R = Results. RQ = Research question.

3.2. Development of the ISJOS framework

To identify indicators for the ISJOS framework and for effective implementation, online semi-structured interviews were conducted with 7 anonymous experts that are involved with on-the-ground mangrove restoration work in various parts of the world, with a total of 73 years of experience, see Table 2. One expert has worked with 40+ mangrove restoration project globally, for which the working area was defined as 'World'.

This Section describes the identification of indicators for the ISJOS framework, but the interview set-up also applies to Section 3.3., which concerns the identification of effective implementation indicators.

As a reading guide, it is helpful to understand the build-up of the ISJOS framework in advance. The framework consists of 'impact themes' in the ecological ceiling and social foundation. Within some of these main themes, there may be one single 'impact dimension' or a subdivision of multiple impact dimensions. Each of these impact dimensions is described with an 'indicator', expressed by a corresponding unit.

Table 2 List of interviewed experts. In randomized order.

Working area	Role	Experience (y)	Type of knowledge
New Zealand, Thailand, Singapore	Assistant Professor at a University	12	Academic knowledge
Puerto Rico, Dominican Republic, Mexico	Program officer at an international environmental NGO	4	Project management
India, Bangladesh, Sri Lanka	Secretary and program manager of a national environmental NGO	14	Academic and field knowledge
Kenya	Intern at a national nature management organisation	3	Academic and field knowledge
Bonaire	Independent researcher commissioned by the local nature management organisation	7	Academic and field knowledge
Jamaica, Grenada, Antigua, Cayman Islands	Academic coordinator of a marine lab and consultant	17	Academic and field knowledge
World	Management of a small scale environmental NGO	16	Academic and field knowledge

3.2.1. Interview Set-up

The interviews addressed the following four themes:

1. The expert's background and personal experience with mangrove restoration projects
2. The expert's perception of the impact of mangrove restoration on protecting a healthy environment (*ecological ceiling*)
    a. Local impacts
    b. Global impacts
3. The expert's view on the impact of mangrove restoration on social and economic needs and interests of humans (*social foundation*)
4. The expert's view on challenges or facilitating conditions in the implementation of effective mangrove restoration arising from the methodology used, external systems on a local scale and/or macro-conditions on a global scale.

The experts were encouraged to answer from their personal practical experience. A detailed overview of the interview framework is available in Appendix 1. Interview results from theme 2 and 3 provided input for the ISJOS Impact Dimensions. Interview results from theme 4 provided input for the Effective Implementation indicators (see Section 3.3.). Questions within theme 2 and 3 (questions 3, 4 and 5) were derived from the 'Thriving City Portrait' developed by the Doughnut Economics Action Lab (DEAL, 2019). In the Results section, these will be referred to as the 'open questions'. To verify the comprehensiveness of answers provided here, additional questions were asked, following the dimensions of the Ecological Ceiling (EC) (question 6a) and the Social Foundation (SF) (question 6b) from the original SJOS framework (see Figure 1). Each dimension was discussed with the questions as shown in Figure 4. In the Results section, these questions will be referred to as 'the verification questions'.

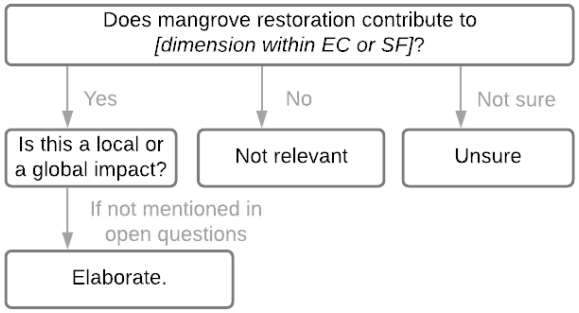

Figure 4 Interview directions for verification questions 6a and 6b.

3.2.2. Interview Analysis

Interview transcripts were analyzed through emergent coding. Unclear answers (e.g. due to language barrier or deficient internet connection) were omitted from analysis. Some of the remaining answers were not possible to include in the emergent coding, as they were either too general or not fitting any of the codes. An overview of the omitted responses can be found in Appendix 2c.

Coding schemes for each question are presented in Appendix 2. To integrate interview results on theme 2 and 3, coding schemes for the questions concerned were merged as follows. Verification questions 6a and 6b were used to complement previously given answers. The corresponding coding schemes (CSs) for questions 6a and 6b are therefore merged with the CSs for open questions 3,4 and 5. See Figure 5.

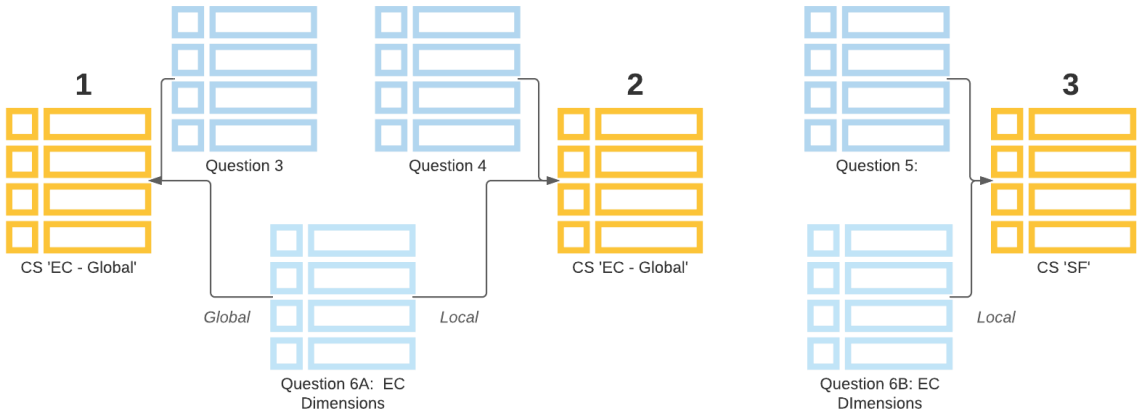

Figure 5 Aggregation of coding schemes (CS) for interview questions 3, 4, 5 and 6, resulting in CS 1, 2 and 3. EC = Ecological Ceiling. SF = Social Foundation.

All answers on question 6b that were coded as a 'global impact' were omitted, as the impact on the social foundation on a global scale tend to be very indirect and are not considered in this study. The resulting coding schemes provide an overview of all impacts suggested by the experts (from now on referred to as 'impact codes') on three levels of the ISJOS model:

1) Impacts on the Ecological Ceiling - Global
2) Impacts on the Ecological Ceiling - Local
3) Local Impacts on the Social Foundation

A decision tree (see Figure 6) was used to determine for each individual impact code whether or not to include it in the ISJOS framework. Firstly, all impact codes referring to negative impacts are included

in the ISJOS framework, to articulate the disservices that may be associated with nature, but are often underexposed (Friess, 2016). Impact themes that comprise of a subdivision of more specified impact codes (e.g. filtering of nutrients and filtering of heavy metals) are included in their entirety. The remaining impact codes are included in the ISJOS framework, unless an impact code is only mentioned by one expert, double listed in another coding scheme, or directly related to another impact in a cause-effect relation. Once included, we speak of an 'impact dimension' in the ISJOS framework. Suggested impacts that were not included after selection, can be found in Appendix 2c.

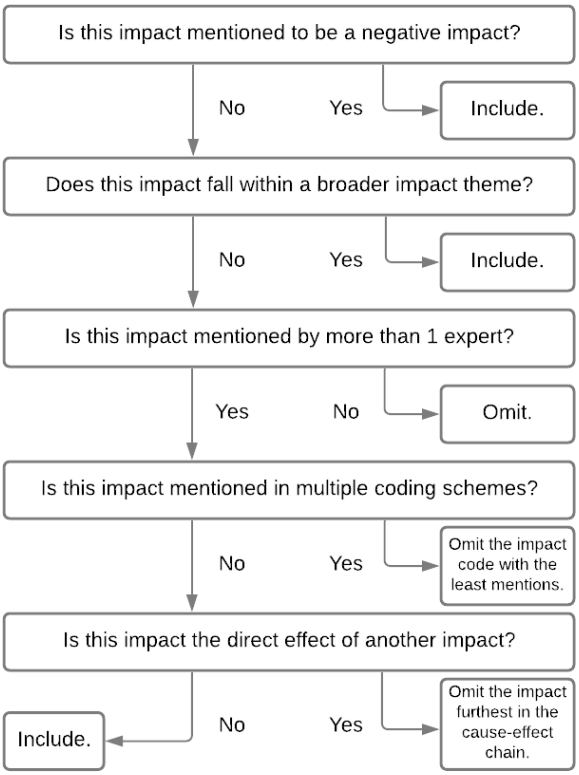

Figure 6 Decision Tree for the inclusion of impacts in the ISJOS framework.

3.2.3. Identification of Indicators for the ISJOS Impact Dimensions

The resulting selection of impact dimensions make up the ISJOS framework. Some of these fall within a broader 'impact theme'. Corresponding indicators for each of the impact dimensions are based on literature review.

The first search was performed on the 30th of November 2021, using the Scopus database and including papers from 2011 onwards. The following search string was applied for each impact (to be inserted in the square brackets) or a comparable description of the impact dimension: Mangrove* AND (restor* OR replant* OR rehabilitat* OR reforest* OR afforest* OR plant* OR recover* OR regener*) AND ("[Main theme]" OR [Comparable description]) OR ("[Impact dimension]" OR [Comparable description]). The resulting papers were screened on relevance. The paper with highest citations count was then used to adopt the indicator from. When no suitable indicator was found, either an indicator from more general, non-mangrove related literature was provided or the author's suggestion. The exact search string and number of search results for each impact is provided in Appendix 3.

To show the relation of ISJOS impact dimensions with the SDGs, the relevant SDG target or indicator is provided as well, if it explicitly refers to the impact dimension concerned. Here, a recently published

characterization of SDG relations with coastal functionalities was interpreted through the lens of mangrove systems (Schipper, Dekker, de Visser, Bolman, & Lodder, 2021). Connections between impact dimension and SDG target or indicator were then validated based on the corresponding methodologies of SDG monitoring.

3.3. Development of Indicators for Effective Implementation

Indicators for effective implementation of mangrove restoration are based on the challenges and facilitating conditions defined by the experts within theme 4 of the interview (see Section 3.2.1.). Questions within theme 4 are based on the three levels of challenges and facilitating conditions in mangrove restoration (see Section 2.6.): methodological, local external systems and global macro-conditions.

Interview results are coded using the coding scheme in Appendix 2d. A distinction is made between factors that were described as 'challenges' or 'facilitating conditions'. Challenges refer to conditions that require an extra effort or solution in order to be overcome. Facilitating conditions are favorable circumstances that don't need any further action other than maintaining them. Sometimes, both are applicable, depending on wording: 'lacking willingness of politicians' describes an undesired state or challenge, whereas 'fostering willingness of politicians' could be a facilitating condition that serves as a solutions to the previous. Where this ambiguity occurred, the expert's replies were phrased and coded as a challenge. Rephrasing a challenge into a facilitating condition is more subjective than vice versa, since there may different ways of dealing with a challenge.

The resulting list provides a set of indicators for effective implementation in the form of 'Yes/No'-questions. Effective implementation is likely when the indicators for Challenges are answered with 'No' (meaning '*not present*', or '*not relevant*') and when the indicators for Facilitating Conditions are answered with 'Yes' (meaning '*in place*').

3.4. Case Study

The ISJOS framework was applied on a local scale with a case study on Bonaire. Here, a local non-profit organization, 'Mangrove Maniacs' (MM), performs several restoration activities in Lac. Details on the restoration site and the work of MM, is provided in Section 4.3.1.

The application of the developed framework consists of two parts. First, a selection of ISJOS impact dimensions is quantified for the restoration progress in the period 2015-2021. Secondly, the work of MM is evaluated along the indicators for effective implementation, based on project information provided by the project's research coordinator (and chair of the foundation's board), Drs. Sabine Engel.

The selection of ISJOS impact dimensions used for the local assessment is based on the equal representation of all three ISJOS levels, data availability, knowledge interests from Mangrove Maniacs and policy priorities from OLB and STINAPA Bonaire as indicated in a dialogue session. To get an understanding of the latter, a dialogue session was organized with representatives from both parties.

3.4.1. Dialogue with OLB and STINAPA Bonaire

The dialogue consisted of a two hour session on 'Doughnut Economics', with the main goal to draft a first doughnut or SJOS for the island of Bonaire. The SJOS of Bonaire provides the frame in which the ISJOS of mangrove restoration or other interventions take place. This is helpful in understanding the policy priorities of OLB and STINAPA Bonaire and their connection with mangrove restoration.

The dialogue was attended by 5 policy officers and an intern from the Spatial Planning department of OLB and one biologist from STINAPA Bonaire, see Table 3.

Table 3 List of attendants of the OLB/STINAPA dialogue session.

Name	Function Title	Organisation
Thyrza Zoons	Thesis student/ Facilitator	Climate Cleanup/ Utrecht University
Constance de Vos	Minute taker	*independent*
Meike Breedveld	Policy Advisor Nature & Environment	OLB
Roland Bruijnesteijn	Policy Advisor Spatial Planning	OLB
Sam Strikker	Intern	OLB
Eva van Voskuijlen	Policy Advisor Nature & Environment	OLB
Meggie Salomonsz	National Government Trainee Nature & Environment	National Government/ OLB
Roxanne-Liana Francisca	Biologist	STINAPA Bonaire
Marialucia de Palm	Policy Advisor Economic Affairs	OLB

The main questions discussed during the dialogue were derived from the 'Thriving City Portrait' developed by the Doughnut Economics Action Lab (DEAL, 2019) and provided the input for a 'Doughnut of Bonaire', indicating the participants' perception of the social foundation priorities for the people of Bonaire and ecological ceiling priorities for the island of Bonaire. A second dialogue session on the perception of OLB and STINAPA Bonaire on mangrove restoration and its connection with the earlier drafted 'Doughnut for Bonaire' was canceled due to COVID-19 restrictions.

3.4.2. Assessment of ISJOS Indicators

The following ISJOS dimensions are discussed for the work of MM: Climate Change Mitigation, Fisheries, Increased Biodiversity Within Mangroves and Spiritual Well-being (see Results section 4.1.2.). The first two allow for comparison with the mangrove restoration potential calculations by Worthington and Spalding (2018). Biodiversity in Adjacent Ecosystems was chosen because it was mentioned as a priority in the OLB/STINAPA dialogue and it represents the local impact on the ecological ceiling in the ISJOS framework. Spiritual Well-being was a specific interest from MM.

The corresponding indicators for these dimensions can be found in Results section 4.1.3. They are discussed with estimations based on the best available data, see Table 4. Where data was not available for Bonaire or Lac, data from a similar system was used as a proxy.

*Table 4 Data sources used to assess the ISJOS indicators for the case study on Bonaire. *Based on a system other than Bonaire/Lac.*

ISJOS dimension	Data	Reference	Value
Climate Change Mitigation	Enhancement of carbon stock	Senger et al., 2021	462.2 Mg CO_2 ha^{-1}
Fisheries	Enhancement of fisheries catch per unit mangrove area*	(Conde, 1996; Hylkema, Vogelaar, Meesters, Nagelkerken, & Debrot, 2015)	74.7 kg ha^{-1} yr^{-1}
Increased Biodiversity within Mangroves	Enhancement of fish species richness	(Hylkema et al., 2015)	100 %
Spiritual Well-being	Community perception data	This thesis	See Section 4.3.5.

Climate Change Mitigation

In a recent study carbon storage differences between healthy and degraded mangrove areas in Lac have been quantified through remote sensing to understand forest structure and in-situ measurements on carbon dynamics (Senger et al., 2021). The spatial distinction between intact and degraded mangroves is in accordance with the classification provided by MM (see Figure 13).

Carbon stock estimates include aboveground biomass, belowground biomass and sediment organic carbon in the first 30cm. The average for degraded mangrove sites was 261 Mg C ha^{-1} and the average for intact mangrove sites was 387 Mg C ha^{-1} (Senger et al., 2021). Therefore, the average difference of 126 Mg C ha^{-1} , or 462.2 Mg CO_2 ha^{-1}, is used in discussing the impact of mangrove restoration on climate change mitigation.

Fisheries

No studies have been carried out on fisheries catch in Lac. Since the indicator for this dimension is adopted from the work of Worthington and colleagues (2018), it is suitable to follow the corresponding methodology to produce an estimate for Lac. This model on mangrove dependency for fisheries is however yet to be published (but see Worthington, Andradi-Brown, et al., 2020).

For this reason, an overview of small-scale fisheries catches in mangrove areas developed by Hutchison et al. (2014, p. 22) was used to obtain the fisheries enhancement value from a mangrove system most similar to Lac. The selected study was performed in the Laguna de Tacarigua, in Venezuela (Conde, 1996). This mangrove area is of the same typology as Lac (see (Worthington, zu Ermgassen, et al., 2020), has similar climatic conditions and carries a protected status as well, which implies a similarly regulated human extraction impact. The fisheries catch per unit mangrove area adopted from this study is 75.7 kg ha^{-1} y^{-1}, which is the value assumed for intact mangroves.

To obtain this value for degraded mangroves, the relative difference was based on a comparison between fish biomass data for different sub-habitats in Lac, including mangroves on the bay-side, pools within the mangroves and backwaters behind the mangroves (Hylkema et al., 2015). For the purpose of estimating the difference in biomass, these sub-habitats have been classified for comparison as follows from Table 5.

Table 5 Classification of Sub-habitats in Lac and corresponding mean fish biomass.

Sub-Habitat (Hylkema et al., 2015)	**Mean Biomass (kg ha^{-1})** (Hylkema et al., 2015)	**Classification**
Mangroves Bay	891.5	Not 'within mangroves'
Mangroves Blue Pools	1150.9	Intact mangroves
Mangroves Dark Pools	750.7	Intact mangroves
Backwaters	12.1	Degraded mangroves

Mean fish biomass in intact mangrove sites was 950.8 kg ha^{-1}. This is 12.1 kg ha^{-1} for degraded mangrove sites. Hence it is assumed that mangrove degradation leads to an average decline in fish biomass of 98.7%, which could potentially be reversed by mangrove restoration.

When applying this relative decline of 98.7% in fish biomass to fisheries catch, it follows that fisheries catch per unit mangrove area is estimated to be 0.96 kg ha^{-1} y^{-1} for degraded mangroves. The resulting difference of 74.6 kg ha^{-1} y^{-1} in fisheries catch between intact and degraded mangroves is used for the discussion on impact of mangrove restoration.

Increased Biodiversity within the Mangroves

To estimate the increase in biodiversity in the mangroves from restoration, the difference in mean fish species richness between intact and degraded mangrove sites is used, based on primary data from Hylkema et al. (2015) and following the classification provided in Table 5. For intact mangroves the averaged value was 10 species per 50 m^2 sample area and this was 5 for degraded mangrove sites. Hence, the biodiversity enhancement value used for discussing the impact of mangrove restoration is a 100% increase between degraded and intact mangroves.

Spiritual Well-being

The impact of mangrove restoration on spiritual well-being is derived from a community perception survey, which is set out in more detail in Section 3.4.4.

From this survey, the outcomes on perceived impacts (questions 6-9, Table 6), the valuation of the ES of 'esthetics' (question 19, Table 6) and the distinction between CB and MM respondents in these outcomes, are used as input to discuss the impact on spiritual well-being. For MM respondents, also their motivation to do mangrove restoration was considered (question 25, Table 6).

3.4.3. Assessment of Effective Implementation Indicators

The effective implementation indicators are assessed based on peer-reviewed and non-academic literature related to the work and working area of MM. For indicators on which no published information was available, the science coordinator of MM was consulted. These references are provided in Section 4.3.4.

3.4.4. Community Perception study

The perception study on the restoration work in Lac is carried out through a survey amongst two different target groups: 1) Citizens of Bonaire with a sedula (local ID card) that are not directly engaged with mangrove activities ('CB', n = 89) and 2) Residents of Bonaire (with or without sedula) that are directly engaged with mangrove restoration through Mangrove Maniacs ('MM', n = 10). Volunteering students that work with Mangrove Maniacs primarily for their education projects were excluded from the survey. A third target group of governance institutions would initially participate in the perception survey through a dialogue, but this was canceled due to COVID-19 restrictions. The surveys for CB and MM can be found in Appendix 4a and 4b, respectively.

Both surveys consisted of two identical sets of questions. The first set of questions aim to allow participants to elaborate on their general idea of positive or negative impacts from the mangroves in Lac on a personal level as well as on the island scale. The second set of questions asked participants to value specific ecosystem services provided by the mangroves in Lac. The questions are based on the summary of mangrove ESs as identified by Mukherjee et al. (2014), adjusted to the knowledge level of the participants. Some ESs are excluded from the questionnaire as they are irrelevant since Lac is a protected RAMSAR area where extractive activities are restricted (e.g. wood and pharmaceutical products). The survey for MM additionally addresses the participants' engagement with Mangrove Maniacs and the benefits they experienced from doing so. Table 6 contains the variables from the CB and MM surveys.

The CB survey was made available in Dutch and Papiamentu, and was distributed online in a Facebook group for Bonairian locals and physically on two separate Saturday markets in the city of Kralendijk. The Papiamentu translation was kindly provided by Mrs. Nancy Persad. To attract participants in the CB survey, two 30 USD vouchers for a local restaurant were raffled amongst the respondents. The MM survey was made available online in English, since this is the main language used at Mangrove Maniacs.

*Table 6 Survey variables. * = only in CB surveys. ** = only in MM surveys.*

	Variable	Survey question	Measurement
1.	**Sedula**	Are you in possession of a sedula?	Yes/No
2.	**Gender**	What is your gender?	Male/Female/I prefer not to say
3.	**Age**	What is your age?	[ ]
4.	**Residency Time**	For how long have you been living on Bonaire?	[ ]
5.	**Education**	What is your highest achieved education?	Primary school/ High school/ MBO/ HBO/ University
6.	**Positive Impacts – Personal**	Do you personally experience any benefits from the mangroves in Lac?	Yes/No/I don't know
		If yes, what are these	[]
7.	**Positive Impacts – Bonaire**	Do the people of Bonaire experience any benefits from the mangroves in Lac?	Yes/No/I don't know
		If yes, what are these	[]
8.	**Negative Impacts – Personal**	Do you personally experience any negative impact from the mangroves in Lac?	Yes/No/I don't know
		If yes, what are these	[]
9.	**Negative Impacts – Bonaire**	Do the people of Bonaire experience any negative impact from the mangroves in Lac?	Yes/No/I don't know
		If yes, what are these	[]
10.	**Awareness of Degradation***	Were you aware of the mangrove degradation in Lac?	Yes/No
11.	**Importance of Restoration***	Do you think it's important to restore the mangroves in Lac?	Yes/No/I don't know
12.	**Awareness of MM Work***	Did you know that Mangrove Maniacs is working on restoration of the mangroves in Lac?	Yes/No
13.	**Participation with MM***	Have you ever participated in the work of Mangrove Maniacs?	Yes/No
14.	**Fisheries**	How important do you find it to restore the mangroves in Lac for the following benefit ('*B*')?	Very important/ Little important/ Neutral/ Not important/ I don't know
15.	**Biodiversity**	"	"
16.	**Coastal Protection**	"	"
17.	**Sediment Trapping**	"	"
18.	**Carbon Sequestration**	"	"
19.	**Esthetics**	"	"
20.	**Tourism**	"	"
21.	**Water Filtration**	"	"
22.	**Protection against SWI**	"	"
23.	**Restoration Satisfaction**	How do you feel about the current extent of restoration activities by Mangrove Maniacs in Lac?	More/ Less/ Just good/ Not necessary/ I don't know
24.	**Involvement with MM****	For how long have you been active with Mangrove Maniacs?	[]
25.	**Motivation for MM****	What are the most important reasons for you to join Mangrove Maniacs?	[]

4. Results

This Chapter discusses the findings for each research question. The expert interview results, the subsequently distilled impact dimensions and their corresponding indicators are presented in Section 4.1. The effective implementation indicators that are distilled from the second part of the expert interviews are presented in Section 4.2. The results of the application of these findings on the case study on Bonaire are presented in Section 4.3., which sets out with a description of the case itself and the contextual findings that emerged from the stakeholder dialogue.

4.1. The ISJOS Framework

4.1.1. Overview of Interview Results

The outcomes of the expert interviews form the basis of the ISJOS framework for mangrove restoration (Figure 8). Appendix 5a shows the interview results for questions 3, 4 and 5 (open questions). Appendix 5b shows the results for question 5a (verification question on the ecological ceiling) and Appendix 5c for question 5b (verification question on the social foundation). The expert numbers were randomly allocated and do not indicate any specific order.

The dimension of ozone layer depletion in question 6a was the only dimension for which none of the experts could identify (a clear) connection with the impacts from mangrove restoration. Some experts however, implied that there may be a positive impact from mangrove restoration on this dimension, as the sequestering of carbon would diminish the driving force of ozone layer depletion. Even though none of the experts was able to state this confidently and their answers were consequently labelled as 'Unsure', these responses are incorrect since there is no known cause-effect relation between carbon sequestration and ozone layer depletion respectively. (There is a cause-effect relation known for the reverse (Ravindran et al., 2001), but this was not discussed in the interviews.)

In some cases, the responses given to the questions did not relate to the question itself. For example, expert 1 mentioned toxin absorption from agricultural chemicals as an impact from mangrove restoration, whereas the question asked was concerning climate change as a planetary boundary. By aggregating the coding schemes for all questions, diversions from the original questions were neutralized.

4.1.2. Dimensions of the ISJOS Framework

Figure 7 shows the coding schemes after aggregation for the three levels of the ISJOS framework, the corresponding expert mentions of this code and the total number of experts that mentioned this code. These codes are from now on referred to as 'impact dimension'. Experts who referred to a certain impact dimension in the open questions 3, 4 or 5 before the complementary questions of 6a and 6b, are highlighted in green. In total, 30 separate impact dimensions have been selected for the ISJOS Framework, of which 3 relate to the global ecological ceiling, 6 relate to the local ecological ceiling and 21 relate to the social foundation. Figure 8 shows the main themes of the ISJOS Framework for mangrove restoration. The amount of impact dimensions within each theme is indicated in brackets.

Impacts on the Global Ecological Ceiling

The selected main themes of impact for the global level of the ecological ceiling are: Climate Change Mitigation, Ocean Acidification Mitigation and Increased Biodiversity. It must be noted that the first two impact dimensions are the direct result of carbon sequestration, but since they address two different planetary boundaries, they are considered separately. Climate change mitigation was mentioned unanimously and straight away in the first set of interview questions, whereas the mitigation of ocean acidification through carbon sequestration was only

Impact on EC: Global

Impact Dimension	*E1*	*E2*	*E3*	*E4*	*E5*	*E6*	*E7*	*Tot*
Climate change mitigation	1	1	1	1	1	1	1	7
Ocean acidification mitigation	1	1	0	1	0	0	0	3
Increased Biodiversity								
Habitat for migratory species	0	0	0	1	0	1	0	2

Impact on EC: Local

Impact Dimension	*E1*	*E2*	*E3*	*E4*	*E5*	*E6*	*E7*	*Tot*
Increased Biodiversity								
Within mangroves	1	1	1	1	1	1	1	7
In adjacent ecosystems	1	0	0	1	0	1	1	4
Water filtration								
Nutrients	0	1	1	1	1	1	1	6
Chemicals	1	1	1	1	1	1	1	7
Sediment trapping	1	0	1	1	0	1	1	5
Erosion control	0	1	1	0	1	1	0	4
Ocean acidification mitigation								
Buffering capacity	0	0	0	0	1	0	0	1

Impacts on SF

Impact Dimensions	*E1*	*E2*	*E3*	*E4*	*E5*	*E6*	*E7*	*Tot*
Reduction of SWI	0	0	0	0	1	0	1	2
Food								
Fisheries, shrimp and crab	1	1	1	1	1	1	1	7
Honey	0	0	1	0	0	1	0	2
Income and Employment								
Restoration work	1	1	1	1	1	1	1	7
Tourism	1	1	1	1	1	1	0	6
Fisheries	1	0	1	0	1	1	1	5
NTFPs	0	0	1	0	0	1	1	3
Timber and charcoal	0	0	1	1	0	0	1	3
Carbon credits	0	1	0	0	0	0	0	1
Education								
Awareness & Nature education	1	1	1	1	1	1	1	7
Training of local community	0	1	1	0	0	0	1	3
Coastal protection								
Housing protection	1	0	1	1	1	1	1	6
Death prevention	0	0	0	0	1	0	1	2
Women's opportunities	0	1	0	1	1	1	1	5
Networks								
New intra- en intercommunal connections	0	0	1	1	1	0	1	4
Local knowledge exchange	0	1	1	0	0	1	0	3
Spiritual Well-being								
Spiritual and cultural value	0	0	1	0	1	1	1	4
Mental health	0	0	1	1	0	0	1	3
Esthetics	1	0	0	1	0	0	0	2
Peace and Equality								
Advocacy	0	0	0	1	1	0	0	2
Dialogue and consensus	0	0	1	0	1	0	0	2

Figure 7 Coding scheme and expert mentions for the three levels of the ISJOS framework. E1 = Expert 1, E2 = Expert 2, etc. EC = Ecological ceiling. SF = Social Foundation. Total = total number of experts whose response corresponded with the code.

Figure 8 The ISJOS Framework for mangrove restoration. The upper boundary shows the themes for global and local impacts on the ecological ceiling (EC). The lower boundary shows the themes of impact on the social foundation (SF). Number of impact dimensions per theme is indicated with arrows.

mentioned by three experts, when specifically asking how mangrove restoration contributes to protection against ocean acidification. One expert mentioned a local impact from mangrove restoration on ocean acidification as a planetary boundary, which is discussed in the next paragraph. Increased biodiversity on the global level through habitat provision for migratory species was mentioned by two experts and includes birds, fish and mammals that are not bound to the mangrove area in question, but depend on it for nurseries and foraging on a seasonal basis.

Impacts on the Local Ecological Ceiling

The main themes of impact selected for the local level of the ecological ceiling are: Increased Biodiversity, Water Filtration, Sediment Trapping, Erosion Control and Ocean Acidification Mitigation.

Here, Increased Biodiversity is subdivided in the increase in biodiversity within the mangroves and in adjacent ecosystems, such as coral reefs and seagrass meadows. Biodiversity increase within the mangrove ecosystem, also including the responses relating its nursery function, was mentioned by all experts and all but one expert mentioned this impact in their first response to the open questions 3, 4 and 5. Two experts emphasized the role of microbial biodiversity which is driving the decomposition of mangrove organic matter and initiating the rest of the food chain within the mangroves. Biodiversity increase in adjacent ecosystems was mentioned by two experts and is the result of the buffer function and to some extent the nursery function that mangroves have as a land-to-sea transition area. This buffer function entails the filtration of nutrients and sediment, thereby preventing land-sourced flows from contaminating seagrass beds and coral reefs, securing a healthy habitat for marine species to flourish in these systems. Furthermore, mangroves provide nursery and space to hide for various marine species that spent only a part of their life in the mangroves. The nursery function of mangroves was mentioned by four experts, but this impact dimension was omitted as it has a direct causal relationship with biodiversity increase within the mangroves as well as in adjacent ecosystems (see Methods, Figure 6 and Appendix 2c).

Water filtration and sediment trapping were coded as separate impact dimensions. Water filtration was sometimes also referred to as ‘bioremediation’, ‘purification’, ‘phytoremediation’ or ‘buffering’. The responses within this theme can be subdivided into two impact dimensions: the filtration of heavy metals and pesticides (chemical pollution), and the filtration of nitrogen and phosphorous (nutrients). The first type of water filtration was mentioned by all experts, whereas nutrient filtration was mentioned by five experts. Expert 5 also mentioned water filtration in relation to the prevention of downstream algal blooms. Sediment trapping was mentioned by five experts. Some highlighted how this impact results in the protection against sedimentation of nearby coral reefs. Expert 6 highlighted how sediment trapping results in the accretion of land-mass, thereby driving the formation of a delta and protecting the land against sea-level rise. Sediment trapping is linked to the water flow from the land. Another impact dimension, erosion control, is linked to the waves and water flows on the sea side. This is mentioned by four experts and includes the response of Expert 2 that uses the term ‘coastline protection’.

The last impact dimension of the local ecological ceiling is a subdivision of the ocean acidification mitigation theme, being the buffering capacity provided by mangroves. Here, ocean acidification is attenuated through the export of dissolved inorganic carbon and alkalinity from mangrove sediments into the sea water. This local impact was only mentioned by Expert 5, but as a subdivision of the broader ocean acidification mitigation theme, it is included in the ISJOS framework.

Impacts on the Social Foundation

The main themes of impact on the social foundation are Reduction of Salt Water Intrusion (SWI), Food Provisioning, Income and Employment, Education, Coastal Protection, Women's Opportunities, Nurturing of Networks, Spiritual Well-being, and Peace and Equality.

Reduction of SWI was mentioned by two experts, as a response to question 6b, concerning the impact of mangrove restoration on water provisioning. Even though the reduction of SWI may be perceived as an ecological impact, these responses suggest a direct effect on fresh water security and is therefore included amongst the impacts on the social foundation.

The impact of food provisioning was mentioned in two different forms: fisheries, shrimp, and crab – which was mentioned unanimously, and honey – which was mentioned by two experts. The availability of fish, shrimp and crab is an impact that follows from the mangrove shelter, feeding and nursery function for these species. The honey production is dependent on bee populations that – in some mangrove areas – are the principal pollinators as there is little wind energy to transport pollen in the mangrove forest.

The income and employment theme comprises various impact dimensions. Jobs created by the restoration project itself were unanimously mentioned by all experts. Examples are the tasks of mangrove seedling or propagule planting, caring for the mangrove nurseries, monitoring the restoration area and the digging of channels required for hydrological maintenance. The second most often mentioned type of income and work impact was tourism. This impact was also the most often mentioned in response to the first set of open interview questions. Other types of income generation are fisheries, non-timber forest products (NTFPs) – such as honey, palm leaves and herbs –, timber and charcoal, and the income generated through carbon credits. Timber and charcoal was often mentioned with a side-note as wood extraction was often seen as impeding the restoration process or conservation efforts. This is therefore mentioned as a separate negative impact. The income generated through carbon credits was only mentioned by one expert who was closely involved with mangrove restoration projects that have been certified to sell carbon credits. It was stated that the income was directly benefiting the local community and used for clean water piping for example. In practice, only few mangrove restoration projects around the world are carbon certified, because of the associated costs, strict requirements, and regulatory uncertainty (Vanderklift et al., 2019).

Within the education dimension, two separate impact dimensions are identified. Awareness raising and the provision of nature education was mentioned by all experts and relates to both formal and informal education on the value of mangrove ecosystems. Training of the local community was mentioned by three experts and refers to a side-activity of restoration efforts that aim to empower the local community to gain ownership over the restoration process. Despite the importance of this side-activity to the social sustainability of the overall effort, this is not per definition part of mangrove restoration in general. Also, this impact dimension was only mentioned by experts when explicitly asking for mangrove restoration impact on the education of people (question 6b).

Coastal protection as a result from mangrove restoration was mentioned in relation to extreme weather (such as storms and hurricanes) as well as climate change induced sea-level rise. Coastal protection is then attributed to wave attenuation from mangrove structure and land mass accretion through sediment trapping, respectively. The distinguished impact dimensions are the protection of housing and urban areas (and the associated avoided costs of displacement and reconstruction) – which was mentioned by six experts, and the prevention of casualties resulting from storm damage and flooding – which is mentioned by two experts. Death prevention was not explicitly mentioned as an impact in first set of open questions.

Similarly, the impact dimension of women's opportunities followed only from the question concerning mangrove restoration impact on gender equality (question 6b). Five experts then confirmed this however, stating that jobs related to both the restoration work and other jobs depending on the mangrove area were primarily women's responsibilities. However, gender role divisions within communities are culture dependent and may therefore be different for each restoration project.

Also the impact dimensions related to the nurturing of networks amongst people were not mentioned immediately, but only in the set of verification questions. Amongst the responses two different impact dimensions could be distinguished. Four experts mentioned the emergence of new connections within the community and amongst different communities, thereby fostering the sense of community support and resilience. For example, expert 3 and 5 associated this with the inclusion of various stakeholders in the restoration process whose collaboration would have been unlikely otherwise. Expert 7 attributed this effect to the engagement of volunteers. The impact dimension of local knowledge exchange refers to the sharing of best practices and lessons learned amongst different projects or organizations intending to start with mangrove restoration. This may also include training for example, but is different from the 'training of local community' impact explained earlier, in the sense that here it is referring to connecting with fellow (aspiring) practitioners.

The impact theme of spiritual well-being consists of three impact dimensions. Of these, spiritual and cultural value was mentioned most often. Of course, this type of valuation of mangrove (restoration) is much dependent on the cultural context. For certain coastal communities, the mangrove forest has a sacred status and thereby contributes to a coastal resident's sense of identity and purpose. Related to this, is the impact dimension of mental health, which was mentioned by three experts. Expert 7 pointed out however, that for many people this connection to nature is lost, thereby reducing its psychological benefits, which in itself may emphasize the importance of educational impacts of mangrove restoration. Closely related to the prior, is the impact of esthetics – mentioned by two experts. Both experts referred to this in the first set of open questions already. Expert 4 also stated that increased esthetics as a result of mangrove restoration was translated into higher land and housing prices in the areas surrounding mangroves.

The last two impact dimensions relate to the theme of Peace and Equality and were both only mentioned in response to the verification questions. Advocacy or 'a greater voice' to marginal stakeholders is mentioned by expert 4 and 5, when being asked about the impact of mangrove restoration on people's political voice. The advocacy and participation opportunities may arise from the stakeholder input process that ideally precedes mangrove restoration projects. The impact of creating dialogue and consensus amongst different stakeholders or community members was mentioned by two experts as well, similarly related to the stakeholder input process. It should be noted however, that both experts also mentioned a possible counter effect of increasing tension and conflict. This is discussed more in detail in the next paragraph.

Negative impacts from mangrove restoration

All negative impacts mentioned in the interviews arose from the questions related to the social foundation, except for the impact of 'Jobs lost in earlier land-use'. This negative impact was mentioned by Expert 1 in response to the question on land conversion impacts of mangrove restoration. If mangrove restoration reverses past uses of the area, there may be job losses related to this former land-use.

The impact of fuel and building material from wood was described with a similar ambiguity. Even though the sale of charcoal and timber is mentioned as an income and employment opportunity, harvesting of wood for these purposes may counteract the restoration process itself, if not done

sustainably. Expert 2 however, pointed out how this was not necessarily a direct consequence if alternative woodlots were provided.

Increased risk of conflict and tension, as opposed to the desired outcome of consensus and dialogue, was mentioned by three experts. This may arise from unclear land ownership, conflicting interests in the area or a limitation of usage rights for the original users that follows from a restoration initiative. The latter is also mentioned as a separate impact by one expert, as this in itself does not necessarily always lead to conflict on the community level, but nevertheless has an adverse impact on people whose livelihood is directly dependent on access and exploitation rights to the mangroves.

Decreased housing space is a negative impact that may occur when mangrove restoration on the landward side takes place or is planned in a (former) residential area. Construction of new houses is then restricted, or current residents are even required to move further inland, which may add to the aforementioned impact of community conflicts. Interestingly, Expert 7 raised the issue of a 'false sense of security' that mangrove restoration might invoke by replanting. That is, the perceived risk attenuation that might incentivize further development of houses and urban infrastructure.

Two experts mentioned the increase in mosquito abundance and associated diseases, such as malaria. Expert 1 however, mentioned that the diseases themselves are in fact not present in the expert's working area, suggesting that the negative impact might partially be a matter of perception and education on the role of mosquitos in disease transmittance. The same applies to the negative impact of 'a muddy perception' of mangroves by people. This is not a tangible adversity, but might still negatively affect people's sense of convenience in their living environment.

4.1.3. Indicators of the ISJOS Framework

Table 7 shows the indicators for the ISJOS impact dimensions, including the corresponding reference (if available) and the relevant SDG target or indicator where applicable. No indicators are defined for the negative impacts, as they tend to have a high degree of intangibility and uncertainty as to their general validity, as will be addressed in the Discussion section.

Where the connection between ISJOS indicators and SDG indicators is discussed, the available SDG indicator metadata as provided by the UN Statistics Division was used as a reference. For each of the quoted SDG indicators, this information can be found in the online metadata repository (UN Statistics Division, 2022).

Climate Change Mitigation

Throughout this research, the impact of mangrove restoration on climate change has been expressed in terms of carbon sequestration potential. A distinction should be made between the short term and long term sequestration of carbon. In the living biomass of mangroves aboveground (stems, branches, leaves) and belowground (roots) carbon is partially sequestered in tree growth, but also released through plant respiration (Howard, Hoyt, Isensee, Pidgeon, & Telszewski, 2014). Long-term carbon sequestration, which we may also refer to as carbon storage, can predominantly be attributed to the underlying sediments in mangrove areas and the dead biomass, such as detritus (Brevik & Homburg, 2004). The majority of mangrove carbon stock is located in the sediments. A more detailed explanation of carbon dynamics in mangrove forests can be found in McLeod et al. (2011). The indicator used in this latter publication for climate change mitigation impact is the aggregate value for sequestered carbon in the aforementioned compartments of the mangrove forest.

SDG Connection

Carbon sequestration is not directly monitored in any of the SDG indicators, but contributes to countries' respective Nationally Determined Contributions (NDCs) as part of their commitments in the

UNFCCC Paris Agreement, which is currently ratified by 197 states. SDG indicator 13.2.1 “Integration of climate change into national policies” includes the number of countries with NDCs, but does not declare anything about the quality or quantity of these commitments (Our World in Data, 2018a).

Ocean Acidification Mitigation

No specific literature was found on the impact of mangrove restoration on global ocean acidification mitigation. This is not surprising, as this impact is directly related to the carbon sequestration potential of mangrove restoration and therefore discussed in the context of climate change mitigation, as in the earlier paragraph. The ocean-atmosphere connection between pH and carbon sequestration through carbon dioxide removal (CDR) is described in complex coupled ocean-atmosphere models and shows that mitigation of ocean acidification with CDR is hampered through the slow turn-over time of deep ocean water masses (Mathesius, Hofmann, Caldeira, & Schellnhuber, 2015). However, when deployed early in time and in combination with stringent emission reduction strategies, CDR and natural carbon sequestration may be an effective pathway to attenuate the decrease in ocean pH (Hofmann, Mathesius, Kriegler, Vuuren, & Schellnhuber, 2019). This impact is described in terms of global seawater pH anomaly.

On the local scale, the impact of mangrove restoration on ocean acidification can be quantified based on biogeochemical interaction with seawater. It is known that the cycling of organic matter in coastal sediments contributes to alkalinity fluxes that attenuate seawater acidity (Hu & Cai, 2011), whereby mangroves have an additional advantage due to their sediment burrows and the resulting pore water hydrology (Tait, Maher, Macklin, & Santos, 2016) that drives carbon exchange with adjacent coastal water. Due to their high production rates, mangrove waters are also known to have high dissolved inorganic carbon levels, thereby contributing to the partial pressure of CO2 in the water and the resulting acidification. The local mitigation potential of mangroves on ocean acidification therefore depends on the ratio between DIC and alkalinity export to the sea, or the ‘buffer capacity’ (Sippo, Maher, Tait, Holloway, & Santos, 2016).

SDG Connection

Both the pH effect on a global scale as well as the DIC and alkalinity concentrations on a local scale are measured variables for SDG indicator 14.3.1 “Average marine acidity (pH) measured at agreed suite of representative sampling stations” (Barbière, Isensee, & Schoo, 2019).

Increased Biodiversity

The concept of biodiversity refers to the variety amongst all flora and fauna species in a certain system. Biodiversity assessments can therefore be a laborious task and different approaches (Moreno et al., 2017) and indices (Mulya, Santosa, & Hilwan, 2021) exist to express the outcomes. Alternatively, the papers found in mangrove (restoration) related literature often used the abundance of one or a few mangrove system key species as a proxy for biodiversity in the context of ecosystem change or restoration (e.g. (Canales-Delgadillo et al., 2019). Therefore, to monitor biodiversity of mangrove restoration, the suggested indicator is the net gain abundance of these key species.

This is also the case for the abundance of migratory birds in mangrove areas when describing the impact on global biodiversity (Putra, Perwitasari-Farajallah, & Mulyani, 2017). Yong and colleagues (2021) describe the global biodiversity impact of a mangrove region as the share of migratory birds of the total population that makes use of the flyway concerned. When an area meets the >1% criterium, it is considered for a RAMSAR site designation. The first, absolute indicator is more suitable here however, because it allows for the aggregate impact from multiple migratory bird species.

Table 7 ISJOS indicators for each impact dimension, corresponding references and relevant SDG targets or indicators. EC = Ecological Ceiling. SF = Social Foundation.

Impact Theme/Dimension	*Indicator*	*Reference*	*SDG connection*
	EC: Global		
Climate change mitigation	CO2 sequestered, above and belowground biomass + sediment (Gt C ha^{-1} y^{-1})	Mcleod et al., (2011)	
Ocean acidification mitigation			
Atmospheric CO_2 removal	pH anomaly (-)	Hofmann et al. (2019)	14.3.1
Increased Biodiversity			
Habitat for migratory species	Net gain abundance of key migrating species (n ha^{-1})	*Author's suggestion*	15.5.1
	EC: Local		
Increased Biodiversity			
Within mangroves	Net gain abundance of key mangrove species (n ha^{-1})	*Author's suggestion*	15.5.1
In adjacent ecosystems	Net gain abundance of key reef/seagrass/terrestrial species (n ha^{-1})	*Author's suggestion*	15.5.1
Water filtration			
Nutrients (nitrogen and phosphor)	Treatment efficiency (%)	Ouyang & Guo (2016)	14.1.1a
Chemicals (heavy metals and pesticides)	Change in HPI, Change in pesticide concentration	Sarath & Puthur (2021), Ivorra et al. (2021)	14.1
Sediment trapping	Adjusted net elevation change (mm y^{-1})	Krauss et al. (2013)	
Erosion control	Wave reduction rate (m^{-1})	(Kamil, Takaijudin, & Hasim, 2021	
Ocean acidification mitigation			
Buffering capacity	DIC/alkalinity export ratio (-)	Sippo et al. (2016)	14.3.1
	SF		
Reduction of SWI	-		
Education			
Awareness & Education	Knowledge and attitude pre & post test (-)	Sigit et al. (2019)	13.3.1.
Training of local community	Number of local community members trained (-)	*Author's suggestion*	
Food			
Fisheries, shrimp and crab	Fisheries enhancement (ha^{-1})	Worthington & Spalding (2018)	2.1.2/2.3.2
Honey	Honey production enhancement (L ha^{-1} y^{-1})	*Author's suggestion*	2.1.2/2.3.2
Income and Employment			
Restoration work	Amount of people employed throughout the restoration effort (fte)	*Author's suggestion*	
Tourism	Income from mangrove related tourism activities (USD y^{-1})	(Su et al., 2021)	14.7

Fisheries	Income from the fishing industry for mangrove related species (USD y^{-1})	(Su et al., 2021)	14.7.1/ 2.3.2.
NTFPs	Income from NTFPs (USD y^{-1})	(Su et al., 2021)	2.3.2.
Timber and charcoal	Income from timber and charcoal (USD y^{-1})	(Su et al., 2021)	
Carbon credits	Carbon credit value (USD Gt^{-1} ha^{-1} y^{-1})	(Jakovac et al., 2020)	
Coastal Protection			
Housing protection	Urban area protected from flooding (ha)	Pérez-Maqueo et al. (2018)	1.5.2/11.5.2
Death prevention	Amount of people protected in case of flooding (ha^{-1})	*Author's suggestion*	1.5.1/ 11.5.1/ 13.1.1.
Women's Opportunities	Share of women involved with restoration as compared to local women's employment (-)	*Author's suggestion*	8.5.1
Networks			
New intra- en intercommunal connections	Number of (volunteering or employed) people engaged with restoration practices	*Author's suggestion*	
Local knowledge exchange	Number of external organisations engaged with restoration practices	*Author's suggestion*	
Spiritual well-being			
Spiritual and cultural value	Community perception survey	*Author's suggestion*	
Mental health	Community perception survey	*Author's suggestion*	
Esthetics	Community perception survey	*Author's suggestion*	
Peace and equality			
Advocacy	Participation pathways in place for mangrove community stakeholders (e.g. stakeholder input process) (Yes/No)	*Author's suggestion*	14.b.1/ 10.6
Dialogue and consensus	Change in mangrove related community conflicts	Fistingrum & Harini, 2021	

A similar approach is applicable to the biodiversity impact on adjacent ecosystems, such as reefs and ecosystems. Depending on which spatial degree of connectivity one wishes to assess biodiversity impact for, one could consider the abundance of reef fish species that nurse in the mangroves, avian species that forage in marine-pelagic waters (Buelow & Sheaves, 2015) or terrestrial mammals, reptiles and amphibian species that contribute to pollination and nutrient transfer with the landward side of mangroves (Rog, Clarke, & Cook, 2017).

SDG Connection

For each type of biodiversity impact described above, it goes that the corresponding indicator directly contributes to SDG indicator 15.5.1 "The Red List Index". This list indicates the extinction risks for aggregated species groups that show serious declines in population size. A net gain abundance in biodiversity as a result of mangrove restoration, would improve the species group's conservation status in the Red List Index. However, not for all mangrove-affected species a Red List Index value is available (e.g. due to data deficiency) (International Union for Conservation of Nature and Natural Resources, 2022).

Water filtration

Chemical abatement by mangroves has a different fate depending on the contaminant. Heavy metals, such as manganese, iron, lead and zinc, accumulate in the rhizosediment and are either stabilized here, or taken up by the mangrove tree. A change in heavy metal contamination due to mangrove restoration is therefore best measured with the heavy metal concentration in the sediment, comparing the restoration area with a reference site (Feng, Zhu, Wu, Ning, & Lin, 2017; Machado, Moscatelli, Rezende, & Lacerda, 2002). An aggregated indicator that accounts for multiple trace metals and their respective impacts is the Heavy Metal Pollutant Index (HPI) (Venkata Mohan, Nithila, & Jayarama Reddy, 2008), which has been used in a mangrove system by (Sarath & Puthur, 2021). High values for this indicator may be perceived as a great sustainability impact, but it should be noted that bioaccumulation of heavy metals has ecotoxicological consequences on the mangroves and the associated food webs as well (Defew, Mair, & Guzman, 2005).

Chemical abatement in terms of pesticide removal is commonly indicated by the difference in pesticide concentration between mangrove water and water at a reference site, but may also be measured in the sediment of mangrove trees, as they show similar remediation trends (Ivorra, Cardoso, Chan, Cruzeiro, & Tagulao, 2021). Chemical pollution in the marine environment, although directly related to SDG 14.1, is not monitored by any of the SDG indicators (United Nations Environment Programme, 2021).

SDG Connection

Nutrient removal by mangroves is predominantly dependent on plant uptake, as mangroves are generally limited by nitrogen and phosphorus availability. In a literature review of the filtering function of natural and constructed (e.g. planted) mangrove areas, the indicator for nutrient removal was defined as the relative treatment efficiency of nitrogen and phosporus concentrations (Ouyang & Guo, 2016). This impact indicator directly affects SDG indicator 14.1.1a "Index of coastal eutrophication", as it measures the in-situ concentration of nutrients and resulting Coastal Eutrophication Potential (United Nations Environment Programme, 2021).

Sediment trapping

The trapping of terrigenous sediment in mangroves is primarily caused by their complex root structures and the anaerobic environment that slows down decomposition processes (Middleton & McKee, 2001). The resulting vertical accretion is however not to be confused with the total elevation of mangrove soils, as other factors play a role in this too, such as subsurface expansion or subsidence and

geologic processes (Krauss et al., 2014). Even if the latter factors are discounted for, vertical accretion is also driven by plant litter deposition and algal mat development, although both of these factors are contributing to inorganic sediment retention as well (McKee, 2011). When adjusted for the contribution from the aforementioned processes, the net elevation change of mangrove soils may be a suitable indicator for its sediment trapping impact and the resulting protection against sedimentation of adjacent ecosystems.

SDG Connection

Although relevant in the context of marine biodiversity protection (SDG Target 14.2 "Protect and restore ecosystems"), sediment trapping is not directly monitored by any of the SDG indicators.

Erosion Control

The main causes of coastal erosion are waves and tidal currents, if not balanced by the sedimentation rate of a mangrove area (Thampanya, Vermaat, Sinsakul, & Panapitukkul, 2006; Winterwerp, Borst, & de Vries, 2005). Most papers therefore refer to the wave attenuation, or 'wave reduction rate' as an indicator for the erosion control impact that may follow from mangrove restoration (Kamil, Takaijudin, & Hasim, 2021). This is equal to the relative wave height reduction per meter covered and it is, amongst others, dependent on the mangrove species composition, forest density, forest age and area width (Yuanita, Kurniawan, Setiawan, Hasan, & Khasanah, 2019).

SDG Connection

Wave reduction for erosion control was not found to have a direct connection to any SDG on the target or indicator level. Nevertheless, it is clearly relevant to multiple of the broader SDGs (e.g. SDG 3 "Good Health and Well-Being" or SDG 11 "Sustainable Cities and Communities").

Reduction of SWI

The literature review did not provide any relevant paper on the effect of mangroves on SWI. Most papers however, refer to the reverse impact of sea-level rise induced SWI on mangroves (e.g. Chambers et al., 2014; Yu et al., 2019).

SDG Connection

Since experts' mention of the impact of SWI reduction was related to the availability of freshwater, one might note that the change in mangrove area is indeed a variable for SDG indicator 6.6.1. "Change in the extent of water-related ecosystems over time" monitoring the progress on the goal for "Clean Water and Sanitation" (United Nations Environmental Programme, 2018). Nevertheless, the methodology behind this SDG indicator never mentions a connection with SWI reduction, but includes mangroves as a sub classification of water-related ecosystems that serve a broader range of clean water purposes.

Awareness & Education

The impact of formal and informal educational activities organized within a mangrove restoration effort is difficult to quantify, especially when seeking a connection with the physical restoration progress. Yet, improved awareness and behavioral change has been effectively quantified through assessment pre and post mangrove restoration related education (Sigit et al., 2019). Considering the actual change in knowledge level amongst different target groups provides a better estimate of improved awareness than simply quantifying a restoration project's efforts in facilitating this, e.g. the number of organized activities or people engaged. Indeed, the latter might be more practical in monitoring, but mangrove specific literature review did not result in any approving studies for this alternative indicator.

With regards to the training of local community members, a case study on the appointment of 'Land and Sea Rangers' amongst indigenous communities in Australia provides a successful example . This study describes how community members were engaged in mangrove restoration and monitoring duties, but does not identify an indicator for its impact (Waltham, Schaffer, Buist, Geyle, & Toby, 2018). Based on this knowledge, the suggested indicator for this impact is the number of local community members trained.

SDG Connection

As for the SDG indicators, most education related indicators are in fact quantified by the (relative) number of people receiving education. Neither of the educational SDGs are directly impacted by awareness and education arising from mangrove restoration efforts, except for SDG indicator 13.3.1. "Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment" (Our World in Data, 2018b). Even though educational activities from mangrove restoration do not directly contribute to the mainstreaming of similar efforts, there may be a direct contribution vice versa, since structural sustainability education would benefit the understanding of local human-nature dependencies and promote pro-environmental behaviour (Sigit et al., 2019).

Food

The literature review did not result in a suitable indicator for the impact of mangrove restoration on food provisioning through either fisheries or honey production. Therefore, the indicator provided by Worthington and Spalding (2018), as discussed in Section 2.4., is adopted for fish, shrimp, and crab food sources. A similar indicator to 'fisheries stock enhancement' is suggested for honey production, being 'honey stock enhancement'.

SDG Connection

Increased fish and honey stocks as a result from mangrove restoration directly impact SDG indicators 2.1.2 "Prevalence of food insecurity", through improved local and healthy food availability, and 2.3.2. "Income of small-scale food producers" . The latter SDG connection will be explained further below.

Income and Employment

For income and employment generated by restoration-related jobs, literature review did not result in a suitable indicator for quantitative analysis. Susilo and colleagues (2017) assessed the opportunity costs related with these jobs, based on community member's willingness to contribute time, but this indicator does not describe the actual employment created by mangrove restoration. Therefore the author's suggested indicator is the number of people employed in full-time equivalent. The generated income may seem a logical indicator as well, but its dependency on wage differences between countries was considered to be less exemplary to the eventual impact made, as the eventual value created ('mangrove restoration') is assumed to be the same for jobs and countries of different pay.

This is different for the various goods and services that are obtained from the restored area. The literature review showed that economic, restoration-related benefits from tourism, fisheries, NTFPs and wood have been quantified by a multitude of studies. For this reason, the indicator of income in USD was adopted from a recent meta-analysis by Su et al. (2021).

Carbon credits provide income through the marketisation of carbon sequestration as an ES. Therefore, jobs creation is not considered in this regard. The indicator used is the value of one credit on the voluntary carbon market. Note here, that carbon credit prices for restored mangroves are different from those for conserved mangroves (Jakovac et al., 2020).

SDG Connection

Income generated through mangrove-related food production, such as fisheries and honey, directly contributes towards SDG target 2.3.2. “Income of small-scale food producers, by sex and indigenous status” (Ergin, Conforti, & Khalil, 2019). This target specifically focusses on marginal groups like (female) fishers and is stated to be improved through non-farming employment as well, which would include mangrove restoration, tourism and wood production, for example. Furthermore, SDG indicator 14.7.1 “Sustainable fisheries as a percentage of GDP in small island developing states, least developed countries and all countries” is affected in the same way, but only through mangrove fisheries. However, this indicator was recently proposed for reclassification, because of multiple limitations in its formulation and methodology, such as the question of what ‘sustainable fisheries’ actually entails . This shows that the measurability of the indicator is still under discussion (Gennari, 2019). SDG target 14.7 also refers to income and employment from tourism activities, but this is not explicitly included in an indicator yet. In a broader sense, any income and employment impact from mangrove restoration contributes to both SDG indicator 8.5.1. “Average hourly earnings of employees” and 8.5.2. “Unemployment rate” .

Coastal Protection

As the impact of coastal protection was mentioned in connection to the social foundation, the indicators were chosen as to represent the desired societal effect, instead of the ecological means to achieve this (as is the case for Erosion Control). No indicator was found for mangrove restoration specifically, but literature was well available for coastal systems in general.

The results from literature review suggested the indicator for protection of houses and built stock is best expressed in avoided economic damage from projected extreme weather or sea-level rise (Pérez-Maqueo, Martínez, Sánchez-Barradas, & Kolb, 2018). This is not only dependent on the extent and composition of the mangrove area, but also on the economic value of the buildings and infrastructure behind them. The impact of housing protection from mangrove restoration is therefore purported to be higher in more developed areas as compared to small coastal communities. To avoid this misleading correlation, it is suggested to standardize the economic values according to a nation’s GDP (Pérez-Maqueo et al., 2018). Another, less often occurring indicator in the literature review, was that of hedonic property value increase resulting from coastal protection (Dundas, 2017), which articulates a more direct economic benefits as compared to avoided costs from damage.

The indicator for death prevention is expressed in the decreased casualty risk for people (Pérez-Maqueo et al., 2018). Here, risk is not dependent on climate and (extreme) weather related variables, but also on the demography of the population concerned, such as the age distribution and socio-economic vulnerability (Pérez-Maqueo et al., 2018; Silver et al., 2019). Death toll on livestock and natural assets is not included in this risk projection, but could create a more complete understanding of economic and ethical adversity of lacking protection from mangroves (Badola & Hussain, 2005).

SDG Connection

Housing protection enforced by mangrove restoration directly decreases “Direct economic loss attributed to disasters in relation to global gross domestic product (GDP)”, which is used as an indicator under both SDG targets 1.5. and 11.5 (indicator 1.5.2 and 11.5.2., respectively). Death prevention secured by mangrove restoration contributes to the “Number of deaths, missing person and directly affected person attributed to disasters per 100,00”, which is used as an indicator under both SDG targets 1.5., 11.5. and 13.1. (indicator 1.5.1., 11.5.1 and 13.1.1., respectively).

Women's Opportunities

A literature review related to restoration cases specifically, only addressed gender equality and opportunities for women as a challenge to be resolved, rather than a benefit inherent to sound restoration practice (B. Brown, Daillah, Nurdin, Soulsby, & Ahmad, 2014; Cormier-Salem, 2017). When broadening the search scope to mangrove SESs in general, some examples of the opportunities created for women are described (Abubakar, 2021; Farran, 2021), but none include an indicator that allows for quantitative impact assessment.

Therefore the 'enhanced inclusion' indicator is suggested based on personal accounts, comprising the share of women involved with restoration relative to the share of women generating income in the SES as a whole. A value > 1 indicates a positive contribution from mangrove restoration.

SDG Connection

The impact of women's inclusion in mangrove restoration directly contributes to keep SDG indicator 8.5.2. down: "Unemployment rate, by sex, age and person with disabilities", although the ISJOS indicator suggested here, requires some conversion in order to contribute statistically. Where women are appointed leadership positions within the mangrove restoration efforts, this specifically contributes to SDG indicator 5.5.2. "Proportion of women in managerial positions" .

Networks

For neither of the two impacts related to network building, did literature review provide a suitable indicator. The search resulted in a high number of suggested papers, but the majority thereof concerned 'community dynamics' as studied in the field of ecology and biogeography. One study in Indonesia quantified the increase in group and institutional dynamics after mangrove recovery, but the described methodology was not sufficiently detailed to conclude that this was directly linked to the restoration effort itself (T Pambudi & Purwoko, 2021).

The suggested indicator for inter- and intracommunal connections is the number of people engaged with restoration practices, either through employment or volunteering. The suggested indicator for improved local knowledge exchange is the number of institutions that have been engaged with the implementation and operations side of the restoration effort.

SDG Connection

No SDG targets or indicators were identified to have a concrete connection with the ISJOS indicators for the Networks theme. Indirectly, both the ISJOS indicator of the number of employees/volunteers and the number of external organizations engaged with mangrove restoration, can contribute to SDG indicators that assess capacity building for and development of national strategies on topics like climate change (SDG indicator 13.b.1.), marine technology for ocean health (SDG indicator 14.b.) and biodiversity (SDG indicator 15.9.1.).

Spiritual Well-Being

Literature review showed that data on spiritual and cultural valuation of mangroves, their impact on people's mental health and their esthetic value was typically obtained through community perception surveys. For this reason, there are no specific indicators defined for the three impact dimensions. Example survey variables for each of the impact dimensions respectively, could include:

1. The extent to which social life and sense of cultural identity are affected by mangrove restoration (Basyuni, Harahap, Wati, & Putri, 2018) or how religious or spiritual beliefs are connected to the mangroves (Sidik Katili, Utina, Tamu, & Nusantari, 2018).

2. The change in self-esteem in relation to self-provisioning capacity, associated senses of stress and anger (Kibria, Costanza, Groves, & Behie, 2019) or the overall perceived contribution of (restored) mangroves to one's mental health (Hsieh, Lin, Shih, & Chen, 2015).
3. Attribution of esthetical value, to the mangrove system as a whole (Md Mijanur Rahman, Jiang, & Irvine, 2018) or spatially comparing the mangrove restoration area and surroundings (Ocelli Pinheiro, Triest, & Lopes, 2021).

The first impact dimension was the only one dimension for which its connection to mangrove restoration, as opposed to mangrove forests in general, was described in literature. Social media analysis was also suggested as a useful methodology for assessing the impact dimension of esthetic value (Ghermandi, Camacho-Valdez, & Trejo-Espinosa, 2020).

SDG Connection

With regards to the ISJOS indicator for mental health impact, there is no concrete connection with the SDGs. Although SDG target 3.4. mentions the promotion of mental health and well-being, the corresponding indicator (3.4.2. "Suicide mortality rate") is not considered suitable to reflect mental health benefits from nature connectedness, such as through mangrove restoration. For the ISJOS indicators for spiritual and cultural value, and esthetics, no connection can be found either, since it is difficult to formulate a prescriptive norm for these impacts to contribute to.

Peace & Equality

Literature review on advocacy for marginal stakeholders in a mangrove SES did not result in any relevant results, neither in relation to mangrove restoration or mangroves in general. The work of Farley, Batker, de la Torre and Hudspeth (2010) however, provides a striking case on how collaboration between stakeholders in mangrove conservation results in powerful advocacy and successful political change. Here, a workshop involving multiple stakeholders was aimed at the protection of mangrove area from shrimp aquaculture conversion and the education of future generations on the value of mangroves at the same time. Presentation of results to the press and local government resulted in the shutdown of aquaculture enterprises, by providing space for the political voice of a broad representation of stakeholders in the workshop process. Based on this, the suggested indicator for this impact dimension is the presence of participation pathways (Yes/No) for marginal stakeholder groups in the input process for decision-making and political influence.

With regards to the stimulation of dialogue and consensus, as to avoid community conflicts, no literature was found for mangrove restoration specifically, but relevant literature was abundant for mangrove management in general. The approaches discussed therein, differed widely and included e.g. dialogic processes towards the creation of community-based institutions for mangrove management (Ounvichit & Yoddumnern-Attig, 2018), the transformation of customary regulation into written law (Maskun, Ilmar, Naswar, & Achmad, 2019) and the appointment of an informal community leader that encourage bottom-up participation in restoration efforts (Purwowibowo & Yuyun Yuningsinh, 2017). These are examples of the various qualitative narratives on the means to achieve consensus in mangrove management. To streamline the possibilities into one indicator, the suggested indicator follows the approach by Fistingrum and Harini (Fistingrum & Harini, 2021), who quantified the change in community conflicts through interviews. This also leaves space for the opposite disservice: a potential increase in conflicts induced by restoration efforts.

SDG Connection

Since the ISJOS indicator for advocacy is binary, there is no quantitative connection with the SDGs. However, if further work on the monitoring of this impact results in a numerical indicator, this could be framed in a way that it contributes to SDG indicators 11.3.2. "Proportion of cities with a direct

participation structure of civil society in urban planning and management that operate regularly and democratically", 14.b.1. "Degree of application of a legal/regulatory/ policy/institutional framework which recognizes and protects access rights for small-scale fisheries" or 16.7.2. "Proportion of population who believe decision-making is inclusive and responsive, by sex, age, disability and population group", for example. Interestingly, SDG indicator 6.b.1. "Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management" marks the gravity of participation pathways for local communities, but such an indicator does not exist under the SDGs on climate change, ocean health and biodiversity, for example. The indicator on dialogue and consensus reached or threatened by mangrove restoration, neither shows a concrete connection with any SDG indicator, but shows great similarities with SDG indicator 16.3.3. "Number of persons who experienced a dispute during the past two years who accessed a formal or informal dispute resolution mechanism, as a percentage of all those who experienced a dispute in the past two years, by type of mechanism", which explicitly distinguishes disputes on land tenure and environmental damage, amongst several categories.

4.2. Effective Implementation Indicators for Mangrove Restoration

The expert interviews resulted in a list of 25 challenges and 35 facilitating conditions in the methodology, in external systems on a local scale and related to global macro-conditions. The factors from the two latter levels are merged in the coding scheme, because the interviews showed that a considerable part of the outcome did not follow a clear categorization amongst either of the two levels. We therefore refer to *internal* factors (related to restoration methodology and organization) and *external* factors (local external systems and global macro-conditions).

Challenges and facilitating conditions that were only mentioned by one expert, are excluded from the list of indicators for effective implementation. This is not to designate them as irrelevant. For the sake of comprehensibility of the list and legitimacy of the indicators, they are left for further validation. Appendix 2d provides the full coding scheme.

4.2.1. Internal Factors

Table 3 shows the list of internal factors mentioned by more than one expert. This includes 5 facilitating conditions for mangrove restoration and 4 challenges. The facilitating condition of a good hydrological regime and water circulation was mentioned by all experts. For example, the tidal range and water circulation capacity were deemed vital to consider in the restoration approach. This may include the restoration of historical freshwater flow, but it may also be facilitated by adjusting disruptive manmade infrastructure. Expert 4 pointed to the importance of restoring the hydrological regime before resorting to mangrove planting.

Education and engagement of the local community was mentioned by five experts. Expert 3 suggested to prioritize the engagement of community member and the local government, before other stakeholders. The same expert also emphasized the need of dialogue for social understanding, which is only successful on a long-term basis, as underlying community interactions are not easily revealed. L:ater, amongst the external factors, this expert then also discussed the importance of social and applied science in the field of mangrove restoration, which would often be underexposed.

The impact of wave energy on fringing mangroves was mentioned by four experts as a challenge that arises from the methodological level. This should be considered when choosing when, where and what kind of mangrove restoration to apply. Seedlings or propagules planted nearby high wave energy areas, are likely to give unsuccessful results. This also links to the facilitating condition of having the scientific and technical knowledge for adequate restoration. Expert 6 mentioned the specific knowledge required on propagation techniques or the maintenance of nurseries in which new mangroves are

grown. Other examples are the knowledge required for hydrological restoration or the technicalities behind blue carbon certification, if the latter is part of a restoration effort. In addition, expert 6 also mentioned the value of traditional knowledge. For example, fishermen that have used the mangroves for generations, may have valuable knowledge on the location of natural water channels that (used to) exist in the restoration area.

Mono-planting was mentioned as a challenge by three experts. Expert 2 explained that some government agencies or even investors seek 'quick and dirty' solutions, mono-planting of mangroves is often used to quickly gain results in terms of planted area. The project targets are set accordingly, giving a wrong impression of the actual impact. Expert 3 suggested to use 'plant survivorship' in stead of 'planted area' indicators for example. Related to this is the challenge of using appropriate mangrove species for the tidal zone in which the planting takes place. Three experts mentioned this, explaining that mangrove species require different inundation times and salinity levels. Inapt planting has yielded many restoration failures.

Good water quality was mentioned by two experts to help restoration efforts thrive. This is then most importantly referring to oxygen and salinity levels. Even though mangroves grow in saline environments, they are still dependent on regular fresh water inflow and oxygen provided from the seaside. The challenge of degraded soils, mentioned by three experts, is often a result of degraded water quality, which leads to die-off of mangroves. Without the root structure and organic debris from mangrove trees, upstream sediment can flow in freely, clogging the hydrological system and further degrading the soil quality. Degraded soil do not allow for regeneration, which makes mangrove restoration virtually impossible. Knowing the driver of mangrove degradation is therefore vital to alleviating the cycle between decreasing water quality and soil degradation. This was mentioned as a facilitating condition by two experts.

Table 8 Internal effective implementation factors. E1 = Expert 1, E2 = Expert 2, etc. C = Challenge. FC = Facilitating Condition. #Experts refers to the total number of experts that mentioned this factor.

Internal factors	E1	E2	E3	E4	E5	E6	E7	FC / C	#Experts
Good water circulation/ hydrological regime	1	1	1	1	1	1	1	FC	7
Education and engagement of local community and government agencies	0	0	1	1	1	1	1	FC	5
Wave impact on the fringe	0	1	1	0	1	0	1	C	4
Availability of scientific and technical knowledge	0	1	0	0	1	1	0	FC	3
Mono-planting	0	1	1	1	0	0	0	C	3
Inapt species used for planting	0	0	1	0	0	1	1	C	3
Good water quality	1	0	0	0	1	0	0	FC	2
Known driver of degradation	0	1	0	0	0	0	1	FC	2
Degraded sediments/soils	0	1	1	0	0	0	0	C	2

4.3.2. External Factors

Table 9 shows the external factors for effective implementation. This includes 8 facilitating conditions and 9 challenges. Enforcement against conversion of mangrove area was the most often mentioned facilitating condition. This could include a legal framework against illegal encroachment and informal settlements for example. Expert 7 emphasized the need for prevention in the first place, such as appropriate governance that discourages mangrove conversion.

The most often mentioned challenge was that of pollution from upstream areas. Experts mentioned several examples from their own experiences, such as run-off from a nearby landfill leading to mangrove die-off, nutrient overload, and pesticides from surrounding agricultural activities or

wastewater flowing down from urban areas. Expert 6 stated that this was even more of a concern for mangroves in riverine deltas, that suffer from interventions in upstream zones more directly.

The following three facilitating conditions (Space to grow inland, Land planning and zoning, Secure land tenure) are tightly interconnected. As many coastal areas in the world face a certain amount of sea level rise and a correspondingly shifting high water later, the outer boundary of a mangrove forest is affected as well. This explains the need for mangroves to be able to move uphill or land inward, and by doing so maintain favorable tidal and water quality conditions. However, urban development and agricultural activities convert an increasing amount of coastal lands, resulting in a 'mangrove squeeze' (see Torio & Chmura, 2013). Perceptive land planning or land zoning is helpful in averting such a squeeze. Expert 4 provides the example of places culverts in newly built roads that would otherwise block the freshwater flow into mangrove forests. Expert 6 point out that adequate land planning goes beyond civil engineering solutions however. For instance, this is also facilitated by securing land tenure and providing clear property boundaries.

Accounting for upstream hydrology is a facilitating condition that is closely connected to the internal facilitating condition of providing for a good hydrological regime within the mangroves. In the context of external factors, however, it refers to the consideration of upstream hydrological changes that are not within restoration control, such as freshwater withdrawal by urban areas or industry. Also the facilitating condition of land planning and zoning is linked to this, as the example of road culverts points out.

Corruption was a challenge mentioned by three experts. It should be kept in mind however, that because of the sensitive nature of this topic, not all experts might have felt the freedom to discuss this from their personal experience. Expert 1 provided the example of untransparent legislation frameworks that prevent accountability of policy makers. Expert 3 illustrated how local representatives would facilitate informal settlements near the mangroves for those in need of housing, in exchange for voting loyalty during elections. In this way, corruption undermines restoration incentives to address the social drivers of degradation in the first place and thereby enhances the aforementioned challenges of bad land planning and pollution control for example.

Similarly, corruption fosters the challenge of lacking political will and democratic political constituencies that are necessary to prioritize mangrove restoration over destructive land uses. On an international level, Expert 3 pointed out that apparent political will is framed in pledges and commitments without enforcement, in some cases empty promises. Interestingly, two experts described an opposing trend of increased political will on the international level. Expert 1 pointed out that increased activism and attention for the value of mangroves has led to a broader recognition for mangrove restoration. Expert 7 mentioned that the political commitment to offset emissions has led to an increased interest in mangrove areas as highly productive areas. The growing demand for blue carbon credits is indeed suggested as a separate facilitating condition by three experts. Expert 4 points out that this interest is mainly coming from large emitters, such as developed countries. Expert 5 adds that the demand for blue carbon credits similarly fosters other co-benefits of mangrove restoration, which underpins the research purpose of this study. When considering global trends however, the tendency to economic growth still inhibits a positive climate for nature regeneration in general, as two experts pointed out.

The presence and development of shrimp aquaculture as an economically attractive alternative for mangrove land use poses a challenge to mangrove restoration initiatives. This is only one example of the challenge of having stakeholders with conflicting views, which Expert 3 pointed out as a reason to initially carefully select which stakeholders to include or not to include in the restoration process.

Expert 4 had experienced that owners of privatized mangrove areas are difficult to convince of restoration benefits. In some cases, experts noticed distrust and resistance from the community against a restoration project, especially where this involved non-local researchers and practitioners. This emphasizes the need for education and engagement of the community, as mentioned amongst the internal factors for effective implementation. On a global scale, advocacy and activism were mentioned as a facilitating condition, especially now that digitalization creates a worldwide global platform for awareness raising. Expert 4 pointed out for example, how international news media had covered activistic protests in favor of mangrove restoration, thereby ultimately keeping the local leaders involved to cease planned urban development in that area.

Lastly, the more practical challenge of hurricanes was put forward by two experts. As mangroves grow in tropical areas, some restoration work is also located in the global 'hurricane belt'. Flooding and storm damage may destroy the restoration set-up, undoing the investments and effort put in so far. Expert 5 pointed out that climate change would only increase the intensity and frequency of these extreme weather events, thereby making some mangrove regions less suitable or feasible for restoration efforts.

Table 9 External effective implementation factors. E1 = Expert 1, E2 = Expert 2, etc. C = Challenge. FC = Facilitating Condition. #Experts indicates the total number of experts that mentioned this factor.

External factors	E 1	E 2	E 3	E 4	E 5	E 6	E 7	FC / C	#Experts
Enforcement against conversion	0	1	1	1	0	1	1	FC	5
Pollution from upstream areas	1	1	1	0	1	1	0	C	5
Space to grow inland	1	0	1	0	1	0	1	FC	4
Adequate financial support	1	1	0	1	0	0	0	FC	3
Land planning and zoning	0	0	1	1	0	1	0	FC	3
Secure land tenure	0	0	1	1	1	0	0	FC	3
Consider upstream hydrology	0	0	1	0	1	1	0	FC	3
Corruption	1	0	1	1	0	0	0	C	3
Lacking political will	0	0	1	1	1	0	0	C	3
Demand for blue carbon credits	0	1	0	1	1	0	0	FC	3
Tendency to economic growth	1	1	0	0	0	0	0	C	2
Wave impact on the fringe	0	0	1	0	1	0	0	C	2
Shrimp aquaculture	0	0	1	0	1	0	0	C	2
Stakeholders with conflicting views	0	0	1	1	0	0	0	C	2
Distrust and resistance from community	0	0	1	0	1	0	0	C	2
Advocacy and activism	1	0	0	1	0	0	0	FC	2
Hurricanes	0	0	0	1	1	0	0	C	2

4.3.3. Indicators for Effective Implementation

The previously described factors are rephrased into questions to provide some guidance on how these factors serve as indicators for effective implementation, see Table 10 and Table 11. A more concrete formulation is purposely avoided, as these indicators should not be used as quantifiable norms by any means. For many indicators, this would require a case-to-case investigation on the most optimal and feasible situation, addressing questions like 'What is the maximum allowable wave impact for mangrove species X in restoration area Y?' or 'To what extent can political support for mangrove restoration be feasibly improved within the means and scope of influence of this restoration project?' Instead, the indicators below are meant to provide a general overview of challenges and facilitating conditions, respectively, that one should take into consideration when increasing implementation success of mangrove restoration.

'Tendency for economic growth' was not included in the list of indicators, as this is considered to be a global trend and therefore not case specific. Neither does it offer any direct opportunities for mangrove restoration projects to overcome this challenge. It therefore does not distinct different mangrove restoration efforts in terms of effective implementation.

Table 10 Internal indicators for effective implementation of mangrove restoration. C = Challenge. FC = Facilitating Condition.

Internal indicator	C/FC
Is there adequate tidal range, inundation time and freshwater inflow for mangrove restoration?	FC
Are there education and engagement programs in place for both local community and government agencies?	FC
Is the wave impact on fringing mangroves too powerful for young trees to grow?	C
Is there sufficient on-site scientific and technical support available?	FC
Are there intimations of mono-planting of mangrove species?	C
Are the mangrove species used inapt for the tidal zone they are planted in?	C
Are oxygen and salinity levels on an adequate level for the mangrove species concerned?	FC
Is the driver of mangrove degradation known?	FC
Are the sediments in which restoration efforts take place, degraded?	C

Table 11 External indicators for effective implementation of mangrove restoration. C = Challenge. FC = Facilitating Condition.

External indicator	C/FC
Is there any enforcement in place against mangrove conversion?	FC
Is there any pollution from upstream areas?	C
Is there any space for the mangrove forest to grow inland?	FC
Is there adequate financial support for the restoration project to be carried out?	FC
Are there perceptive land planning schemes available that account for the presence of the mangrove area?	FC
Are landownership and property boundaries within and surrounding the mangrove area well defined?	FC
Is upstream hydrology allowing for sufficient freshwater inflow?	C
Are there intimations of corruptive practices by local authorities?	FC
Is there a lack of support from policy makers and local leaders?	C
Is the restoration effort providing for the blue carbon credit demand?	FC
Does shrimp aquaculture play a major economical role in the area?	C
Are there stakeholders with views or interests that do not support mangrove restoration?	C
Are there intimations of distrust or resistance from the community against restoration practitioners?	C
Is the mangrove restoration area located in an hurricane affected region?	C
Does the restoration project actively contribute to advocacy efforts for mangrove restoration, e.g. through its outreach and external communication?	FC

4.3. Case Study

Before discussing the results of the local assessment and the perception study, context on the case study with Mangrove Maniacs on Bonaire is provided in Sections 4.3.1 and 4.3.2. The sections thereafter discuss the assessment of the ISJOS indicators, effective implementation indicators and community perception, respectively.

4.3.1. Background

About the Site

The mangrove forests of Bonaire are mostly located in the largest lagoon of Bonaire, called Lac. It includes four mangrove species, dominated by red (*Rhizophora mangle*) and black (*Avicennia germinans*) mangroves. Lac covers approximately 700 ha in the south-east part of the island (Wells & Debrot, 2008) and is used by waterbirds for feeding and breeding and as a nursery by various fish species. For this reason, Lac has been designated as a protected area under the RAMSAR convention (Ramsar Sites Information Service, 2021), is a recognized Important Bird Area (BirdLife International, 2008) and is submitted to several international wildlife conservation treaties (Mangrove Maniacs, 2021). Furthermore, Lac is a tourism hotspot and provides various recreational activities, ranging from kayaking, to windsurfing and snorkeling.

Despite its protected status, the mangrove forest in Lac is deteriorating at the landward side of the forest. This is the result of high sediment influx coming from the overgrazed land, on which invasive goats and donkeys roam freely. Excessive sediment deposition is depriving the mangrove area from freshwater inflow, creating hypersaline and low water quality conditions.

Unlike mainland Dutch municipalities, Bonaire is not part of a Dutch province. The provincial governance tasks, amongst which nature conservation, are therefore carried out by the local authorities on Bonaire: het Openbaar Lichaam Bonaire (OLB). OLB has commissioned Stichting Nationale Parken (STINAPA) Bonaire with the management of the protected natura area on Bonaire, including the National Marine Park, which includes Lac.

About the Project

The first mangrove restoration efforts followed from an extensive ecological baseline study of Lac, which i.a. suggested to improve water circulation in the mangrove forest (Debrot, Meesters, de León, & Slijkerman, 2010). From 2015, after an initial study on concrete management actions (Wösten, 2013), a four year project was jointly executed by OLB and STINAPA Bonaire. Most of the work was carried out by volunteers, of which a smaller group of mangrove enthusiasts decided to continue the work even beyond the project deadline. In 2021, Mangrove Maniacs was founded as an independent NGO for local stewardship of this ecosystem. They are commissioned by STINAPA Bonaire to maintain and restore the mangroves in Lac.

The physical restoration work of Mangrove Maniacs consists of the maintenance of mangrove channels for water flow (Figure 9), the growing of mangrove seedlings in nurseries (Figure 10) and the planting of terrestrial vegetation (Figure 11) on the Northwest side of Lac to prevent downstream sedimentation, which may be expanded further on the South coast in the future. Mangrove Maniacs is also engaged in multiple community programs, has hosted multiple excursions, expert workshops and restoration events for various target groups (e.g. “Extra Hulp Voor de Mangrove Maniacs,” 2021; “TCB Hosted Press from National Geographic Traveler Netherlands and DUIKEN Magazine,” 2021; Mangrove Maniacs, n.d.), and provides the weekly opportunity for laymen and regular volunteers to join the restoration activities in the field.

Figure 9 Mangrove restoration through the clearance of channels for improved water circulation. Overgrown branches and peat blocks are removed, to broaden the channels towards the backside of the mangrove forest. (T. Zoons, personal archive)

Figure 10 Mangrove restoration includes the maintenance of nurseries in which mangrove seedlings and propagules are grown to an appropriate size for outplanting. (S. Engel, personal communication, 19-12-2021)

Figure 11 Erosion control through outplanting of terrestrial vegetation (A. Verhoeven, personal communication, 19-12-2021)

Figure 12 shows the working area of Mangrove Maniacs in Lac. The highlighted lines show natural and created channels. Green channels are maintained and in good condition. Orange channels require maintenance. Purple channels have been overgrown and are on the planning for future work. Red channels have been aborted and yellow areas highlight not the channels, but mangrove fringes that are maintained by Mangrove Maniacs. The lost and restored mangrove areas are indicated in Figure

13 and Table 12. Even though a total loss of 9.4 ha has been observed because of sargassum influx and decreased water quality, Mangrove Maniacs contributed 16.4 ha of restored mangrove area to the net gain of the described mangrove area.

Figure 12 Mangrove restoration area in Lac, Bonaire. Channels are highlighted. (S. Engel, personal communication, 17-12-2021)

Figure 13 Degraded (red) and restored (green) Mangrove areas in Lac, Bonaire. (S. Engel, personal communication, 17-12-2021)

Table 12 Restored and lost mangrove area in Lac.

Number	Area name	Mangrove species	Loss/Improved	Since	Area size (m²)
1	Isla Yuwana	Red	Improved	2017	43260
2	Black Mangrove	Black	Improved	2015	100000
3	Behind Rancho	Red/Black	Improved	2021	20866
4	Behind Rancho II	Black	Loss (sedimentation)	2014	-54622
5	Fringe	Red	Loss (sargassum influx)	2018	-12025
6	Behind Fogon Rancho	Red/Black	Loss (sedimentation)	2014	-27166
Total					**164126**

4.3.2. Dialogue with OLB and STINAPA Bonaire

The outcomes of the dialogue session with OLB and STINAPA Bonaire as governing institutions of Bonaire's mangroves are summarized in Appendix 6. This represents a first draft of a possible SJOS for Bonaire from the perspective of policy makers, indicating the most relevant EC and SF dimensions for the island and people of Bonaire. For the EC, 4 dimensions were identified. For the SF, 13 dimensions were identified. During the dialogue, 3 additional dimensions were identified that serve as boundary conditions for realizing the other 17.

The dimensions of the SJOS for Bonaire that show overlap with the ISJOS for mangrove restoration are: Recreation, Food, Economy & Income, Spatial Planning and Land-use, Waste Disposal, Erosion, Information Provision. These dimensions (and their interpretations by the dialogue participants) provide direct grounds for the benefit of mangrove restoration on Bonaire. The explanations below follow directly from the dialogue minutes, which can be made available on request.

Recreation

Mangrove restoration contributes indirectly to the priority of increasing recreation facilities, as the tourism sectors organizes kayak and snorkel tours through and along the mangroves. Furthermore, the mangroves contribute to the beneficial water conditions for windsurfers in the adjacent bay.

Food

Although extractive activities are not allowed in the mangroves of Lac, artisanal fishing in and around the bay is permitted. With the presence and restoration of mangroves, the fish available for food consumption is directly supported. Fisheries as food provisioning is of significant importance to Bonaire as an island, since the availability of many other food sources is dependent on import. The policy priority to enhance local food production therefore underpins the need of mangrove restoration.

Economy and Income

The dimension of Economy and Income in the SJOS for Bonaire is mostly concerning the notice of social balance and security. In contrast with many other places in the world, the majority of immigrants and temporary residents on Bonaire have a Western and wealthy background. This is led to increasing food and housing prices and a disfigured image of the average income level, for example, which in turn decoupled economic growth and interests from its original beneficiaries. Meaningful jobs that serve to close this gap, were mentioned as a possible solution. Mangrove restoration related jobs and the resulting income opportunities in fisheries, tourism and recreation may contribute to this. It should be noted however, that employment opportunities with MM so far have been limited.

Spatial Planning and Land-use

As the Spatial Planning dimension in the SJOS for Bonaire was inter alia interpreted to comprise of a nature regenerative component, for example through restoration, mangrove restoration could directly contribute to this. Although MM is not yet planting mangroves in the Lac area, reforestation efforts on the south western coasts are already in trial and reforestation with terrestrial species has been successfully employed to decrease downstream sedimentation. Nature restoration and reforestation is however not explicitly part of the Spatial Development Plan Bonaire (ROB) (OLB, 2010).

Waste disposal

Proper management of solid waste and waste water was mentioned as a priority to prevent environmental pollution, especially in relation to the nutrient-poor conditions required in coral reefs. The water filtration capacity of mangroves, of chemical pollution as well as nutrients, is directly addressing these policy priorities, albeit along an end-of-pipe approach to waste pollution.

Erosion

The dimension of erosion in the ecological ceiling for Bonaire refers to the land erosion that results from overgrazing by goats and donkeys. Since this in itself is the predominant driver of mangrove degradation on Bonaire, mangrove restoration efforts by MM also focus on prevention of this cause. This then does not entail the actual reforestation or hydrological rehabilitation of the mangrove area, but the terrestrial reforestation activities and educational efforts may well contribute to eventual erosion control.

Information provision

Information provision was mentioned as one of the three boundary conditions for safeguarding the ecological ceiling and social foundation of Bonaire. The connection of mangrove restoration to this dimension is already illustrated through the role of educational efforts in facilitating erosion control, for example. Both the dimensions of Education and Networks in the ISJOS for mangrove restoration are clearly connected to the policy goal of improved information provision. This could, inter alia,

include the engagement of local community members in the restoration activities, contribution to educational programs and the facilitation of knowledge exchange amongst practitioners and policy makers.

4.3.3. Sustainability Impact of Mangrove Maniacs

The application of the ISJOS framework on the work of Mangrove Maniacs was carried out for the following impact dimensions: Climate Change Mitigation, Fisheries, Increased Biodiversity within Mangroves and Spiritual Well-being. Quantitative estimations are summarized in Table 13 and based on simple, linear cause-effect (restoration-impact) relationships. Spiritual Well-being is discussed separately, along a qualitative approach.

Table 13 Summary of quantitative estimations of ISJOS indicators for MM.

ISJOS Impact Dimension	Dependent Variable	Independent Variable	Result
Climate Change Mitigation	Restored Area (ha)	Enhancement of carbon Stock	7580 Mg CO_2
Fisheries	Restored Area (ha)	Enhancement of fisheries catch	1225.1 kg y^{-1}
Increased Biodiversity within Mangroves	Restored (Yes/No)	Enhancement of species richness	5

The independent variables used for estimating these ISJOS indicators are provided in Section 3.4.2. The dependent variables are based on the scenario that, based on current MM capacity and plans, the improving areas indicated in Table 12 are to be fully restored in the future. In that projection, 7580 Mg CO_2 is estimated to be stored in comparison to continuous degradation of the areas concerned. Furthermore, full recovery of these area is estimated to result in a fisheries enhancement of 1225.1 kg y^{-1}, additional to the fisheries catch if these areas remained degraded. Biodiversity within the restored areas is estimated to increase with 5 species, in terms of species richness, which is a doubling of biodiversity as compared to degraded mangroves.

Spiritual Well-being impact from Mangrove Maniacs

The results for the ISJOS impact theme of Spiritual Well-being follow directly from the community perception survey, for which the results are presented in Section 4.3.5. To follow along with the structure of this research, the paragraphs below explain these survey results more specifically in relation to the ISJOS indicators for spiritual well-being.

When asked to identify the personally perceived positive and negative impacts from mangrove restoration, two CB respondents mentioned benefits to mental health. More specifically, they described experiences of increased happiness and a sense of calm resulting from time spent in or near the mangroves. These mentions emerged only from respondents who filled out the Dutch survey and not from respondents who filled out the Papiamentu survey. However, the appreciation of the view and beauty of nature was mentioned in both respondent groups: by 6 times in response to the Dutch survey and once in response to the Papiamentu survey.

In response to the questions concerning perceived impacts on Bonaire as a whole (as opposed to the personal level), beauty of nature and sense of calm were mentioned by two respondents to the Dutch survey. Interestingly, cultural value of mangroves was referred to by one respondent here as well, whereas this was not mentioned in a personal context. Amongst MM respondents, a sense of happiness was the most often mentioned personal impact perceived, followed by the beauty of nature. With regards to the impacts perceived on Bonaire as a whole, happiness was also mentioned by two respondents.

Esthetics as a ES from mangroves was explicitly discussed in the survey, and was valued equally by respondents to the Dutch and Papiamentu survey. Respectively, 86% and 84% of these respondents considered the esthetics of mangroves as a ‘very important’ or ‘a little important’ reason to restore

the mangrove area in Lac, although the relative contribution of 'very important' valuations amongst respondents to the Papiamentu survey was higher. Also amongst MM respondents, the ES of esthetics was considered 'very important' or 'a little important' by 85% of the respondents.

4.3.4. Effective Implementation score for Mangrove Maniacs

Positive outcomes in this assessment for internal factors Table 14 Mangrove Maniacs score on the internal indicators for effective implementation of mangrove restoration. C = Challenge. FC = Facilitating Condition. NA = not applicable. SE = based on consultation with MM research coordinator, S. Engel.Table 14Table 14) and external factors (Table 15) are highlighted. Positive outcomes mean that indicators for challenges are scored with 'No' and indicators for facilitating conditions are scored with 'Yes'. Indicators that were not applicable to the case of MM, were scored with 'NA'.

Out of the 9 indicators for internal challenges and facilitating conditions, 4 were scored positively. The indicators for wave impact, mono-planting, appropriate species use and sediment quality were not applicable, since planting is currently not part of the restoration efforts in Lac. The only internal indicator that implied space for improvement, was the facilitating condition of education and engagement programs. MM is involved with multiple educational programs on a yearly basis, but does not have any formal collaborations with government institutions.

Out of the 15 indicators for external challenges and facilitating conditions, 12 were scored positively. Two external factors showed opportunities to improve implementation effectiveness: Lacking Political Will and Demand for Blue Carbon. Support from local government institutions is considered deficient, but possibilities to improve this may well lie within the means of MM as genuine efforts to reach out in this regard have not been undertaken yet (S. Engel, personal communication, 06-01-2022). As the restoration results of Mangrove Maniacs is not verified by any carbon offsetting standards, it is currently not tapping into the increasing demand for blue carbon. The carbon verification potential is however one of MM's research interests (Mangrove Maniacs, 2022b). For one indicator, upstream pollution, there was not enough data available to make a useful assessment. However, water quality measurements within and outside Lac are currently being arranged for.

Table 14 Mangrove Maniacs score on the internal indicators for effective implementation of mangrove restoration. C = Challenge. FC = Facilitating Condition. NA = not applicable. SE = based on consultation with MM research coordinator, S. Engel.

Internal indicator question	C/FC	Score	Substantiation	Reference
Is there adequate tidal range, inundation time and freshwater inflow for mangrove restoration?	FC	**Yes**	Hydrological restoration is the core focus of MM work.	See Section 4.3.2.
Are there education and engagement programs in place for both local community and government agencies?	FC	No	Various educational programs, but, no formal engagement programs with local government institutions.	SE
Is the wave impact on fringing mangroves too powerful for young trees to grow?	C	NA	Planting within Lac is not performed yet.	
Is there sufficient on-site scientific and technical support available?	FC	**Yes**	Two commissioned independent researchers, broad academic network through student internships and PhD research.	
Are there intimations of mono-planting of mangrove species?	C	NA	Planting within Lac is not performed yet.	
Are the mangrove species used for planting inapt for the tidal zone they are planted in?	C	NA	Planting within Lac not performed yet.	
Are oxygen and salinity levels on an adequate level for the mangrove species concerned?	FC	**Yes**	Data not published yet.	SE
Is the driver of mangrove degradation known?	FC	**Yes**	Excessive sedimentation through inland overgrazing	(Wösten, 2013)
Are the sediments in which planting efforts take place, degraded?	C	NA	Planting or sediment analysis within Lac is not performed yet.	

Table 15 Mangrove Maniacs score on the external indicators for effective implementation of mangrove restoration. C = Challenge. FC = Facilitating Condition. SE = based on consultation with MM research coordinator, S. Engel.

External indicator questions	C/FC	Score	Substantiation	Reference
Is there any enforcement in place against mangrove conversion?	FC	**Yes**	RAMSAR site and Important Bird Area (IBA)	(BirdLife International, 2008; Ramsar Sites Information Service, 2021)
Is there any pollution from upstream areas?	C	-	Data not available yet.	
Is there any space for the mangrove forest to grow inland?	FC	**Yes**	Mudflats behind the mangrove belt allow for landward growth.	
Is there adequate financial support for the restoration project to be carried out?	FC	**Yes**	Adequate financial support for the capacity available.	SE
Are there perceptive land planning schemes available that account for the presence of the mangrove area?	FC	**Yes**	The ROB prevents further development of the area surround the mangroves.	(OLB, 2010)
Are landownership and property boundaries within and surrounding the mangrove area well defined?	FC	**Yes**		SE
Is upstream hydrology allowing for sufficient freshwater inflow?	FC	**Yes**	Relatively 'fresh' water comes from connectivity with open bay.	SE
Are there intimations of corruptive practices by local authorities?	C	**No**		SE
Is there a lack of support from policy makers and local leaders?	C	Yes	The space for improvement may in the first place be with MM, seeking the right OLB lead on erosion control policy, for example.	SE
Is the restoration effort providing for blue carbon credit demand?	FC	No	No carbon certification scheme in place.	
Does shrimp aquaculture play a major economic role in the area?	C	**No**		
Are there stakeholders with views or interests that oppose mangrove restoration?	C	**No**		SE
Are there intimations of distrust or resistance from the community against restoration practitioners?	C	**No**		SE
Is the mangrove restoration area located in an hurricane affected region?	C	**No**	Bonaire is not located within the Hurricane region.	
Does the restoration project actively contribute to advocacy efforts for mangrove restoration, e.g. through its outreach and external communication?	FC	**Yes**	Outreach through multiple channels on a local and international level, including newspaper, television, and radio engagement.	(Mangrove Maniacs, 2022a)

4.3.5. Perceived Impact by the People of Bonaire

Sociodemographic characteristics of respondents

In total, 100 questionnaires were taken for the CB survey. After exclusion of non-sedula owners, the sample size consisted of 89 participants, of which 56% did the Dutch survey ('NL') and 44% did the Papiamentu version ('PAP'). The results of the CB survey are presented along this language distinction, as it may illustrate the differences between autochthonous and allochthonous citizens of Bonaire. The average participant's age and residency time in Bonaire for the CB-NL surveys was 47±13 years and 5±16 years, respectively. Average age and residency time for the CB-PAP surveys was 44±15 years and 25±18 years, respectively. The age and residency time distribution of respondents in this sample shows that both NL and PAP respondents are predominantly aged over 30 years and the NL respondents have a more varied and on average shorter residence time. The latter reflects the high (temporary) immigration rate of Dutch people from the European part of the Netherlands. Figure 14 and Figure 15 show the distribution of gender and level of education amongst the CB participants. Gender balance was carefully taken into consideration during the market days, but the eventual number of female

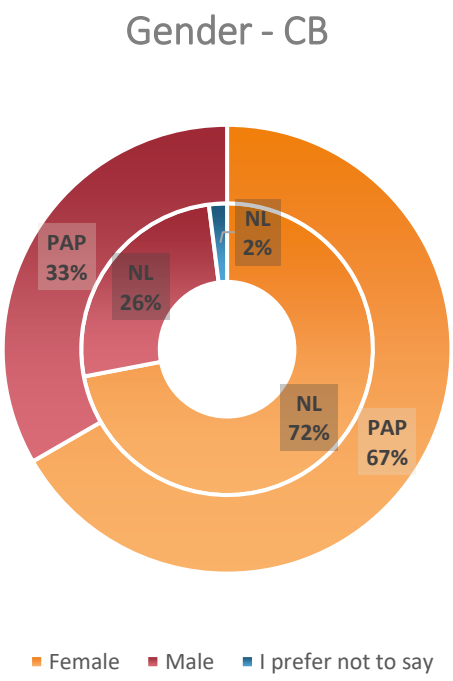

Figure 14 Gender distribution amongst CB survey participants. Outer ring: PAP surveys. Inner ring: NL surveys.

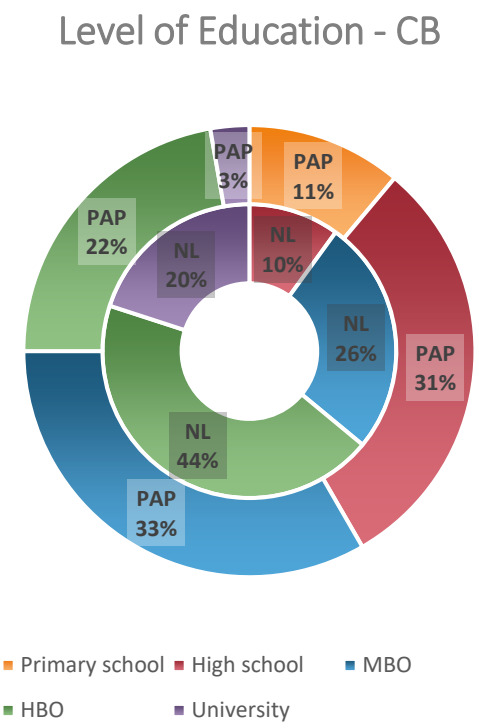

Figure 15 Level of Education distribution amongst CB survey participants. Outer ring: PAP surveys. Inner ring: NL surveys.

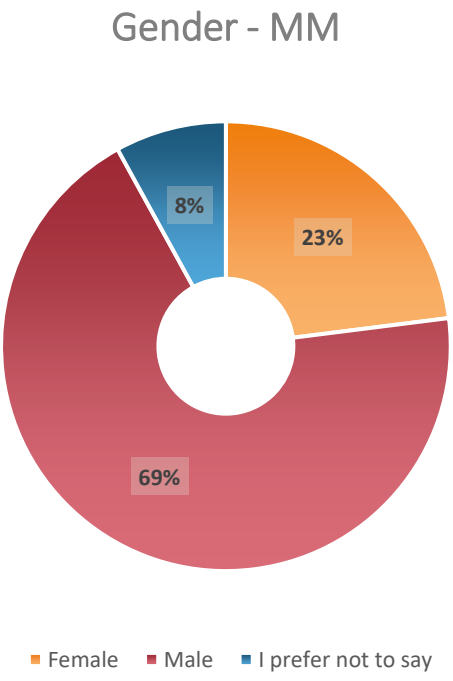

Figure 16 Gender distribution of MM surveys.

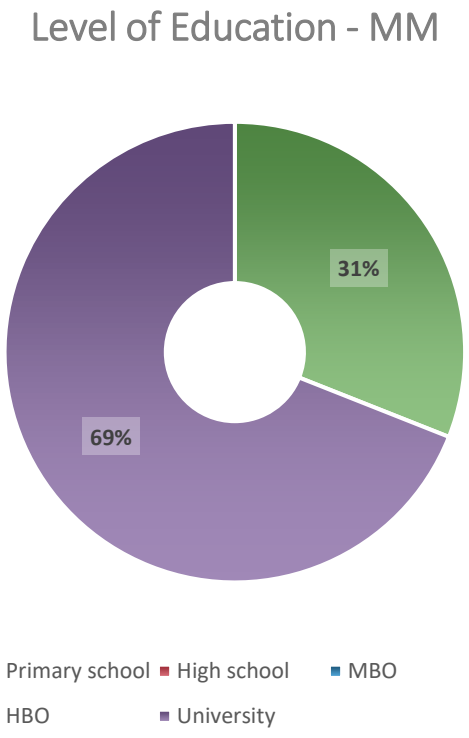

Figure 17 Distribution of level of education of MM surveys.

participants was larger in both the NL and PAP samples. More than half (62%) of the NL respondents had pursued higher education (HBO or University), whereas this was 25% for the PAP respondents, which reflects typical community patterns on Bonaire.

Amongst the Mangrove Maniacs organization, 14 people (hereafter referred to as 'MM') took part in the survey for target group 2. After exclusion of a research student, the sample size consisted of 13 participants, of which 9 participants were in possession of a sedula and 4 were not. The average age was 48±13 years and the average residency time in Bonaire 7±10 years. Figure 16 and Figure 17 show the distribution of gender and level of education amongst MM participants. All participants received HBO or university education.

Perceived Impact from Mangrove Restoration on Bonaire

Figure 18 shows the perception of impacts for citizens of Bonaire, presented separately for PAP and NL respondents. Comparing the overall perception of negative and positive impacts, positive impacts perceived on a personal level and for Bonaire as a whole, were most often confirmed amongst PAP respondents (by 29% and 33% respectively) as well as NL respondents (by 46% and 56% respectively). Amongst both PAP en NL respondents, positive impacts for Bonaire as a whole were also more often confirmed as compared to positive impact perceived on a personal level. 63% of PAP respondents indicated they did not personally experience any positive impacts, whereas this was 22% by the NL respondents. The only negative impact perceived on a personal level, came from PAP respondents. For Bonaire as a whole, only 8% and 6% of NL and PAP respondents confirmed their perception of negative impacts. The questions concerning perceived impact on Bonaire as a whole structurally resulted in the highest shares of 'I don't know' responses, ranging from 29% to 36%.

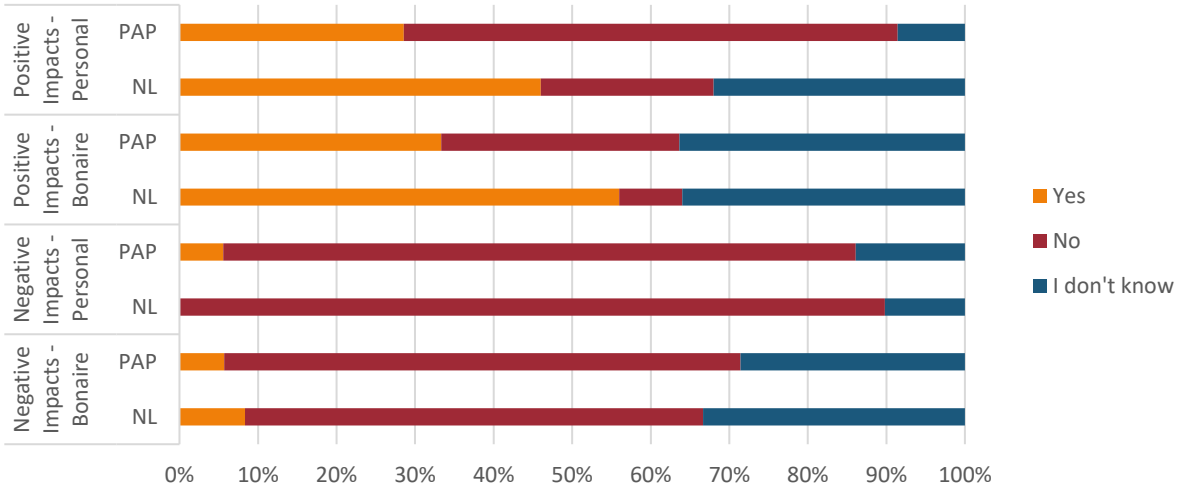

Figure 18 CB Perception of negative and positive impacts of mangrove restoration on a personal level ('Personal') and for the island of Bonaire ('Bonaire'). PAP = Papiamentu surveys. NL = Dutch surveys.

Figure 19 shows the perception of impacts for those engaged with Mangrove Maniacs. Also here, positive impacts on both a personal level as well as for Bonaire as a whole, were more strongly confirmed than negative impacts. In fact, none of the MM respondents negated positive impacts of mangrove restoration on the whole of Bonaire and 100% of the respondents negated the existence of negative impacts on a personal level.

Respondents were also asked to identify the positive or negative impacts if they believed there were any. However, not all respondents who answered 'Yes' to any of these four question, provided their corresponding examples. The following suggested positive impacts as perceived by CB and MM respondents must therefore be interpreted as indicative only. Table 16 and Table 17 show the results for perceived benefits on a personal level and Bonaire as a whole, respectively.

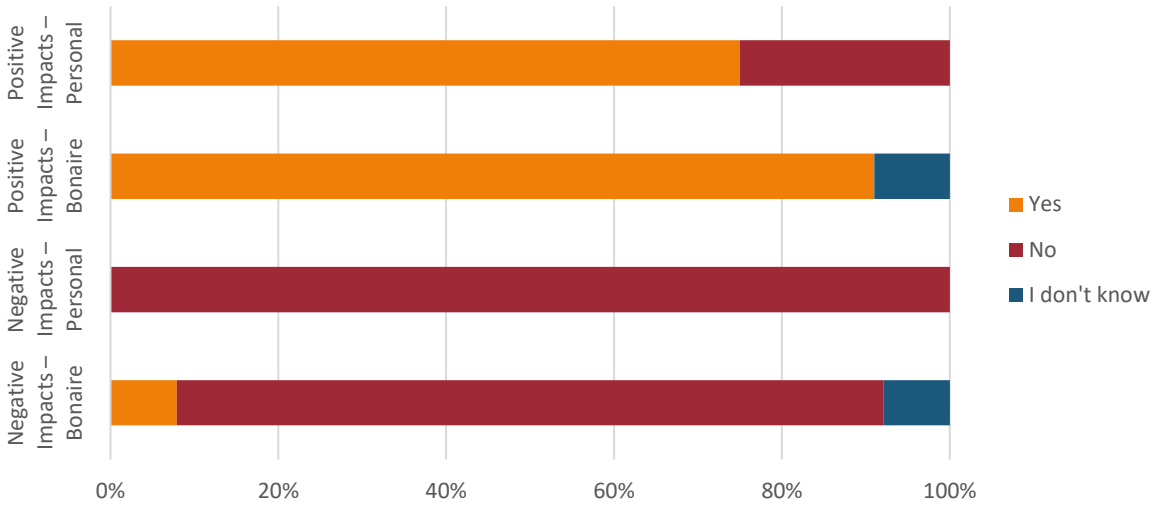

Figure 19 MM Perception of negative and positive impacts of mangrove restoration on a personal level ('Personal') and for the island of Bonaire ('Bonaire').

Table 16 Perceived positive impacts from mangrove restoration on a personal level. CB = Citizens of Bonaire. MM = Mangrove Maniacs. NL = Respondents in the Dutch survey. PAP = Respondents in the Papiamentu survey. N = number of mentions.

	CB-NL	n		CB-PAP	n		MM	n
1.	Regeneration & Biodiversity	7	1.	Hiding/nursery place for fish	4	1.	Happiness	6
2.	Beauty of nature	6	2.	Tourism	1	2.	Beauty of nature	3
3.	Sports & recreation	4		Water filtration	1	3.	Sports & recreation	2
4.	Hiding/nursery place for fish	3		Clean air	1	4.	Employment: research	1
5.	Coastal protection	2		Beauty of nature	1		Personal contribution to restoration	1
6.	Tourism	1		Coastal protection	1			
	Employment: fishing	1		Regeneration & General biodiversity	1			
	Happiness	1		Erosion control	1			
	Calmth/ stress relief	1		NTFPs	1			
				Shadow	1			

Table 17 Perceived positive impact from mangrove restoration for the whole of Bonaire. CB = CItizens of Bonaire. MM = Mangrove Maniacs. NL = Respondents in the Dutch survey. PAP = Respondents in the Papiamentu survey. N = number of mentions.

	CB-NL	n		CB-PAP	n		MM	n
1.	Hiding/ nursery place for fish	7	1.	Hiding/nursery place for fish	3	1.	Regeneration & General biodiversity	4
2.	Regeneration & General biodiversity	6	2.	Regeneration & General biodiversity	2	2.	Coastal protection	3
3.	Coastal protection	5		Coastal protection	1	3.	General environmental benefit	3
4.	Employment: fishing	4		Employment: fishing	1	4.	Happiness	2
5.	Tourism	3		NTFPs	1	5.	Tourism	2
	Reef health/ biodiversity	3				6.	Nursery/hiding place for fishes	1
6.	Employment: tourism	2						
7.	Water filtration	1						
	Clean air	1						
	Beauty of nature	1						
	Sports and recreation	1						
	Calmth/ stress relief	1						
	Cultural value	1						

A listing of perceived negative impacts is not provided, due to a lack of replies on these questions. The only response with regards to negative impacts perceived on the personal level was from a PAP respondent, indicating concerns for wild growth of mangroves, which would obstruct access to the mangrove channels and surrounding roads. Responses that regarded negative impacts on Bonaire as a whole, differed between NL and PAP respondents. One PAP response to this question addressed the issue of wild growth as well and mentioned the maintenance required to manage this. Another PAP response mentioned the decrease in wind flow in the area. The NL responses suggested a perceived negative impact for the whole of Bonaire from increased mosquito presence and increased disturbance by tourists driving their SUVs in the area. Furthermore, additional comments were provided by three PAP respondents that knowledge and information on the impacts of mangrove restoration were lacking.

Valuation of Mangrove Ecosystem Services in Lac

The valuation of specific mangrove ESs in Lac by citizens of Bonaire and Mangrove Maniacs is presented in Figure 20 Figure 21 Ecosystem Service valuation of mangroves in Lac by MM.. Amongst PAP respondents, the services most often valued as 'Very important' were coastal protection (85%), followed by biodiversity (79%), fisheries (78%), sediment trapping (77%) and tourism (76%). Amongst NL respondents, biodiversity received the most 'very important' responses (96%), followed by fisheries (92%), carbon sequestration (90%) and coastal protection (90%). In general, NL respondents more convincingly valued ESs as 'very important' than PAP respondents. The biggest differences occurred for services related to tourism and carbon sequestration, of which the first was clearly valued as more important by PAP respondents and the latter was valued as more important by NL respondents. Tourism and esthetics received the lowest valuation from NL and PAP respondents altogether. Respondents that indicated to be unsure about their perception of a specific ES – despite the short description provided in the question, were found most commonly amongst PAP respondents, with 14% of them responding 'I don't know/Unclear' to the questions concerning fisheries and protection against SWI. This was 13% for the service of carbon sequestration. Amongst NL respondents, this type of response never made up more than 6% of the total NL responses.

The valuation of specific mangrove ESs in Lac by those engaged with Mangrove Maniacs is presented in Figure 21. None of the MM respondents provided an 'I don't know/Unclear' response to any of the ESs. Also here, biodiversity was most often valued as 'very important' or 'a little important' (100%), together with the same distribution for the service of sediment trapping. Also water filtration and coastal protection received a 100% valuation for 'very important' or 'a little important', albeit with a higher share of the latter response. Tourism received the lowest valuation, with 21% of respondents indicating this to be 'not important' in considerations for mangrove restoration.

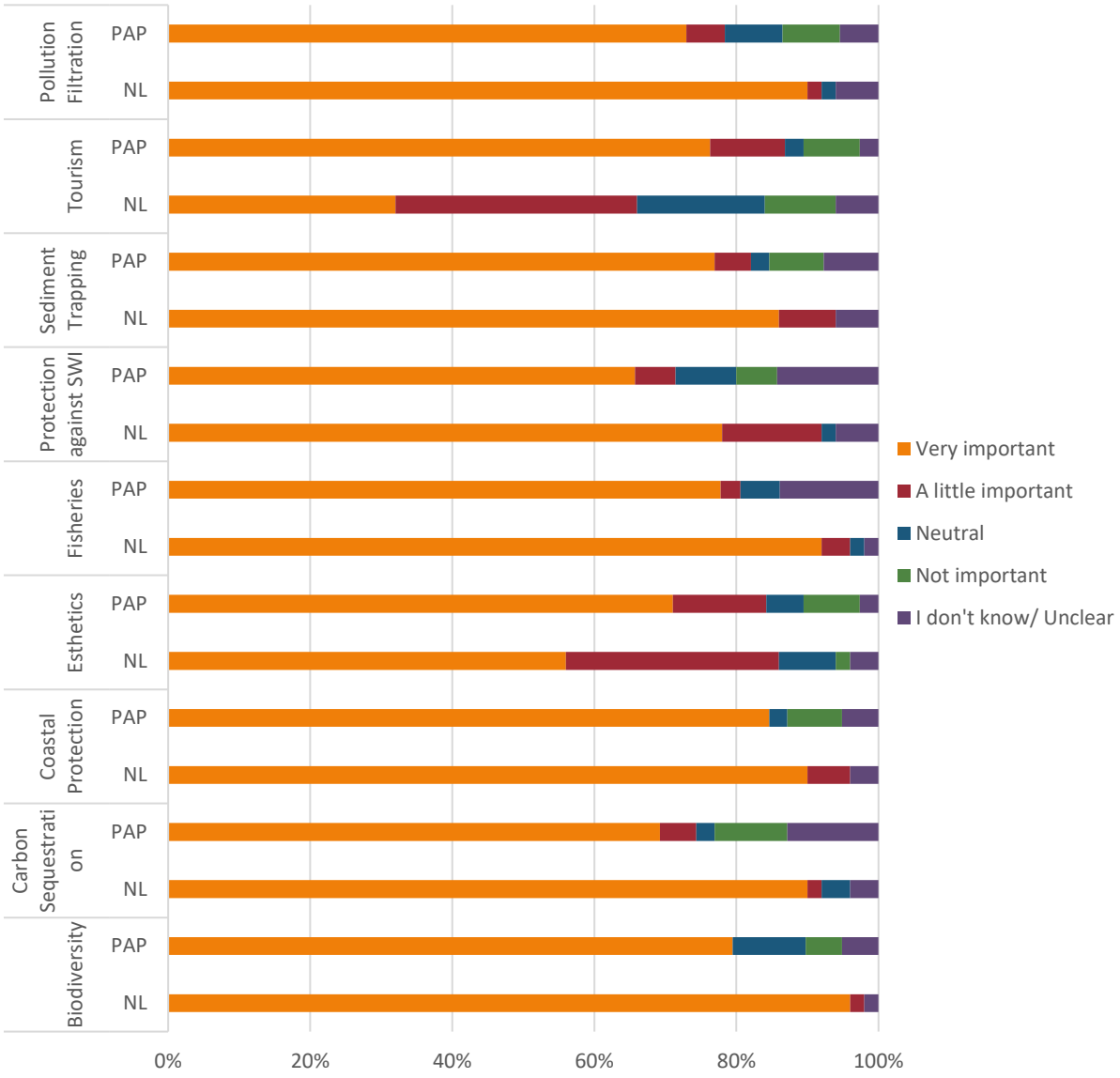

Figure 20 Ecosystem Service valuation of mangroves in Lac by CB.

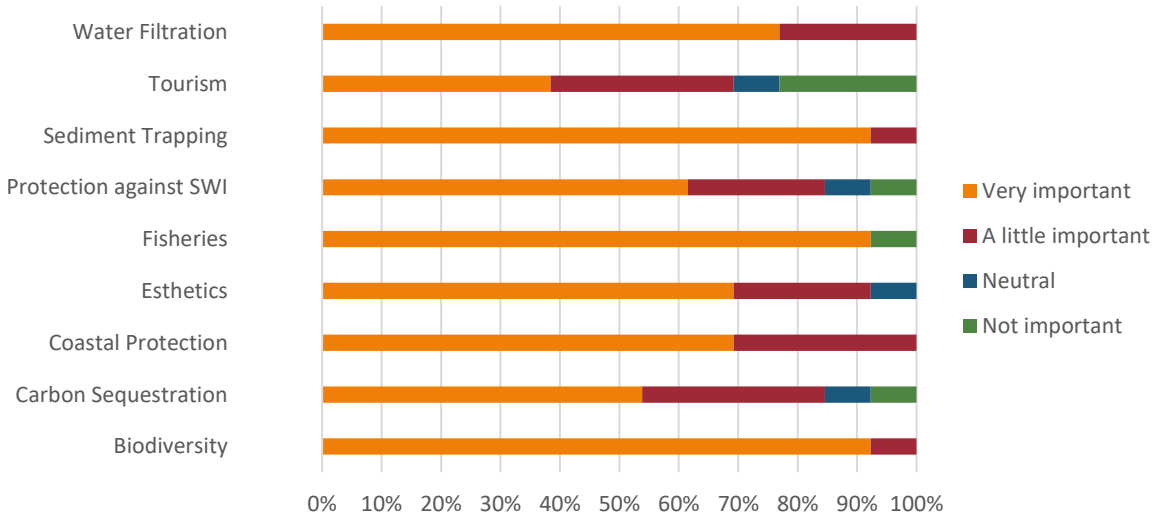

Figure 21 Ecosystem Service valuation of mangroves in Lac by MM.

5. Discussion

The aim of this study was to identify and apply a framework of indicators for mangrove restoration to understand its sustainability impact and conditions for effective implementation. To recognize the extent to which this research has achieved this, each of the sub-questions are discussed on three aspects. First, the limitations and implications of their methodologies are addressed (Section 5.1.), then the implications of the results are discussed in the context of existing theory (Section 5.2.), followed by a reflection on their meaning in the broader academic and societal context (Section 5.3.).

5.1. Methodological caveats

Throughout this research, various qualitative research methodologies have been employed. Below, the caveats related to the development of the ISJOS framework, effective implementation indicators and the local case study are discussed consecutively.

5.1.1. Limitations of the development of the ISJOS framework

The ISJOS framework is in the first place based on expert interviews and in a second stage verified with existing academic literature. The wide geographic distribution of experts' working areas allowed for a comprehensive analysis of different contexts. On the other hand, the online interview setting and intercultural and language barriers posed minor challenges to the interpretation of some of the respondents' answers. Due to time constraints, it was not always possible to clarify these passages. In general, the expert-based interview approach proved very useful in incorporating non-academic knowledge of mangrove restoration, especially where it touched upon the societal tendencies around restoration efforts (e.g. land ownership issues, corruption or the role of women). This is visible from the amount of defined impact dimensions, for which no concrete indicator was found in existing literature.

Contextual differences in mangrove restoration expertise

The number of times that an impact was mentioned by the experts was assumed to be representative for its legitimacy in the framework and single time mentions were therefore omitted from the framework. However, these single time mentions of impacts can be the result of a more specialized focus of the expert on a specific aspect of restoration, such as hydrology or community engagement. Another explanation might be the personal priorities and interests that experts may have in other impacts. Despite their omittance from the ISJOS framework, the impacts that were only mentioned by one expert may put forward interesting topics for further research.

A similar prejudice seems particularly apparent in the number of mentions of positive and negative impacts. Understandably, experts on mangrove restoration are likely to have a stronger interest in the positive impacts of their work than the negative impacts, which results in a social desirability bias in their interview responses (Börger, 2012). An example are the incorrect responses provided by some experts, concerning the impact of mangrove restoration on ozone layer depletion. For this reason, the less often discussed negative impacts, were all included in the ISJOS framework.

A narrow scope for literature review

In order to translate the dimensions identified through interviews, into measurable indicators, a literature review was carried out. As the screened papers only included those published after 2011, relevant studies before have not been considered. Furthermore, a lot of mangrove restoration related research is described with different terms, such as: coastal wetlands, marshlands, estuaries or lagoons. These terms were not included in the search string, but could potentially contribute to the identification of literature in which suitable indicators have already been suggested, as will be explained in section 5.2.1.

Suggestions from mangrove restoration practice that merit closer investigation

Restricted selection of impact dimensions for the final inclusion in the ISJOS model was necessary to maintain the scope of this thesis within time limits and the author's academic proficiency. Appendix 2c shows which suggested impacts, both positive and negative, were not included in the framework. Despite the substantiation for not including them, some of these impacts may bring forth useful insights in understanding the total impact potential of mangrove restoration.

Impacts on the global level of the SF were omitted from analysis, but may well contribute significantly to the overall value of mangrove restoration. One example is the enrichment of science and consultancy opportunities that mangrove restoration projects commonly foster – this thesis being the case in point –, which touches upon the ISJOS themes of Networks, Education, and Income & Employment. Also increased awareness through global media engagement and decreased risk of climate related conflicts were mentioned in relation to the theme of Peace & Equality, and find resonance in the notion that investment in natural capital and its resources should be seen as investment in international peace and security (Matthew, Halle, & Switzer, 2002).

Negative impacts were not included with a corresponding indicator. However, in understanding trade-offs that exist between different impact from mangrove restoration, it is important to make disservices explicit as well. Some, such as smell and disease transmission (Friess et al., 2021), have already been described, but are yet to be quantified through an indicator. Future research could build on this thesis by investigating the trade-offs between these negative indicators and their related positive indicators. For example, if mangrove restoration benefits the protection of houses, but at the same time restricts the rights or space available to increase housing for a growing population, how can these counteracting impacts be integrated into one indicator? And how do these trade-offs balance out in future projections for both impacts?

5.1.2. Limitations of the development of effective implementation indicators

The identification of indicators for effective implementation have not been verified through literature review and are fully based on the interview outcomes. The challenges and facilitating conditions represented by the indicator questions are phrased to resemble the original responses as closely as possible. In some cases, this resulted in awkward, unspecific phrasing, such as 'Is the wave impact on fringing mangroves too powerful for young trees to grow?' (Table 11 External indicators for effective implementation of mangrove restoration. C = Challenge. FC = Facilitating Condition.Table 11). Drawing on the expert-based experiences analyzed in this thesis, local applications should use an empirical basis to define concrete, measurable, goals in overcoming these challenges and creating the facilitating conditions.

5.1.3. Limitations of the assessment of Mangrove Maniacs

Application of the ISJOS framework

The impact dimensions that are discussed for the work of Mangrove Maniacs, were partly based on the policy priorities defined in the dialogue with OLB and STINAPA. It is important to note however, that most of the OLB representatives were employed by the Spatial Planning department, whereas representatives from other departments would have likely enriched the discussion with different, perhaps even conflicting, views and interest. Since power relations were not considered, it is not sure how well dialogue participants represent the prevailing power dynamics that govern the island of Bonaire.

The indicators on Fisheries Enhancement, Biodiversity Increase and Climate Change Mitigation, rest on two assumptions. The first being the scenario that the areas assessed are fully recovered and the second being the assumption that comparison between degraded and intact mangroves in Lac is

representative for this full recovery. Ecological outcomes between natural and outplanted mangroves are different and require caution with such assumptions (Su et al., 2021). The case described in this research however, concerns hydrological restoration and subsequent natural regeneration, which is why the comparison between degraded and intact mangroves is deemed justified.

Furthermore, the sustainability impact estimated for Climate Change Mitigation and Fisheries is based on the areas that have been observed to be improving. However, there may be additional impact that emerge from the avoided loss of mangrove areas through the hydrological rehabilitation work of MM, but there was no data available to include this. This means that the estimates are on the conservative side. On the other hand, they are largely based on data comparison between intact and degraded mangroves, whereas the initial state of the improved mangrove area was not explicitly qualified and may not be as deteriorated as assumed here.

Also Lac specific data was lacking for the indicator for fisheries enhancement. The use of a parameter derived from a similar SES in Venezuela was deemed appropriate because of corresponding mangrove typology, climatic conditions and legislative status. However, mangrove fishery catch is driven by many other factors, including environmental drivers (e.g. nutrient and freshwater input) that determine potential fishable biomass, anthropogenic drivers (e.g. fish-stock condition) that determine actual fishable biomass and socio-economic drivers (e.g. alternative livelihoods and cultural traditions), which in turn determine the eventual fishery catch (Hutchison, Spalding, et al., 2014). The latter set of drivers is further explored in a global model of mangrove associated fisheries (zu Ermgassen et al., 2020), which indicated that small-scale mangrove associated fishing intensity in the Dutch Caribbean is lower than in Venezuela.

Application of the effective implementation indicators

For most of the effective implementation indicators, no context specific literature was available for Lac and/or Bonaire. Consultation of the science coordinator was the best available knowledge on these indicators, but may have resulted in a bias towards a positive outcome for the work of MM. This underpins the provision that this checklist on implementation effectiveness is only to be used indicatively and can serve as a basis for a more detailed assessment by independent parties.

5.1.4. Limitations of the community perception study

The surveys conducted amongst the MM target group resulted in a relatively small sample size. Considering that Bonaire has a population of 26.805 registered residents (Centraal Bureau voor de Statistiek, 2021) and Mangrove Maniacs has a steady core of a few tens of volunteers, the relative sample size of the MM target group is two order of magnitudes bigger than the 3.3‰ represented in the CB study.

The distribution between NL and PAP respondents in the CB surveys is different from the population demographics for Bonaire, with over 14% of residents coming from the European Netherlands originally (Centraal Bureau voor de Statistiek, 2018). This can be attributed the fact that many Bonairian residents speak both languages and some autochthonous residents may have filled in a Dutch questionnaire. Furthermore, a small minority of Spanish speaking Bonairians were not able to participate in the study. Female respondents were generally overrepresented, which is likely due to the physical surveys being conducted at two local markets that are typically visited by women.

5.2. Implications of Results

Notwithstanding the methodological limitations described before, this thesis suggests that there is a case for using the ISJOS framework as an alternative for more conventional Impact Assessment frameworks in mangrove restoration, and it complements this approach with an analysis of factors

that affect implementation effectiveness. The following paragraphs discuss the results found for each of the research questions and their connection to the aim of this thesis.

5.2.1 Findings from the ISJOS framework for mangrove restoration

The novel approach to impact assessment presented here, and the example application on mangrove restoration provides two layers of results and implications to discuss. The usefulness and shortcomings of the ISJOS framework is illustrated in the context mangrove restoration and the sustainability impact of mangrove restoration is discussed along the structure of the ISJOS framework. This interrelationship between the two layers has resulted in an alternating focus in the following paragraphs.

The ISJOS framework complements other SJOS applications

Following earlier applications of the SJOS framework on the national (e.g. Roy & Pramanick, 2020), regional (e.g. Fang et al., 2021) and city level (Gemeente Amsterdam, 2020), this study is the first to apply it to the level of an intervention. These previous applications of the SJOS have focused on determining a sustainability state, reasoned through a bottom-up approach. Other applications of the SJOS prescribe how the global SJOS can be shared amongst different system components (top-down), such as individuals, industry sectors (Hjalsted et al., 2021) or nations (Lucas, Wilting, Hof, & van Vuuren, 2020), although the 'just' component is often not included in this 'top-down' approach: only the planetary boundaries are considered.

Whereas these examples all concern outlooks on the 'available space' itself, the ISJOS framework presented in this thesis concerns the contribution thereto, or safeguarding thereof. The framework for Impact on the Safe and Just Operating Space allows initiators of interventions, investors and policy-makers to understand and quantify their contribution to (enhance) sustainability on a local and global level. Once the SJOS for a system is known and a fair distribution thereof is determined for its beneficiaries, the ISJOS helps to operationalize the realization of these sustainability goals, be it the SDGs on a global level or more specific targets on a smaller scale. This of course, preconditions that future studies structurally include the 'just' aspect or the social foundation of the SJOS as well.

A more holistic view on mangrove restoration impact assessment

For mangrove restoration, the ISJOS framework identifies 10 impacts that serve the protection of our planetary boundaries and 20 impacts that foster our human needs and interest. This means that, beyond the impact of carbon sequestration, mangrove restoration nurtures 29 other impacts that help us to remain within the Safe and Just Operating Space for humanity (Raworth, 2017). This is clearly a more diversified and broader impact than considered by earlier assessments of mangrove restoration.

The most recent review study of mangrove restoration benefits, by Su and colleagues (2021), identified 26 ecological impacts from 188 articles, which contain multiple subclassifications of an impact that is summarized as a single dimension in the ISJOS framework (e.g. biodiversity amongst different species groups or accumulation of different compounds). When aggregating these subclassifications, the number of 'main' ecological impacts in this meta-analysis can be distilled to 8, of which 'Litter Decomposition' and 'GHG Emission' do not have a corresponding dimension in the ISJOS framework. As opposed to what one might conclude, this does not disprove the comprehensiveness of the ISJOS framework. 'GHG Emission' may indeed be an ecological function, but can be considered an adverse component of the carbon sequestration dimension in the ISJOS framework. 'Litter Decomposition' is not directly related to any of the ISJOS framework dimensions, but neither does it directly contribute to the social foundation or protect the ecological ceiling. Of course, litter decomposition in the mangrove ecosystem is the starting point of the food chain (Kawaida, Nanjo, Ohtsuchi, Kohno, & Sano, 2021), of which the impacts are represented by the biodiversity and food dimension in the ISJOS framework. Two impacts from the ISJOS framework that were not incorporated in this review study,

are ocean acidification mitigation processes on a global and local level. Besides ecological functions, this study by Su et al. (2021) also considers 9 economic benefits, which were all found in the ISJOS framework as well, but it does not consider the social impacts related to Women's Opportunities, Peace & Justice, Networks or Spiritual well-being. From this, it can be concluded that the ISJOS framework is a more all-inclusive framework for mangrove restoration benefits, than the analysis provided by the most recent literature review on this subject.

It should be noted however, that this meta-analysis focused on benefits that could be quantified through a comparison between natural, degraded and restored mangrove areas (Su et al., 2021). Indeed, for social benefits like 'Women's Opportunities' and 'Networks' it is difficult to define quantifiable metrics related to 'mangrove area restored', let alone to translate this into monetary value. This might have been the reason that these impacts are not included in the review study. The ISJOS framework however, takes a different approach for these benefits as the next paragraphs explain.

Social sustainability benefits of mangrove restoration are underexposed

The ISJOS framework not only pronounces the ESs that are boosted through the ecological effect of restoration, but also the sustainability benefits that emerge from the human endeavor itself. As we can see from Figure 8, this concerns the impact dimensions: Education, Income & Employment, Women's Opportunities, Networks, Peace & Equality and Spiritual Well-Being. (Impacts from Income & Employment can, in fact, directly result from the area restored when it relates to fisheries or NTFP extraction, for example, but it is directly related to the organizational set-up when it concerns restoration-related jobs.) It is not a coincidence that neither of these impact dimensions, except for Education, were part of the meta-analysis on mangrove restoration benefits by Su and colleagues (2021). The literature review in this thesis confirms that indicators for these impacts are still underdefined in existing literature.

Each of the dimensions and their indicators have been elaborately discussed in Sections 4.1.2 and 4.1.3. A large part of the impact dimensions in the social foundation did not give any relevant search results in the literature review. This does not necessarily indicate that the impact was unknown or not studied before, but often the impact has been studied in a context different from mangroves restoration, as is the case with death prevention through protection by coastal ecosystems in general (Pérez-Maqueo et al., 2018) or enhanced peace and equality through advocacy emerging from mangrove conservation (Farley et al., 2010) instead of restoration. Still however, a similar knowledge gap appears for mangrove ESs in general as well, although esthetics and cultural and educational value have been quantified to some extent (Himes-Cornell, Grose, & Pendleton, 2018). From this, it can be concluded that social sustainability benefits of mangrove restoration are underrepresented in our comprehension of its impact potential.

The ISJOS framework includes non-spatiotemporal indicators

Yet, the ISJOS framework suggests indicators for these benefits as well, building on literature that provided relevant narratives where tangible data was lacking. By doing so, the ISJOS framework links sustainability impact not solely to the ecological extent of restoration success (e.g. 'restored area') but also to societal parameters, such as well-being, employment and political participation. After all, the conditions that describe restoration progress do not only vary over space or time, but also in the degree of their manifestation. For example, women's share in income generation in a society may not be correlated with the time in which mangrove restoration is performed or with its spatial extent, but it may well increase by the mere employment and extent of the restoration initiative as such.

These impacts do not follow from the spatiotemporal progress of mangrove restoration, but from human choices in the design of the intervention. Ruzol et al. (2020) refer to this as the "materialist-idealist divide" and encourage to consider network transformation in a SESs alongside the conventional measures for mangrove restoration. Other impacts described in this study, such as social cohesion, a volunteer network and a community's sense of ownership – relating to the ISJOS indicators of Networks, Peace & Equality and Spiritual Wellbeing, respectively – are concluded to emerge from the material success of restoration.

The notice that indicators of this kind are more difficult to translate in economic values is widely recognized (Himes-Cornell, Pendleton, & Atiyah, 2018b). But the essence of the ISJOS framework is to articulate intervention impacts in relation to their corresponding boundaries – that being the social foundation or the ecological ceiling. In that sense, a price label becomes irrelevant in understanding the contribution of an intervention to local or global sustainability goals. Similarly, the philosophy behind the original SJOS is not to pursue an ambition of economic growth, but the contrary: to debunk the fixation on GDP as a proxy for progress and instead illustrate the need for revision of our economic thinking (Raworth, 2017). Cost-benefit analyses on mangrove restoration may indeed require monetized values to some extent, but restoration costs for mangroves are already found to be the most cost-effective of all wetland restoration interventions (Taillardat et al., 2020).

Cross-scale interpretation of mangrove restoration impact

Indicator selection and inclusion of social indicators in the ISJOS framework was also marked as a challenge for SJOS operationalization by Hossain and Ifejika Speranza (2020), who reviewed empirical applications of the SJOS concept on the regional scale. As an opportunity to overcome this challenge, they suggested to translate global issues into regional issues and vice versa, thereby connecting both scales and maintaining coherence with existing indicator frameworks. This is also applied in the ISJOS framework, as it is primarily built on knowledge on the regional level (the expert interviews) using the global SJOS dimensions as guiding questions, and eventually links the ISJOS impact indicators back to the global context through relevant SDG targets and indicators.

From the expert interviews, it appears that some themes from the global SJOS concept are difficult or irrelevant to downscale to the intervention level. With regards to the ecological ceiling, the planetary boundaries for Freshwater Withdrawals, Air Pollution and Ozone Layer Depletion showed the least connection with mangrove restoration. With regards to the social foundation, no theme was convincingly excluded from a downscaled connection with mangrove restoration. However, input from experts was contradicting for the themes of Political Voice, Social Equity, Gender Equality, Housing, Energy and Water. For these themes, experts did not agree on the relevance of a connection between the global planetary boundary and the impact from mangrove restoration.

This disagreement may be due to the different geographic contexts that experts operate in or it may exhibit different interpretations of what these global themes entail on the intervention level. It is for this reason that only those themes that were confirmed (by >1 experts) to have a downscaled connection with mangrove restoration, were included in the ISJOS framework. The literature review validated these intervention-level interpretations, except for the global theme of Water. The impact of SWI reduction from mangrove restoration that some experts associated the Water theme with, was not described in literature.

Conversely, for 16 out of the 30 ISJOS impact indicators, a direct, quantifiable connection with an existing SDG target or indicator was defined. This underpins the contribution of local mangrove restoration to global level goals. Academic literature on mangroves and mangrove restoration generally refers to its broader the connection with SDG 13 ('Climate Action'), SDG 14 ('Life below

Water') and SDG 15 ('Life on Land') (e.g. Agaton & Collera, 2022; Chow, 2017; Su et al., 2021), but rarely explicates the exact contribution towards these goals. From the ISJOS framework, it follows on a more detailed level how mangrove restoration can be incorporated in models that project human impact and interventions on the SDGs.

5.2.2. Findings from effective implementation indicators in mangrove restoration

The 'checklist' of challenges and facilitating conditions in mangrove restoration presented in this thesis offers a basic feasibility estimation for aspired restoration initiatives. By no means do they compare to the detailed feasibility studies, legal assessments and stakeholder analyses required for proper project development. Still, the indicator questions may serve as a basis for investors in the project sourcing phase and for running restoration initiatives to overcome challenges or to promote the desired facilitating conditions.

The relevance of this overview follows directly from the work of Worthington and Spalding (2018). The 'restorability factor' proposed therein, refers directly to the challenges and facilitating conditions that may complicate or ease restoration efforts, independent of their potential sustainability potential. However, it was mostly biophysical conditions that were accounted for in this model study, as these are more feasible to make global projections for. The authors acknowledged that challenges and facilitating conditions arising from socio-economic context or methodological choices that are made on a case-to-case basis, were not included. The indicators for effective implementation therefore complement the earlier work of Worthington and Spalding (2018) with expert-based knowledge from various socio-economic contexts.

Internal factors that go beyond restoration technicalities

An number of criteria regarding the internal factors for effective implementation – or the restoration methodology – has been discussed by Lewis et al. (2009) and was later revised (Lewis, Brown, & Flynn, 2019). The criteria discuss site selection, goal-setting, and monitoring and reporting. Each of the four main criteria is defined with more specific sub-prerequisites for successful restoration. From the 9 internal indicators that followed from the expert interviews in this research, 7 indicators correspond with the methodological criteria developed by Lewis et al. (2009). The indicators on 'education and engagement of local community and government agencies' and 'availability of scientific and technical support' were not included in this earlier work, although educational impact was mentioned as a result from the restoration process. Apparently, engagement with local stakeholders and knowledge capacity an sich were not considered as methodological criteria for restoration success, although field-practitioners did mention this to be a facilitating condition for effective implementation. The importance of both of these internal factors are however confirmed by a case-study on four different mangrove management projects in Indonesia (Damastuti & de Groot, 2017). It was found that community participation and organizational support were one of the most important variables to explain the outcomes, given that institutional sustainability of these facilitating conditions is provided for.

The distinction between mangrove restoration and rehabilitation

It is worth noting that the revised work of Lewis, Brown and Flynn (2019) refers to 'rehabilitation' instead of 'restoration'. It follows the semantic reasoning that rehabilitation is a special kind of restoration that concerns the return of specific ESs, which is usually the focus of land use managers, in contrast with the return of pre-existing ecosystem conditions as a whole, which is usually the focus of ecologists and conservationists (Dale, Knight, & Dwyer, 2014). This distinction matters, because the research in this thesis concerns the regeneration of mangroves for the purpose of protecting the ecological ceiling and the social foundation This may involve a wider variety of solutions – and

associated challenges or facilitating conditions – than those that focus on solely restoring previously existing mangrove areas as a goal on its own merits.

5.2.3. Findings from the assessment of Mangrove Maniacs

In the assessment of the work of Mangrove Maniacs, it is important to note that only the hydrological work – that is, the clearing and maintenance of channels – was considered. Planting is carried out limitedly on the South West coast of Bonaire. Planting within the degraded mangrove areas in Lac is planned for the near future, which makes the ISJOS framework and indicators for effective implementation even more relevant.

Findings from the ISJOS framework application

The impact values for MM on the indicators for Climate Change Mitigation and Fisheries allow for comparison with the Mangrove Restoration Potential Map (MRPM) (Worthington et al., 2018). Here, it should be noted that the model used for this projection categorized the mangroves of Bonaire as 'fringing systems', thereby distinguishing it from 'lagoonal', 'estuarine' and 'deltaic' systems, which have a different set of oceanographic, geologic and ecologic characteristics. (Worthington, zu Ermgassen, et al., 2020). Fringing mangroves along the open coast are known to experience more saline conditions and wave energy. The relevance of this typology follows from the fact that the aforementioned conditions determine productivity and the resulting benefits for humans. The overall restoration potential score projected by the MRPM for Bonaire as a whole, is 52% (Worthington et al., 2018).

The MRPM value for below- and aboveground CO_2 storage in Lac mangroves is 108.8 Gg. It should be kept in mind, that the MRPM tool has estimated the 'Restorable Area' to be 28ha and thereby includes all mangrove area on Bonaire. However, even when accounting for the 16.4 ha used in the MM calculations, the MRPM estimation is over 6 times higher than the estimation based on carbon stock data in Lac. This can be explained by the decision of the MRPM developers to represent carbon storage not as an enhancement per se, but including avoided losses that would occur from soil carbon decomposition if mangroves were not restored (Worthington et al., 2018). Attribution for this carbon post would indeed amount to 'enhanced' soil carbon values similar to the discrepancy found here (Sanderman et al., 2018b).

For enhanced Fisheries, the MRPM value was 2,000 $\times 10^{-3}$ y^{-1}, referring to the number of commercially viable fishes added to coastal waters per year. The Enhanced Fisheries Catch indicator in the ISJOS framework is however expressed in kg y^{-1} and therefore not directly comparable. For this reason, an averaged fish mass of 84.5 g was derived from the same study in Lac to eliminate the mass unit (Hylkema et al., 2015, Table 3). Note that values from both the 'blue' and 'dark' mangrove pool sites are averaged here. The resulting estimation for enhanced Fisheries value for Lac is then 37, 811 y^{-2}. When using averaged fish mass for mangrove 'bay' sites, the enhanced Fisheries value for Lac is lower: 13,688 y^{-1}. Regardless of the choice of averaged fish mass, the MRPM estimation is three magnitudes higher than the estimation produced with Lac specific data. Indeed, the fish biomass values from Hylkema et al. (2015) do not distinct fishable sizes, but neither does the MRPM estimation from Worthington et al. (2018). Also here, the 'Restorable Area' projected by the MRPM is 28ha in total, including all of Bonaire, whereas 16.4 ha is used in the MM calculations, but this does not explain the major discrepancy between the two estimations. A review study by Bosire and colleagues (Bosire et al., 2008) describe the results of an unpublished study on fisheries enhancement in a 7 ha restored mangrove area in Vietnam, which is of the same magnitude as estimated for the 16.4 ha area in Lac. This suggests that the approach used in this thesis provides a better approximation in terms of magnitude, as compared to the MRPM projection. Note that Hylkema and colleagues (2015) observed that the fish species found in the degraded mangrove area of Lac did not include any nursery species

that would usually migrate into the bay area where fishing takes place, which means that the actual fish enhancement value in Lac is indeed more likely to be lower than higher, than our estimation.

Enhanced coastal protection is another impact variable that is available in the MRPM. Even though this was not part of the assessment in this thesis, it is worth noting that this was calculated to be 0 in the aforementioned tool, building on earlier work by Losada et al. (2018). However, they only considered flooding scenarios from tropical storms, which is indeed less of a threat to Bonaire and of which the exposure to people or infrastructure is limited in the area of Lac. However, storm surges may become more frequent due to climate change. Also, climate change induced sea-level rise was not included, whereas this poses a serious threat to the low-lying Southern part of Bonaire (Debrot & Bugter, 2010). Because of this, the projection for enhanced coastal protection from mangrove restoration seems to be underestimated in the MRPM, notwithstanding that sediment trapping and land-accretion by mangroves were recognized to benefit coastal protection (Losada et al., 2018).

The Increased Biodiversity indicator for mangrove restoration estimated a doubling effect on fish biodiversity within the mangroves. Only few studies have researched fish species richness in restored and degraded mangroves, which makes it difficult to compare the estimation for Increased Biodiversity impact (Bosire et al., 2008). Also the type of mangrove forest (age, species, hydrology) complicates a sensible comparison and no study on this subject was included in the meta-analysis of mangrove restoration benefits by Su and colleagues (2021). However, increased species richness of co-occuring indicator species, such as shrimps (Crona & Rönnbäck, 2005), suggest that a similar trend can be true for fish species richness.

Spiritual well-being is as a more strongly perceived impact amongst CB-NL respondents as compared to the CB-PAP respondents, which suggests that autochthonous residents of Bonaire generally attach more value to the tangible benefits. This is not surprising, considering that the majority of European Dutch migrants on Bonaire are strongly driven by their quest for a different, more leisured and comfortable lifestyle or career path with the associated mental well-being benefits (Hondius, 2020). The valuation of esthetics as a specific ES that is enhanced through mangrove restoration, did not suggest a difference between these two groups, however. This implies that the beauty and scenery of mangroves serves not so much a fulfillment of spiritual well-being to autochthonous residents of Bonaire, but other associated benefits, such as opportunities for recreation and tourism. The fact that those engaged with Mangrove Maniacs confirmed ‘happiness’ as the most important impact personally perceived from mangrove restoration, validates the widely recognized correlation between knowing and understanding nature on one hand and self-reported well-being (Capaldi A., Dopko L., & Zelenski, 2014), and has been confirmed for the context of mangrove restoration in Mexico before (Allgood, Hofberg, Musikanski, Michelini, & Moser, 2019). Subjective well-being has also been proposed as a legitimate policy indicator in nature management and restoration (Takahashi, Uchida, Ishibashi, & Okuda, 2021).

Findings from the application of effective implementation indicators

Mangrove Maniacs scored positive on almost all applicable indicators for effective implementation, both internally and externally. This is partly related to the fact that the area of Lac has been granted a protected status and that stewardship of the mangrove area is not politically or culturally disputed. However, one of the main challenges that Mangrove Maniacs is facing is the external ecological impact of sediment influx, which is driven by overgrazing by feral donkey and goat populations (Debrot et al., 2010; Lott, 2001). These invasive species have acquired significant cultural status on the island and, in contrast to the mangroves, management of their presence is heavily impeded by the dominant cultural perception of their importance and their role in Bonaire’s charm as a tourist destination .

As Mangrove Maniacs is currently not structurally engaged with local governance, this might provide an internal opportunity to consistently address the problem of sediment influx. Academic research on Bonaire has provided ample evidence on the causes and effects of sediment influx in Lac (Roberts, Hanley, Williams, & Cresswell, 2017), as well as suggestions for solutions that tackle the problem at its root-cause (Amrit et al., 2013; Roberts, 2017; Roberts, Cresswell, & Hanley, 2018). Related to this is the challenge of lacking support from policy makers and local leaders that was not scored positively in the effective implementation framework. Since active outreach to these stakeholders is not in place yet, it raises the question of how this can best be initiated from the side of Mangrove Maniacs. The ISJOS framework provides a useful tool to explicate the contribution of mangrove restoration efforts towards the broader sustainability goals of Bonaire, as drafted in Section 4.3.2.

Another external factor that leaves space for improvement is the operationalization of blue carbon financing to spur the financial capacity and local political support available for mangrove restoration. The work of Mangrove Maniacs is not yet verified under a carbon-offsetting standard, but standards for mangrove restoration are being increasingly widely developed. In general mangrove restoration projects are not suitable for registration under the Clean Development Mechanism of the Kyoto protocol, as the requirements for this are often too rigorous to be achieved and associated costs are too high (Lovell, 2010). Instead, most coastal wetland projects are certified for the voluntary carbon market, for example along the methodologies currently through standards like Verra's Verified Carbon Standard (Verra, n.d.) or Plan Vivo (The Plan Vivo Foundation, 2013). The current momentum for blue carbon financing is resulting in the development of alternative approaches, including accounting standards that look beyond the carbon-offsetting potential alone (e.g. the New Blue Carbon Accelerator Fund (IUCN, 2021)). The latter might be more interesting for mangrove restoration project like Mangrove Maniacs, that is still ten to a hundred times smaller compared to the currently carbon certified mangrove restoration projects (Wylie, Sutton-Grier, & Moore, 2016).

A remark should be made on the challenge of aquaculture impact, which is not yet an issue on Bonaire or restoration of the Lac area. However, in a recent publication on "A nature inclusive vision for Bonaire in 2050" (Verweij et al., 2020), aquaculture development is proposed just south of the mangroves of Lac. It is not likely that such an activity will actually take place within Lac itself, due to its protected status, but the risk of waste effluents and soil acidification can still pose a threat to the mangrove health and restoration effectiveness if not managed with due diligence (Deb, 1998).

Findings from the community perception study

The outcome that positive perception of mangrove restoration in Lac was higher for both NL and PAP respondents indicates that residents on Bonaire have a generally supportive attitude towards mangrove restoration. The slightly higher confirmation of positive impacts for Bonaire as whole, as opposed to the positive impact perceived personally, suggests that respondents are well aware of the fact that mangrove restoration also serves broader needs of the island and community that go beyond them as individuals. Amongst the specific ESs discussed in the survey, services that can be more directly associated with personal gain, such as tourism (generates income) and esthetics (provides pleasure), were indeed found to be relatively less important, compared to other services.

Interestingly, NL respondents consistently provided higher values than PAP respondents for almost all ESs, except for Tourism and Esthetics. In Section 5.2.3. it was already put forward that autochthonous Bonairians possibly attach more value to the tangible benefits that result from esthetics, of which tourism and recreation opportunities are of course an example. After all, the island of Bonaire is highly dependent on its tourism sector and the associated jobs (Amrit et al., 2013). One may find it surprising that the ES of Fisheries was valued higher by NL respondents than by PAP respondents, but this can be explained by the fact that actual employment in the fisheries sector is low (de Graaf et al., 2016) and

European-Dutch residents on Bonaire are more often engaged in SCUBA-diving (Howe, 1994), thereby more closely connected to the underwater world and its fauna.

The responses from Mangrove Maniacs generally show a much higher certainty in responses. Valuation of specific ESs did not even count any 'I don't know' response. It shows that structural participation in the restoration activities of Mangrove Maniacs contributes to a thorough understanding and positive perception of the mangrove system itself. Similar correlations have been described for volunteering in the maintenance of city parks (Dresner, Handelman, Braun, & Rollwagen-Bollens, 2014) and in environmental stewardship programs in Texas (Lope & Weave, 2021), for example. Also self-reported impact of 'happiness' by MM volunteers was striking in comparison to CB respondents and adds to the impacts that were identified through the expert interviews. Mental health benefits were mentioned in these interviews in relation to the presence of mangroves in general, but not from doing the restoration work itself.

5.3. Mangrove Restoration Potential in a Broader Context

Mangrove restoration is just one example of many different coastal and marine NbS that can be employed to enhance the SJOS for humanity. This section will briefly touch upon the potential of mangrove restoration in 'the bigger picture' and how the implications of this research apply to the wider range of NbS in the marine environment.

5.3.1. Taking mangrove restoration from potential to scale: financing beyond blue carbon

Mangrove forests currently occupy less than 140,000 km^2 of the earth's surface, to which restoration could roughly add another 10,000 km^2 (Worthington et al., 2018). However, their atmospheric carbon removal potential per surface area is exceptionally high as compared to other ecosystems. This means that, despite their small global area, the same amount of carbon that is stored in other types of ecosystems, can be stored in a much smaller area of mangrove forest. This may be particularly interesting for countries with extensive tropical coastlines, for example (Taillardat et al., 2018), and for investors that seek to offset carbon emissions on the organization or project level.

On the other hand, mangrove's marginal global cover and wide dispersion make it virtually impossible to have restoration efforts comply with the minimum carbon sequestration requirement of 5000 tons CO_2 per year for the compliance market (which functions on a cap-and-trade-basis by compliers). Even the currently largest certified mangrove restoration project, Mikoko Pamoja in Kenya, does not come close with its 3000 tons in CO_2 credits issued per year (Rashid, Wanjiru, Huxham, Shilland, & Ruzowitzky, 2020).

In this incompatibility, we see how mangrove restoration is commonly viewed as a climate solution in the first place, with 'co-benefits' in the second place; a framing that is especially noticeable in the discourse around 'blue carbon'. Also from the view of mangrove conservation, only 20% of the global mangrove forests currently qualifies for blue carbon financing when considering additionality based on the immediate threat of loss or degradation of these mangroves (Zeng et al., 2021). This share would contribute 33.8 Mt CO_2 y^{-1} towards global climate change mitigation efforts, but only half of this potential is estimated to be financially sustainable, meaning that the relative profitability between development and maintenance costs and carbon credit revenue is positive within a 30 year time frame. We should ask ourselves whether this fixation on carbon sequestration effectively incentivizes the right – or full scale of – solutions. The Global Reporting Initiative, which provides guidelines in corporate sustainability reporting, warns for a 'carbon tunnel vision' that tends to decouple climate ambitions from the broader sustainability agenda (Nybo Jensen, 2021). Putting equal value on other sustainability benefits, would increase both the additionality of a conservation or restoration effort and its profitability – that is, to the extent that sustainability benefits can be aptly monetized.

Standards that account for impacts beyond that of carbon sequestration alone, are particularly interesting to mangrove restoration efforts, as this research has identified 29 other impacts of sustainability value. Alternative verification methodologies that support such an approach are increasingly available in the voluntary carbon markets (which function on voluntary purchases by businesses, investors and individuals) and are promising in taking mangrove restoration to scale. Also Mikoko Pamoja for example, is certified by the Plan Vivo standard, which has identified the impact of the project on 8 SDGs, including non-spatiotemporal impacts in the ISJOS framework like advocacy and women's opportunities (Plan Vivo Foundation, n.d.). Another recently developed financial instrument that follows the same line of thinking are SDG bonds (Bina, 2019), which cater for the growing need of business and investors to embed a more holistic concept of sustainability in their strategies.

5.3.2. The importance of regeneration at the coast in changing times

The impact from mangrove restoration as identified through the ISJOS framework may also evolve over time as our knowledge of the EC and SF boundaries develops, and our strategies in protecting them mature. One example is the wide-spread aspiration to achieve a circular economy, which is shared by governments and business globally (WCEF+Climate, 2021) and further necessitated by the COVID-19 pandemic (Yuan, Wang, Sarkar, & Ok, 2021). Developments in the field of biomimicry allow us to add new value to the most ubiquitous polymers on earth, such as cellulose and lignin in biomass, which are the building blocks of a circular economy (Benyus, 2001). Such innovation shows how the outcomes for nature regeneration from a holistic impact assessment – are never static and depend on changes in our way of life – changes that are inevitable in the foreseeable future. From this, we can understand that NbS will become increasingly valuable as findings in the fields of biomimicry and economic theory proceed.

But, what then, is the position of coastal regeneration in this specifically? This can be demonstrated along the three main compartments of the ISJOS framework if we consider an example of 'changing times' par excellence: a changing climate.

It has become inevitable that climate change will affect all of humanity, jeopardizing our SF. Over a third of the global population lives at or near the coast and millions directly dependent on its natural capital (S. Brown et al., 2014; Maul & Duedall, 2005). NbSs that protect against and help adapt to the effects of climate change will therefore serve a major part of the global population, if employed in these coastal areas. For example, coastal protection by mangrove forests will become more important as coastal populations keep growing and climate effects are becoming more pressing. Note here, that indeed, the requirements to maintain the SF will change (in fact increase) because of this. Additionally, NbSs at the coast provide the jobs that are so much needed in these densely populated areas (Boyle & Kuhl, 2021; Saunders et al., 2020).

Looking from the EC point of view, marine and coastal systems comprise of the planet's largest carbon sinks. This does not only include coastal wetlands, but also plankton, kelp forests and seaweed farming for example. Altogether, these systems provide a lot of potential to address the need for climate mitigation. This argument may seem contradictory to the previous notion that a 'carbon tunnel vision' should be avoided, but it is not. The supposition that impact assessments and associated investments should consider the full range of benefits and trade-offs, does not refute the necessity to invest in solutions that, inter alia, have a high climate mitigation potential.

Finally, building on the two previous arguments, the fact that marine and coastal NbSs are less commonly trialed and employed than their terrestrial counterparts, may conceal relatively large advancements that are yet to be realized in the protection of our EC and the nurturing of our SF. In this thesis, the ISJOS framework only assessed this potential for mangrove restoration, but the

interconnectedness of ecosystems merits further investigation. This is especially true for the unique seascape connectivity between mangroves, salt marshes, seagrass and coral reefs (Olds et al., 2016). The potential for integration with other marine and coastal NbSs is also acknowledged in the Mikoko Pamoja project. Here, incorporating seagrass conservation in the existing project is being explored, starting off with community and stakeholder consultations to map out perceived impacts alongside the actual impacts (Rashid et al., 2020). In line with this, the broader scientific community is encouraged to apply the methodology and frameworks presented in this thesis to similar nature regenerative interventions, especially in the field of coastal wetland restoration and consider the interconnectedness between coastal and marine ecosystems by integrating them into one ISJOS assessment, as would be relevant for the synergies that arise from interventions in mangrove, salt marsh, seagrass and/or coral ecosystems.

6. Conclusion

With the United Nations' declaration of 2021-2030 being the 'UN Decade on Ecosystem Restoration' and the 'UN Decade of Ocean Science for Sustainable Development', the international community has created a global momentum to boost nature regeneration at the coast and translate knowledge into meaningful and constructive action. That is why, in this thesis, I deliberately chose to not only build on academic knowledge, but to retrieve primary data from experts in the field. Interviews with field-practitioners from all over the world and a local case study on Bonaire revealed real-life impacts and disservices, community perceptions, and the boundary conditions that field-practitioners face in the employment of such projects. This knowledge fills the gaps that exist in the recognition of coastal wetland as nature-based solutions for a myriad of sustainability challenges (C. J. Brown et al., 2021).

Throughout this thesis, three research questions have guided the development and application of a framework to assess the sustainability impact and effective implementation of mangrove restoration and similar interventions. The final outcomes for these questions are summarized below, followed by recommendations for further research and applicability.

6.1. A novel impact assessment of mangrove restoration

My first research question aimed to identify relevant indicators for the impact of mangrove restoration. The Impact on the Safe and Just Operating Space (ISJOS) framework provides a comprehensive overview of these indicators, by delineating sustainability impact relative to planetary boundaries: the 'ecological ceiling' (EC), and minimum social standards: the 'social foundation' (SF). Expert-based indicators for mangrove restoration are determined for 10 impact dimensions within the EC and 20 impact dimensions within the SF. Global and local mitigation of ocean acidification through carbon dioxide removal and mangrove buffer capacity were two EC impacts that have received little notice in the literature on mangrove restoration benefits, although their impact was confirmed by experts when explicitly discussing the corresponding planetary boundary. With regards to the SF impacts, the indicators relating to women's opportunities, peace & justice, networks or spiritual well-being were found to be similarly underexposed. These impacts come into existence not through spatiotemporal progression of the restoration effort, but by the grace of the human intervention itself. This aspect of mangrove restoration impact is rarely considered due to difficulties in monetizing its value. The ISJOS framework builds on a useful philosophy to work around this challenge and complements existing scientific theory on mangrove restoration impact with a more explicit consideration of all boundaries relevant to humanity and the earth system.

The plurality of impacts on both the global and local level shows that the case for mangrove restoration goes far beyond its climate change mitigation benefit alone and hence, that it should be quantified accordingly. Optimal positioning of coastal and marine NbS in general as a means to protect both the SF and EC, requires the development of suitable financing and policy solutions, in which the ISJOS framework can play a contributory role. In this thesis, the ISJOS framework is tailored to mangrove restoration, but the conceptual framework and methodology that support it, can be applied to any human intervention.

6.2. Challenges and facilitating conditions in mangrove restoration

My second research question aimed to identify the factors that influence effective implementation of mangrove restoration. Indicators on these factors were formulated based on expert interviews, following an analogous approach to the development of the ISJOS framework. Challenges and facilitating conditions that relate to the restoration methodology resulted in 9 internal factors. While criteria for successful mangrove restoration are commonly related to the biophysical aspects of

restoration, two additional factors emerged from the expert interviews as equally important: sufficient scientific and technical support on-site, and the organization of education and engagement programs for both local community and government agencies. An additional 17 external factors were found to emerge from local external systems or global macro-conditions. From these, enforcement against conversion, pollution from upstream areas, and space for mangroves to grow inland and adapt to sea-level rise, were most commonly mentioned by experts.

The internal and external factors for effective implementation are translated into guiding indicator questions, which help future restoration efforts in realizing their full sustainability potential. By doing so, it enriches the academic literature stream on the concept of a safe and just operating space as it helps to put the ISJOS framework into a more practical feasibility context.

6.3. Lessons learned from the work of Mangrove Maniacs

My third research question aimed to understand how the actual and perceived sustainability impact of mangrove restoration on Bonaire is assessed along the previously proposed indicator frameworks. Here, the hydrological restoration work of Mangrove Maniacs served as a case study. As the 30 different impact dimensions of the ISJOS framework require a wide range of expertise and empirical assessments to properly quantify the full sustainability impact of Mangrove Maniacs, only a selection of five indicators were discussed: Climate Change Mitigation, Fisheries, Increased Biodiversity Within Mangroves and Spiritual Well-being. For most of these, earlier studies in the Lac area served as a source for primary data, but estimations for climate change mitigation and enhanced fisheries catch showed large diversion from earlier projections in the Mangrove Restoration Potential Map (Worthington et al., 2018). Enhanced biodiversity was approximated through fish species richness, for which comparable studies are hardly available. From the outcomes for spiritual well-being, it can be postulated that this differs between autochthonous and immigrated residents of Bonaire. The perception of Mangrove Maniacs volunteers revealed the highest impact for this dimension, which fits in well with existing theories on nature connectedness and self-reported well-being.

Mangrove Maniacs scored positively on almost all indicators for effective implementation. Because the current work does not entail any structural outplanting of mangroves, some indicators did not apply, but will be in the near future. With regards to the internal factors, Mangrove Maniacs has yet to develop systemic engagement with local government in their outreach. The external indicator on lacking political support, which was also assessed negatively, is of course closely related to this. Another external opportunity to further foster mangrove restoration is the increasing demand for carbon credit and rapidly growing range of standards available for carbon-offsetting via the voluntary carbon market.

6.4. Recommendations

One may have noticed that the reference to mangrove restoration as a Natural Climate Solution (NCS) in the first chapters of this thesis, has shifted towards a conceptualization of this intervention as a Nature-based Solution (NbS) throughout the rest of the report. This is due to the recognition that the multipotency of mangrove restoration, and the broader scope of coastal wetland restoration, is better manifested in the latter term. It is therefore, first and foremost, proposed to adjust impact assessment of these interventions, through our perception and the word we use to describe them: as Nature-based Solutions. Elaborating on this, the following recommendations and research priorities are suggested:

1. To further develop the frameworks presented here, future research regarding mangrove impact assessment should focus on:
    a. Verification of the impacts that were only mentioned by one expert and therefore not included in the ISJOS framework, for example through a Delphi approach amongst a larger or more diverse group of mangrove restoration experts.
    b. Definition of impact indicators by expanding the literature review to mangrove-related literature, including associated ecosystems.
    c. The development of indicators for negative impact dimensions that allow for quantitative assessment, for example by consulting other stakeholders than restoration practitioners themselves, and integrate them in existing ISJOS impact indicators to account for trade-offs.
    d. Understanding the connection between the different factors for effective implementation and the ISJOS impact dimensions.
2. The findings for the case study on Bonaire imply that mangrove restoration in Lac can benefit from:
    a. Specific analyses and gathering of empirical data on the different ISJOS impact dimensions, especially those that show overlap with the drafted SJOS for Bonaire.
    b. Relating their ISJOS results to local policy priorities, as a first attempt to organize this, was cancelled due to COVID-19.
    c. Translating their ISJOS result to the SDG level through the relevant SDG targets and indicators identified in this research.
    d. Diversification of outreach and communication towards Dutch and Papiamentu speaking people, based on the different valuation of benefits from mangrove restoration.
    e. Creating advantageous boundary conditions for the full realization of their sustainability potential, by organizing structural collaboration with local government and tapping into the increasing demand for blue carbon solutions through upcoming financial instruments that consider sustainability impact beyond the carbon potential alone.
3. With regards to the practical application of these findings in society:
    a. Businesses and investors are encouraged to use the ISJOS impact dimensions for mangrove restoration in impact assessment for financial instruments, thereby considering value beyond carbon credits alone.
    b. Government and multilateral institutions can use the ISJOS impact dimensions for mangrove restoration in understanding how mangrove restoration contributes holistically to their sustainability goals on both a local and global level.
    c. Field practitioners and NGOs that seek to initiate mangrove restoration efforts should use the effective implementation indicators to account for challenges and facilitating conditions that go beyond the more conventional methodological considerations alone.

Appendix 1: Expert Interview Framework

Introduction

- This interview is part of a thesis research project for Utrecht University in the Netherlands, in collaboration with Climate Cleanup and Mangrove Maniacs.
- This research is about the sustainability wide impact of mangrove restoration on both a local and global scale, to get an understanding of the holistic value of restoration efforts for policymakers, investors, and business for example.
- The interview will take 75 minutes
- We will first go briefly through 1) your background as an expert on mangrove restoration, then 2) have a closer look at your perception of the impacts of mangrove restoration on the health of the whole planet, the natural environment on a regional scale and the well-being of the local community, and we finish with 3) discussing the challenges and facilitating conditions that you have encountered in mangrove restoration.
- Your participation in this interview is completely voluntary. If at any point you feel that you want to stop with the interview, you are entirely free to do so. You may also decide not to answer any specific question during this interview.
- Your participation in this interview is anonymous unless you wish to be specifically mentioned as a representative from your restoration project. The information acquired from this interview is for research purposes only and transcripts will not be shared with third parties.

0. **Do you understand and agree with the statements above and therefore freely consent to participate in this interview?** YES/NO
0. **Do you agree with this interview being recorded for the purpose of transcript writing?** YES/NO

Expert's Background

1. **What is your current (occupation in) relation to mangrove restoration?**
2. **What is your experience with mangrove restoration?**

- Amount of years:
- Projects + locations (may these be mentioned in my research?):
- Type of knowledge (theoretical/field work/governance/etc):
-

Impact Dimensions

3. **How does mangrove restoration impact the health of the whole planet?**
4. **How does mangrove restoration impact a region's natural environment?**
5. **How does mangrove restoration impact the well-being of the local community?**

➔ *Safe and Just Operating Space Framework (Raworth, 2017) is presented to the interviewee.*

6. **Which of these dimensions are impacted through mangrove restoration on a local/global scale?**
   A: Does mangrove restoration contribute to the protection of [*EC dimensions*]
   B: Does mangrove restoration contribute to [*SF dimensions*]

Challenges and facilitating conditions for implementation

7. **What challenges or facilitating conditions (can) occur in relation to the restoration methodology?**
8. **What external systems on a local scale impact effective implementation of mangrove restoration?**
9. **What macro-conditions on a global scale impact effective implementation of mangrove restoration?**

Appendix 2: Interview Coding Schemes

A. Coding Scheme for Interview Questions 3, 4 and 5*

Question 4	Question 5	Question 6
Carbon sequestration	Sediment trapping and protection of adjacent ecosystems against sedimentation	Provisioning of fuel and building material (charcoal and timber)
Biodiversity	Nursery for marine species	Income and employment from tourism
Nursery for marine species	Biodiversity	Income and employment from restoration
Oxygen provision	Erosion control	Income and employment from NTFPs
	Weather cooling (through tree transpiration)	Income and employment from fisheries
	Water filtration (nutrients and heavy metals)	Income and employment from timber and charcoal
	Benefits fisheries	Esthetics
		Income from carbon credits
		Provision of fuel (charcoal)
		Cultural and spiritual value
		Coastal protection against storms (through wave attentuation)
		Coastal protection against sea-level rise (through land mass accretion)
		Positive psychological effects
		Raising awareness
		Cose-effective solution for SIDSs and developing countries
		'Muddy' perception
		Mosquitos

* Codes in red, indicate negative impacts.

B. Coding Scheme for Interview Questions 6A and 6B*

Question 6A	Question 6B
Climate mitigation: carbon sequestration	Food: fisheries and crab harvesting
Ocean acidification mitigation: carbon sequestration	Food: honey production
Ocean acidification mitigation: mangrove buffering capacity	Avoided import of fisheries products
Water filtration: heavy metals and pesticides	Global fish supply through global supply chain
Water filtration: nutrients and phosphorous	Fish as a healthy alternative to unhealthy food sources
Erosion control	Clean air
Jobs lost in earlier land use	Food safety through water filtering
Increased biodiversity within mangroves	Mental health benefits
Habitat for migratory birds	Coastal protection: death prevention from storms and flooding
Increased biodiversity in adjacent ecosystems	Medicinal products for local use
Air filtration	Spiritual and cultural value
	Mosquitos
	Awareness raising & Nature education
	Training of local community
	Contribution to science
	Income and employment: tourism
	Income and employment: fisheries
	Income and employment: NTFPs
	Income and employment: timber and charcoal
	Income and employment: restoration work
	Income and employment: science and consultancy
	Sense of ownership and responsibility
	Risk of conlict (on land use and tenure)
	Stimulation of dialogue and consensus (on land use and tenure)
	Environmental justice in case of resource deprivation through mangrove degradation
	Prevention of climate related peace disruptions
	Advocacy for mangrove community actors
	Global awareness and media attention
	Create level playing field through stakeholder input process
	Reduced access/rights of mangrove community
	Cost-effective solution for SIDSs and developing countries
	Increased opportunities for women
	Coastal protection: safeguarded houses
	Decreased housing space
	Fuel and building material (charcoal and timber)
	Local knowledge exchange and collaboration
	Global knowledge exchange and collaboration (e.g. science)
	New inter- and intracommunal connections
	Shading effect as an alternative to air-conditioning
	Reduction of salt water intrusion

* Codes in red, indicate negative impacts.

C. Omitted Results from Interviews*

Unclear/Indirect*	Global SF**	Decision Tree***
Protection of world cultural heritage	Avoided import of fisheries products	Fish as a healthy alternative to unhealthy food sources
Sustainability for future generations	Global fish supply through global supply chain	Accessibility of coastal protection for SIDSs and developing countries
Retention of water flow	Contribution to science	Clean air
Buffer function between the land and the sea	Income and employment: science and consultancy	Create level playing field through stakeholder input process
Reduction of expenditures through coastal protection	Prevention of climate related peace disruptions	Environmental justice in case of resource deprivation through mangrove degradation
Shared values from the mangroves between different religious communities	Global awareness and media attention	Food safety through water filtering
Provision of alternative wood lots	Cost-effective solution for Small Island Developing Countries and developing countries	Medicinal products for local use
Clean water piping funded by blue carbon credits	Global knowledge exchange and collaboration (e.g. science)	Sense of ownership and responsibility
Nitrogen and phosporous filtering prevents groundwater pollution from algal blooms		Shading effect as an alternative to air-conditioning

* Interview responses that were not coded, due to vagueness of the response or the highly indirect relevance of the suggested impact itself.

** Interview responses that were coded as *Global* impacts on the SF (not considered in this study).

*** Coded impacts that were omitted after the selection of impact dimensions (see Figure 6).

D. Coding scheme for questions 7, 8 and 9

Question 7 (Internal factors)	Question 8 & 9 (External factors)
Good water circulation/ hydrological regime	Enforcement against conversion
Education and engagement of local community and government agencies	Pollution from upstream areas
Wave impact on the fringe	Space to grow inland
Availability of scientific and technical knowledge	Adequate financial support
Mono-planting	Land planning and zoning
Inapt species used for planting	Secure land tenure
Good water quality (oxygen and salinity levels)	Consider upstream hydrology
Known driver of degradation	Corruption
Degraded sediments/soils (don't support regeneration)	Lacking political will
Removal of degraded sediments	Increased interest in/ demand for blue carbon credits
Controlled sea-ward sediment influx, e.g. through sediment trapping structures (e.g. roots)	Shrimp aquaculture
Ecological side-assessments	Stakeholders with conflicting views
Natural regeneration	Distrust and resistance from community
Sufficient seedling and propagule supply	Hurricanes
Provision of alternative woodlots	Advocacy and activism
Provision of alternative cooking fuels	Tendency to economic growth
Interconnectivity with adjacent ecosystems	Adequate sargassum response
Effective targets (e.g. survivorship targets in stead of planting targets)	Maintain political accountability
Dialogue with community for improved social understanding	Legal protection of the mangrove area
Advocacy and activism	Inclusion of mangrove restoration as an offset/compensation measure in EIA
Clear additionality of blue carbon	Insect pollination
Permanence of blue carbon	Incorporation of mangroves in NDCs
Integration of traditional knowledge	Good leadership
Economic valorisation of the mangroves	Policy frameworks that implement principles of ecosystem management
Allowance of local artisinal (extractive) activities	Tidal inundation (hydrology)
Sufficiently wide band of mangrove forest	Positive local perception of mangrove area
System of early warning signals in governance strategy	Cultural controversy and conflicts around the area to be restored
Rotational harvesting schemes	High demands and time pressure from investors
Transport capacity of people to the restoration area	Quick and dirty' approach by governments
Ambiguous testimonials from the community	Threatened safety of conservationists
Lacking financial resources	Shortage of government staff to monitor landholdings
	Bureaucracy
	High sediment influx
	Tweak conversation on mangrove restoration to broader ESs instead of just blue carbon
	Invasive species
	Sea-level rise adding to mangrove squeeze
	Applied knowledge and social science less common

Appendix 3: Literature Review on Impact Indicators

ISJOS Impact theme/dimension	*Output (n)*	*Search string in Scopus (AND PUBYEAR > 2010)*	*Success*
Climate change mitigation	325	TITLE-ABS-KEY (mangrove* AND (restor* OR replant* OR rehabilitat* OR reforest* OR afforest* OR plant* OR recover* OR regener*) AND "climate change mitigat*" OR "carbon sequestration")	Yes
Ocean acidification mitigation			
Atmospheric CO_2 removal	5	TITLE-ABS-KEY (mangrove* AND (acidification OR "ocean acidification") AND ("carbon dioxide" OR carbon OR CO2) AND (remov* OR sequestrat*))	No
Local buffering capacity	10	TITLE-ABS-KEY (mangrove* AND (acidification OR "ocean acidification") AND buffer*)	Yes
Increased biodiversity			
Migratory species	210	TITLE-ABS-KEY (mangrove* AND ("increas* biodiversity" OR habitat) AND migrat*)	*
Within mangroves	4	TITLE-ABS-KEY (mangrove* AND "increas* biodiversity")	*
In adjacent ecosystems	0	TITLE-ABS-KEY (mangrove* AND "increas* biodiversity" AND (adjacent OR seascape OR connect*)	*
Water filtration			
Nutrients (nitrogen and phosphor)	158	TITLE-ABS-KEY (mangrove* AND (restor* OR replant* OR rehabilitat* OR reforest* OR afforest* OR plant* OR recover* OR regener*) AND (filtrat* OR purificat* OR *remediat* OR accumulat* OR remov*) AND (nutrient OR phosphor* OR nitrogen*) AND NOT metal)	Yes
Chemicals (heavy metals and pesticides)	38	TITLE-ABS-KEY (mangrove* AND (restor* OR replant* OR rehabilitat* OR reforest* OR afforest* OR plant* OR recover* OR regener*) AND ((sediment W/3 quality) OR (water W/3 quality)) AND (filtrat* OR purificat* OR *remediat* OR accumulat* OR remov*) AND (chemical* OR "heavy metal*" OR *ticide))	Yes
Sediment trapping	47	TITLE-ABS-KEY (mangrove* AND ((sediment W/2 trapping) OR (sediment W/2 retention)))	Yes
Erosion control	19	TITLE-ABS-KEY (mangrove* AND erosion AND control AND (shore* OR coast*))	Yes
Water/ Reduction of SWI	28	TITLE-ABS-KEY (mangrove* AND (saltwater W/2 intrusion))	No
Education			
Awareness & Education	21	TITLE-ABS-KEY (mangrove* AND (restor* OR replant* OR rehabilitat* OR reforest* OR afforest* OR plant* OR recover* OR regener*) AND ((awareness W/2 rais*) OR "nature education" OR "environmental education"))	Yes
Training of local community	36	TITLE-ABS-KEY (mangrove* AND (restor* OR replant* OR rehabilitat* OR reforest* OR afforest* OR plant* OR recover* OR regener*) AND training)	No
Food			
Fisheries, shrimp and crab	25	TITLE-ABS-KEY (mangrove* AND (restor* OR replant* OR rehabilitat* OR reforest* OR afforest* OR plant* OR recover* OR regener*) AND ((food W/2 provision*) OR (food W/2 source)) AND (fish* OR shrimp* OR crab*))	No
Honey	1	TITLE-ABS-KEY (mangrove* AND ((food W/2 provision*) OR (food W/2 source)) AND honey)	No
Income and Employment			
Restoration work	96	TITLE-ABS-KEY (mangrove* AND (restor* OR replant* OR rehabilitat* OR reforest* OR afforest* OR plant* OR recover* OR regener*) AND (income OR employment OR job*))	No

Tourism			*
Fisheries			*
NTFPs			*
Timber and charcoal			*
Carbon credits			Yes
Coastal protection			
Housing protection	34	TITLE-ABS-KEY (mangrove* AND (restor* OR replant* OR rehabilitat* OR reforest* OR afforest* OR plant* OR recover* OR regener*) AND (coast* W/4 protection) AND (hous* OR urban* OR build*))	No
Death prevention	7	TITLE-ABS-KEY (mangrove* AND (coast* W/4 protection) AND (death OR casualt* OR fatal*))	No
Women's opportunities	10	TITLE-ABS-KEY (mangrove* AND wom* AND (opportunit* OR equal* OR justice))	No
Networks			No
New intra- en intercommunal connections	215	TITLE-ABS-KEY (mangrove* AND (restor* OR replant* OR rehabilitat* OR reforest* OR afforest* OR plant* OR recover* OR regener*) AND (network OR connect* OR (commun* W/4 dynamic*)) AND NOT (benthic OR tree OR microbio* OR *web))	No
Local knowledge exchange	137	TITLE-ABS-KEY (mangrove* AND (restor* OR replant* OR rehabilitat* OR reforest* OR afforest* OR plant* OR recover* OR regener*) AND (network OR (("local knowledge" OR "traditional knowledge" OR knowledge) AND exchange)))	No
Spiritual well-being			
Spiritual and cultural value	38	TITLE-ABS-KEY (mangrove* AND (restor* OR replant* OR rehabilitat* OR reforest* OR afforest* OR plant* OR recover* OR regener*) AND (spiritual OR cultural) AND (value OR well-being OR benefit OR impact))	*
Mental health	16	TITLE-ABS-KEY (mangrove* AND (mental* OR psych*) AND (value OR well-being OR benefit OR impact OR health))	*
Esthetics	33	TITLE-ABS-KEY (mangrove* AND (value OR well-being OR benefit OR impact) AND (esthetic* OR beaut* OR aesthetic*))	*
Peace and equality			
Advocacy			No
Dialogue and consensus	216	TITLE-ABS-KEY (mangrove* AND (dialogue OR consensus OR conflict* OR disput*))	Yes

*Indicator for the ISJOS framework on mangrove restoration is the author's suggestion, based on a general conformity observed in a multitude of papers from the literature review or based on an indicator used in a meta-analysis of relevant literature.

Appendix 4: Community Perception Surveys

A. Perception survey for citizens of Bonaire (CB)

Introduction

1. Are you in possession of a sédula?
2. What is your gender?
3. What is your age?
4. For how many years have you been living on Bonaire?
5. What is your highest achieved education?
6. What is your main occupation?

Perceived impact from mangrove restoration in Lac

7. Do you personally experience any benefits from the mangroves in Lac? (If yes, please specify)
8. Do the people of Bonaire experience any benefits from the mangroves in Lac? (If yes, please specify)
9. Do you personally experience any negative impact from the mangroves in Lac? (If yes, please specify)
10. Do the people of Bonaire experience any negative impact from the mangroves in Lac? (If yes, please specify)

Awareness of mangrove restoration in Lac

11. Did you know that the mangroves in Lac are threatened and degrading?
12. Do you think it's important to restore the mangroves in Lac?
13. Are you aware of the mangrove restoration efforts in Lac by Mangrove Maniacs?
14. Have you ever been involved with the work of Mangrove Maniacs?

Valuation of mangrove ESs in Lac

Mangrove forests offer various benefits to humans and nature, which may be an incentive to restore degraded mangrove forests. How important do you find it to restore the mangroves in Lac for the following benefits? If you are not sure, you may always answer 'I don't know/ Unclear'.

15. Mangroves are a nursery for many marine species. This contributes to the food provisioning (**fisheries**) for people. To me, this incentive to restore mangroves is:
    a. Not important
    b. Neutral
    c. A little important
    d. Very important
    e. I don't know/ Unclear
16. Mangroves are a nursery for many marine species and birds. This contributes to **biodiversity**, include that of the adjacent coral reefs for example. To me, this incentive to restore mangroves is:
17. Mangroves provide a barrier to wind and waves during hurricanes and storms. They provide **coastal protection**. To me, this incentive to restore mangroves is:
18. Mangroves filter sediment particles from land-sourced water flow. In doing so, they **protect against sedimentation** of coral reefs for example. To me, this incentive to restore mangroves is:
19. Mangroves have a very high carbon sequestration rate, meaning that can take up a lot of CO_2 (the driver of climate change) from the atmosphere. Mangroves can therefore **mitigate climate change**. To me, this incentive to restore mangroves is:
20. Mangroves provide unique natural scenery. Some people therefore value mangroves for their **beauty**. To me, this incentive to restore mangroves is:
21. Mangroves provide a unique experience of nature. This attracts a lot of people, resulting in opportunities for **tourism and recreation**. To me, this incentive to restore mangroves is:
22. Mangroves are capable of **filtering pollution** from water flows from the land. Thereby mangroves prevent the pollution from entering the sea. To me, this incentive to restore mangroves is:
23. Mangroves **protect the land against salt water intrusion**, thereby keeping it from reaching fresh groundwater. To me, this incentive to restore mangroves is:
24. How do you feel about the current extent of restoration activities by Mangrove Maniacs in Lac?
    a. The current efforts in mangrove restoration are just right.
    b. Efforts in mangrove restoration should be increased.
    c. Efforts in mangrove restoration should be increased.
    d. Mangrove restoration is not necessary.
    e. I don't know.

B. Perception survey for Mangrove Maniacs (MM)

Introduction

1. Are you in possession of a sédula?
2. What is your gender?
3. What is your age?
4. For how many years have you been living on Bonaire?
5. What is your highest achieved education?
6. What is your main occupation?

Working with Mangrove Maniacs

7. For how long have you been active with Mangrove Maniacs?
8. What are the most important reasons for you to join Mangrove Maniacs?

Perceived impact from mangrove restoration

9. Do you personally experience any benefits from the mangroves in Lac? (If yes, please specify)
10. Do the people of Bonaire experience any benefits from the mangroves in Lac? (If yes, please specify)
11. Do you personally experience any negative impact from the mangroves in Lac? (If yes, please specify)
12. Do the people of Bonaire experience any negative impact from the mangroves in Lac? (If yes, please specify)

Valuation of mangrove ESs in Lac

Mangrove forests offer various benefits to humans and nature, which may be an incentive to restore degraded mangrove forests. How important do you find it to restore the mangroves in Lac for the following benefits? If you are not sure, you may always answer 'I don't know/ Unclear'.

13. Mangroves are a nursery for many marine species. This contributes to the food provisioning (**fisheries**) for people. To me, this incentive to restore mangroves is:
    a. Not important
    b. Neutral
    c. A little important
    d. Very important
    e. I don't know/ Unclear
14. Mangroves are a nursery for many marine species and birds. This contributes to **biodiversity**, include that of the adjacent coral reefs for example. To me, this incentive to restore mangroves is:
15. Mangroves provide a barrier to wind and waves during hurricanes and storms. They provide **coastal protection**. To me, this incentive to restore mangroves is:
16. Mangroves filter sediment particles from land-sourced water flow. In doing so, they **protect against sedimentation** of coral reefs for example. To me, this incentive to restore mangroves is:
17. Mangroves have a very high carbon sequestration rate, meaning that can take up a lot of CO_2 (the driver of climate change) from the atmosphere. Mangroves can therefore **mitigate climate change**. To me, this incentive to restore mangroves is:
18. Mangroves provide unique natural scenery. Some people therefore value mangroves for their **beauty**. To me, this incentive to restore mangroves is:
19. Mangroves provide a unique experience of nature. This attracts a lot of people, resulting in opportunities for **tourism and recreation**. To me, this incentive to restore mangroves is:
20. Mangroves are capable of **filtering pollution** from water flows from the land. Thereby mangroves prevent the pollution from entering the sea. To me, this incentive to restore mangroves is:
21. Mangroves **protect the land against salt water intrusion**, thereby keeping it from reaching fresh groundwater. To me, this incentive to restore mangroves is:
22. How do you feel about the current extent of restoration activities by Mangrove Maniacs in Lac?
    a. The current efforts in mangrove restoration are just right.
    b. Efforts in mangrove restoration should be increased.
    c. Efforts in mangrove restoration should be increased.
    d. Mangrove restoration is not necessary.
    e. I don't know.

Appendix 5: Expert Interview Results*

A: Expert interview results for questions 3, 4 and 5

Expert nr.	1	2	3	4	5	6	7
Q2: Impacts on planetary health	Carbon sequestration	Climate mitigation through carbon sequestration; Biodiversity	Carbon sequestration; Nursery for fish, crabs, shrimps;	Carbon sequestration; Provision of oxygen	Carbon sequestration; Protection of world heritage; Insured biodiversity	Carbon sequestration;	Carbon sequestration;
Q4: Impact on local environment	Benefits fisheries; Protection against sedimentation of coral reefs through sediment trapping; Filtering of sediments; Nursery for fish species that also exist in coral reefs and seagrass beds	Biodiversity; coast line protection; sustainability for future generations	Local weather cooling through tree transpiration; Filtering of run-off water (nutrients, heavy metals, and sediment trapping); Erosion control; Source of biodiversity through leaf decomposition and the resulting food chain;	Retention of water flow from the land; Nutrient filtration; Nurseries and habitat for fish, crabs, birds; Healthier reefs and seagrass beds trough sediment trapping and nutrient filtering;	Prevention of erosion	Brings shrimp, crabs, and bees into the system; Mangrove area expands naturally through lateral branching of the root system; Sediment trapping; Land mass accretion and formation of delta; Microbial biodiversity (cyanobacteria, fungi) that feed on leaf litter, attract fish and crab; Nursery and hiding place for fishes; Water filtration; Extensive bird biodiversity	Provision of habitat for (shell) fish and mammals, such as tigers Buffer function between the land and the sea: protect corals from sediment and nutrients from run-off water; Nursery function for fish;
Q5: Impact on people's well-being	Provision of building material (although not in expert's working area); Tourism; (In)direct employment in restoration, tourism, and fisheries; Esthetics; 'Muddy' perception; Mosquitos (but the associated diseases do not occur in expert's working area); Income from tourism and fisheries	Income from carbon trading schemes	Building material; Fuel source; sale of charcoal; Non-timber forest products (honey, herbs, palm leaves) and resulting craftmanship; Tourism; Spiritual value of mangroves for local community; Wind and storm surge protection through wave attentuation	Positive psychological effects; Storm buffer through wind and wave breaking; Wood provisioning; Esthetics and monetary land value; Protection against flooding; Making adjacent ecosystems more suitable for tourism	Spiritual value to the community; Tourism; Physical protection against storms; Habitat and nurseries for fish and other commercially valuable species; Ecotourism	Protection from storms and cyclones; Income and employment through honey production and shrimp and crab collection; Protection against sea-level rise through land mass accretion; Cultural value; Tourism;	Raising awareness amongst people; Reduction of flood risk in coastal areas; More cost-effective solutions for developing countries and SIDSs;

B: Expert interview results for question 6A

Expert nr.	1	2	3	4	5	6	7
Climate Change	Carbon sequestration (*global*)	Carbon sequestration (*global*)	Carbon sequestration (*global*); Protection against wind, waves, storms (*local*)	Carbon sequestration (*global*)	Carbon sequestration (*global*); Protection against wind, waves, storms (*local*)	Carbon sequestration (*global*);	Protection against sea-level rise and increased intensity and frequency of storms (*local*); Carbon sequestration (*global*);
Ocean Acidification	Carbon sequestration (*global*)	Carbon sequestration (*global*)	Not relevant	Carbon sequestration (*global*)	Buffering capacity (*local*)		Unsure
Chemical Pollution	Toxin absorption, e.g. from agriculture (*local*)	Purification of the ecosystem (*local*)	Heavy metal remediation from run-off (*local*);	Heavy metal absorption (*local*);	Bioremediation of heavy metal pollution (*local*);	Water filtration (*local*);	Filtering function (*local*);
Nitrogen and phosphorus loading	Unsure	Buffer function reduces flow to adjacent ecosystems (*local*)		Phytoremediation of nitrogen and phosphorus rich discharge water (*local*);	Filtering of nitrogen and phosphorus (*local*);	Microbiome contributes to nitrogen fixation and phosphorus reduction (*local*);	Filtering function (*local*);
Freshwater withdrawals	Not relevant	Not relevant	Unsure	Not relevant	Unsure	Not relevant	Unsure;
Land conversion	Planting increases vegetation cover (*local*) (although alternative land uses are limited in expert's working area); Prevention of wood harvesting and aquaculture (*local*); Jobs lost in earlier land uses (*local*)	As a compensatory measure in Environmental Impact Assessments for building projects (*local*)	Nature regeneration (*local*)	Less converted land after restoration;	Reversing conversion back to it's natural state (*local*);	Protection against soil erosion in the lower strectch of the mangrove range (*local*);	Conversion of old shrimp ponds (*local*); Mangrove restoration could lead to a perceived allowance of mangrove conversion on the landward side/ fake sense of security (*local*);
Biodiversity loss	Increase in animal and plant abundance and diversity (*local*)		Increased diversity of species living within the mangroves (not necessarily the trees themselves) (*local*); Enhancement of mangroves as a keystone species (*local*);	Incerased biodiversity (*local*); Habitat for migratory bird species (*global*);	Preserves biodiversity by providing habitat (*local*);	Protection of seagrass beds and coral reefs against pollution (*local*); Increased biodiversity of (migrating) birds (*global*), mammals and fish, through microbial biodiversity in mangroves (*local*);	Increasing biodiversity, also outside of the system through the interconnectedness of ecosystems (*global*);
Air pollution	Not relevant	Not relevant	Unsure	Unsure	Air filtration (*local*)	Carbon sequestration (*global*)	Carbon sequestration (*global*)
Ozone layer depletion	Unsure	Not relevant		Unsure	Unsure	Unsure	Unsure

C: Expert interview results for question 6B

Expert nr.	1	2	3	4	5	6	7
Food	Nursery function of mangroves benefits fisheries (*local*)	Food provisioning through fisheries (*local*)	Clams, mussels, fish, crabs (*local*)	Food supply of fish and crabs (*local*); Local fisheries avoid import of food resources (*global*)	Food from fisheries (*local*); Food from fishieries going through global supply chain (*global*)	Shrimp and crab production for export (*local* and *global*); Honey production (*local*);	Subsistence fishing by coastal communities and crab harvesting (*local*); Global trade of shrimps (*global*);
Health	Food from fisheries is a healthy food source as compared to alternatives (*local*); No air pollution in mangroves (*local*)	Unsure	Food security (*local*); Food safety through water purification (*local*); Psychological benefits of green space (*local*)	Improved mental health (*local*); Nutritional value of fish replacing less nutrituous alternatives in the community (snacks) (*local*);	Coastal protection and death prevention from storms (*local*); Mosquitos and diseases (*local*)	Medicinal products for local people (but not commercially harversted because mangroves cannot be harvested) (*local*);	Mangroves are of cultural importance to the local communities, thereby affecting mental health - but for most people this connection to nature is lost (*local*); Flood safety (*local*);
Education	Topic in primary and secondary education leads to awareness and connection with nature (*local*); Outreach to adults and local journalists (*local*)	Knowledge dissemination through training of the local community leads to understanding of the value of mangroves (*local*); and through research activities and publications (*global*)	Increase people's understanding of mangrove ecosystems (*local*)	Incorporation of mangrove ecosystems in formal STEM education (science, technology, engineering, mathmetics) (*local*); Contribution to science (*global*);	Provision of on-the-ground learning and appreciation for mangrove resources (*local*); Foreigners travel to learn from these systems (*global*);	Nature education (*local*); Scientific research on mangroves (*global*);	Engagement and training of local community (*local*);
Income and work	Income through tourism and fisheries (*local*); Reducation of expenditures through coastal protection (*local*)	Employment (e.g. 'community scouts' that monitor activities) (*local*); Attraction of green tourism enterprises (*local*)	Fishing activities (*local*); Honey production (*local*); Seedling production and sale for planting (*local*) (although not the preferred approach by expert)	Employment (e.g. nurseries, sediment excavation) (*local*); Scientists and consultants (*global*);	Income associated with food (*local*); Ecotourism (*local*); Income from the restoration work, e.g. digging channels, nursery care and tree planting (*local*);	Employment opportunities in monitoring and training (mostly women) (*local*); Tourism and bird guides (*local*); Shrimp, crab, and honey production (*local*);	Payed opportunities to do mangrove restoration (*local*); Income through fisheries, shellfish harvesting, medicinal products and wood extraction (*local*);
Peace and justice	Unsure	Provisioning of local ownership and responsibility (*local*)	Conflict because of unclear land tenure (*local*); Dialogue and consensus on land tenure (*local*)	Unsure	Peace building opportunities accross borders within a mangrove area (*local and global*); Tension within communities because of diffferent interests (*local*); Tension amongst original users when resource use is limited for restoration/conservation (*local*) Addressing	Shared values from the mangroves between different religions provides community strength (*local*) (this is very indirect, no direct effect known);	Carbon sequestration contributing to climate change mitigation would help avoid climate change related peace disruptions *(global*)

					environmental justice when communities are deprived of the mangrove benefits due external degredation (*local*);		
Political voice	Not relevant	Unsure	Not relevant (but may be part of restoration project)	Advocacy for mangrove community interests (*local*); Global movement and media coverage empowering other restoration projects (*global*);	A greater voice to e.g. small holder farmers or fishermen through the stakeholder input process (*local*); A greater voice to SIDSs in international politics (*global*);	Not relevant	Unsure
Social Equity	Not relevant	Conflicts of interests amongst community members (*local*)	Not relevant	Not relevant	Create a more level playing field for different stakeholders (*local*); Removal of rights of mangrove community for the purpose of restoration/conservation (*local*);	Not relevant	Better access to flood risk reduction for developing countries, increasing social equity (global);
Gender equality	Not relevant	More prominent role for women in restoration activities (*local*)	Not relevant	Balanced representation of men and women through fund requirements (*global*);	Provision of livelihood for women, which are the majority of people involved (*local*); Promotion of women involvement through funder's goals and indicators (*local*);	Majority of people involved are women, because they often stay at home and now what happens in the surrounding mangroves (*local*);	Women in some communitities have ownership rights in the mangroves, which should not be lost (*local*);
Housing	Coastal protection (*local*)	Not relevant	Building materials (*local*); Coastal protection (*local*)	Safer housing facilities (*local*);	Preventing the construction of housing on restoration sites (*local*); Protection of existing housing from weather disasters (*local*);	Protection of housing against the ocean (*local*);	Mangrove restoration might require people to move inland a bit further (local); Flood risk reduction contributes to quality of housing (*local*);
Networks	Unsure	Knowledge exchange on a regional scale between projects and their partners (*local*)	Connecting neighbouring villages, NGOs, local governments through training (*local*)	International networks and knowledge exchange between restoration projects (*global*); New community connections from the restoration cooperation (*local*);	The engagement of various stakeholders enhances networks (*local*); Better mutual understanding of needs and interests (*local*); Involvement of international NGOs and sharing ownership of projects, e.g. Global Mangrove Alliance, Blue Carbon Initiative (*global*);	Distribution of knowledge to different projects through the local community involved (*local*); Knowledge exhange within the international mangrove community through professionals (*global*);	Team environments with lots of volunteers (*local*);

Energy	Not relevant	Provision of alternative wood lots for fuel and building material (*local*)	Fuel from wood (but this is often a problem)	Fuel wood (*local*)	Charcoal production for cooking or heating (*local*) (but this is controversial); Provision of shade in stead of air-conditioning (*local*);	Fuel wood (if there are no restrictions) (*local*);	Charcoal from wood (but this shouldn't be promoted (*local*);
Water	Not relevant	Clean water piping funded by income generated through blue carbon credits (*local*)	Unsure	Not relevant	Nitrogen and phosphorous filtering prevents algal blooms that would also diminish groundwater quality (*local*); Reduction of salt water intrusion (*local*);	Not relevant	Protection against salt intrusion (*local*);

* Responses that explicitly refer to a negative impact from mangrove restoration are highlighted in red. Furthermore, for questions 6a and 6b, each suggested impact is coded as 'local' or 'global', depending on the expert's perception of the scale of impact. When experts pronounced doubts about their answer or explicitly stated that the question concerned was beyond their expertise, their response was labelled as 'Unsure'. When experts stated that mangrove restoration had no or not a clear impact on the dimension in question, their response was labelled as 'Not relevant'.

Appendix 6: Outcomes of Dialogue Session with OLB and STINAPA

This overview represents a first draft of a possible SJOS for Bonaire from the perspective of policy makers, indicating the most relevant EC and SF dimensions for the island and people of Bonaire. The participant's interpretation of these dimensions is given through specifications, indicators, or solutions for desired change.

Dimension	Interpretation
Social Foundation	
1. Education	- Better quality
2. Recreation	- Enough (sports) facilities
3. Inclusive and Fair Policy	- Improved recognition of local citizens *[author's note: alongside the perceived focus on temporary residents and tourists]* - Fair financial market
4. Healthcare Infrastructure	
5. Food	- Local availability - Healthy and safe
6. Housing market	- Affordable - Accessible
7. Safety	- In the water: swimming lessons - In traffic
8. Economy & Income	- Qualitative growth - Social balance & safety net - Meaningful jobs - Increased social minimum
9. Cultural Integration	- Improved mutual understanding
10. Urban Infrastructure	- Street lightning - Road network - Internet/ Fibre optic cables
11. Healthy and Clean Environment	- Sewage system - Sanitary facilities - Waste management
12. Transport	- Capacity
13. Political Voice	- Participation - Shared vision
Ecological Ceiling	
1. Spatial Planning and Land-use	- Less construction - Mortuaria - More restoration/ reforestation/ healthy coral reefs
2. Waste Disposal	- Healthy (drinking)water
3. Erosion	- Improved goat management
4. Population Growth	- 'Handle demographic growth'/ Carrying capacity
Boundary conditions	
1. Legislation	- Clearer
2. Enforcement	- Effective (and in effect at all)
3. Information Provision	- Awareness - Nature education - Policy communication (e.g. Masterplan Bonaire) should be clearer en more accessible

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