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Working with nature

The environmental and policy feasibility of nature-based adaptation (NbA) to address anthropogenic stress in the Rhine and Mekong deltas

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Summary

Worldwide, deltas are increasingly threatened by anthropogenic stress. Adapting to these threats is a pressing and unavoidable necessity, as currently more than 500 million people live in and depend on deltas. Paradoxically, conventional approaches to address flood risks are rigid, they cause, exacerbate or facilitate existing threats, and they result in the deterioration of surrounding ecosystems. A robust and flexible alternative is nature-based adaptation (NbA), which aims to preserve natural ecosystems. It assumes that dynamic ecosystems are resilient and can provide cost-effective protection against threats, conserve biodiversity, and provide benefits to communities.

However, adaptation capacities are limited which may result in losses and damages. Therefore, to sustainably manage deltas, it is critical to gain a better understanding of the potential for NbA in different contexts. This thesis studies the feasibility of NbA in the Rhine and Mekong deltas, two highly contrasting cases. First, a systematic literature review was conducted to compile the set of existing NbA options in deltas and coasts. Next, environmental and policy constraints to NbA were assessed. I argue that sea-level rise, subsidence, sediment availability and land-use may constrain NbA in deltas. Data on these variables were obtained and analysed. Additionally, I contend that adaptive governance is a prerequisite for the implementation of NbA. Toward that end, the Rhine and Mekong delta plans were analysed using the adaptive governance framework by DeCaro et al. (2017a).

Currently, only nine NbA strategies for deltas exist in the literature. Although most principles for adaptive governance are present in the delta plans, indicating that from a policy perspective there are opportunities for NbA in the Rhine and Mekong deltas, from an environmental perspective NbA is highly constrained. Seven of the nine NbA strategies face serious implementation constraints in the Rhine and Mekong deltas due to projections of environmental change. Therefore, there is an urgent need to combine strategies for mitigation, adaptation, and dealing with loss & damage. This also has implications for governance. As NbA is highly constrained, adaptive governance alone is not the best framework to manage future challenges. I contend that combining adaptive, transformative and interactive governance may be the best way to sustainably manage the Rhine and Mekong deltas.

These results enhance our understanding of the potential for NbA to address anthropogenic stress in the Rhine and Mekong deltas, and potentially in other deltas worldwide too. In addition, the results open up important new questions for future research.

Key concepts

Anthropogenic stress | deltas | nature-based adaptation | adaptive governance | limits to adaptation

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1. Introduction

1.1. Background of the problem

We currently live in the Anthropocene, a geological time-period that is unique in the sense that it is characterised by the human domination of the Earth's geophysical processes (Steffen et al., 2011). We are rapidly changing our environment through various anthropogenic activities, which have raised concerns about the future of the Earth's ecosystems and their capacity to continue providing the services needed for both human and non-human survival (Steffen, Crutzen & McNeill, 2007). The impacts of human interference with the natural world are especially visible in river deltas, where many economic, social and environmental changes are progressing much faster and more intensely compared to the global average (Nicholls, Adger, Hutton & Hanson, 2020).

Today's river deltas were created approximately 6000-8000 years ago through sediment deposition and accumulation, as the river flow enters slow-moving waters near river mouths (Syvitski, 2008; Renaud et al., 2013). Deltas are dynamic systems and they naturally evolve by the interaction of sediment deposition, redistribution and loss. The deposition of sediments creates productive, low-lying coastal areas with fertile soils that support intensive agriculture and growing cities (Dunn et al., 2019; Nicholls et al., 2020). At present, more than 500 million people live in deltas, meaning that approximately 7% of the world population lives on less than 1% of the global total land area (Dunn et al., 2019; Nicholls et al., 2020). Delta populations are projected to further increase in the future.

However, the low elevation of deltas also means that their inhabitants are vulnerable to various threats. At the global scale, anthropogenic climate change causes sea-level rise and changing weather patterns. This may increase the occurrence of storm surges, extreme tides and wave impacts, and subsequently the risk of flooding (Renaud et al., 2013). At the regional scale, human changes to the river's catchment change water and sediment delivery to the delta. Deltas naturally subside relative to sea levels due to sediment compaction and tectonic movements. Therefore, deltas need a continued supply of sediment from the upstream catchment to keep from drowning (Dunn et al., 2019). However, dam construction significantly reduces sediment delivery to the delta and thus accelerates subsidence. Many deltas worldwide are subsiding, which increases their vulnerability to floods, salinization and permanent inundation (Minderhoud et al., 2017). At the local scale, groundwater abstraction and drainage of embanked areas also exacerbate natural subsidence (Seijger, Ellen, Janssen, Verheijen & Erkens, 2017). Combined with deforestation in coastal areas, groundwater abstraction and drainage increase flood vulnerability which places regional economies and delta-citizens at risk (Seijger et al., 2017; Nicholls et al., 2020). Furthermore, changes in water levels due to groundwater pumping may cause salinization of groundwater, waterlogging and land-loss (Wada et al., 2010) This, in turn, threatens the productivity of agricultural lands, food security and the livelihoods of many people (Dunn et al., 2019; Nicholls et al., 2020).

Worldwide, it has been estimated that these threats affect hundreds of millions of vulnerable people, important infrastructure and tourism, with significant losses to national economies and impacts on livelihoods (Reguero, Bresch, Beck, Calil & Meliane, 2014). Therefore, adapting to these threats is a pressing and unavoidable necessity. The lives of delta-citizens are at stake (Craig & Ruhl, 2019). Paradoxically, many of the conventional approaches used to address anthropogenic stress either cause, exacerbate or facilitate already existing problems in deltas (Seijger et al., 2017). For example, land reclamation and dike construction, to protect the land from flooding, result in a loss of water-storage area during floods. Additionally, natural sediment deposition and thus land rise in these areas is reduced (Temmerman et al., 2013). Furthermore, conventional, hard engineering solutions, such as dams or levees (Van Wesenbeeck et al., 2014), result in the deterioration of natural systems, loss of ecosystem services and rigidity of flood defences that cannot be easily adapted to changing environmental conditions in the future (Borsje et al., 2011; Van Wesenbeeck et al., 2014). Therefore, there is a need for adaptation approaches that minimise the human impact on our ecosystems (Borsje et al., 2011).

An alternative to conventional adaptation is nature-based adaptation (NbA). This relatively new approach aims to work together with nature by preserving ecosystems and their biodiversity. It starts from the assumption that dynamic, natural ecosystems are resilient and can provide cost-effective protection against anthropogenic stress (Nicholls et al., 2020). The resilience and self-organising properties of ecosystems ensure flexibility to seasonal changes and climate extremes, which is essential for flood protection. At the same time, NbA strategies invest in the long-term health of ecosystems so that they can continue to provide ecosystem services well into the future (Nicholls et al., 2020). NbA is guided by sustainable, adaptive management approaches (Hale et al., 2009; Fernandino, Eliff & Silva, 2018). There is an increasing interest in working with nature (Hale et al., 2009; Nicholls et al., 2002) and studies have demonstrated that implementing NbA at the local scale can be more sustainable and efficient than conventional adaptation (e.g. Barbier et al., 2008; Shepard, Crain & Beck, 2011; Zhang et al., 2012). Especially concerning uncertain future scenarios due to climate change, sea-level rise and changing peak river discharges, people are hesitant to invest in rigid flood defences (Van Wesenbeeck et al., 2014). NbA is much more flexible and provides an alternative to structural planning.

1.2. Problem definition and knowledge gap

Conventional adaptation strategies may no longer be suitable to deal with the full range of challenges that currently threaten river deltas because these strategies are rigid and deteriorate surrounding ecosystems. This is problematic because ecosystems support and constrain social and economic progress and determine the ultimate boundaries and safe operating space of human development (Rockström et al., 2009; Craig & Ruhl, 2019). It is therefore critical to consider ecosystems and invest in the long-term resilience of our environment. This is especially relevant in the context of deltas, because delta ecosystems, such as coastal and riverine wetlands, are naturally dynamic and rich in biodiversity. In addition, they provide ecosystem services, such as carbon sequestration and flood protection, that are valuable to human and non-human life (Nicholls et al., 2020). However, so far, interest in ecological aspects of adaptation has been scarce (Enríquez-de-Salamanca, Diaz-Sierra, Martín-Aranda & Santos, 2017; Craig & Ruhl, 2019; Mechler, Bouwer, Schinko, Surminski & Linnerooth-Bayer, 2019). As delta populations will face challenges in the future that go far beyond our current experience (Nicholls et al., 2020), a new, flexible adaptation approach is required that recognises the mediating role of ecosystems. This is where NbA comes in.

However, the application of NbA approaches to deltas is still relatively new and global research on the topic remains limited (Temmerman et al., 2013; Van Wesenbeeck et al. 2014). Besides, many factors can constrain the feasibility of NbA in deltas. For example, delta ecosystems such as coastal wetlands need a minimum amount of sediment delivery to survive increasing rates of relative sea-level rise (Adam, 2002; Gilman, Ellison, Duke & Field, 2008). The restoration of delta ecosystems also requires a lot of space, more than conventional adaptation strategies. In densely populated areas, this space is not available and people may not be willing to give up their land (Colls et al., 2009; Temmerman et al., 2013). Conventional adaptation is also more familiar and public trust in hard adaptation infrastructures is high. Shifting to another approach therefore requires willingness to change. In addition, NbA is often applied at the local level. Scaling up to regional or global levels may be difficult (Temmerman et al., 2013).

Currently, a knowledge gap exists regarding the potential for, and limitations to, NbA (Mechler et al., 2019). To protect deltas from flooding and to prevent the occurrence of loss & damage to people and their livelihoods, it is imperative to identify the factors that constrain the feasibility of NbA.

1.3. Research objectives

This thesis aims to contribute to the aforementioned knowledge gap by studying constraints to NbA in deltas. The overall goal is to assess the feasibility of NbA in the two highly contrasting cases of the Rhine-Meuse-Scheldt delta in the Netherlands (from now on simply referred to as the Rhine delta) and the Mekong delta in Vietnam.

This overall goal is further divided into three objectives. The first objective is to compile the current suite of NbA strategies for deltas. Knowledge of the current tools at hand is needed to determine potential limitations to these tools. The second objective is to assess the environmental feasibility of NbA in the Rhine and Mekong deltas. Rapid anthropogenic-driven environmental change is one of the most important challenges we are facing today because it significantly deteriorates ecosystem health (Craig & Ruhl, 2019). As ecosystems can only provide effective protection against anthropogenic stress if they are healthy and resilient, current and future environmental limits to NbA in deltas are crucial to consider. In addition to environmental limits, policies are one of the most important determinants of the adaptive capacity of an area (Cosens et al., 2017). Policies significantly influence the attractiveness and feasibility of conserving ecosystems and applying NbA strategies to deal with climate risks (Kapos, Wicander, Salvaterra, Dawkins & Hicks, 2019). Besides, policies play an important role in promoting the change from conventional adaptation to NbA and in cultivating trust among the public. The third objective is therefore to assess the policy feasibility of NbA in the Rhine and Mekong deltas. Combining an environmental and a policy perspective is highly relevant because deltas in particular are areas characterised by the interaction of dynamic natural processes and human activities. An understanding of both the natural and the social systems in deltas is therefore important.

1.4. Research questions

To attain the objectives, the following main research question is formulated: *To what extent are various nature-based adaptation strategies feasible to address anthropogenic stress to the Rhine and Mekong deltas?* This question is further divided into three sub-questions:

(1) What delta-specific nature-based adaptation strategies currently exist in the literature?
(2) To what extent do projections of environmental change in the Rhine and Mekong deltas enable or constrain the feasibility of nature-based adaptation?
(3) To what extent do current policies in the Rhine and Mekong deltas enable or constrain the feasibility of nature-based adaptation?

1.5. Research framework

This thesis employs a mix of quantitative and qualitative methods to answer the research questions (Figure 1). To answer the first sub-question, a systematic literature review will be conducted resulting in a list of NbA strategies specific to deltas (Figure 1a). The feasibility of these strategies in the Rhine and Mekong deltas firstly depends on environmental factors (Figure 1b), which will be quantitatively assessed using published data on sea-level rise, subsidence, sediment availability and land-use for both deltas (Figure 1c). Furthermore, the feasibility of NbA also depends on policies in the Rhine and Mekong deltas that may enable or constrain their implementation. This will be qualitatively assessed by analysing the Rhine and Mekong delta plans against legal and institutional design principles for adaptive governance by DeCaro et al. (2017a) (Figure 1e). Assessing to what extent environmental factors and policies enable the feasibility of NbA enhances our understanding of the usefulness of NbA to deal with anthropogenic stress in the Rhine and Mekong deltas (Figure 1f) and potentially in other deltas too.

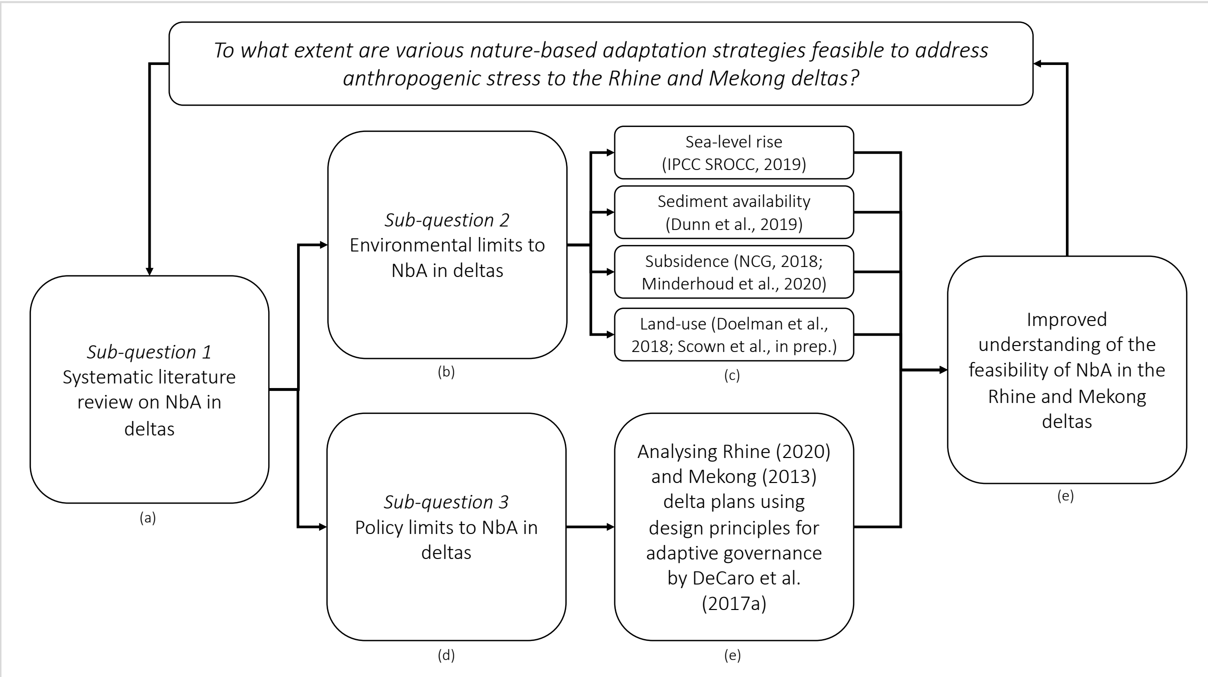

Figure 1. Schematic overview of the different research phases in this thesis.

1.6. Scientific and societal relevance

To date, most research on adaptation has largely overlooked the mediating role of ecosystems and the environment (Enríquez-de-Salamanca et al., 2017; Mechler et al., 2019), even though environmental degradation is not just a challenge, but the most important challenge of our time (Craig & Ruhl, 2019). Healthy ecosystems provide goods and services that allow human societies to exist. As conventional adaptation measures are inflexible and often exacerbate environmental problems, they are limited to deal with current and future anthropogenic stress to deltas. To avoid the occurrence of loss & damage, it is essential to document and evaluate the effectiveness of NbA (Mechler et al., 2019). Research on environmental change needs to study limits to adaptation, in particular gathering evidence on potential limitations to NbA in different contexts (Mechler et al., 2019). This thesis contributes to filling this knowledge gap in the literature by identifying environmental and policy constraints to NbA in the Rhine and Mekong deltas, which underlines the scientific relevance.

Furthermore, deltas are extremely important in the global economy and support large human populations and ecological diversity (Sebesvari et al., 2016). People in deltas around the world are directly exposed to the effects of global climate change and other anthropogenic activities such as groundwater abstraction and dam construction, which could significantly impact their livelihoods (Hale et al., 2009; Boda & Jerneck, 2019). Failing to adapt to these threats would jeopardise the achievement of multiple Sustainable Development Goals (SDGs), ultimately undermining sustainable development in deltas (United Nations, 2015; Boda & Jerneck, 2019). In the face of uncertain future scenarios, there is a need for adaptive approaches to delta-planning that build on the resilience and regenerative capacity of ecosystems and reduce the adverse impacts of human activities (Hale et al., 2009; Sebesvari et al., 2016). It has been argued that NbA has the potential to help achieve the full range of SDGs (Cohen-Shacham et al., 2019). Effectively implementing NbA strategies to avoid the occurrence of loss & damage to people and livelihoods is therefore highly relevant from a societal perspective as well.

2. Conceptual framework

This thesis is underpinned by two conceptual frameworks. The first framework encompasses the three pillars of climate action recognised by the UNFCCC: mitigation, adaptation, and loss & damage (Mechler et al., 2019), and is outlined in section 2.1. The second framework is that of NbA and will be discussed in section 2.2.

2.1. Mitigation, adaptation, and loss & damage

A continued increase in human interference with natural processes could trigger abrupt and irreversible changes to the environment (Rockström et al., 2009). Some of these changes are already visible, such as scarcity in critical resources, changing air and seawater temperatures, rising sea levels, ecosystem degradation and a reduced capacity of the Earth to absorb our wastes. As a result, we are witnessing an increase in the occurrence of disasters (Renaud, Sudmeier-Rieux & Estrella, 2013). This is a constant reminder that we are placing our contemporary societies at risk (Steffen et al., 2011). A disaster is defined as a significant disruption of the functioning of a community or society that results in widespread losses and damages (UNISDR, 2009). Disasters occur when the effects of a hazard event, such as flooding, overwhelm the ability of a community or society to deal with the losses and damages incurred (Estrella & Saalismaa, 2013).

However, the impacts of disasters can be anticipated and prevented through human efforts (Estrella & Saalismaa, 2013). Two common strategies have been mitigation and adaptation. The Intergovernmental Panel on Climate Change (IPCC) defines mitigation, in a climate change context, as anthropogenic interventions either to reduce the sources or enhance the sinks of greenhouse gases (Figure 2a) (IPCC, 2001). For a long time, mitigation has been prioritised by scientists and policy-makers. First, because they believed that mitigation would be effective. Second, because it was uncertain to what extent environmental changes would occur and how to adapt to them (Schipper, 2006). However, during the late 1990s and early 2000s, scientific evidence suggested that mitigation was reaching its limits (Figure 2b). It had failed to reduce anthropogenic greenhouse gas emissions (James et al., 2014). Planned greenhouse gas mitigation efforts would not prevent global warming from exceeding the 2^{o}C limit as aspired to in the 2015 Paris Agreement (Mechler & Schinko, 2016). Therefore, it was recognised that mitigation alone is insufficient to reduce the consequences of anthropogenic activities. Including adaptation measures became a necessity (Figure 2c) (Schipper, 2006).

Adaptation is defined as adjustments made in ecological or social systems as a response to anthropogenic changes to the Earth system or their effects (IPCC, 2001). In other words, mitigation focuses on the sources of human changes to Earth's climate and ecosystems, whereas adaptation deals with its consequences (Schipper, 2006; Mechler et al., 2019). Adaptation measures can take many shapes and forms depending on the local context, ranging from building flood defences, setting up early warning signals for storms and switching to drought-resistant crops, to redesigning communication systems and government policies (UNFCCC, n.d.). Adaptation strategies aim to eliminate or reduce the potential losses and damages resulting from anthropogenic stress (UNFCC, n.d.) and are therefore essential to protect people, livelihoods and ecosystems. However, in recent years, it has been recognised that adaptation may also be limited in its capacity to deal with threats (Figure 2d). Climate risks may exceed the adaptation possibilities of communities and countries. Especially vulnerable countries may have to deal with adaptation gaps (Mechler & Schinko, 2016).

The concept of loss & damage was introduced as a third pillar to deal with the limits associated with adaptation and to underline that human-induced threats to the Earth system may significantly impact the lives and livelihoods of many people worldwide (Figure 2e). Loss & damage refers to actual or potential manifestations of anthropogenic stress that may negatively affect social and ecological systems (James et al., 2014). It deals with the residual impacts of climate change that remain after mitigation and adaptation have been implemented (Mechler et al., 2019). Loss & damage includes sudden, extreme events such as flooding, and slow events such as glacial retreat and desertification (James et al., 2014). Losses are characterised by their irreversibility. For example, the permanent destruction of an ecosystem. Damages, on the other hand, can be repaired, such as damage to buildings (Huq, Roberts & Fenton, 2013; Boyd, James, Jones, Young & Otto, 2017). Loss & damage occurs when the costs of adaptation are not recuperated or when adaptation efforts are insufficient, ineffective or impossible (Huq, Roberts & Fenton, 2013).

Although mitigation and adaptation are valuable strategies that can help to prevent and anticipate the impacts of disasters, both also have their limitations. To avoid the occurrence of loss & damage to ecosystems and people, it is important to understand and estimate where and when losses and damages occur and how these are linked to human activities (James et al., 2014). This remains a major challenge. One contribution to tackling this challenge is identifying potential environmental and policy limits to one type of adaptation strategy, specifically NbA, which is the aim of this thesis (Figure 2f).

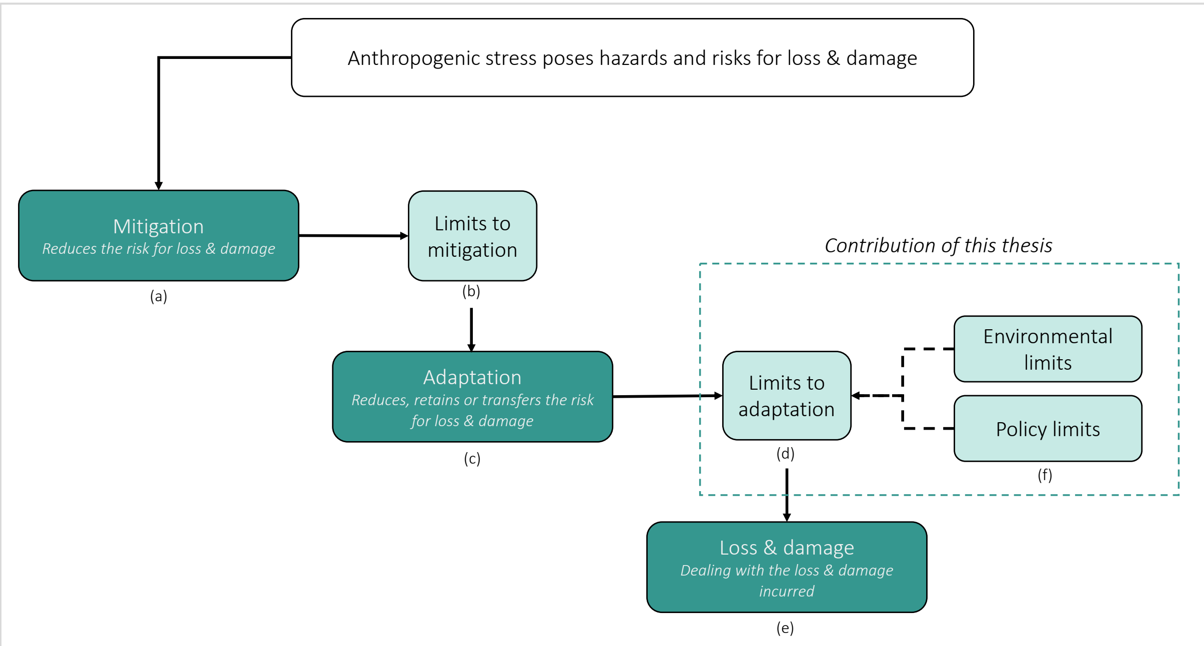

Figure 2. Conceptual framework showing how hazards and risks resulting from anthropogenic stress can result in the occurrence of loss & damage. Mitigation and adaptation may be limited in their capacity to address these risks. Therefore, dealing with loss & damage is inevitable. The contribution of this thesis, distinguished by the dashed box, is assessing the environmental and policy limits to adaptation, specifically NbA. The figure is adapted from Mechler et al. (2019, p.526).

2.2. Nature-based adaptation

The second framework that underpins this thesis is the concept of NbA. NbA is one specific strategy of adaptation that builds on biodiversity and ecosystem processes to adapt to the adverse impacts of anthropogenic stress.

2.2.1. Working with nature

Traditionally, most adaptive responses to reduce natural and human-induced risks in deltas employed large-scale hard engineering interventions (Hale et al., 2009; Cheong et al., 2013; Triyanti & Chu, 2018). This conventional approach heavily relies on technological strategies, which are designed and managed to be simple, replicable and predictable (Eggermont et al., 2015). It involves identifying a threat and using synthetic, engineered structures to reduce or eliminate that threat. Examples include sea-walls, rock revetments, dikes and levees. This hard engineering has long been perceived as the ultimate solution to address climate and non-climate risks (Cheong et al., 2013; Temmerman et al. 2013).

However, conventional adaptation strategies are reaching their limits. We are currently witnessing an increasing trend in many slow and rapid onset disasters. Climate change will likely increase the unpredictability and magnitude of such disasters, causing many deaths, injuries and economic losses each year (Renaud, Sudmeier-Rieux & Estrella, 2013; Triyanti & Chu, 2018). Conventional adaptation structures are rigid and adapting to environmental conditions requires a large investment. This is a huge disadvantage in the face of increased uncertainty regarding disasters (Van Wesenbeeck et al., 2014). Engineered structures are also challenged by rising maintenance costs (Temmerman et al., 2013; Ferrario et al., 2014). Besides, in the process of building hard adaptation structures, ecosystems are often destroyed. This further reduces the resilience and adaptive capacity of ecosystems to anthropogenic stress (Hale et al., 2009; Temmerman et al., 2013; Van Wesenbeeck et al., 2014). Hard adaptation infrastructures can negatively impact local morphology, hydrodynamics, and sediment and nutrient budgets (Cheong et al., 2013). This further increases risks, as ecosystem degradation results in the exposure of vulnerable communities and assets to threats (Reguero et al., 2014).

In light of these limitations, there is an urgent need for a new adaptation approach that minimises anthropogenic interference with the natural world, recognises the complexity of natural systems, and provides innovative, sustainable and cost-effective protection against threats (Borsje et al., 2011; Eggermont et al., 2015). Over the last decades, the incorporation of natural processes and ecosystems into adaptation and risk management gained more interest (Triyanti & Chu, 2018). Compared to hard engineering, which focuses on eliminating uncertainty, NbA incorporates uncertainty and allows natural systems to remain dynamic. NbA can be defined as a strategy that is inspired and supported by nature and departs from the assumption that natural, healthy ecosystems are resilient and supportive (Cohen-Shacham et al., 2019). In this way, ecosystems provide natural protection against various threats, such as flooding. In addition, healthy ecosystems are self-organising, which is why NbA is much more flexible and adaptive. This is a major advantage compared to conventional adaptation strategies (Cheong et al., 2013; Van Wesenbeeck et al., 2014; Eggermont et al., 2015). NbA has also been shown to be effective for disaster risk reduction (Ferrario et al., 2014; Reguero et al., 2014; Temmerman et al., 2013).

NbA is based on the idea that ecosystems can help to fight the drivers and impacts of anthropogenic stress. It therefore builds on biodiversity and ecosystem processes (Colls, Ash & Ikkala, 2009; Seddon, Turner, Berry, Chausson & Girardin, 2019). By protecting, sustainably managing and restoring natural ecosystem processes and biodiversity, the resistance and resilience of ecosystems to anthropogenic stress is enhanced, which significantly increases their adaptive capacity to threats (Figure 3) (Eggermont et al., 2015). In this way, ecosystems can provide cost-effective protection against anthropogenic stress and may continue to provide ecosystem services well into the future, while simultaneously enhancing societal well-being and providing biodiversity benefits (Figure 3) (Hale et al., 2009; CBD, 2009; Sheddon et al., 2019). An example of NbA is coastal defence through the maintenance and restoration of natural mangroves or other coastal wetlands, to protect against coastal flooding and erosion (CBD, 2009).

NbA is embedded in a theory of ecosystem conservation and restoration that emphasises positive feedbacks that may create synergies (Cheong et al., 2013). Such a positive feedback loop is illustrated in Figure 3. Research has shown that incorporating positive interactions into designs of nature-based strategies may increase community recovery, stability and resilience to stress, while simultaneously providing ecosystem services such as coastal protection (Cheong et al., 2013). Therefore, the focus shifted from reducing threats to a certain target to both reducing threats and maximising positive interactions between the target and the ecological surroundings. Due to these positive interactions, NbA often applies to multiple management goals at the same time (Hale et al., 2009). These strategies reduce disasters and provide protection, while simultaneously contributing to, for example, maintaining water quality, carbon sequestration, biodiversity conservation, ecosystem resilience, livelihood sustenance and food security, and the creation of recreational space (CBD, 2009; Colls et al., 2009; Borsje et al., 2011; Temmerman et al., 2013).

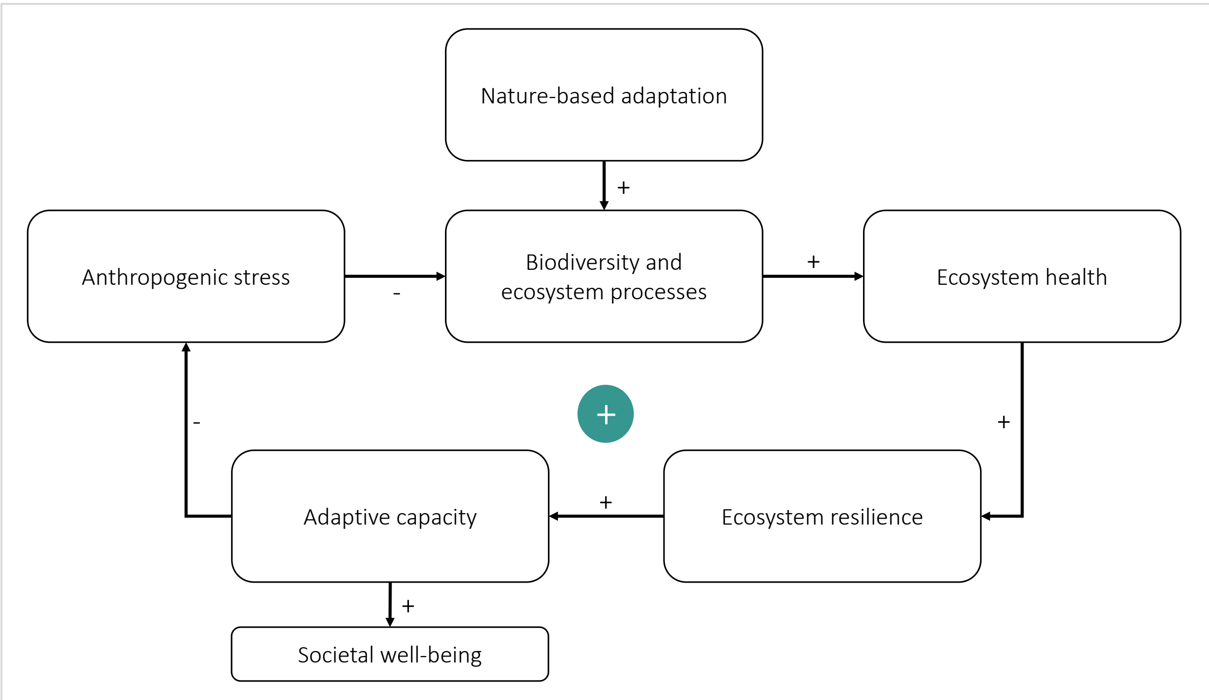

Figure 3. Conceptual framework showing the positive feedback loop underlying NbA. Anthropogenic stress negatively impacts biodiversity and ecosystem processes, which reduces ecosystem health and resilience, and subsequently their adaptive capacity. This further increases the negative impacts of anthropogenic stress. NbA, however, positively impacts both biodiversity and ecosystem processes. This increases ecosystem health and resilience, which ensures that ecosystems can function as a natural buffer against anthropogenic stress as their adaptive capacity is enhanced. This also improves societal well-being.

However, just like conventional adaptation measures may be limited to deal with threats, there are also some general limitations to the implementation of NbA. First, a knowledge gap exists regarding the effectiveness of created ecosystems, due to a lack of long-term studies (Temmerman et al., 2013). Second, public perception is important. Local communities may oppose the idea that their 'valuable' land is given up to create space for ecosystems (Colls et al., 2009; Temmerman et al., 2013). Lastly, it should be underlined that the successful implementation of NbA is context-dependent (Temmerman et al., 2013). For example, some regions may lack the financial resources to update their coastal protection. In other regions, future climate change may be too extreme. Nature-based protection against threats may only be effective under scenarios of climate change where temperature increase remains below 2-3 °C (Colls et al., 2009). Here, it will be further explored how environmental factors and current policies may enable or constrain the implementation of NbA.

2.2.2. Adaptive governance

The natural behaviour of ecosystems is characterised by unpredictability, complex dynamics, scale dependencies and sharp, discontinuous change (Holling, 1987; Bodin & Crona, 2009). This variability is often undesirable from an economic and social perspective because it increases uncertainty. Therefore, governance systems often treat natural systems as if they are linear and relatively unchanging (DeCaro, Arnol, Boama & Garmestani, 2017b). As a result, conventional adaptation strategies focussed on reducing or eliminating uncertainty, to control the dynamic nature of ecosystems and increase the predictability of their behaviour (Holling, 1987). However, measures aiming to keep natural dynamics constant often result in unanticipated consequences such as a loss of resilience and an increase in the vulnerability of an ecosystem (Holling, 1987). NbA does not aim to eliminate uncertainty, but incorporates it. NbA aims to build healthy, natural and dynamic ecosystems because it increases their resilience and adaptive capacity to anthropogenic stress (Figure 3) (Munang et al., 2013).

However, the governance of dynamic ecosystems is very complex. Mainstreaming NbA into actual policies remains challenging. Governance is one of the main challenges that nature-based disaster risk reduction and adaptation faces (Triyanti & Chu, 2018). It has been argued that top-down, centralised governance is not suitable to deal with ecosystem complexities, as it may lead to overly rigid and narrow policies (Bodin & Crona, 2009; DeCaro et al., 2017a). Instead, adaptive governance underlines the importance of actively managing resilience to address uncertainty and potential surprises (Folke, Hahn, Olsson & Norberg, 2005). This is especially important in the context of NbA, because these strategies aim to keep ecosystems in their most natural and dynamic state. After all, this increases the resilience of ecosystems and their capacity to provide effective protection against threats. Therefore, I contend that adaptive governance is a prerequisite for the successful implementation of NbA. Adaptive governance builds on theories of resilience and incorporates feedback from changing ecosystems before they transform into an undesirable state (Ostrom, 2007; Triyanti & Chu, 2018). Adaptive governance facilitates and embraces the cooperation of a broad set of environmental actors, organisations and institutions which enhances conditions for flexibility, creativity, innovation and responsiveness needed to quickly and effectively adapt governance systems to changes in ecosystems (Folke et al., 2005; Wamsler, 2015; DeCaro, Chaffin, Schlager, Garmestani & Ruhl, 2017a). In this way, adaptive governance stimulates social learning, experimentation and participation that is required to deal with the uncertain, complex and ever-changing nature of ecosystems on which NbA strategies are based (Decaro et al., 2017b).

3. Methodological framework

3.1 Research strategy

This thesis employs a mixed-method design by combining quantitative and qualitative analyses to answer the research questions. Quantitative analyses of data on sea-level rise, subsidence, sediment availability and land-use are needed to assess the environmental limits to NbA in the Rhine and Mekong deltas. In contrast, a qualitative approach is needed to analyse policy documents and assess the policy limits to NbA in the Rhine and Mekong deltas.

This thesis also adopts a comparative design. Comparative case studies typically cover two or more cases and thereby provide insights into why particular interventions work or fail to work in different contexts. This entails studying similarities, differences and patterns across different cases that share a common goal; in this case, adaptation to anthropogenic stress in deltas. NbA is not suitable for all areas and its feasibility heavily depends on the location. Comparing the Rhine and Mekong deltas provides an understanding of how the local context influences the success of nature-based solutions and how to tailor interventions to the context to achieve desirable results. Besides, NbA has already been somewhat adopted in the United States and Europe, but one a much larger scale in Asia (Temmerman et al., 2013). Therefore, the Rhine and Mekong deltas were chosen as two highly contrasting cases, which will be briefly introduced in chapter 4.

3.2. Data collection and methods

This section describes what information is required to answer the research questions, what methods were used to obtain the data, and how the data were subsequently analysed. Each sub-question required a different method of data selection and analysis.

3.2.1. Sub-question 1

To answer the first sub-question, information is needed on what delta-specific NbA strategies currently exist and how these are described in existing peer-reviewed publications. A systematic literature review was conducted to obtain this information, using the search engine Scopus. The search for NbA in deltas resulted only in seven articles. Therefore, the search was broadened to also include coastal adaptation options. The search string that was used required the articles to include either ecosystem-based or nature-based adaptation in either deltas or coasts in their title, abstract or key words[1]. This resulted in various articles discussing ecosystem-based or nature-based adaptation for deltas and along coasts in general, or examples of specific strategies. The publications discussing specific strategies were used to construct a list of delta-specific and coastal NbA strategies.

In addition to the NbA strategies identified through the systematic literature review, additional nature-based strategies were found in other scientific papers, indicating that these papers did not include the search terms in their title, abstract or key words, and in grey literature which includes for example reports published by the United Nations Environment Program (UNEP). To ensure completeness, these NbA strategies were also included in this thesis.

[1] Search string: TITLE-ABS-KEY (“ecosystem-based” OR “nature-based” AND “adaptation” AND “delta” OR “coast”)

3.2.2. Sub-question 2

The publications found through the systematic literature review also provided environmental requirements for the success of the NbA strategies. This information is essential to answer the second sub-question. The requirements for certain NbA strategies were linked to projections of environmental change in the Rhine and Mekong deltas. If these environmental variables did not align with the requirements for certain NbA strategies, the feasibility of that strategy was assumed to be limited. I assume in this thesis that sea-level rise, subsidence, sediment availability and land-use are especially important in the context of NbA in deltas. Current (2020) and future (up until 2100) values for the environmental variables were included in this thesis. This is essential information to be able to conclude on the future environmental feasibility of NbA in the Rhine and Mekong deltas. The data were arranged and analysed in Microsoft Excel, version 16.16.20, by making graphs that visualise trends over time.

3.2.2.1. Sea-level rise

Sea-level rise data were obtained from the IPCC's Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC, 2019). The data for the Rhine and Mekong deltas is based on the RCP4.5 climate scenario. This scenario was chosen because it represents a 'middle-of-the-road' scenario. Median estimates for average regional sea-level rise in a 1 arc degree (equivalent to approximately 110km at the equator) buffer off the coast of the two deltas are used in this thesis, including the 5th and 95th percentiles of the SROCC model ensemble, meaning that 90% of the model simulations fall within this range. Sea level values for 2020, 2050 and 2100 were used.

3.2.2.2. Subsidence

Land subsidence is defined as "a gradual settling or sudden sinking of the Earth's surface owing to subsurface movement of earth materials" (Galloway, Jones & Ingebritsen, 1999, p. 1). Some of the principles causes of subsidence are groundwater abstraction causing aquifer system compaction, drainage of organic soils, underground mining and natural compaction due to tectonics (Galloway, Jones & Ingebritsen, 1999). Subsidence is often a local issue and can therefore significantly vary for different parts of a delta, especially for large deltas such as the Mekong delta. Some areas in a delta can be almost stable while other areas experience rapid subsidence. Therefore, average subsidence rates are not representative of the whole delta. Instead, maximum, median and minimum subsidence rates were used here. The median represents the value at which half of the delta area is subsiding faster and half is subsiding slower; it is the middle value. Maximum and minimum rates were also used to show that some parts of the delta may subside significantly faster while other parts may even experience an uplift.

Subsidence data for the Rhine delta were obtained from the Dutch Centre for Geodesy and Geo-informatics (NCG, 2018). The values for 2020 are the maximum, median and minimum annual subsidence rates in meters per year. From here, expected elevation change for future years was calculated by multiplying by the number of years. For example, the value for 2050 was obtained by multiplying the median, maximum and minimum values for 2020 by 30 years. This assumes annual subsidence rates are constant over time.

Subsidence data for the Mekong delta were obtained from Minderhoud, Middelkoop, Erkens & Stouthamer (2020). The authors provide projections of extraction-induced subsidence and subsequent elevation loss in the Mekong delta following six mitigation and non-mitigation extraction scenarios using a 3D hydrogeological model. The choice was made to use the non-mitigation B1 scenario, which assumes a moderate increase in groundwater abstraction and represents a continuation of the past trend (Minderhoud et al., 2020). The results are based on their best estimate model, where the overconsolidation rate (OCR) equals 1.63 (see Minderhoud et al., 2020). Projections were provided for 2020 to 2100 at 10-year intervals.

3.2.2.3. Sediment availability

Sediment availability data were obtained from Dunn et al. (2019). Both the Rhine and Mekong sediment fluxes were calculated by Dunn and others using the BQART model (Syvitski & Milliman, 2007). The Rhine and Mekong data are based on different future climate scenarios. Therefore, the scenarios that are most similar to and accord with a 'middle-of-the-road' scenario were chosen.

Data for the Rhine delta are based on climate and water data from the Royal Netherlands Meteorological Institute (KNMI) and Deltares. Here, the choice was made to use the G_h scenario. This is a moderate projection of future climate change, assuming a worldwide temperature increase of approximately 1^{o}C in 2050 and 1.5^{o}C in 2100 (KNMI, 2015). The G_h scenario also includes the influence of (future) dams on sediment availability. For the Rhine delta, sediment availability data were available for 1990, 2000, 2050 and 2080. It is assumed that from 2080 until 2100, sediment availability will remain relatively stable as most upstream dams in the Rhine catchment have already been built.

Data for the Mekong delta are based on climate and water data from the WBMsed model (see Dunn et al., 2019). The choice was made to use the RCP4.5 scenario, again because this is assumed to be the 'middle-of-the-road' scenario and is roughly comparable to the G_h scenario in terms of projected future climate change. This scenario also includes the effect of future dams that are currently planned to be built in the Mekong river. 30-year averages were used for the years 1990, 2000, 2010, 2020, 2050, 2080 and 2100, as suggested by Frances Dunn (pers. comm.).

In addition, sediment availability data were used to calculate sediment availability as a percentage of the historical load. This indicates to what extent current sediment availability for the Rhine and Mekong deltas differs from the sediment availability before the rivers were modernised by the construction of dams and the building of dikes. For the Rhine delta, the 19th-century sediment load was higher than it is now, approximately 4.2 Mt/year (Erkens, 2009). This point of reference was chosen because in the 19th century, land-use in the Rhine delta was different and large dams in the Rhine river had not been built yet (Erkens, 2009). The Mekong river was largely undeveloped until approximately 1990. However, now the river is experiencing rapid dam constructions. For the Mekong delta, a historical, pre-dam load of 160 Mt/year was used (Walling, 2008; Kondolf, Rubin & Minear, 2014).

3.2.2.4. Land-use

Land-use data for both deltas were obtained from the IMAGE integrated assessment model used in Doelman et al. (2018). The land-use data used in this thesis are based on the SSP2 scenario, again because this is considered to be the 'middle-of-the-road' scenario roughly comparable with the RCP4.5 and G_h scenarios. Similarity between the scenarios used is important for consistency and to be able to compare and integrate the results. The fraction of different land-use types within the Rhine and Mekong deltas was provided by Scown et al. (in prep.), who used the 30-arc minute (approximately 60km x 60km at the equator) land-use grid from IMAGE. In the dataset, a distinction is made between urban land-use, cropland, pasture and other land-uses. Here, it is assumed that urban land-uses and cropland are fixed and cannot be easily removed or relocated. Contrastingly, pasture and other land-uses are relatively more flexible and could, if required, be relocated in for example times of flooding. Therefore, it is assumed here that urban land-use and cropland constrain NbA, and therefore these are included in the data analysis. For both deltas, data were available for 2020, 2050 and 2100. The data for 2020 is not observed but modelled.

3.2.3. Sub-question 3

To answer the third sub-question, information is needed about the current policies in the Rhine and Mekong deltas. This information was obtained by analysing the Rhine and Mekong delta plans (Deltaprogramma, 2020; Mekong delta plan, 2013). The delta plans will be briefly introduced below.

3.2.3.1. Rhine and Mekong delta plans

The Rhine delta plan is published every year. It is an initiative in which the national government, provinces, municipalities and regional water authorities collaborate with civil society organisations, research institutes, businesses and citizens (Deltaprogramma, 2020). The collaboration centres around three main themes which all have their plan within the Rhine delta plan: a delta plan for water safety, for freshwater, and for spatial adaptation. The measures proposed in these plans are (sometimes partly) financed through the Delta fund. Every year, the delta commissioner presents the new delta plan to Minister of Infrastructure and Water Management, who is ultimately responsible for the delta plan. The delta commissioner also promotes the implementation of the delta plan and monitors its progress (Deltaprogramma, 2020).

The Mekong delta plan was produced through an international collaboration between Vietnam and the Netherlands. The Mekong delta plan aims to respond to the consequences of climate change and ensure sustainable socio-economic development of the Mekong delta (Mekong delta plan, 2013). Different stakeholders were included in the developing process. In Vietnam, these partners included the Ministry of Natural Resources and Environment and the Ministry of Agriculture and Rural Development. In the Netherlands, the partners included the Dutch government, Royal HaskoningDHV, Wageningen University, Deltares, Rebel and Water.nl (Mekong delta plan, 2013). In contrast to the Rhine delta plan, the Mekong delta plan is not legally binding. It has no formal status in the Vietnamese administrative system. The Mekong delta plan proposes future measures and strategies the Vietnamese government should take to tackle challenges related to climate change and socio-economic development. It functions as a guideline to provide strategic advice to the Vietnamese government (Mekong delta plan, 2013). It is assumed here that the measures and strategies that are proposed in the Mekong delta plan are actually implemented, which is needed to analyse potential policy constraints to NbA in the Mekong delta and compare these constraints with the Rhine delta. This is a valid assumption because the purpose of analysing the delta plans is to explore the policy feasibility of NbA in both deltas and to assess to what extent NbA could be a suitable alternative to conventional adaptation strategies. The aim is not to identify hard policy limitations to NbA but to build a foundation for future research.

3.2.3.2. Framework for adaptive governance

I argue that adaptive governance is a prerequisite for the successful implementation of NbA. Many governance principles for designing and evaluating policies oversimplify the complexity, non-linearity and dynamism of natural systems such as deltas. Often, a one-size-fits-all solution is applied to address threats. However, such solutions are based on rigid and linear conceptualisations of the dynamics of natural systems and hinder adaptive management (Ruhl, 2010). This is critical because legal and institutional structures shape opportunities for incorporating nature-based strategies. To successfully govern future deltas, policies should incorporate the complexities and uncertainties that are inherently associated with natural systems behaviour. Therefore, the delta plans were analysed using the framework by DeCaro et al. (2017a), which conceptualises the extent to which laws and institutions create favourable conditions for self-organisation, flexibility and adaptation.

The DeCaro et al. (2017a) framework provides legal and institutional design principles for adaptive governance. Legal design principles concern "(a) elements of official legal systems that determine structure, authority, function, and guidelines for government agencies and private centres of activity and (b) rules and regulatory systems that deal with compliance" (DeCaro et al., 2017a, p.12). In contrast, "institutional design principles refer more broadly to features of rule-governed systems" (DeCaro et al., 2017a, p.12). Institutional design principles promote cooperation by enhancing transparency, credibility and enforceability. An example is river compacts, that clarify socio-political and geographic boundaries of a problem and therefore the jurisdiction of various stakeholders (DeCaro et al., 2017a).

As the framework includes both legal and institutional design principles, it is highly relevant to use in this thesis. That is because complex governance problems, such as the sustainable management of future deltas, involves not only formal governmental institutions but also informal stakeholders, such as businesses and civil society organisations, governance systems and processes (DeCaro et al., 2017a).

The five legal and four institutional design principles will be briefly introduced in the next sections. A summary and overview of all the principles can be found in Table 1. This table includes a description of the design principles and key concepts that reflect an operationalisation of each principle, which, in turn, will be used for analysing the Rhine and Mekong delta plans.

3.2.3.3. The legal design principles

The first legal design principle is reflexive law. Normally, laws establish ground rules for society, ensuring a sense of security and stability. However, they can be quite rigid, which hinders adaptive responses to changes in the environment or society (DeCaro et al., 2017a). For environmental laws to enable flexible decision-making, they should emphasise standards and general principles. In other words, laws should guide decision-making without specifying ultimate solutions, because exact solutions "could become outdated or too rigid when socio-ecological conditions change" (DeCaro et al., 2017a, p.12). Goals, standards and ground rules are fixed, while final solutions are left open. This can be done by including "minimum requirements (floors), maximum thresholds (ceilings), or general guidelines (principles)" into environmental laws (DeCaro et al., 2017a, p.12). Floors, ceilings and principles are therefore chosen as key concepts associated with reflexive law that will be used to analyse the delta plans.

The second legal design principle is legal sunsets. This principle pertains to the idea that "formal sunsets on existing legal provisions enhance adaptive capacity" (DeCaro et al., 2017, p.13). By allowing incremental revisions over specific periods and creating windows of opportunity, laws and policies can be reassessed, which allows for a change in direction if needed (DeCaro et al., 2017a). In this way, adaptive governance is safeguarded. The key concepts chosen for analysis of this design principle in the delta plans are incremental revisions after specific periods, planned or scheduled windows of opportunity, and a distinction between short-term and long-term measures. The latter allows for implementing short-term plans and leaving long-term options open so that these can be changed if socio-ecological conditions change.

The third legal design principle is legally binding authority, which means that environmental stakeholders need some recognised authority to make their own decisions and implement plans (DeCaro et al., 2017a). Governance systems dealing with complex and ever-changing natural systems often include multiple stakeholders, organisations and structures that form a partnership. Laws, therefore, need to recognise and legitimise the authority of various stakeholders and allow them to make their own decisions (DeCaro et al., 2017a). Laws or formal rules that legitimise decision-making latitude for environmental stakeholders are therefore the key concepts associated with legally binding authority that will be used to analyse the delta plans.

The fourth legal design principle is legally binding responsibility. This means that in addition to laws that legitimise decision-making latitude for stakeholders, laws also need to formally assign these stakeholders certain responsibilities. The legally binding devolution of responsibility at different governance scales is necessary for adaptive governance (DeCaro et al., 2017a). Vesting stakeholders with responsibilities enhances their motivation to help solve environmental dilemmas (DeCaro et al., 2017a). Therefore, laws or formal rules defining and assigning responsibility to stakeholders are the key concepts associated with legally binding responsibility used to assess the delta plans.

The last legal design principle is tangible support, which means that environmental stakeholders need technical and financial support to make decisions and implement solutions (DeCaro et al., 2017a). If administrative or technical support is insufficient, environmental stakeholders cannot successfully self-organise which may result in adaptive and cooperative failures (DeCaro et al., 2017a). Therefore, the key concepts for this legal design principle that will be used to analyse the delta plans are support in the form of funds, technology, information, guidance or training.

3.2.3.4. The institutional design principles

The first institutional design principle is well-defined boundaries. This means that the socio-political and ecosystem boundaries of a certain environmental dilemma are well-defined and recognised (DeCaro et al., 2017a). This is essential to clarify the legal and institutional jurisdiction of various national and international stakeholders. The key concepts associated with this principle used to analyse the delta plans are compacts or agreements specifying socio-political and ecosystem boundaries.

The second institutional design principle is participatory decision-making. It is essential for adaptive governance that affected stakeholders can influence the design and implementation of decisions (DeCaro et al., 2017a). To facilitate the inclusion of a variety of stakeholders, participation methods and processes are required through which these affected stakeholders can influence the decisions being made by higher authorities. Therefore, processes and methods enabling and stimulating stakeholder participation are the key concepts associated with participatory decision-making that are assessed in the delta plans.

The third institutional design principle is internal enforcement, which refers to all the internal mechanisms that various organisations and collectives may have to monitor and enforce the compliance of environmental stakeholders (DeCaro et al., 2017a). Monitoring can be done by internally elected auditors or boards consisting of representatives. Effective enforcement can be achieved through, for example, grants stimulating desired behaviour and fines discouraging undesired behaviour (DeCaro et al., 2017a). Therefore, the key concepts associated with internal enforcement include mechanisms for stakeholder compliance, such as periodic check-ups or mandatory progress reporting, and enforcement mechanisms such as financial incentives.

The final institutional design principle is internal conflict resolution. Internal conflict resolution refers to all the internal mechanisms that various organisations and collectives may have to ensure neutral and transparent conflict resolution (DeCaro et al., 2017a). Communication and quasi-formal courts are given as examples of mechanisms to resolve disputes before going to an external venue (DeCaro et al., 2017a). These are therefore also chosen as key concepts for internal conflict resolution and will be used to analyse the delta plans.

3.2.3.5. Method of analysing the delta plans

After identifying the key concepts used to assess the delta plans for each of the design principles of the DeCaro et al. (2017a) framework, the next step in analysing the delta plans was to assign each principle its own colour. Afterwards, the Rhine and Mekong delta plans were thoroughly read and pieces of text that either specifically mentioned the key concepts associated with a design principle (Table 1, third column) or that in some other way seemed to indicate a design principle were highlighted with the colour associated with that design principle (i.e. coding the documents). Quotations from the delta plans were used to provide specific illustrations of each principle and to support the results. However, as the Rhine delta plan is written in Dutch, these quotations needed to be translated into English. Appendix 9.1. includes an overview of the quotations in Dutch and the English translations. Technically, the English translations are not quotations, because the Dutch sentences could not be translated verbatim without ending up with incorrect sentences. However, quotation marks were used nevertheless in the results section on the Rhine delta plan to distinguish between my text and the sentences that came from the delta plan. The Mekong delta plan is written in English so no translations were required.

If the Rhine and Mekong delta plans did not include a design principle, it was assumed that these principles are absent, which can constrain the feasibility of NbA in that delta. The principles that were found to be present were then further judged based on their clarity and frequency. Clarity refers to whether a principle is mentioned explicitly or implicitly. If a piece of text specifically mentioned key concepts associated with a design principle, that principle was found to be explicitly present. If a piece of text did not specifically mention key concepts but in some other, less obvious way referred to a design principle, that principle was found to be implicitly present. All the highlighted pieces of text were counted which gave an indication of the frequency of each design principle. Some principles were mentioned a few times (< five times) throughout the delta plans, while others were mentioned often (> five times). Thus, the design principles could be absent from the delta plans, they could be implicitly and infrequently present, implicitly and frequently present, explicitly and infrequently present, and explicitly and frequently present. This indicates the relative importance given in the delta plans to a certain design principle.

Table 1. The legal and institutional design principles for adaptive governance by DeCaro et al. (2017a). The second column provides a short description of what the principles entail and the third column shows an operationalisation of the principles in the form of key concepts used to assess the delta plans.

Legal design principles	*Description*	*Key concepts used to assess delta plans*
1. Reflexive law	Laws should not rely on static rules when flexibility is needed; legal systems need to emphasise standards and general principles instead of specific rules about final solutions so that decision-makers have legal guidance but also flexibility when they need to make decisions	Minimum requirements (floors), maximum thresholds (ceilings), general guidelines (principles)
2. Legal sunsets	Laws include planned periods of evaluation in which environmental policies and agreements can be re-examined, renegotiated and modified if needed; this allows for safeguarding security and stability without jeopardising flexibility	Incremental revisions after specific time-periods, planned windows of opportunity, distinction between short- and long-term measures
3. Legally binding authority	The authority of environmental stakeholders to make decisions, implement solutions and carry out plans is institutionalised in binding legislation, to ensure decision-making latitude for stakeholders	Laws or formal rules legitimising decision-making latitude for stakeholders
4. Legally binding responsibility	The devolution of responsibility to resolve or contribute to a resolution or dilemma needs to be formally defined and assigned, to motivate stakeholders to help resolve environmental dilemmas	Laws or formal rules defining and assigning responsibility
5. Tangible support	Devolution of responsibility may be overwhelming without genuine decision-making authority or proper technical and financial support; therefore, support from the central government is required	Support in the form of funds, technology, information, guidance or training

Institutional design principles	*Description*	*Key concepts used to assess delta plans*
1. Well-defined boundaries	Socio-political and ecosystem boundaries of environmental dilemmas are well-defined, which aids in clarifying the legal and institutional jurisdiction of stakeholders	Compacts or agreements about socio-political and ecosystem boundaries
2. Participatory decision-making	Affected stakeholders can influence the design and implementation of strategies through participatory decision-making, which allows for the inclusion of a variety of environmental stakeholders	Processes or methods enabling and stimulating stakeholder participation
3. Internal enforcement	Organisations and collectives have internal mechanisms to monitor and enforce compliance, in addition to external monitoring, enforcement and graduated sanctioning to safeguard rules	Monitoring mechanisms such as periodic check-ups or mandatory progress reporting, and enforcement mechanisms such as financial incentives
4. Internal conflict resolution	Internal mechanisms for neutral and transparent conflict resolution	Communication, internal ‘quasi-formal’ courts to resolve disputes

4. Case descriptions

4.1. Rhine-Meuse-Scheldt delta, the Netherlands

4.1.1. Geomorphology

The Rhine-Meuse-Scheldt delta is formed by the coalescence of three rivers: The Rhine, the Meuse and the Scheldt. The Rhine river is the largest of the three. It is 1233 km in length and also the third largest river in Europe (Renaud et al., 2013). The Rhine originates in Switzerland and flows through Germany before entering the Netherlands. Together with the Meuse river, which is 950 km in length, and the Scheldt river, which is 350 km in length, both originating in Northern France, the Rhine formed a delta that covers approximately two-thirds of the Netherlands (Figure 4) (Renaud et al., 2013). The delta area is located in the south-eastern corner of the North Sea Basin. The low-lying delta plain is 25,347 km^2, which makes it the largest delta in Europe. It is part of a coastal plain that extends from Denmark in the North to the Strait of Dover in the south (Berendsen, 1998).

The hydrological regime of the Rhine river is determined by the spatio-temporal distribution of rainfall, snow storage and snowmelt in the Alps and the German and French middle mountain ranges further down the river (Asselman et al., 2000). Maximum runoff of the river occurs during summer, as the snow cover melts (Pfister, Kwadijk, Musy, Bronstert en Hoffmann, 2004). The estimated mean water discharge of the Rhine is 2200 m^3/s and the estimated suspended sediment load is 3.2 Mt/year. The Waal branch of the Rhine river is the main distributary on the delta plain, carrying approximately two-thirds of the Rhine discharge and suspended sediment load (Middelkoop, Erkens & van der Perk, 2010). The Rhine delta plain can be divided into an upper and a lower part. The upstream part is characterised by wide, meandering channels. Towards the western part of the Netherlands, the downstream channels are narrower and larger in number (Middelkoop, Erkens & van der Perk, 2010). Vast regions of the delta plain are below sea level (Kabat et al., 2009).

The Rhine delta is mostly composed of silt and originated from the deposition of marine and fluvial sediments. However, now it is mainly shaped by human intervention (Pfister et al., 2004; Renaud et al., 2013). In the Rhine delta, almost all the natural intertidal areas are now characterised by the embankment of polders and reclaimed land (Hoitink, Wang, Vermeulen, Huismands & Kästner, 2017). The delta is highly engineered through canalisation, the creation of drainage systems, the embankment of rivers and coastal protection (Renaud et al., 2013).

4.1.2. Climate

The Rhine encounters relatively little variability in climate, although different parts of the river do experience differences in annual precipitation. The upstream parts of the river receive up to 2000 mm of precipitation per year. This occurs as snow on average above 3050 meters above mean sea level (Pfister et al., 2004). Further downstream, the German part of the Rhine basin is characterised by a temperate oceanic climate that gradually changes into a continental climate from northwest to southeast. Here, annual rainfall ranges from 570 to 1100 mm (Pfister et al., 2004). In the Netherlands, precipitation is evenly distributed throughout the year and reaches an average of 800 mm (Pfister et al., 2004). The average temperature in January is 3 ^oC and in August 17.5 ^oC (KNMI, 2011).

As the meteorological and physiographical conditions are relatively heterogeneous throughout the Rhine basin, different rainfall patterns may result in different flood hydrographs. Therefore, flooding on the Rhine floodplain is often regional (Pfister et al., 2004).

4.1.3. Challenges

The Netherlands is a densely populated country, with approximately 511 people per km^2 (World Bank, 2018). Most of the population is concentrated in the coastal lowlands of the Rhine delta (Kabat et al., 2009). Although large areas of the coastal delta plain are below sea level, 9 million people live in this area. The area is also of great economic importance. Approximately 65% of the Dutch gross national product, which equals to about €400 billion, is generated in Rhine delta (Kabat et al., 2009). The area is home to the Rotterdam harbour, which is the largest harbour in Europe, and Schiphol airport. Both are of critical importance for the Dutch economy and serve as important international transport routes for both people and goods (Kabat et al., 2009).

It comes as no surprise that the Dutch people are committed to protecting themselves against flooding. Therefore, the delta is heavily engineered and shaped by human interventions (Renaud et al., 2013). Most of the damming of the Rhine delta was initiated by destructive floods that occurred in 1953 and inundated the southwest coast with metres of water (Kabat et al., 2009; Renaud et al., 2013). This led to the first delta plan, committed to improving flood protection systems in the Netherlands. It included interventions such as canalisation, drainage systems, polders, embankments and coastal protection structures, which increased safety levels (Renaud et al., 2013). However, they also shortened the coastline and former estuarine inlets were transformed into static freshwater lakes such as Lake Grevelingen (Van Wesenbeeck et al., 2014). Although this increased the freshwater availability in the region and stimulated local agricultural communities, the water quality and morphodynamics of the lakes rapidly deteriorated (Renaud et al., 2013). As a result, species richness decreased, habitats disappeared and the overall ecosystems simplified. In the process, many ecosystem services were lost (Nienhuis, 1978). This illustrates how hard adaptation may negatively impact surrounding ecosystems.

In addition, although coastal and riverine embankments reduce the occurrences of floods, it also reduces the deposition of new sediments on the deltaic plain. Together with drainage and land reclamation, this resulted in subsidence of the Rhine delta. Most of the delta's land surface is below sea level and the land is likely to sink further in the future (Van Wesenbeeck et al., 2014). Combined with sea-level rise, this increases the vulnerability to flooding, storm surges, and the risk of permanent inundation, which in turn threatens the lives and livelihoods of the delta's inhabitants. Thus, although the Rhine delta is heavily protected by dikes and dunes, there is no guarantee that these embankments will be sufficient in the face of future relative sea-level rise (Kabat et al., 2009). Furthermore, the embankment of wetland areas triggers additional sea-level rise, as the storage area for flood water is lost. This causes water levels to rise faster in the remaining channels of the Rhine delta. Since 1930, effective sea-level rise in the Rhine delta is up to 15 mm per year, which is approximately five times the coastal rate (Temmerman & Kirwan, 2015).

4.2. Mekong delta, Vietnam

4.2.1. Geomorphology

The Mekong delta area has a roughly triangular shape and is located in Southern Vietnam (Ta, Nguyen, Tateishi, Kobayashi & Saito, 2005). The low-lying delta plain is approximately 62,520 km^2, of which 52,100 km^2 is located in Vietnam (Nguyen, Ta & Tateishi, 2000; Ta et al., 2002). In terms of basin size and water and sediment discharge, the Mekong delta is the largest delta in Southeast Asia and the third-largest delta in the world (Milliman & Syvitski, 1992; Renaud et al., 2013; Brunier, Anthony, Goichot, Provansal & Dussouillez, 2014). The Mekong river originates in the mountainous area of Tibet at an altitude of almost 5000 meters (Walling, 2008). The river is approximately 4350 km long and runs through various countries, including Myanmar, Laos, Thailand and Cambodia, before entering Vietnam (Nguyen, Ta & Tateishi, 2000; Ta et al., 2002).

The hydrological regime of the Mekong river is determined by seasonal snowmelt runoff in the mountainous area where the river originates and the seasonal monsoon over the rest of the basin (Walling, 2008). The estimated mean water discharge of the Mekong is 14,500 m^3/s. Historically, the estimated suspended sediment load was approximately 160 Mt/year (Brunier et al., 2014; Walling, 2008). The river has two main channels that run through the delta plain, called the Mekong channel and the Bassac channel. The Mekong channel is further divided into four smaller channels called distributaries (Ta et al., 2002). The delta plain is divided into an upper and a lower part. The upper plain is dominated by fluvial processes and is occupied by swamps and flood plains. This area lies approximately 0.5 to 1.5 meters above mean sea level (Ta et al., 2005; Nguyen, Ta & Tateishi, 2000). The lower delta plain is influenced by marine processes and has a well-developed beach-ridge system. These ridges are 3 to 10 meters above mean sea-level and trend from northeast to southwest (Ta et al., 2005; Nguyen, Ta & Tateishi, 2000). At present, the delta is mainly composed of mangrove forests, beach ridges and tidal flats (Ta et al., 2005).

The Mekong delta was originally characterised as a tide-dominated delta. The sediments carried by the river, consisting mainly of silt, clay and sand, are deposited in the receiving basin of two different tidal regimes, that of the South Chinese Sea and the Gulf of Thailand (Nguyen, Ta & Tateishi, 2000). The South Chinese Sea is characterised by semi-diurnal tides with an amplitude of 2.5-3.8 meters. The Gulf of Thailand is characterised by diurnal tides with an amplitude of 0.5-1.0 meters. These different tidal regimes control the processes of sediment deposition in the coastal area of South Vietnam (Nguyen, Ta & Tateishi, 2000). Over time, the morphology of the Mekong delta changed and suggests a shift towards a more wave-influenced environment. The delta evolved from a tide-dominated to an intermediate tide- and wave-dominated delta during the late Holocene (Ta et al., 2002).

4.2.2. Climate

Compared to the Rhine river, the Mekong river encounters considerable variability in climate as it flows through various countries, ranging from cool, temperate conditions in the headwaters, where the high mountains are permanently covered with snow, to the tropical conditions of the southern part of the basin (Walling, 2008). The delta's climate is characterised as humid tropical. Mean annual rainfall is 1700 mm and temperatures are stable during the year, with an average of 27-30 °C (Nguyen, Ta & Tateishi, 2000). Furthermore, the delta's climate is dominated by a monsoon. The rainy season is 6 months and stretches from May/June to October/November, during which approximately 75% of the discharge occurs (Brunier et al., 2014). The remainder is considered to be the dry season (Nguyen, Ta & Tateishi, 2000; Ta et al., 2002), during which less sediments are transported by the Mekong river and deposited on the deltaic plain. During the rainy season, larger volumes are transported toward the South Chinese Sea. This has resulted in a sediment surplus which formed the south-eastern coastal plain (Nguyen, Ta & Tateishi, 2000)

4.2.3. Challenges

The Mekong delta is currently home to approximately 20 million people (Schmitt, Rubin & Kondolf, 2017). The area is densely populated with up to 500 persons per km^2 (Walling, 2008; Tran, 2016) due to its fertile soils (Minderhoud et al., 2017). The Mekong delta provides 50% of Vietnam's food production and 90% of its rice production, making this country the world's second-largest rice exporter. More than 200 million people rely on the delta for food and the region is considered as Southeast Asia's most important food basket (Brunier et al., 2014; Minderhoud et al., 2017, Nguyen, Ta & Tateishi, 2000; Anthony et al., 2015).

However, human activities are threatening the Mekong delta. The construction of dams in upstream countries has destabilised the geomorphology of the delta by reducing the sediment supply to the delta plain and river mouth (Renaud et al., 2013; Brunier et al., 2014). As a result, the delta shoreline has significantly eroded over the last decades (Anthony et al., 2013). Furthermore, riverbed sand-mining is practised on a large scale, which resulted in the deepening of the Mekong and Bassac channel beds. This loss of bed material in the channels may aggravate problems such as salt-water intrusion and erosion (Brunier et al., 2014). It may also destabilise channel banks (Hung, Tanaka, Tu & Viet, 2006), which threatens settlements, infrastructure and farms (Brunier et al., 2014). As a solution, dikes and embankments were constructed. However, these have their own negative impacts, such as increased flow velocities causing flood hazards and erosion (Renaud et al., 2013). The Mekong delta is also vulnerable to interventions such as channel construction and agricultural intensification, which may cause changes in hydrology, sediment processes and nutrient transport (Renaud et al., 2013).

Besides, the Mekong delta is sinking rapidly. Subsidence rates in the delta exceed global eustatic sea-level rise (Erban, Gorelick & Zebker, 2014), which strongly increases the delta's vulnerability to flooding and storm surges, saltwater intrusion, salinization of groundwater, coastal erosion and permanent inundation (Minderhoud et al., 2017; Minderhoud et al., 2020). This would significantly threaten the lives and livelihoods of the 18 million inhabitants of the Mekong delta and also the area's agricultural productivity (Minderhoud et al., 2020). It has been proposed that groundwater exploitation is the main cause of subsidence in the delta. Economic growth stimulated cultivation, urbanisation and industrialisation, but also resulted in increasing water demands. As surface waters are often polluted, groundwater abstraction is the main source to meet water demands (Wagner, Tran & Renaud, 2012). If groundwater abstraction continues to increase as it did over the last decades, the Mekong delta is likely going to be inundated by the end of this century (Minderhoud et al., 2020).

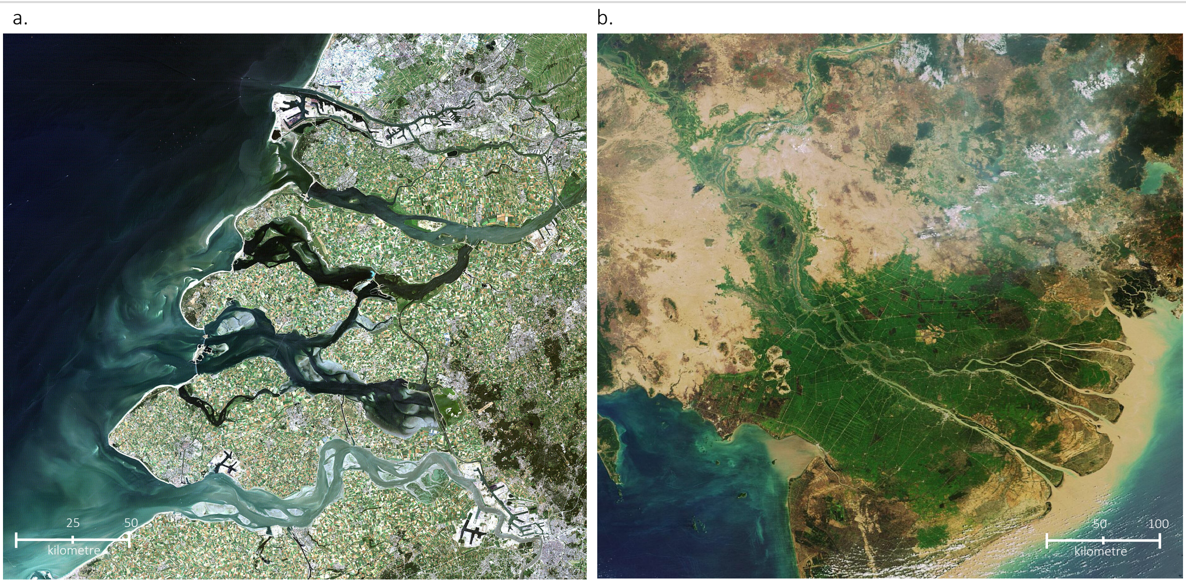

Figure 4. Satellite images of the Rhine delta (a) and the Mekong delta (b). Source: http://www.esa.int. Scale bars were added.

5. Results

5.1. The current suite of NbA in deltas

A total of 40 peer-reviewed articles were found in the systematic literature review that included either ecosystem-based or nature-based adaptation in deltas or coasts in their title, abstract or key words. The oldest article was published in 2006 and the newest in 2019. The number of peer-reviewed articles published on the subject has increased steadily over this period (Figure 5). However, only 14 of the 40 articles found described specific NbA options for either deltas or coasts. In addition, the overwhelming majority of these 14 articles focus on coastal wetland restoration, whereas the other strategies are underrepresented and often only discussed in a small section in one of the publications. The remaining 26 articles discussed more generally the need for NbA in coastal and delta areas but did not provide specific strategies or approaches. Only the 14 articles describing specific NbA options for deltas or coasts were used further in this thesis (Figure 5, teal bars).

Seven broad types of NbA in deltas or coasts were identified from the systematic literature review, and two additional strategies were found in papers and grey literature that were not returned in the literature search results. These nine NbA strategies are summarised in Table 2, with the jagged line distinguishing the two additional approaches from the seven returned in the literature search. Sections 5.1.1. through 5.1.9. present the strategies for NbA in deltas or coasts in more detail.

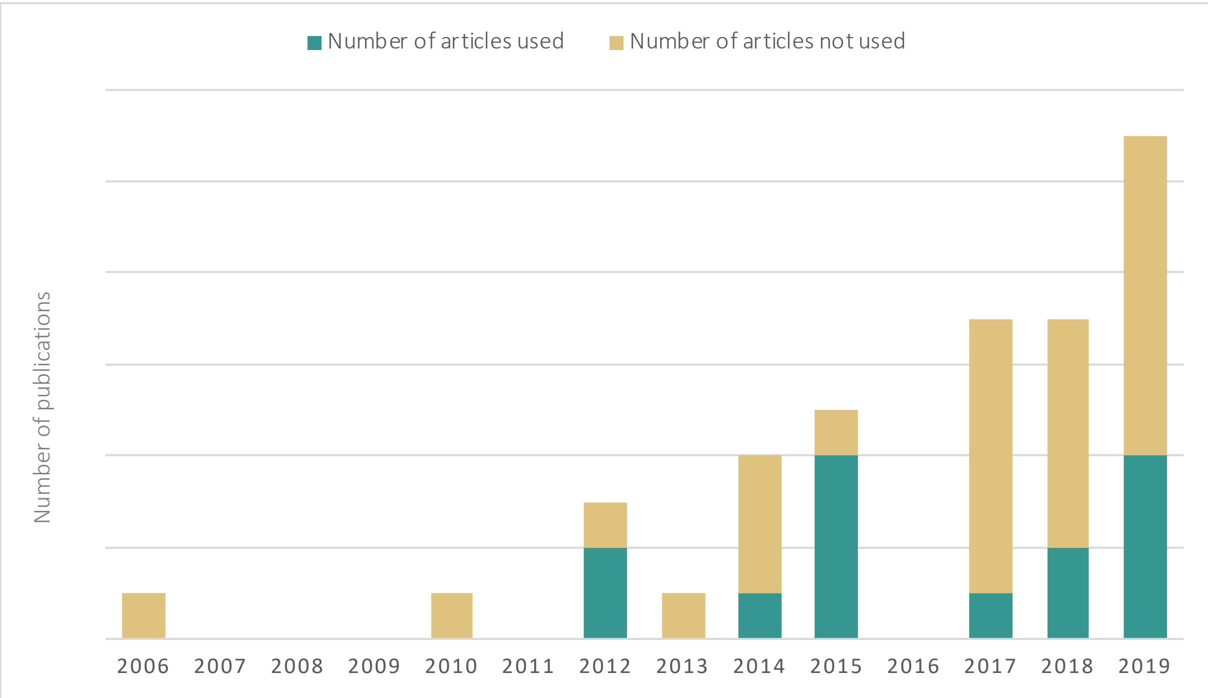

Figure 5. Number of peer-reviewed articles published per year on NbA in deltas and coasts found through the systematic literature review (n = 40). The chart distinguishes between the number of articles that were used in this study to develop a list of delta-specific NbA strategies (n = 14), indicated with teal, and the articles that were not used (n = 26), indicated with light brown.

Table 2. Overview of NbA strategies for deltas. The table includes a brief description of each of the strategies and provides references to the articles that were found through the systematic literature search. The table distinguishes between the strategies found through the systematic search and the approaches found in other scientific papers or grey literature which were added to ensure the completeness. The distinction is indicated by the jagged line.

Nature-based adaptation approach	*Description*	*References*
1. Coastal wetland restoration	Coastal wetlands are areas between marine and terrestrial environments that provide natural flood protection due to wave attenuation and sediment accretion that results in surface elevation. Through these processes, coastal wetlands adapt to changing environmental conditions (e.g. saltmarshes and mangroves)	Pramova et al. (2012); Schmitt & Albers (2014); Sierra-Correa & Kintz (2015); Baker et al. (2015); Goeldner-Gianella et al. (2015); Gracia et al. (2018)
2. Riverine wetland restoration	Riverine wetlands are located next to rivers and streams and function as a natural buffer against flooding by attenuating peak flows, maintaining channel base flows and retaining water. Sediment deposition on riverine wetlands can result in land elevation	Lewis & Ernstson (2019)
3. Reforestation of riparian zones	Forests provide natural protection against flooding because they regulate base flows during dry periods and peak flows during heavy rainfall events. Their roots also stabilise the soil and thereby prevent erosion	Pramova et al. (2012); Baker et al. (2015)
4. Restoration of dynamic dune systems	Dunes naturally protect the hinterland from flooding. Natural, dynamic dune systems are more resilient than fixed ones, because they are covered with vegetation that traps sediment and fixes it in place, and the system is allowed to migrate landward to persist in response to coastal erosion	Gracia et al. (2018); Castelle et al. (2019)
5. (Re)construction of biogenic reefs	Biogenic reefs are hard structures created by the activity of different bivalve species (e.g., oyster and mussel reefs). They reduce the impact of incoming waves and storm surges, and subsequently coastal erosion, due to their rough surface. They also facilitate sediment deposition, shoreline stabilisation and are adaptive to environmental change	Gracia et al. (2018); Morris et al. (2019)
6. Restoring seagrass beds	Seagrasses reduce wave speed and dissipate wave energy. Furthermore, they stabilise and maintain sediments and reduce re-suspension in shallow regions, countering coastal erosion	Gracia et al. (2018)
7. Ecological enhancement of dikes	Ecological enhancement of dikes involves a widening of the dike and the inclusion of vegetation. Vegetation on dikes, such as grasses and woody vegetation, reduces erosion, binds the soil together and improves dike stability	Scheres & Schüttrumpf (2019)

8. Restoring natural sedimentation processes	Deltas need a continued supply of sediments to prevent them from subsiding and being permanently inundated. By temporarily breaching embankments and allowing water to enter low-lying delta plains, sediments are reintroduced which mimics natural land-building processes. As a result, the delta plain is more likely to be able to keep up with sea-level rise (e.g. tidal river management, river diversions)	Amir et al. (2013); Day et al. (2016)
9. Beach nourishment	In the face of future relative sea-level rise and subsequent coastal erosion, beach nourishment aims to maintain the current beach profile. It involves dredging sand from offshore locations or quarries onto the beach or shoreface. The coastline is then artificially built up by natural sediments that are distributed by tides, waves and the wind	UNEP (2016)

5.1.1. Coastal wetland restoration

Coastal wetlands are defined as areas located between marine and terrestrial environments that are seasonally or continually inundated by seawater (Murray, Phinn, Clemens, Roelfsema & Fuller, 2012; Baker et al., 2015). Wetlands naturally protect the land against flooding through two functions. First, they are characterised by cohesive materials and are less dynamic compared to non-cohesive, sandy equivalents. Second, wetlands are often densely vegetated which attenuates waves when inundated (Möller, 2019). Vegetation also increases sediment deposition which in turn results in surface elevation. Wetland vegetation only establishes at elevations where plant species can withstand periodic inundation, which is why wetlands are often naturally elevated above mean sea level (Möller, 2019). Through these processes, wetlands can adapt to hydrodynamic and ecological conditions, allowing them to persist during times of change where engineered structures cannot (Möller, 2019). Furthermore, wetlands provide additional ecosystem services such as carbon storage and sequestration, sediment and nutrient filtering, they function as habitats for different species and provide a recreational area (Baker et al., 2015; Möller, 2019). Two types of coastal wetlands will be discussed here: saltmarshes and mangroves.

5.1.1.1. Saltmarshes

Saltmarshes occupy much of the low-lying coastal areas that are vulnerable to sea-level rise, which makes them especially suitable as an adaptation strategy (Shepard, Crain & Beck, 2011). Saltmarshes are intertidal areas covered with herbaceous vegetation or low woody vascular plants and are regularly inundated by seawater during high tides (Adam, 2002; Hughes & Paramor, 2004). Once stabilised and vegetated, saltmarshes reduce flood risk from sea-level rise by increasing water storage capacity during floods and by reducing wave height and energy (Colls, Ash & Ikkala, 2009; Shepard, Crain & Beck, 2011). A northwest European vegetated salt marsh of only 40 meters in width can reduce non-breaking waves by 14-15% in height, even during storm surges (Möller, 2019). Wave attenuation takes place in the first 80 meters of saltmarshes. After those 80 meters, wave attenuation is negligible (Möller & Spencer, 2002). Furthermore, saltmarsh vegetation stabilises shorelines by promoting sediment deposition and reducing erosion (Shepard, Crain & Beck, 2011). Therefore, saltmarshes may be able to maintain the coastline relative to sea-level rise through sediment accretion (Cahoon et al., 2006; Kirwan & Temmerman, 2009).

However, saltmarshes are vulnerable to sea-level rise (Adam, 2002; Van Loon-Steensma & Vellinga, 2013). If sea levels rise rapidly due to anthropogenic activities, vertical accretion of marshes may fail to keep up with the water, resulting in land submergence. If this inundation is great enough, vegetation may be stressed or killed (Kirwan & Temmerman, 2009). Similarly, saltmarshes can be lost if the wetland surface subsides below the level that is adequate to support vegetation (Boesch, Levin, Nummedal & Bowles, 1983). In addition, sediment availability is important for saltmarshes' capacity to provide flood protection. Sediment deprivation resulting from dam construction and groundwater abstraction is constraining saltmarsh development worldwide (Adam, 2002). Although saltmarshes can be restored through depolderisation, which entails reconnecting polders to the sea by partly breaching or completely dismantling dikes (Goeldner-Gianella, Bertrand, Oiry & Grancher, 2015), people may oppose such measures. Saltmarsh restoration requires a lot of space, which may result in the need for people to give up their land (Goeldner-Gianella et al., 2015).

5.1.1.2. Mangroves

The low-latitude equivalent of saltmarshes are mangroves, the largest percentage of which are found in tropical areas between 10° N and 10° S latitude (Sierra-Correa & Kintz, 2015). Mangroves are intertidal forest ecosystems consisting of bushes and trees. They are located on muddy soils in sheltered saline to brackish environments (Quartel, Kroon, Augustinus, van Santen & Tri, 2007). Mangrove trees have special root systems suitable for both water and air supply, allowing them to survive in environments with oxygen-poor soils (Augustinus, 2004). Mangroves play an important role in wave attenuation and stabilising coastal lands. Therefore, these forests can protect coastal communities from sea-level rise, tropical storms, tsunamis and erosion (Quartel et al., 2007; Duke et al., 2007; Pramova, Locatelli, Djoudi & Somorin, 2012). Compared to a flat, sandy surface, mangroves significantly reduce wave energy and height due to their dense network of trunks, branches and above-ground roots (Spalding, McIvor, Tonneijck, Tol & Eijk, 2014; Schmitt & Albers, 2014). Furthermore, mangroves add organic matter to the soil and capture riverine and coastal sediments, thereby elevating the land (Spalding et al., 2014). Therefore, mangroves are a viable nature-based strategy to protect the land against flooding and erosion (Nicholls, 2015).

However, mangroves are becoming smaller and more fragmented, resulting in a loss of ecosystem services (Duke et al., 2007). One of the causes is the construction of sea dikes around mangroves for infrastructure or agricultural lands (Phan, van Thiel de Vries & Stive, 2015). This is problematic because mangroves need a minimum width to promote sedimentation and to be efficient in wave attenuation (Phan, van Thiel de Vries & Stive, 2015). Sea-level rise is another cause of recent and future reductions in the area and health of mangroves (Gilman et al., 2008; Sierra-Correa & Kintz, 2015). Like saltmarshes, mangroves may be unable to keep pace with sea-level rise. Sea-level rise can cause mangroves to migrate landward to maintain their optimal location. However, this landward migration may not be possible due to infrastructural development or hillslopes (Harty, 2004). Subsidence of mangrove areas creates a similar landward migration-effect to that of sea-level rise. Especially if sediment availability to the area is reduced due to dam or seawall construction, mangroves may be permanently inundated with causes the forests to degrade (Gilman et al., 2008).

5.1.2. Riverine wetland restoration

Riverine wetlands lie adjacent to rivers and streams. There are different types of riverine wetlands and they vary from narrow riparian corridors along small streams to large river floodplains (Steven & Lowrance, 2011). Riverine wetlands receive their water and sediment from rivers and play an important role in flood defence because they attenuate peak flows, maintain channel base flows, and they retain water during floods (Steven & Lowrance, 2011; Lewis & Ernstson, 2019; Van Wesenbeeck et al., 2013). Furthermore, they provide additional ecosystem services, including nutrient retention and cycling, regulation of water quality of regional surface waters through a purification process, they increase biodiversity and provide natural areas and nurseries for different species (Steven & Lowrance, 2011; Van Wesenbeeck et al., 2013; Keesstra et al., 2018).

At present, many riverine wetlands are degrading. A variety of anthropogenic activities cause this degradation, including reduced sediment availability due to upstream dam construction and embankments along the river, which reduces the input of sediments into the floodplain, accelerated subsidence due to groundwater, gas or petroleum abstraction, and saltwater intrusion due to sea-level rise, which may alter wetland's hydrology (Day et al., 2016). Furthermore, reduced or eliminated input of river water and sediments into the wetlands through flood control defences such as embankments and the closure of distributaries also leads to the deterioration of riverine wetlands (Day et al., 2016).

To stop these degradation processes, the historical dynamics of a river need to be restored (Lewis & Ernstson, 2019). Restoration can also be achieved by transforming floodplains in the delta back to nature, instead of using them for building settlements, infrastructure or agriculture. This may increase the water discharge capacity of a river system, but also requires a lot of space which therefore involves land-use change (Fliervoet, van den Born, Smits & Knippenberg, 2013).

5.1.3. Reforestation of riparian zones

Forests provide natural protection against flooding and it has been shown that a river's peak flow increases significantly after logging has occurred (Leyer, Mosner & Lehmann, 2012). Forests increase water infiltration into the soil and delay the amount of time water needs to flow towards rivers, thereby regulating base flows during dry periods and peak flows during heavy rainfall events. These are essential ecosystem services for climate change adaptation (Pramova et al., 2012; Leyer, Mosner & Lehmann, 2012). Furthermore, forests' roots stabilise the soil and therefore prevent erosion, which further reduces the impact of erosion on infrastructure, settlements and water-use in deltas (Pramova et al., 2012). Forests provide ecosystem services in addition to flood protection, such as rainfall recycling, generating flows of atmospheric water vapour, carbon storage and sequestration, habitats for various species, recreational areas, and increased water infiltration and subsequently groundwater recharge, which may counter subsidence and water stress during droughts (Pramova et al., 2012; Leyer, Mosner & Lehmann, 2012; Baker et al., 2015).

However, forests in riparian zones have changed during the last decades. Many rivers have been artificially narrowed by the construction of dikes to convert forested floodplains into arable land (Leyer, Mosner & Lehmann, 2012). Efforts to restore forests in riparian zones should aim at restoring the natural mechanisms of a self-sustainable ecosystem. However, this may not be feasible in areas where economic interests prevail, such as navigation, agriculture, flood protection and power production, because reforestation of riparian zones requires more space compared to embankments (Mosner, Schneider, Lehmann & Leyer, 2011). Planting may be a short-term measure where success can be achieved relatively fast (Mosner, Schneider, Lehmann & Leyer, 2011).

5.1.4. Restoration of dynamic dune systems

Sandy coasts cover approximately 31% of the world's ice-free shoreline. Most of the sandy beaches are backed by coastal dunes (Castelle et al, 2019). Beaches and dunes form dynamic systems that may act as a natural buffer against flooding, thereby reducing erosion rates and mitigating the effects of sea-level rise and saltwater intrusion (Renaud, Sudmeier-Rieux, Estrella, & Nehren, 2016). Natural dune systems are more dynamic and thus resilient than fixed dunes. First, because natural dunes are covered by coastal vegetation that stabilises the physical environment by trapping wind-blown sediments and fixing it in place (Gracia et al., 2018). Second, because the beach-dune exchanges are maintained and the entire coastal system is given the space to migrate landward to persist in response to coastal erosion (Castelle et al., 2019). Besides, natural dunes are characterised by variations in topography, thereby providing differences in exposure to overwash, flooding, wind, sediment transport and salt spray. Such variability creates a variety of microhabitats and landscape diversity, which is why dynamic dune systems nest unique and fragile ecosystems (Renaud et al., 2016; Castelle et al., 2019).

Currently, coastal dunes are threatened by anthropogenic activities such as urban expansion, which reduces the space available for dune systems, recreational development for tourism, and relative sea-level rise which accelerates coastal erosion processes (Brown et al., 2013; Renaud et al., 2016). During the last decade, many coastal dunes were actively managed by minimising erosion and submersion hazards and by preventing sand encroachment into settlements and onto agricultural lands (Castelle et al., 2019). As a result, natural dune systems changed into uniform, static features. This reduced vegetation dynamics and natural community diversity, and subsequently the ecosystem services provided by dynamic dune systems (Castelle et al., 2019). Furthermore, managed, uniform dunes may progressively narrow and disappear, resulting in a significant increase in the exposure of the hinterland to submersion and overwash (Castelle et al., 2019). Therefore, maintaining dynamic dunes, through restoring vegetation cover of sand-binding species at the seaward face of the dune and by providing space for dunes to migrate landward, is an important nature-based solution against coastal hazards (Gracia et al., 2018; Castelle et al., 2019). However, providing sufficient space for dunes to migrate landward may be problematic in densely developed coastal areas.

5.1.5. (Re)construction of biogenic reefs

Different types of bivalve species, such as oysters and mussels, exist in estuarine and temperate marine environments. These species form biogenic reefs, which are hard, compact structures. These structures, in turn, provide habitats that support a unique set of other organisms (Gracia et al., 2018). Oysters are generally found between 64° N and 44° S latitude. Similarly, mussels are found in many temperate areas worldwide to a depth of 10 meters (Gracia et al., 2019). Oyster and mussel ecosystems add hard substrates to soft and unstable bottoms within a sedimentary system. Their shell beds can also exist above the substrate, attached to objects such as stones, shipwrecks or discarded bottles (Gracia et al., 2019). As the surface of biogenic reefs is often uneven and rough, they reduce the impact of direct water flow, wave energy and storm surges, thereby minimising coastal erosion (Kochmann, Buschbaum, Volkenborn & Reise, 2008; Morris et al., 2019). Furthermore, biogenic reefs act as dams by holding pools of water. This increases the immersion time above the shoreward bank margin, facilitating sediment deposition and stabilising the shoreline (Palumbi et al., 2009; Gracia et al., 2018). Additional ecosystem services provided by biogenic reefs, including an increase of biodiversity, water filtration and reduced turbidity by extracting phytoplankton and (in)organic particles from the water, and they accumulate carbon in their shells (Gracia et al., 2019).

Anthropogenic activities such as extensive resource extraction and reduced freshwater input increase the vulnerability of biogenic reefs to wave action (Beck et al., 2011; Seavey, Pine, Frederick, Sturmer & Berrigan, 2011; Rodriguez et al., 2014). Restoring or creating biogenic reef structures is therefore important and this may be a suitable nature-based strategy to adapt against the threats of coastal inundation, especially since biogenic reefs are adaptive to environmental change. Under low to moderate wave and tidal currents, these reefs can recover quickly from storm events and accrete at a rate equal to or greater than relative sea-level rise (Gracia et al., 2019; Morris et al., 2019). Besides, the construction of biogenic reefs has been shown to induce accretion of sediments on the lee side of the reef, which enabled salt marsh and mangrove development along the coastline (Gracia et al., 2019).

5.1.6. Restoring seagrass beds

Seagrasses are a grass species that adapted to the marine environment and evolved from land into the sea. They are permanently submerged and attached to sediments on the ocean floor (Gracia et al., 2018). Different types of seagrass species exist in different environments. In tropical areas, species such as *Thalassia testudinum* and *Syringodium filiforme* are abundant, whereas in higher latitudes *Zostera spp.* covers vast areas of the ocean floor (Gracia et al., 2018). Seagrasses influence their hydrodynamic environment by reducing incoming wave speed, dissipating wave energy and stabilising sediments. Furthermore, seagrass ecosystems alter bottom roughness through their roots and the vertical flow profile, particularly when their canopy heights are at least 15% of the height of the water column (Ondiviela et al., 2014; Gracia et al., 2018). Additionally, due to their ability to dampen waves, seagrasses stabilise and maintain sediments and reduce re-suspension in shallow regions, which counters coastal erosion (Orth et al., 2006; Gutiérrez, Pantoja, Tejos & Quiñones, 2011; Garcia et al., 2018). Shallow waters and low-wave environments provide optimal conditions for seagrasses to enhance coastal protection (Ondiviela et al., 2014). Other services provided by seagrass ecosystems include habitat provision, shelter and food for marine species, carbon production and export, nutrient recycling and enhanced biodiversity (Orth et al., 2006; Gracia et al., 2018).

However, sediment and nutrient loading, physical disturbances, the introduction of invasive species and diseases, commercial fishing and aquaculture all threaten seagrass ecosystems (Orth et al., 2006). Additionally, sea-level rise is impacting seagrasses worldwide. Sea-level rise requires seagrasses to migrate landward to maintain their optimal position in shallow environments. However, humans have significantly altered natural coasts by building coastal infrastructures such as breakwaters, groins and harbours. These human infrastructures obstruct the landward migration of seagrasses (Orth et al., 2006). Other climate change-induced threats that impact seagrass ecosystems include increases in sea-surface temperature and increased frequency and intensity of storms (Orth et al., 2006). The protection and restoration of seagrass ecosystems is important because waves can be reduced by 10-30% in dense seagrass areas compared to a bare ocean floor (Gracia et al., 2018).

5.1.7. Ecological enhancement of dikes

Worldwide, dikes are often used to protect low-lying lands from both the sea and rivers. Therefore, dike safety is important in dike designs. Sea dikes must be able to withstand incoming waves, currents and storm surges, whereas river dikes need to effectively cope with peak flows (Scheres & Schüttrumpf, 2019). Traditionally, dikes have a steep slope and a stone or asphalt revetment along the dike toe (Van Loon-Steensma & Schelfhout, 2017). Dikes can be ecologically enhanced through widening and greening of dikes (Scheres & Schüttrumpf, 2019).

Compared to dikes with a steep slope of around 1:3 and grey revetments, wide dikes with a grass-covered, shallow slope of around 1:7 positively impacts nature, recreation and tourism (Scheres & Schüttrumpf, 2019). The impact of wider dikes on the surrounding area is limited. It has been argued that wide dikes may result in the loss of original habitats. However, in the process of building wider dikes, new habitats such as grass meadows are also created, which have an ecological value in itself (Scheres & Schüttrumpf, 2019). Besides, compared to traditional dikes, wide, green dikes are associated with lower initial building costs, they are easier to repair and their adaptability to environmental change is higher (Van Loon-Steensma & Schelfhout, 2017).

Vegetation also plays an important role in ecologically enhancing dikes. Dense vegetation cover on dikes has been shown to reduce dike erosion (Scheres & Schüttrumpf, 2019). Gasses absorb rainfall and increase surface roughness, thereby protecting against splash and interrill erosion and trapping sediments. The roots bind the soil together and affect infiltration, reinforce the soil and protect against rill and gully erosion (Scheres & Schüttrumpf, 2019). The grass species used should be chosen based on the local climate, soil and hydraulic conditions. Ideally, the species planted on the dike should correspond to native species (Scheres & Schüttrumpf, 2019). In addition, woody vegetation in the form of forest-like stocks, tree rows or solitary trees can be used to ecologically enhance dikes (Scheres & Schüttrumpf, 2019). Woody vegetation improves dike stability due to their strong, deep roots.

Furthermore, woody vegetation provides a habitat for species, balances water quality and temperature, and provides cultural, recreational and aesthetic functions (Scheres & Schüttrumpf, 2019).

5.1.8. Restoring natural sedimentation processes

Deltas are dynamic systems and, due to sediment compaction and tectonics, they naturally subside relative to sea levels. Therefore, a continued supply and deposition of sediment is crucial to prevent deltas from being permanently inundated. However, anthropogenic activities are significantly reducing the natural deposition of new sediments on low-lying delta plains. First of all, due to upstream dam construction which traps sediments behind the dam (Dunn et al., 2019). Additionally, embankments that disconnect the river from adjacent low-lying plains obstruct sediments from depositing on those plains (Van Wesenbeeck et al., 2014). Various strategies can be used to restore natural sedimentation processes. Here, tidal river management and river diversions are discussed.

One strategy to increase sediment deposition on delta plains is to take advantage of tide movements (Amir, Khan, Khan, Rasul & Akram, 2013). Tidal river management involves temporarily breaching dikes and allowing sediment-borne tidal water to flow onto an embanked, low-lying area during flood tide. During the period that water is stored here, sediment deposition occurs (Shampa & Paramanik, 2012; Amir et al., 2013; Van Staveren, Warner & Khan, 2017). During ebb tide, the water, which now carries less sediment, flows out of the tidal basin and erodes the downstream riverbed, which also increases the drainage capacity of the river (Amir et al., 2013). Tidal river management can thus elevate the land and maintain proper drainage capacities, and it simultaneously reduces waterlogging, restores the natural environment, and conserves the ecology of wetlands (Amir et al., 2013). However, it also requires strong participation, commitment and sacrifice of local stakeholders. Flooding delta plains requires a lot of space. Therefore, people are required to temporarily give up their land and move to another location. This period could last from 3 to 5 years, which depends on the tidal volume and the size of the area to be elevated through sedimentation (Amir et al., 2013). During these years, the area is not suitable for agriculture but can be used for aquaculture (Van Staveren, Warner & Khan, 2017).

Another strategy, similar to tidal river management, is river diversions. Due to levees and embankments, rivers are hydrologically isolated from the deltaic plain. As a result, there is a lack of fluvial sediment input, which, combined with natural submergence processes, can contribute to accelerated coastal land loss (Snedden, Cable, Swarzenski & Swenson, 2007). Controlled river diversions can be constructed to reintroduce river water back into the deltaic plain (Snedden et al., 2007; Day et al., 2016). This would allow sediments and freshwater to enter low-lying plains adjacent to the river, which mimics natural land-building processes (Kolker, Miner & Weathers, 2012; Day et al., 2016). As water passes from the relatively narrow river into a receiving basin, flow velocities are reduced. Lower flow velocities allow sediments to sink and deposit, thereby promoting vertical accretion (Kolker, Miner & Weathers, 2012). In addition to sedimentation, river diversions provide freshwater to reduce salinity stress on the delta plain, iron to complex with sulphide which reduces sulphide toxicity, and nutrients which can stimulate wetland productivity and ecological restoration (Day et al., 2016). However, large-scale diversions have raised questions about the risk of increased flooding duration and permanent inundation. This would have large ecological consequences, such as reduced biomass production for plant species, but it also threatens human livelihoods and infrastructures (Day et al., 2016). Like intertidal river management, river diversions also require significant land-use change.

5.1.9. Beach nourishment

Beach nourishment aims to maintain the current beach profile, which helps to maintain the presence of beaches to combat coastal erosion along sandy shorelines (Smith, Slott, McNamara & Murray, 2009; UNEP, 2016). It involves depositing sand dredged from offshore locations or quarries onto the beach or the foreshore (UNEP, 2016) Subsequently, wind and wave action spread the sand along the coastline (Smith et al., 2009). In this way, the shoreline is artificially built up with natural sediments (UNEP, 2016). One advantage of beach nourishment compared to structural adaptation is that nourishment can easily be adapted to changes in future coastal patterns. In the long run, it is often also less costly compared to infrastructural adaptation (Charlier & De Meyer, 1995). However, beach nourishment is not a permanent solution. Wind and water will continually impact on the beach and eventually carry away the deposited sand. Therefore, beach nourishment needs to be carried out periodically (UNEP, 2016). Additionally, the impact of wind and water erosion on the beach is likely to increase in the future due to climate change-induced developments such as relative sea-level rise and an increase in the frequency and intensity of storms.

Beach nourishment has both positive and negative effects. The positive effects are that it provides coastal protection, supports tourism, provides benefits for biodiversity, and improves water regulation and purification (UNEP, 2016). However, for beaches to provide adequate protection against coastal erosion and flooding, they require more space than hard engineering structures (Temmerman et al., 2013). The wider the beach, the more protection it can provide. This is difficult for densely populated coastal areas (UNEP, 2016). Another problem with beach nourishment is that depositing sand directly onto the beach has negative ecological consequences. It disturbs local habitats and buries animals and organisms residing on the beach (Temmerman et al., 2013; UNEP, 2016). This problem can be addressed by creating a hook-shaped sand peninsula on the shoreface, as has been done off the coast of the Netherlands. Tides, waves and the wind then naturally distribute the sand towards beaches and dunes (Temmerman et al., 2013). However, an important issue remains with dredging sand from offshore locations. This can alter the profile of the ocean floor, which may in turn impact waves and currents. It also negatively affects the marine ecosystem from which the sand is dredged (UNEP, 2016).

5.2. Projections of environmental change in the Rhine and Mekong deltas

5.2.1. Sea-level rise

Average sea levels are projected to rise in the coming century for both the Rhine and Mekong deltas under RCP4.5 (Figure 6). According to the median estimate, the two deltas are projected to experience a similar rise in sea levels from just under 0.1 meters in 2020 to just over 0.5 meters in 2100.

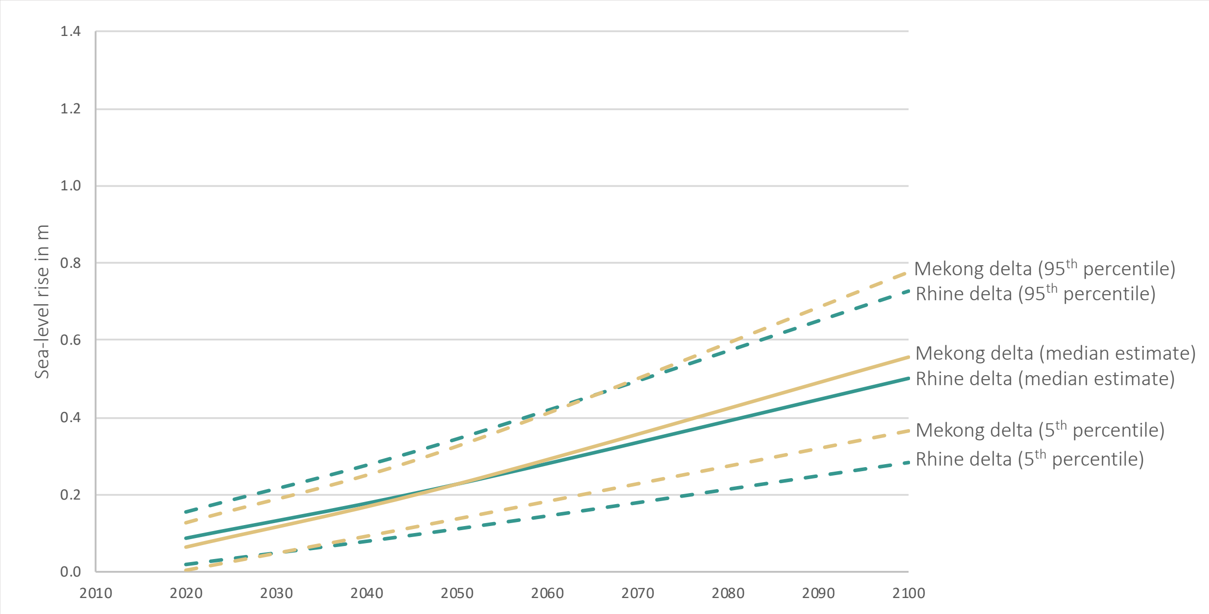

Figure 6. Average regional sea-level rise in meters for the Rhine (teal) and Mekong (light brown) deltas under RCP4.5. The figure includes the median estimate (solid line) and the 5th and 95th percentiles (dashed line) of the model ensemble. Data were obtained from the IPCC (2019).

5.2.2. Subsidence

According to median projections of subsidence, both the Rhine and the Mekong delta are projected to sink in the coming century (Figure 7). The Mekong delta is projected to subside more compared to the Rhine delta between 2020 and 2100. However, different parts of a delta usually experience different rates of subsidence and this is illustrated by the relatively large difference in maximum, median and minimum projections of subsidence for both deltas. Minimum subsidence projections indicate that some parts of the Rhine and Mekong deltas would experience an uplift of the land, whereas projections of maximum subsidence indicate that parts of the Rhine delta could sink up to 1 meter and parts of the Mekong delta up to 2 meters by the end of this century.

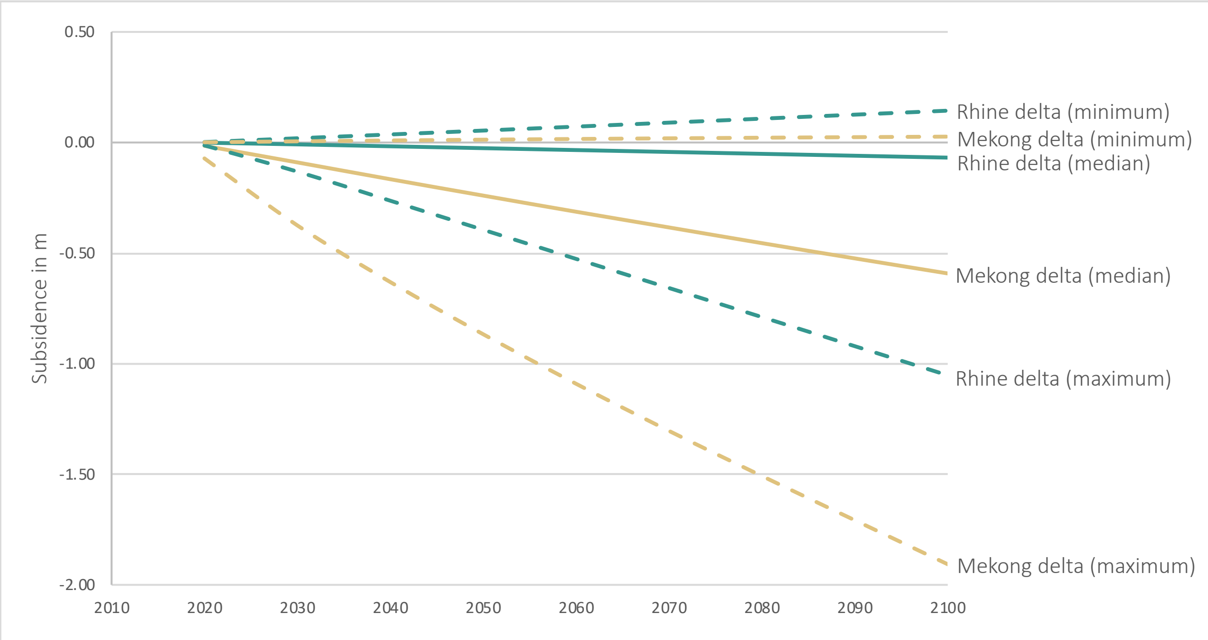

Figure 7. Subsidence in meters for the Rhine (teal) and the Mekong (light brown) deltas. The figure includes median (solid line), maximum and minimum (dashed line) projections of subsidence. Subsidence data for the Rhine delta were obtained from NCG (2018) and for the Mekong delta from Minderhoud et al. (2020).

5.2.3. Sediment availability

The Rhine and the Mekong deltas are both projected to experience a decline in sediment availability over time assuming a 'middle-of-the-road' scenario (Figure 8). Especially striking is the significant drop in sediment availability in the Mekong delta between 1990 and 2020. After 2020, sediment availability is projected to continue to decline in the Mekong delta although it stabilises from 2050 onwards at approximately 27 Mt/year. The Rhine delta receives very little sediment compared to the Mekong delta. Although it is projected to decline slightly, this is hardly visible in Figure 7. Sediment availability in the Rhine delta also stabilises from 2050 onwards at approximately 3.2 Mt/year.

Interestingly, although the Rhine delta receives little sediment compared to the Mekong delta, the sediment that the Rhine delta receives in 2020 is still about 85% of its historical pre-dam sediment load. This means that even before the construction of dams, the Rhine river carried much fewer sediments than the Mekong river. The Mekong delta currently receives about 25% of its historical pre-dam sediment load. For both deltas, however, this percentage is projected to further decline in the coming century to approximately 75% for the Rhine delta and just under 20% for the Mekong delta (Figure 9).

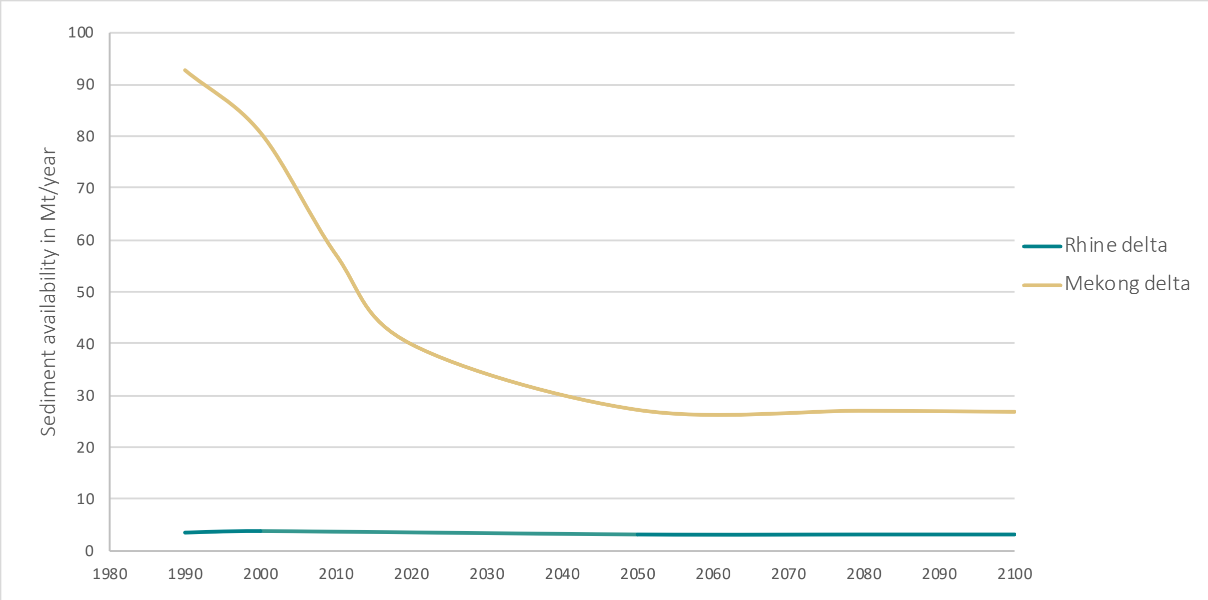

Figure 8. Average sediment availability in Mt/year at Lobith for the Rhine delta (teal) and at Kratie for the Mekong delta (light brown). Data for the Rhine delta are based on the G_h-climate scenario of the KNMI. Data for the Mekong delta are based on RCP4.5. Both scenarios include the building of future planned dams. Data were obtained from Dunn et al. (2019).

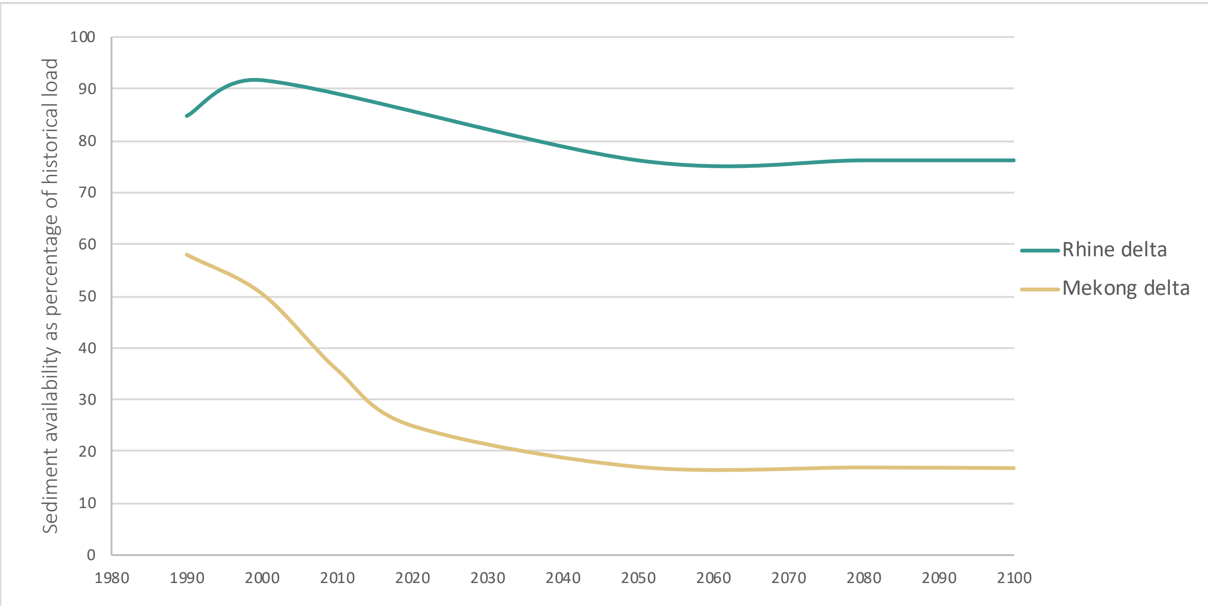

Figure 9. Sediment availability as percentage of historical, pre-dam sediment load for the Rhine (teal) and the Mekong (light brown) deltas.

5.2.4. Land-use

The fraction of fixed land-use, which in this thesis includes urban land-use and cropland, is projected to remain relatively stable at approximately 0.55 for both the Rhine and Mekong deltas under SSP2 (Figure 10). Thus, in the coming century, fixed land-use occupies just over half of the total land-use in both deltas. The other half consists of pasture land and other land-uses. Although the fraction of fixed land-use increases slightly between 2020 and 2050, it declines again between 2050 and 2100.

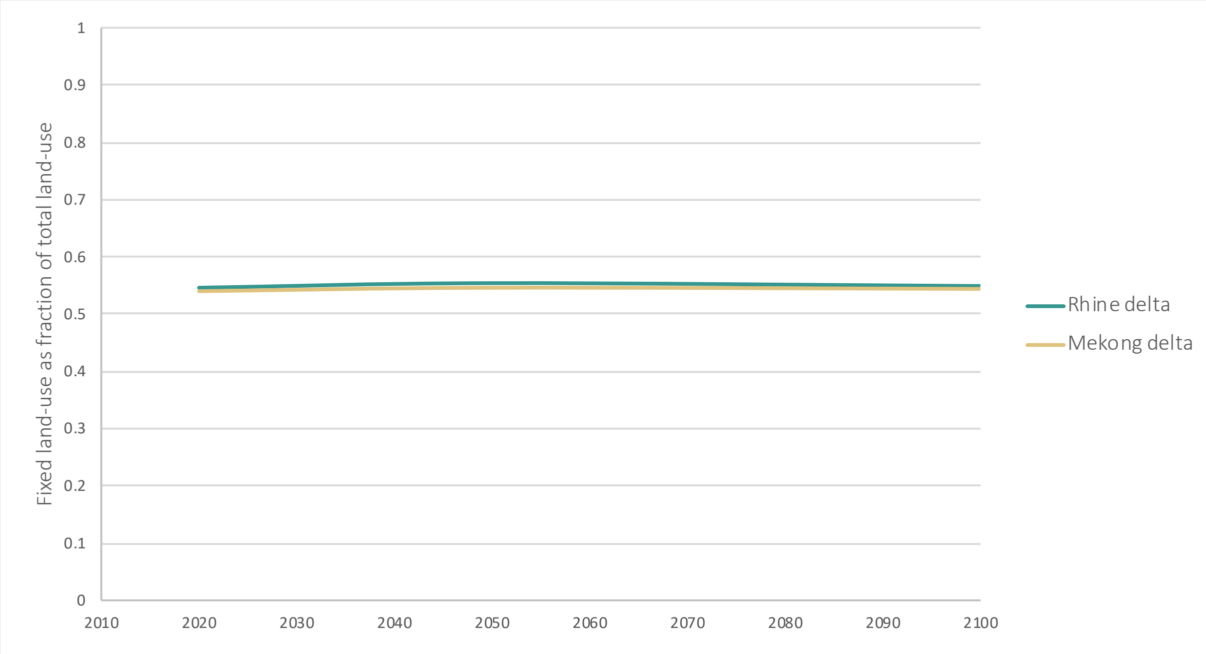

Figure 10. Fixed land-use (urban and cropland) as a fraction of total land-use for the Rhine (teal) and Mekong (light brown) deltas under SSP2. Data were obtained from Doelman et al. (2018) and Scown et al. (in prep.). The value for 2020 is modelled, not observed.

5.2.5. Summary

The results show that three of the four environmental variables included in this thesis are projected to change significantly in the coming century, which adds to the uncertainty regarding the feasibility of NbA. In the Rhine and Mekong deltas, sea levels are projected to rise. Both deltas are also projected to experience subsidence. Parts of the Rhine delta could sink up to 1 meter and parts of the Mekong delta could sink up to 2 meters by 2100. Together, this results in high rates of relative sea-level rise, especially for the Mekong delta. Under median estimates, sea levels in the Rhine delta are projected to increase with approximately 414 mm and the land is projected to sink approximately 67 mm between 2020 and 2100. This adds up to 481 mm relative sea-level rise between 2020 and 2100, or an average of 6 mm/year. Sea levels in the Mekong delta are projected to increase with approximately 492 mm and the land is projected to sink approximately 577 mm between 2020 and 2100 under median estimates. This adds up to 1069 mm relative sea-level rise between 2020 and 2100, or an average of 13 mm/year.

Sediment availability is projected to decline in both deltas, which is especially visible for the Mekong delta. Compared to the Mekong delta, the Rhine delta receives very little sediment. Reduced sediment availability may result in accelerated relative sea-level rise. The only environmental variable that is projected to remain relatively stable is the fraction of fixed land-use. It shows that in the coming century, fixed land-uses occupy just over half of the land-use in both deltas.

5.3. Principles for adaptive governance in the Rhine and Mekong deltas

5.3.1. Rhine delta plan

5.3.1.1. Legal design principles in the Rhine delta plan

Reflexive law

The principle of reflexive law is present in the Rhine delta plan. The delta plan distinguishes between delta decisions, preferred strategies and local projects. These concepts should be considered as a scale, from general guidelines to local applications. Delta decisions provide an overarching and general vision for the future of the Rhine delta, preferred strategies are region-specific applications of the general delta decisions, and projects tackle specific issues at the local scale (Deltacommissaris, n.d.). In other words, delta decisions provide an overall goal whereas preferred strategies and projects fill in the details. Although these concepts are mentioned in the Rhine delta plan, they are not properly explained. Other sources had to be consulted to find out what exactly the difference between the concepts is. Therefore, reflexive law is implicitly present in the Rhine delta plan. Additionally, the principle is not frequently present in the Rhine delta plan (< five times).

In 2014, five broad delta decisions for different parts of the Netherlands were proposed. One for water safety, one for fresh water, one for the IJsselmeer region, one for the Rhine-Meuse delta, and one for spatial adaptation. The delta decisions are an overall vision for the Netherlands and provide long-term direction for tackling flood risk management, freshwater supplies, and a climate-proof and water-robust design of the country (Deltacommissaris, n.d.). They function as general guidelines which is an indication of reflexive law. The five delta decisions are translated into region-specific preferred strategies (Deltaprogramma, 2020). These preferred strategies function as a compass for the measures that are going to be implemented at the local level in projects. "The preferred strategies of DP2015 [the 2015 delta plan] are designed adaptively, so that they can be adapted if required by changing circumstances" (Deltaprogramma, 2020 p.13). This illustrates that the preferred strategies can be adapted to changing circumstances if necessary. Local projects are even more specific than preferred strategies and are included in the delta plans for water safety, freshwater and spatial adaptation (Deltacommissaris, n.d.). The preferred strategies and projects can more easily be adapted to changing circumstances than the delta decisions, so that the delta decisions can continue to provide an overall long-term vision for the future of the Rhine delta even when local conditions change (Deltaprogramma, 2020). This illustrates how the Rhine delta plan does not rely on static rules. The delta decisions provide standards and procedures that guide decision-making and implementation at the local level.

Legal sunsets

The principle of legal sunsets is clearly illustrated in the Rhine delta plan. It is mentioned that the delta decisions and preferred strategies are reassessed after specific periods. Therefore, legal sunsets are explicitly present. However, only a few illustrations of legal sunsets are provided throughout the Rhine delta plan (< five times).

The Rhine delta plan explicitly states that strategies and measures can be adapted to new developments. "In the delta plan, the choice was made for an adaptive approach: new developments and insights can be a reason to adjust previously established preferred strategies and (delta) decisions. This can be done every year if developments require this. The steering group of the delta plan decided in 2017 to also carry out a systematic reassessment every six years" (Deltaprogramma, 2020, p. 19). This clearly illustrates revisions after specific periods, indicating legal sunsets. However, annual changes in the delta decisions and preferred strategies are only made if developments absolutely require this because there are multiple advantages to adjusting strategies periodically (e.g. every six years) instead of annually, such as stability, consistency and coherence (Achtergronddocument F, 2017). Therefore, in the Rhine delta plan, the choice was made to readjust delta decisions and preferred strategies after six-year intervals if possible, but they can be yearly adjusted if environmental, social and economic conditions require this (Deltaprogramma, 2020).

Legally binding authority

The Rhine delta plan is legally grounded in the Dutch Delta law and the Water law (Deltaprogramma, 2020). These laws legitimise the decision-making latitude of stakeholders that are included in the Rhine delta plan. Therefore, legally binding authority is explicitly present in the Rhine delta plan. The Delta law and the Water law were consulted to find out exactly what levels of government and which stakeholders are allocated the authority to make decisions, implement solutions and carry out plans. The existence of the Delta law and the Water law is mentioned infrequently (< five times) throughout the delta plan.

The Delta law (2012) stipulates that a delta plan must be established annually. This law also specifies that there must be a delta commissioner who is authorised to establish and implement the delta plan (Deltacommissaris, n.d.). The delta commissioner is authorised to promote consultation with and collaboration between relevant stakeholders, monitor progress on the implementation of the delta plan and report on this progress to the Minister of Infrastructure and Water Management (Deltaprogramma, 2020). Lastly, the Delta law provides for the Delta Fund to finance the delta plan (Deltacommissaris, n.d.). This illustrates that the authority of the delta commissioner is institutionalised in binding legislation, which legitimises the commissioner's decision-making latitude.

The Water law (2020) brings together legislation on water quality management, flood protection, surface and groundwater management, water-use and services. The law also includes a section on the organisation of water management. By order in council, water systems can be designated to fall either within the jurisdiction of the central government or within the jurisdiction of lower governments (Waterwet, 2020). In most cases, the central government is not concerned with designing measures and strategies for regional water systems or to combat flooding. According to the Water law, the provinces are authorised to decide on measures concerning the public living environment, development of regional areas and nature. Additionally, provinces can determine which governmental body takes care of the regional water systems, which are often the regional water authorities. These regional water authorities are also authorised to take measures to prevent damage to water management structures (Waterwet, 2020). Municipalities, in turn, are authorised to collect and process rainwater runoff. Municipalities can also take measures to prevent adverse consequences of either exceptionally high or low groundwater levels. Additionally, they are authorised to decide on local spatial planning (Waterwet, 2009). This clearly shows that the authority of different governmental levels is institutionalised in the Water law, which illustrates the principle of legally binding authority.

Legally binding responsibility

The principle of legally binding responsibility is absent from the Rhine delta plan. It is only described in the delta plan that the Minister of Infrastructure and Water Management is ultimately responsible for progress on the Rhine delta plan (Deltaprogramma, 2020). Further responsibilities are not discussed and therefore it remains unclear how the responsibility to resolve or contribute to a resolution or dilemma is assigned to various environmental stakeholders.

Tangible support

The Rhine delta plan clearly illustrates the principle of tangible support. Various examples of support in the form of funds, information and guidance are explicitly present in the delta plan. Furthermore, tangible support is also frequently present in the Rhine delta plan (> five times). Some illustrations will be presented here but more examples can be found in the delta plan.

Especially tangible support in the form of funds is mentioned often throughout the Rhine delta plan. The delta plan is financially supported by the Delta Fund. This fund aims to finance various measures and services that are essential for protecting the Netherlands against flooding and water scarcity. "The Delta Fund holds the financial resources to finance investments in water safety, freshwater and water quality, and the central governments' management and maintenance activities that pertain to this. A subsidy can also be granted from the Delta Fund to finance measures for water safety, freshwater and water quality of other governmental authorities" (Deltaprogramma, 2020, p.73). This illustrates that subsidies can be granted to local governments, indicating support in the form of funds. In 2019, the central government worked on an amendment to the Water law. "This amendment makes it possible to make financial contributions from the Delta Fund to decentralised authorities for taking measures against flooding" (Deltaprogramma, 2020, p 66). Activities that are financed through the Delta Fund are for example the so-called impact projects. "Local governments that execute these projects can get help in the form of a contribution of €25,000 per impact project while other governments are inspired" (Deltaprogramma, 2020, p.67). This again indicates financial support, but the results of the impact projects can also inform and inspire other local governments, which indicates support in the form of information or experience.

For the delta plan on spatial adaptation, "the Minister of Infrastructure and Water Management has made extra funds available for stimulating and facilitating climate adaptation: in total €20 million for 2019 and 2020. […] This is meant for process support, pilots, and knowledge development and knowledge sharing. The acquired knowledge is available through the Knowledge Portal (Kennisportaal) and the Platform Climate-proof Together (Samen Klimaatbestendig)" (Deltaprogramma, 2020, p.66). The latter forms an important link between policy and practice. "The platform was established in 2018 and due to positive experiences, it was decided to prolong the activities until 2020. The Ministry of Infrastructure and Water Management made funds available for this from the extra €20 million impulse" (Deltaprogramma, 2020, p.67). Within the platform, stakeholders can exchange experiences to aid each other in finding the optimal solution to a particular climate-related problem (Deltaprogramma, 2020). This illustrates support in the form of funds to stimulate the sharing of knowledge and information. Furthermore, "in 2019, extra funds were made available for research. This gave an extra boost to knowledge development and knowledge distribution" (Deltaprogramma, 2020, p.61). This also illustrates funds and information as tangible support.

An example of tangible support in the form of information and guidance can be found municipalities' capacity to regulate climate-adaptive spatial planning. In theory, municipalities should be able to use their instruments to regulate and secure climate-adaptive spatial planning. "There are various reasons why this is currently not or insufficiently done, in particular municipalities' unfamiliarity with the possibilities of decentralised regulation for climate-adaptive building and lack of a sense of urgency and required capacity. Therefore, in 2019 a guide for local authorities will be established" (Deltaprogramma, 2020, p.15). This guide can support the establishment of environmental visions in which "goals and ambitions for spatial adaptation are included and connected with plans for, for example, public space, energy transition, construction and in municipal regulations" (Deltaprogramma, 2020, p.69). This guide, therefore, provides information to local authorities and guides them in climate-adaptive spatial planning.

5.3.1.2. Institutional design principles in the Rhine delta plan

Well-defined boundaries

The principle of well-defined boundaries is explicitly present in the Rhine delta plan. The delta plan provides numerous illustrations of compacts or agreements about socio-political and ecosystem boundaries. These illustrations are also frequently present in the Rhine delta plan (> five times).

The Rhine delta plan acknowledges the international character of river systems. The Rhine, Meuse and Scheldt rivers all cross international borders. To deal for example with the international character of the Scheldt, “Flanders and the Netherlands work together in the Flemish-Dutch Scheldt Commission (Vlaams-Nederlandse Scheldecommissie) on an agenda for the future” (Deltaprogramma, 2020, p.95). Additionally, “the Netherlands and North Rhine-Westphalia have conducted research together in the Working Group High Water (Arbeitsgruppe Hochwasser) on flood risks in the border area. This is relevant because a flood in the German part of the border area has consequences for the Netherlands and vice versa” (Deltaprogramma, 2020, p.88). This indicates that the ecosystem boundaries of the rivers and the Rhine delta are recognised and well-defined. The Flemish-Dutch Scheldt Commission and the Working Group High Water are illustrations of international cooperation to effectively deal with issues relating to rivers. Such compacts indicate well-defined socio-political boundaries.

Another example of well-defined socio-political boundaries is the program WAVE2020 of the delta plan on water safety, which aims to “improve flood risk management and coordinate the efforts of the 25 safety regions” (Deltaprogramma, 2020, p.30). Within each of the safety regions, impact analyses of floodings are currently being executed. By doing this in different safety regions, it remains clear what areas should be included in the impact analyses and what can be ignored as it belongs to another safety region. As the boundaries of the safety regions are clear, carrying out impact analyses remains manageable. It also clarifies the jurisdiction of each region. Similarly, to realise the ambitions of the delta plan for spatial adaptation, the Netherlands is divided into 42 working regions. “The working regions monitor the progress in their area and report about this. The existing seven bodies of consultation in turn report on the basis of this the progress to the delta commissioner” (Deltaprogramma, 2020, p.57). Dividing the Netherlands into different regions with well-defined boundaries ensures that the tasks and jurisdiction of these regions are clear. This is important for collective problem-solving.

Participatory decision-making

The Rhine delta plan frequently illustrates the principle of participatory decision-making (> five times). Numerous illustrations of processes and methods that enable and stimulate stakeholder participation were found, indicating that the principle is explicitly present in the Rhine delta plan. A few illustrations will be discussed here. More illustrations of the principle can be found in the delta plan.

It is clearly indicated that the Rhine delta plan is a product of the collaboration between different stakeholders. “The Rhine delta plan is a national program. The central government, provinces, municipalities and regional water authorities work together in an innovative way, based on input from civil society organisations, knowledge institutes, citizens and businesses” (Deltaprogramma, 2020, p.112). The ambition is to, where possible, […] stimulate “the participation of [local] governments, businesses and citizens in the preparation of plans and measures” (Deltaprogramma, 2020, p.20). “Participation of citizens and businesses […] is important, because more than half of the Netherlands is privately owned” (Deltaprogramma, 2020, p.63). Especially if measures have a significant impact on the living environment, such as dike enhancements, then “stakeholders are involved as early as possible” (Deltaprogramma, 2020, p.32). “For participation, the system distinguishes between five levels of ambition, in line with the participation ladder: informing, consulting, advising, co-producing and (co-) decision-making” (Deltaprogramma, 2020, p.21).

“Co-production is the most chosen level in the implementation of the region-specific preferred strategies” (Deltaprogramma, 2020, p.21). This means that environmental stakeholders can participate in designing these strategies, but they have no vote in the final decision-making process. The extent to which stakeholders can participate in implementation projects depends on the content of the project. "Participation at the project level therefore shows a varied picture" (Deltaprogramma, 2020, p.21). Sometimes the choice is made for informing, other times for (co-)decision-making. Some examples will be provided here that illustrate how the participation of stakeholders in projects varies.

For example, for assessing and designing flood defences, "the Ministry of Infrastructure and Water Management has, together with Deltares, developed a method for using more expert and experiential knowledge for a Customised Assessment (*Beoordeling op Maat*)" (Deltaprogramma, 2020, p.28). This illustrates how Deltares, an independent, Dutch research institute, participated to co-produce a method to better design and assess flood defences in the Netherlands. Another example can be found in the program for Integrated River Management (*Integraal Riviermanagement*). "In 2018, the Minister of Infrastructure and Water Management expressed the intention to set up a program for Integrated River Management together with governments, businesses and civil society organisations in the river area" (Deltaprogramma, 2020, p.28). A steering committee has been established, in which the government, the region and the staff of the delta commissioner are represented. "In 2019 and 2020, the parties work on an integrated vision for the future of the river system. Some policy choices are also prepared" (Deltaprogramma, 2020, p.28). This shows that stakeholders can influence the measures being made, which again indicates co-production.

In another program, that focuses on safeguarding and enhancing the spatial quality of the coastal zone between the Dutch cities of Hoorn and Amsterdam, different stakeholders work together under the supervision of the province of Noord-Holland. "The parties identify opportunities and carry out projects to combine dike enforcements with nature conservation, recreation, tourism and cultural history" (Deltaprogramma, 2020, p.83). This illustrates stakeholder participation in the form of advising and consulting, but also in the implementation phase. The last example discussed here concerns a collaboration between the municipality of Rotterdam and the port of Rotterdam. "Together with involved parties, the municipality of Rotterdam and the port of Rotterdam develop area-oriented water safety strategies for all areas outside of the embankments in the region" (Deltaprogramma, 2020, p.85). This indicates co-production of strategies.

Internal enforcement

Internal enforcement is explicitly present in the Rhine delta plan. Throughout the Rhine delta plan, it is explicitly stated that stakeholders are obliged to report on their progress to a higher authority. However, internal enforcement is infrequently mentioned in the delta plan (< five times).

For example, as has been briefly described under well-defined boundaries, municipalities, regional water authorities, provinces and the central government work together to realise the ambitions of the delta plan on spatial adaptation. This collaboration is divided into 42 working regions. "The working regions monitor the progress in their area and report about this. The existing seven bodies of consultation in turn report on the basis of this the progress to the delta commissioner" (Deltaprogramma, 2020, p.57). The delta commissioner, in turn, reports about this progress annually to the Minister of Infrastructure and Water Management, who is ultimately held responsible for all policies concerning water safety (Deltaprogramma, 2020). This clearly illustrates that stakeholders have to periodically report on their progress to a higher authority, indicating internal enforcement.

Another way in which internal enforcement in the Rhine delta takes place is through financial incentives. "Financial incentives can stimulate citizens and businesses to design their own lands in a climate-proof way. Especially local governments are very interested in this" (Deltaprogramma, 2020, p.67). However, this approach is not yet applied everywhere. "In the spring of 2019, four municipalities started a pilot […] in which they are experimenting with differentiation of sewage taxes and subsidisation of greening activities" (Deltaprogramma, 2020, p.67). Taxes and subsidies are financial incentives that can be used to enforce desired behaviour.

Internal conflict resolution

The principle of internal conflict resolution is explicitly present in the Rhine delta plan. However, only one illustration of this principle was found (< five times) and the example comes from a specific project, the Flood Protection Program (Hoogwaterbeschermingsprogramma). In other words, the principle is not present throughout the entire delta plan, but rather in one section.

The Flood Protection Program is an implementation project of the delta plan for water safety. This project established several so-called alliance principles. "The administrative alliance principles provide further information about the cooperation" (Deltaprogramma, 2020, p.34). One of these principles is transparency. According to this principle, "we are open to each other; if our individual interest clashes with the collective interest, we will discuss this" (Deltaprogramma, 2020, p. 34). Another principle focuses on predictability. According to this principle, "we discuss risks and issues at an early stage, so that we can control them and make decisions carefully" (Deltaprogramma, 2020, p.34). The last principle worth mentioning here focuses on reliability: "we make clear agreements with each other and honour them" (Deltaprogramma, 2020, p.34). This illustrates that straightforward and transparent agreements are made to which stakeholders should comply, and that open communication is stimulated in the case of disputes, so that disputes can be resolved quickly and fairly. This clearly indicates internal conflict resolution.

5.3.2. Mekong delta plan

5.3.2.1. Legal design principles in the Mekong delta plan

Reflexive law

The principle of reflexive law is absent from the Mekong delta plan. The delta plan does not provide illustrations of laws or policies that, instead of relying on static rules, emphasise minimum requirements, maximum thresholds or general principles.

Legal sunsets

The Mekong delta plan clearly illustrates the principle of legal sunsets. The delta plan distinguishes between short-, mid- and long-term measures. This ensures that long-term strategies can be left relatively open, so that they can be changed if socio-ecological conditions change. A distinction between short- and long-term measures is one of the identified key concepts related to legal sunsets. Therefore, the principle of legal sunsets is explicitly present in the delta plan. However, the principle is mentioned only a few times (< 5 times).

The Mekong delta plan states that "a primary focus is given to no-regret and priority measures that should be taken in the short- to mid-term (2050). […] For the mid- to long-term (2100), additional measures are presented that are specifically designed to prepare the delta to cope with, and adapt to, the more extreme impacts of climate change" (Mekong delta plan, 2013, p.82). The short-term, no-regret measures are worth implementing regardless of what happens in the future. Strategies planned for the long-term are flexible and left open to ensure that they can be adapted to climate change-related, environmental and socio-economic developments. This ensures flexible adaptation to unforeseen events. According to the Mekong delta plan, with this "back-casting approach, more specific but also more creative options can open up to move step by step towards the realisation of the desired future for the delta" (Mekong delta plan, 2013, p.17). Chapter 7 in the Mekong delta plan describes the measures that should be implemented in the delta. For each of the measures, it is clearly indicated whether they should be implemented in the short-, mid- or long-term.

Legally binding authority

The principle of legally binding authority is present in the Mekong delta plan. The plan proposes the establishment of a legally mandated entity, the Mekong delta planning commission, that should have sufficient decision-making latitude to effectively and sustainably manage land and water issues in the Mekong delta (Mekong delta plan, 2013). It is proposed that the authority of the commission is institutionalised in binding legislation, indicating legally binding authority. This principle is therefore explicitly present in the Mekong delta plan. However, it is mentioned only a few times (< five times).

To safeguard a sustainable future for the Mekong delta, it is proposed that an institutional governance entity is established, legally mandated to direct, plan, financially approve and coordinate water resources management and adaptation plans for the delta (Mekong delta plan, 2013). This Mekong delta planning commission would function as an inter-provincial platform. It is argued that it is essential that this entity "becomes institutionally embedded within the governance structure of Vietnam, and the delta region in particular. Ideally, this entails the establishment of a legally mandated entity that is integrated and cross-sectoral in nature and capacity, and as such can act as a custodian of the Mekong delta plan, its amendments and refinements, as well as subsequent elaboration into detailed programs" (Mekong delta plan, 2013, p.73). The Mekong delta planning commission would also be authorised to review and assess sectoral, departmental and provincial plans on consistency and alignment with the overall development strategy for the delta. This means that "local authorities keep their mandate, but are bound to coordinate their planning and interventions through the commission" (Mekong delta plan, 2013, p.73). The commission, in turn, "should be equipped with the necessary powers, such as the ability to get information, develop its own knowledge base and enter into dialogue with authorities on their shared responsibility in the basin" (Mekong delta plan, 2013, p.73). This shows that the authority of the Mekong delta planning commission would be institutionalised in legislation. The commission therefore would have sufficient decision-making latitude.

Legally binding responsibility

Legally binding responsibility is explicitly present in the Mekong delta plan. The delta plan provides illustrations of laws that define and assign responsibilities to various stakeholders. However, only a few examples of these laws are present in the Mekong delta plan (< five times).

The first illustration of legally binding responsibility in the Mekong delta plan is the Law on Water Resources. This law defines and assigns the responsibilities related to water resources management. The law "clearly stipulates the rights and duties of water extraction and use. It assigns the Ministry of Natural Resources and Environment as well as the Provincial People's Committee as responsible to carry out the granting, renewing, adjusting, suspending and revoking of licenses on water resources" (Mekong delta plan, 2013, p.77). The second illustration of legally binding responsibility can be found in the following quotation. "Service provision and the operation and maintenance of water infrastructure, notably the repair of dikes and canals, are typically allocated at provincial and district levels" (Mekong delta plan, 2013, p.78). This shows how governance entities at provincial and district levels are given the responsibility for operating and maintaining water infrastructure. However, even though provincial entities have received more responsibilities as a result of decentralisation efforts, their human capacity to deal with challenges remains limited. This is even more true for district and commune levels. Thus, although responsibilities are assigned to local authorities, they usually have to deal with a shortage in the number and quality of their educated officials (Mekong delta plan, 2013).

Tangible support

The Mekong delta plan explicitly includes the principle of tangible support. Various illustrations of government support in the form of funds, information, guidance or training were found. Additionally, this legal design principle was found to be present very frequently (> five times) throughout the Mekong delta plan. Various examples will be given here, however more can be found in the delta plan.

Most of the illustrations of tangible support in the Mekong delta plan take the form of funds. In chapter 4 of the delta plan, four distinct possible and plausible future socio-economic scenarios are explored. When considering both the physical system of the delta and its richness, the agro-business industrialisation scenario is argued to be the most viable and sustainable in the long run (Mekong delta plan, 2013). Although the "predominantly rural economy of the delta has been well established and developed over the last three decades, primarily as a result of the dedicated investment and support by the Government of Vietnam" (Mekong delta plan, 2013, p.53), further development in the direction of the agro-business industrialisation scenario is required for the Mekong delta to be sustainable in the future. To achieve this, the establishment of an agriculture development fund is proposed, which indicates tangible support in the form of funds (Mekong delta plan, 2013). Furthermore, the Vietnamese government should be "active and supportive in the value chain of the agro-business by investing in, and providing for, direct services – notably research and development, state operated breeding and hatcheries, and trade regulation and certification support services" (Mekong delta plan, 2013, p.64). This provision of services needs to be combined with "investments in favourable infrastructural developments, in particular waterways and management, that account for sustainable water quality intake, disposal and treatment requirements […], as well as transport and energy services" (Mekong delta plan, 2013, p.65). This again illustrates governmental support in the form of funds. Additionally, for each of the specific flood management measures presented in chapter 7 of the delta plan, examples are given of how these measures could be financially supported.

Other forms of tangible support were also found in the Mekong delta plan. For example, to achieve a sustainable, agri-business industrialisation, "the governance of the Mekong delta should focus [...] on more strategic guidance in planning, budgeting and project approval for all sections in line with the desired development" (Mekong delta plan, 2013, p.72). This indicates that the Vietnamese government should provide support in the form of guidance. Additionally, the importance of support in the form of information is also underlined. "Sufficient data, data rights and access to data are crucial for the success and cooperation and coordination between the Mekong delta provinces as well as between regional and national government agencies. A Joint knowledge agenda would be the first step in the right direction" (Mekong delta plan, 2013, p.77). The Mekong delta plan assumes that "joint fact finding, coherent data collection and open sources […] are of utmost importance to make the right decisions for delta management" (Mekong delta plan, p.97). And lastly, an example of support in the form of training was also found in the delta plan. As mentioned under the principle of legally binding authority, many regional government entities struggle with a shortage in the number and quality of educated officials. As a response to this, "each province in the Mekong delta formulated plans for human resources development. Planning, economics and climate change adaptation are on top of the list in most provinces. The Netherlands' financed NICHE program aims to train more professional staff in these fields by strengthening the capacity of the Vietnam National University in Ho Chí Minh City" (Mekong delta plan, 2013, p.78).

5.3.2.2. Institutional design principles in the Mekong delta plan

Well-defined boundaries

The principle of well-defined boundaries is explicitly present in the Mekong delta plan. The delta plan provides numerous illustrations of agreements about socio-political and ecosystem boundaries. These illustrations are also frequently present in the Mekong delta plan (> five times).

Chapter 7 of the Mekong delta plan proposes land and water management measures that for the Mekong delta. Some of these measures are developed for the delta as a whole, others for the distinguished regions of the upper, middle and lower delta (Mekong delta plan, 2013). It is recognised that "the arrangements for flood control, securing of adequate freshwater supplies in the dry season, salinity intrusion, regulation and management of an adequate and healthy brackish water zone for aquaculture, coastal defence, etc. are all typically measures that need to be considered at the delta level, [but] in their impact and influences they go beyond the boundaries of local governance and policy jurisdiction, e.g. restraining of seasonal flood regimes in the upper delta by construction of permanent dikes alters the peak flow regime of the river and its branches further downstream the delta, imposing additional costs and risks for flood and bank erosion control downstream [...]" (Mekong delta plan, 2013, p.72). This illustrates that the Mekong delta plan acknowledges that different parts of the delta require different strategies and that these strategies impact the delta as a whole. The ecosystem boundaries of the Mekong river and the delta are therefore well-defined.

The Mekong delta plan also acknowledges the international character of the Mekong river, which again illustrates well-defined ecosystem boundaries. This underlines the need for international cooperation, which, in turn, also indicates well-defined socio-political boundaries. "The Mekong delta has a larger upstream part of the river outside its borders than within its own jurisdiction" (Mekong delta plan, 2013, p.16). The delta heavily depends on upstream developments, the impacts of climate change on the entire river basin, and the measures taken in riparian countries of the Mekong river. To deal with this, "it is essential that Vietnam conducts an active foreign policy" (Mekong delta plan, 2013, p.79). "Having a platform to discuss the management of the river basin as a whole is invaluable. Good examples of successful international cooperation of border crossing rivers are the Indus (India-Pakistan) and the Rhine (Switzerland, Germany, France, the Netherlands), the water directives used in the European Union show good coordination of river management among countries" (Mekong delta plan, 2013, p.79). Therefore, the Mekong delta plan acknowledges that "institutional arrangements that facilitate cross-border decision making and true integration of planning and measures" are required (Mekong delta plan, 2013, p. 16). Such institutional arrangements clarify ecosystem and socio-political boundaries, which is an indication of well-defined boundaries.

Participatory decision-making

Participatory decision-making is clearly included in the Mekong delta plan. The delta plan provides various illustrations of processes and methods that enable stakeholder participation. This principle is therefore explicitly present. Furthermore, illustrations of participatory decision-making are frequently provided (> five times). Some examples are given here, but more can be found in the delta plan.

It is described that already in the preparatory phase of establishing the Mekong delta plan, various knowledge institutes were included. "The process of making a Mekong delta plan started with an expert assessment of the current state of the delta using the abundant existing data" (Mekong delta plan, 2013, p.14). Data were provided by “the Southern Institute for Water Resources Planning, the Mekong Delta Development Research Institute and Climate Change Research Institute of the Can Tho University, the Division of Water Resources Planning and Investigation for the South of Vietnam, and the sub-institute of Hydrometeorology and Environment of South Vietnam” (Mekong delta plan, 2013, p.14).

In the process of formulating the actual strategies to be included in the Mekong delta plan, again various stakeholders were consulted. The Ministry of Natural Resources and Environment and the Mekong delta plan-team “involved a good number of stakeholders and experts, regional and national” (Mekong delta plan, 2013, p.100). These include “experts and specialists from different sectors with a bird’s-eye view across the sectors, decision-makers of local, provincial and national authorities, [and] representatives from organisations for e.g. industry, fishery, transport, agri- and aquaculture” (Mekong delta plan, 2013, p.19). Additionally, the Mekong delta plan underlines that “international organisations like the World Bank, ADB, UNDP and different non-governmental organisations are stakeholders in the sense that they have a good understanding of integrated development and that they are capable of influencing projects in the delta in conformity with a delta plan approach” (Mekong delta plan, 2013, p.19). Furthermore, it is emphasised in the delta plan that the Mekong delta planning commission “should account for multiple stakes, interests of economic development in the delta and an overall beneficial outcome at the delta level” (Mekong delta plan, 2013, p.72). The commission should organise meetings through which “the provinces will be able to view and jointly translate national policies in light of user functions such as agricultural and rural development, environmental and natural resource functions” (Mekong delta plan, 2013, p.73). This illustrates the inclusion of stakeholders in the establishment of the delta plan.

The Mekong delta plan also emphasises that the private sector has an important role to play in the implementation of the delta plan. For example, although the government of Vietnam plays an important role in the provision of services, ensuring a conducive regulatory environment, and investing in infrastructural developments, “investments and developments in technology, supply base and product development should be placed within the agro-business chain, possibly through public-private partnerships and private investments” (Mekong delta plan, 2013, p. 65). Public-private partnerships are an excellent example of a mechanism for stakeholder participation. It is also underlined in the delta plan that the agro-business industrialisation scenario “thrives with the active participation and investments of private sector enterprises that invest in modernisation, product development and innovation, and economies of scale” (Mekong delta plan, 2013, p.70). To achieve this, the private sector can “take a more active role in research and development, financing and product development and marketing services” (Mekong delta plan, 2013, p.64).

And lastly, now that the Mekong delta plan has been established, the inclusion of stakeholders is also perceived to be important in translating the visions and strategies into action. “Securing connections with and involvement of universities, research institutes, the private sector and other stakeholders” is imperative (Mekong delta plan, 2013, p.102).

Internal enforcement

Internal enforcement is absent from the Mekong delta plan. The delta plan does not provide illustrations of mechanisms to monitor and enforce stakeholder compliance.

Internal conflict resolution

The principle of internal conflict resolution is present in the Mekong delta plan. The delta plan discusses a mechanism to resolve factual disputes, but the key concepts associated with internal conflict resolution were not found in the delta plan. Therefore, internal conflict resolution is implicitly present. Additionally, it is only mentioned once in the delta plan (< five times).

The Mekong delta plan underlines the importance of equal access to information because this can reduce conflicts. "Relevant (provincial and district) authorities need to have better access to relevant (water, land-use, environmental, etc.) data and information to guide planning, decision making and licensing. Currently, data and information are insufficiently available or scattered among many different (over 200) relevant research institutes as well as the more than 19 multilateral and 26 bilateral international donor agencies" (Mekong delta plan, 2013, p.77). As a result, there is much uncertainty and ambiguity about facts which can result in conflicts between different stakeholders. To reduce and resolve conflicts, joint fact-finding is stimulated in the Mekong delta plan. This requires the establishment of one team, comprised of experts and decision-makers representing all relevant stakeholders in the Mekong delta, that gathers relevant information about the delta. By gathering all information in one place and including representatives of various stakeholder groups, factual disputes can be resolved. This, therefore, illustrates a mechanism for resolving conflicts about facts. Joint fact-finding may ensure that "relevant authorities become more capable to effectively manage, operate, maintain and enforce the rules and policies for land and water in the Mekong delta" (Mekong delta plan, 2013, p.77).

5.3.3. Summary

Most of the legal and institutional design principles for adaptive governance are, to varying degrees of clarity and frequency, present in the Rhine and Mekong delta plans. The Rhine delta plan includes one more principle than the Mekong delta plan. In the Rhine delta plan, four out of five legal design principles and all institutional design principles are present. Legally binding responsibility is the only principle that is currently missing. Of the eight principles present in the Rhine delta plan, seven are explicitly present and one implicitly present. In the Mekong delta plan, four out of five legal design principles and three out of four institutional design principles are present. Reflexive law and internal enforcement are currently missing from the Mekong delta plan. Of the seven principles identified in the Mekong delta plan, six are explicitly present and one implicitly present. The principles that are implicitly present in the delta plans show that the intention is there, but it should be made more explicit and formalised. The emphasis in both delta plans is on tangible support, well-defined boundaries and participatory decision-making. These principles are mentioned explicitly and very frequently throughout the delta plans.

6. Discussion

6.1. NbA as a strategy to address anthropogenic stress to deltas

Anthropogenic stress is rapidly changing our environment, which can cause tipping points in the Earth system. Tipping points in the cryosphere may already be dangerously close and model simulations suggest extreme sea-level rise as a result (Lenton et al., 2019). Floodings are a constant threat to societies in deltas and along coasts. This threat is likely to increase further in the future. The limitations of hard infrastructural adaptation to deal with these threats are illustrated by the Dutch Deltaworks in the southwestern part of the Netherlands, which significantly disrupted sediment fluxes in former estuaries and overall resulted in reduced ecosystem health (Van Wesenbeeck et al., 2014). NbA is often portrayed as the ultimate alternative to hard infrastructural adaptation. It has been argued that NbA is not only more cost-effective and sustainable but also provides ecosystem benefits such as water quality improvement, carbon sequestration, habitat provision, fisheries production and recreation (Hale et al., 2009; Temmerman et al., 2013). In theory, NbA seems like a great opportunity to adapt to the adverse consequences of anthropogenic activities in deltas.

However, currently, delta managers only have nine NbA strategies at hand. Besides, until now most research focussed on coastal wetland restoration and the other strategies get much less attention. This indicates a lack of research on NbA for deltas and coasts specifically. The Rhine and Mekong deltas are also projected to experience significant environmental change in the coming century, which likely constrains the feasibility of NbA. In contrast, most of the design principles for adaptive governance are present in the Rhine and Mekong delta plans which provides an opportunity for the incorporation of NbA. The extent to which the environment and current policies in the Rhine and Mekong deltas enable or constrain the feasibility of NbA will be further discussed in sections 6.2. and 6.3.

6.2. Environmental constraints on NbA in the Rhine and Mekong deltas

Here, the nine broad NbA strategies for deltas will be linked to the environmental variables included in this thesis. However, first, some implications of the projections of environmental change in the Rhine and Mekong deltas will be discussed.

6.2.1. Implications of environmental change

Sea levels and subsidence are projected to increase in the coming century for the Rhine and Mekong deltas, which results in high rates of relative sea-level rise. The maximum rate of relative sea-level rise that deltas can survive is also strongly influenced by the availability of sediments (Kirwan et al., 2010). Sediment availability in the Rhine delta seems to be relatively stable in the coming century. However, as a percentage of historical sediment load, it declines from about 85% in 2020 to 75% in 2100. In comparison to the Mekong delta, the amount of sediment the Rhine delta receives is very low. Sediment availability in the Mekong delta is currently only about 25% of the historical load and is projected to further decline to just under 20% in 2100. This reduction in sediment availability is largely attributable to dam construction in the upstream river (Dunn et al., 2019). Dams trap sediments in their reservoirs, as water velocities slow down. Coarse materials are more likely to be trapped behind dams, whereas fine sediments can often pass and travel further downstream. However, these fine sediments are less likely to deposit on the deltaic plain, because they are light and can therefore easily be carried to the sea (Kondolf et al., 2018). Therefore, the projected decline in sediment availability for the Rhine and Mekong deltas likely translates into an even larger reduction in sediment deposition on the delta plains

(Kondolf et al., 2018). This may constrain the feasibility of NbA strategies that require a minimum amount of sediment to survive increasing rates of relative sea-level rise. Model simulations predict that, if sediment supply to the Mekong delta follows the projected decline and current rates of sediment mining and groundwater pumping continue, the Mekong delta could be almost completely drowned by the end of this century (Schmitt, Rubin & Kondolf, 2017; Kondolf et al., 2018). In the Netherlands, approximately a quarter of the land is below sea level and 59% of the country is susceptible to flooding (PBL, n.d.). If relative sea levels continue to rise and sediment availability remains low, this area could be permanently inundated if not protected.

Land-use trends are relatively stable in the Rhine and Mekong deltas and show that just over half of the total land area in both deltas is occupied with fixed land-uses, including urban areas and croplands. In the Rhine delta, these fixed land-uses are concentrated along rivers and the coast. The Randstad is the most densely populated and urbanised area of the Rhine delta, with population densities up to 1500 people per km^2 (PBL, n.d.). It is also the most vulnerable area to flooding because it lies adjacent to the coast and large parts of the Randstad lie below sea levels (PBL, 2016). Most of the larger cities in the Rhine delta are located in the Randstad. These cities developed adjacent to rivers and the coast because of the favourable position for trade (De Mulder, De Pater & Fortuijn, 2018). Agricultural developments are also concentrated in this low-lying, fertile part of the Netherlands (Rongwiriyaphanich, 2014). The same is true for the Mekong delta. Population densities in the districts along the Mekong and Bassac channels are up to 1000 people per km^2 (Renaud & Kuenzer, 2012). The concentration of people along rivers and canals is mostly attributable to the seasonal floods during the wet season, which brings fertile sediments that create productive agricultural lands along river banks (Keskinen, 2008; Renaud & Kuenzer, 2012). In addition, approximately half of the Mekong delta population lives within 40 km from the coast (Schmitt, Rubin & Kondolf, 2017).

Hence, the areas that are most vulnerable to flooding in the Rhine and Mekong deltas and where NbA strategies would be most needed to prevent the occurrence of loss & damage, are also the areas where fixed land-uses are mostly concentrated. This may constrain the feasibility of NbA strategies that require a lot of space. Although non-fixed land-uses such as pastures and other land-uses could, in theory, be moved to another location to provide more space for NbA, such land-use change is also not easy. It requires significant resources and willingness of people to move (Colls, Ash & Ikkala, 2009; Temmerman et al., 2013).

6.2.2. Effect of environmental change on the feasibility of NbA

For each of the nine delta-specific NbA strategies, it will be discussed which environmental variables included in this thesis constrain the success of that strategy. An overview of this discussion is provided in Figure 11. If one or more environmental variables constrain a strategy, the feasibility of that strategy to address anthropogenic stress in the Rhine and Mekong deltas is assumed to be limited. Sea-level rise, subsidence, reduced sediment availability and land-use change are all issues that may be very difficult to address. Slowing down the rate of global climate change requires strong international collaboration with countries that may have diverging preferences. The same is true for ensuring a continued supply of sediments to the deltas. Although subsidence and land-use change are local issues, they do require strong participation and willingness of the public to change. Therefore, I assume here that opportunities for NbA exist when none of the environmental variables constrain the feasibility of a NbA strategy.

6.2.2.1. Coastal wetland restoration

Until now, most research on NbA in coastal areas and deltas focussed on the restoration of coastal wetlands. Therefore, coastal wetland restoration is the only NbA strategy for which quantified, hard thresholds were found in the literature with which the projections of environmental change could be compared. Thresholds were found for relative sea-level rise and the space required for coastal wetlands.

The feasibility of coastal wetland restoration in the Rhine delta is constrained by sediment availability and potentially by land-use, whereas in the Mekong delta this strategy is constrained by all environmental variables included in this thesis (Figure 11). I assume that saltmarsh restoration is suitable for the Rhine delta and mangrove restoration for the Mekong delta. Research has shown that saltmarshes can survive rates of relative sea-level rise of 10 up to 50 mm/year (Kirwan, Temmerman, Skeehan, Gunenspergen & Fagherazzi, 2016). This threshold largely depends on the concentration of suspended sediments in the water that floods the saltmarsh and on the local tidal range (Kirwan et al., 2016). Projected relative sea-level rise for the Rhine delta is 6 mm/year. If saltmarshes are indeed as resilient as we think, this indicates that sea-level rise and subsidence do not limit the feasibility of coastal wetland restoration in the Rhine delta. Mangroves, in contrast, likely cannot sustain a relative sea-level rise of more than 6.1 mm/year (Saintilan et al., 2020). Projected relative sea-level rise for the Mekong delta is 13 mm/year. This rate is considerably higher than the maximum threshold that mangroves can survive (Saintilan et al., 2020). Coastal wetland restoration in the Mekong delta is therefore highly limited by sea-level rise and subsidence.

The restoration of coastal wetlands also depends on sediment availability and land-use. Sediment availability is projected to decline for both deltas in the coming century. This could worsen the effect of relative sea-level rise on the feasibility of coastal wetland restoration. Besides, coastal wetlands require a minimum width to provide effective protection and they need to be able to migrate landward in response to relative sea-level rise. For coastal saltmarshes, research has shown that wave attenuation mostly takes place in the first 80 meters of a saltmarsh (Möller, 2020). A critical width of 140 meters has been identified to sustain a healthy mangrove forest (Phan, van Thiel de Vries & Stive, 2015). Saltmarshes and mangroves thus do not necessarily have to take up a significant amount of space. However, the thresholds are difficult to couple with the land-use trends for the Rhine and Mekong deltas. In this thesis, fixed land-use as a fraction of total land-use for the whole deltas was analysed, but this does not indicate where these land-uses are located. Although fixed land-uses are concentrated along the coast in the Rhine and Mekong deltas, exactly how much space there is for coastal wetland restoration remains uncertain. Therefore, land-use is a potential constraint on coastal wetland restoration in the Rhine and Mekong deltas and is indicated with a striped box in Figure 11.

6.2.2.2. Riverine wetland restoration

Riverine wetland restoration in the Rhine and Mekong deltas is constrained by all environmental variables included in this thesis (Figure 11). The projected sea-level rise and subsidence may result in salt intrusion in the Rhine and Mekong deltas. Salt intrusion has been shown to alter and deteriorate the hydrology of riverine wetlands, reducing the health of these ecosystems and subsequently their capacity to provide flood protection. As salt intrusion mostly occurs near river mouths, there may be possibilities for riverine wetland restoration further upstream the rivers. However, sediment availability is also important for riverine wetland restoration, as these wetlands need to be able to accrete relative to the river. As sediment availability in both deltas is projected to decline and may translate into even lower sediment deposition, the feasibility of riverine wetland restoration in the Rhine and Mekong deltas is significantly reduced. Besides, transforming floodplains back into nature to restore riverine wetlands requires a lot of space. Fixed land-uses in the Rhine and Mekong deltas are concentrated along rivers, which likely limits the available space for riverine wetland restoration.

6.2.2.3. Reforestation of riparian zones

Land-use is the only environmental variable included in this thesis that constrains the feasibility of reforestation of riparian zones in the Rhine and Mekong deltas (Figure 11). Restoring forests in riparian zones requires a lot of space. However, as cities and agricultural lands in the Rhine and Mekong deltas are mostly located along river banks, this space may not be available. This constrains the feasibility of reforestation of riparian zones.

6.2.2.4. Restoration of dynamic dune systems

The restoration of dynamic dune systems in the Rhine and Mekong deltas is constrained by sea-level rise, subsidence and land-use (Figure 11). Natural dune systems are covered with vegetation and they need to be able to migrate landward in response to coastal erosion. As relative sea-levels are projected to rise in the Rhine and Mekong deltas in the coming century, coastal erosion will likely increase. This limits the capacity of dune systems to provide effective protection against flooding. Besides, for dune systems to migrate landward, the land behind the dunes needs to be empty. However, half of the Rhine and Mekong deltas consist of fixed land-uses which are concentrated in coastal areas. Land-use change is likely to be difficult as people may oppose having to move to another location. As a result, dune systems are trapped between rising relative sea levels on one side and infrastructures and agricultural fields on the other side. The ability of dune systems to migrate landward may, therefore, be limited.

6.2.2.5. (Re)construction of biogenic reefs

None of the environmental variables included in this thesis constrain the feasibility of (re)construction of biogenic reefs as a NbA strategy in the Rhine and Mekong deltas (Figure 11). Therefore, this strategy provides an opportunity for delta managers to include NbA. Biogenic reef structures can significantly reduce the impact of incoming waves, thereby minimising coastal erosion (Kochmann et al., 2008; Morris et al., 2019). It may, therefore, contribute to the feasibility of NbA strategies that are threatened by coastal erosion, such as the restoration of dynamic dune systems and beach nourishment. Furthermore, biogenic reefs function as dams. They trap water that would normally flow back toward the sea during low tides, which facilitates sediment deposition on the shoreline side of the reefs. In this way, the coastline is stabilised and it has even been shown to contribute to the development to coastal wetlands due to increased sediment availability (Palumbi et al., 2009; Gracia et al., 2018).

6.2.2.6. Restoration of seagrass beds

The restoration of seagrass beds in the Rhine and Mekong deltas is constrained by sea-level rise and may also be constrained by land-use (Figure 11). The optimal position of seagrasses is in shallow, low-wave environments. The environments where seagrasses are currently settled are likely to be significantly altered by the projected sea-level rise in the Rhine and Mekong deltas. In response to sea-level rise, seagrasses migrate landward to maintain their optimal position. However, this landward migration can be obstructed by coastal infrastructures, such as breakwaters, groins and harbours. Over half of the Rhine and Mekong deltas are occupied with fixed land-uses and these urban areas and croplands are concentrated in coastal areas. However, this does not provide much information about the presence and location of breakwaters, groins and harbours because such infrastructures are not located on the land but reside in seawater. Therefore, the results of this thesis provide insufficient information about whether or not there is enough space available for seagrass migration in the Rhine and Mekong deltas. This is indicated with a striped box in Figure 11.

6.2.2.7. Ecological enhancement of dikes

None of the environmental variables included in this thesis constrain the feasibility of the ecological enhancement of dikes in the Rhine and Mekong deltas (Figure 11). Creating wider dikes with a gentle slope positively impacts nature, recreation and tourism (Scheres & Schüttrumpf, 2019). Further enhancing dikes by adding grasses or woody vegetation reduces dike erosion, balances water quality and temperature, and provides a habitat for a variety of species (Scheres & Schüttrumpf, 2019). Ecologically enhancing dikes provides an opportunity for delta managers to include NbA into current adaptation strategies, as it protects the hinterland from flooding while simultaneously providing multiple benefits to the surrounding ecosystems and communities.

6.2.2.8. Restoration of natural sedimentation processes

The restoration of natural sedimentation processes in the Rhine and Mekong deltas is constrained by sediment availability and land-use (Figure 11). Sufficient sediment needs to be available to restore natural sedimentation processes. However, the sediment that is carried by the Rhine and Mekong rivers is lower than the historical sediment load. Besides, it mostly consists of fine sediments as coarse materials are trapped behind dams, which may result in very little sediment deposition. In addition, measures such as tidal river management and river diversions require a lot of space because lands along the coast and rivers have to be temporarily flooded. This would require significant (intermittent) land-use change because urban land-uses and agriculture are mostly located along the coast and river banks in the Rhine and Mekong deltas. This is problematic. Fixed land-uses are very difficult to relocate. Besides, even the relocation of non-fixed land-uses requires strong participation and willingness of people to move to another location.

6.2.2.9. Beach nourishment

Beach nourishment in the Rhine and Mekong deltas is constrained by relative sea-level rise and land-use (Figure 11). Beach nourishment needs to be carried out periodically, as waves and wind carry away the deposited sand. Wave impacts will likely increase in the coming century as the Rhine and Mekong deltas are projected to experience an increase in sea levels. Both deltas are also projected to subside, which together with sea-level rise worsens coastal erosion. Besides, for beaches to provide adequate protection against flooding, they need to be relatively wide. The wider the beach, the more protection. Therefore, they require much more space than engineering structures. For coastal areas such as the Rhine and Mekong deltas where population densities are very high and a large percentage of the croplands can be found, this space is likely not available.

6.2.2.10. Summary

In the coming century, more environmental variables constrain the feasibility of NbA in the Mekong delta compared to the Rhine delta, indicated by the larger number of light brown boxes for the Mekong delta in Figure 11. This is mostly attributable to the high rates of subsidence the Mekong delta is projected to experience due to continued groundwater abstraction (Minderhoud et al., 2020), which likely results in extreme rates of relative sea-level rise. However, the total number of NbA strategies that face serious implementation constraints is the same for the Rhine and Mekong deltas. Currently, seven of the nine NbA strategies in the Rhine and Mekong deltas are constrained by one or more of the environmental variables included in this thesis. Implementing these seven strategies may be very difficult and they are likely to be less effective if implemented. NbA in the Rhine and Mekong deltas is, therefore, highly constrained by the projections of environmental change. (Re)construction of biogenic reefs and ecological enhancement of dikes are the only two strategies that are not constrained by any of the environmental variables in the Rhine and Mekong deltas. These strategies are likely to be successful if implemented and provide opportunities for the incorporation of NbA in both deltas.

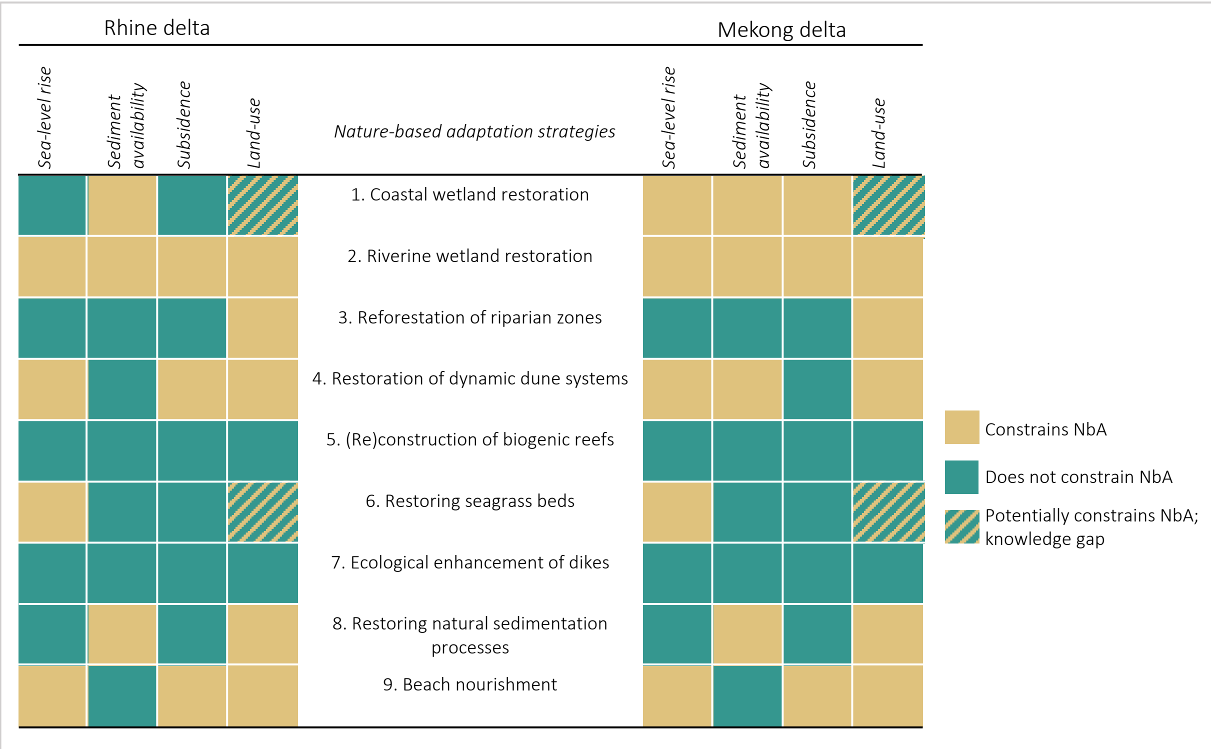

Figure 11. Overview of the nine NbA strategies identified in existing publications (down the middle) and the environmental variables that enable or constrain the NbA strategies in the Rhine delta (left) and the Mekong delta (right). Light brown boxes indicate constraints. Teal boxes show that an environmental variable does not constrain the incorporation of a NbA strategy, indicating opportunities. Striped boxed indicate potential constraints. Further research is needed to identify these variables as opportunities or constraints.

6.3. Policy constraints on NbA in the Rhine and Mekong deltas

The principles for adaptive governance seem to have been an inspiration for the stakeholders included in the establishment of the Rhine and Mekong delta plans. Both delta plans enable the feasibility of NbA because of their good coverage of most principles. There are likely even fewer policy constraints on NbA in the Rhine delta compared to the Mekong delta, because the Rhine delta plan includes one more principle than the Mekong delta plan. In addition, the Rhine delta plan has a formal status in the Dutch administrative system whereas the Mekong delta plan has no formal status. This indicates that the Netherlands is probably further advanced in their policies concerning delta management than Vietnam is. This is not surprising, as the Dutch have already been protecting themselves against water since the Middle Ages (Schreuder, 2001).

The degree to which the Rhine and Mekong delta plans encompass the legal and institutional design principles for adaptive governance is summarised in Figure 12. Figure 12 clearly illustrates the strengths and limitations of the delta plans regarding adaptive governance. The strengths and limitations affect the feasibility of NbA in different ways. The strength of the Rhine and Mekong delta plans lies in the emphasis on tangible support, well-defined boundaries and participatory decision-making. The limitations of the delta plans are illustrated by the principles that are currently lacking. For the Rhine delta plan, this is legally binding responsibility. The limitations of the Mekong delta plan are reflexive law and internal enforcement. The strengths and limitations of the Rhine and Mekong delta plans will be discussed in more detail in the sections below.

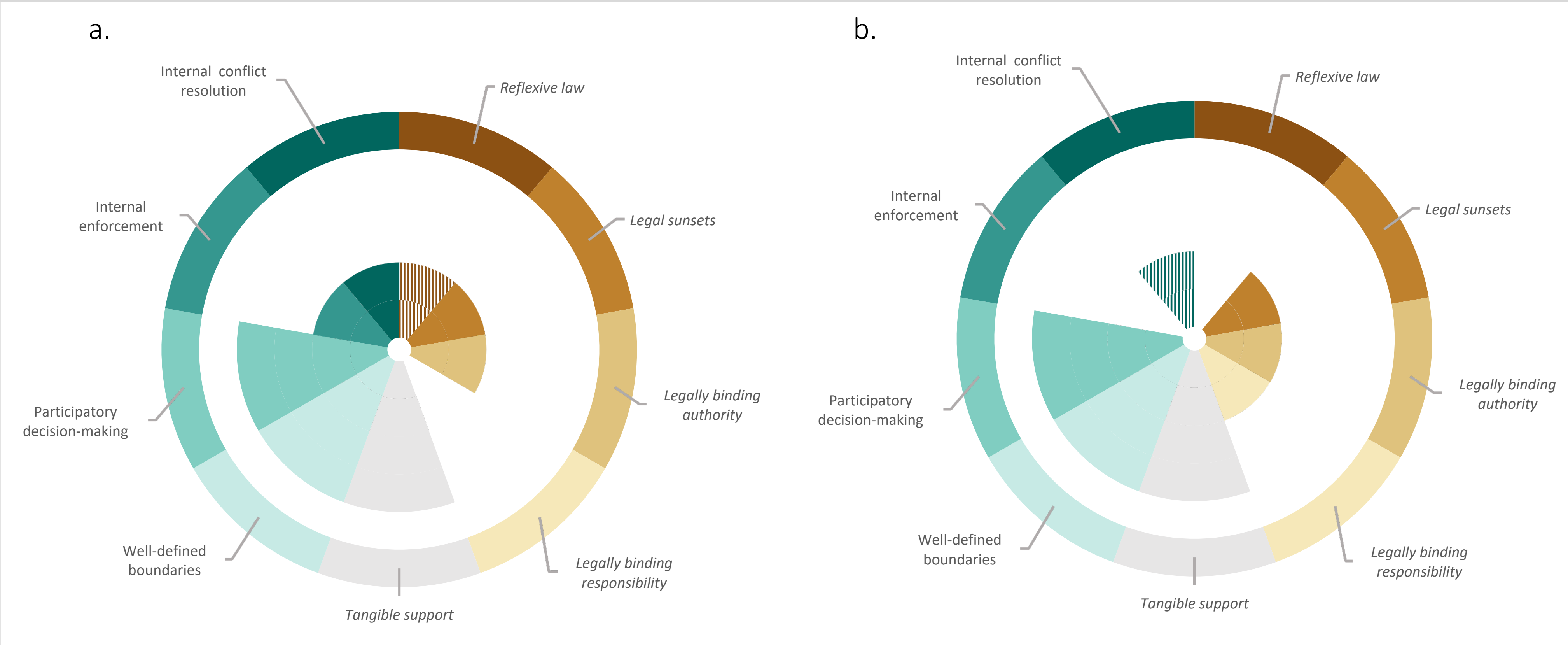

Figure 12. Overview of the results of the Rhine (a) and Mekong (b) delta plan analyses. Radiating bars indicate the frequency with which the legal (in *italics*) and institutional design principles (in normal text) for adaptive governance were found to be present in the delta plans. No bar indicates the absence of a principle and hence a constraint on NbA, short bars indicate a low frequency (< five times) and long bars indicate a high frequency (> five times). The chart also distinguishes between principles that are explicitly present (in uniform colours) and principles that are implicitly present (in striped patterns) in the delta plans.

6.3.1. Strengths of the delta plans

The Rhine and Mekong delta plans both strongly emphasise the principles of tangible support, well-defined boundaries and participatory decision-making. These principles are explicitly present and mentioned very frequently in both delta plans (Figure 12). It is not surprising that these principles are perceived as important. Governance in the Netherlands has a long tradition of cooperation, consensus building and democratic self-rule among a variety of stakeholders (Schreuder, 2001). This is called the polder model. It originated in the Middle Ages when low-lying areas of the land were reclaimed from bodies of water and subsequently protected by dikes against future flooding. Windmills were placed on the dikes to pump the water from the polders into a canal. Strong participation and cooperation between a variety of stakeholders was necessary to maintain this system and ensure its proper functioning (Schreuder, 2001). This indicates that the principle of participatory decision-making is simply deeply rooted in Dutch tradition and culture. It logically follows that tangible support and well-defined boundaries are also emphasised in the Rhine delta plan because these principles are supportive of participatory decision-making. Tangible support ensures that stakeholders have sufficient resources to effectively participate and well-defined boundaries is needed to clarify jurisdictions which facilitates cooperation and collective problem solving (DeCaro et al., 2017a). It is not striking that the same principles are emphasised in the Mekong delta plan. After all, the Mekong delta plan is the result of a collaboration between the Vietnamese and Dutch governments. Presumably, the Dutch government emphasised the same principles in helping to create a plan for the Mekong delta. The importance of these principles for NbA is discussed below. This underlines why three these principles enable the incorporation of NbA in the Rhine and Mekong deltas.

Delta-specific NbA strategies build on and incorporate the dynamic behaviour of deltas. Therefore, the governance systems responsible for the management of deltas inherently have to deal with many uncertainties and complexities. This requires flexibility in decision-making, responsiveness, innovation and creativity, which can be achieved by incorporating a wide variety of environmental stakeholders with their own perspectives and knowledge (Folke et al., 2005; Wamsler, 2015; DeCaro et al., 2017a). The involvement of various stakeholders, in turn, also contributes to awareness-raising and consensus-building (Jongman, 2018). In this way, participatory decision-making is very important for NbA in the Rhine and Mekong deltas. This principle underlines the importance of local knowledge, consensus building, and long-term social learning in the management of dynamic ecosystems (Wheeler, 2000; Cox, Arnold & Tomás, 2010). Local and regional stakeholders "have first-hand and low-cost access to information about their situation and thus a comparative advantage in devising effective rules and strategies for that location, particularly when local conditions change" (Cox, Arnold & Tomás, 2010, p.9). Therefore, these stakeholders should be able to participate in making plans and implementing NbA strategies (Ostrom, 2010).

For stakeholders to be able to successfully participate in the decision-making processes and implementation phase of NbA, proper technical, financial and informational support is required (Wheeler, 2000; DeCaro et al., 2017a). That is because the capacity of an organisation, institution or stakeholder to execute a task satisfactorily very much depends on whether that organisation, institution or stakeholder has sufficient access to the resources needed to perform that task (Marshall, 2008). This underlines the importance of tangible support for the incorporation of NbA strategies in the Rhine and Mekong deltas. Furthermore, tangible support stimulates experimental processes as stakeholders are encouraged to devise their own strategies, which in turn contributes to social learning (DeCaro et al., 2017a). Social learning is important for sharing knowledge about how to deal with all the complexities and uncertainties associated with implementing NbA strategies in deltas.

Working together with a variety of different stakeholders may be overwhelming and cause some confusion if jurisdictions are unclear. To ensure that the management of the Rhine and Mekong deltas remains feasible, both logistically and politically, socio-political and ecosystem boundaries should be well-defined (DeCaro et al., 2017a). It has been argued that one of the most important tasks of environmental governance is defining the boundaries of natural resources that cross territorial borders (Moss & Newig, 2010), such as rivers and deltas. For the successful implementation of NbA strategies, different stakeholders have to work together to solve the problems that may emerge. If socio-political and ecosystem boundaries are well-defined, this makes collectively solving problems easier (Ostrom, 2010; DeCaro et al., 2017a). However, caution is required, because defining boundaries too rigidly obstructs flexible participation of stakeholders. In some cases, "fuzzier social and geographic boundaries" are required to facilitate flexible arrangements (Cox, Arnold & Tomás, 2010, p.6).

6.3.2. Limitations of the delta plans

To optimise the policy feasibility of NbA in the Rhine and Mekong deltas, is it essential that the principles that are currently missing from the delta plans are also included. However, the limitations of the Rhine and Mekong delta plans are minimal and therefore also have a small effect on the overall policy feasibility of NbA in both deltas.

6.3.2.1. Limitations of the Rhine delta plan

The Rhine delta plan does not include the principle of legally binding responsibility (Figure 12). Although it is indicated in the delta plan that the Minister of Infrastructure and Water Management is ultimately responsible for progress on the delta plan, further responsibilities are not assigned to different stakeholders. This constrains the feasibility of NbA in the Rhine delta, because if different stakeholders are formally assigned with the responsibility for implementing NbA strategies to combat flooding, then they are more likely to be motivated to help contribute to this cause (Ostrom, 2010; DeCaro et al., 2017a). Furthermore, evidence has shown that by formally placing the responsibility to attain certain sustainability standards by local governments, collaboration, coordination and resource sharing between these local governments increased (Wheeler, 2000; DeCaro et al., 2017a). An opportunity for the inclusion of legally binding responsibility lies in existing laws that already formally define the decision-making latitude of stakeholders in the Rhine delta, such as the Water law and the Delta law. These laws could also include a section that defines and assigns responsibilities to other stakeholders. In this way, not only legally binding authority is included but also legally binding responsibility, which may trigger novel stewardship activity (DeCaro et al., 2017a). This means that regional and local governments, civil society organisations, businesses and other stakeholders are more likely to perceive themselves as being responsible for the successful implementation of NbA to prevent the Netherlands from flooding.

6.3.2.2. Limitations of the Mekong delta plan

Reflexive law and internal enforcement are absent from the Mekong delta plan (Figure 12). Reflexive law, which prescribes that laws should define procedural norms instead of specifying outcomes as an ultimate result, allows for flexible decision-making at lower levels of government that is required to deal with dynamic ecosystems (Garmestani & Benson, 2013). The central government takes on an oversight role to ensure that outcomes are met, but how these outcomes should be realised is not dictated. This is important for NbA in deltas because NbA aims to increase the resilience of deltas by allowing them to remain dynamic. As a result, socio-ecological conditions in deltas are likely to change much more frequently. Rigid, national policies specifying exact solutions can therefore rapidly become outdated (Garmestani & Benson, 2013; Benson, Llewellyn, Morrison & Stone, 2014). However, instead of enhancing flexibility and adaptability of governance systems by leaving final solutions open, a study on adaptive freshwater management found that policy development in the Mekong delta often does not systematically tackle uncertainty in this way (Ha, Dieperink, Dang Tri, Otter & Hoekstra, 2018). This is attributed to a lack of funds allocated to experiment with different governance solutions at the local level (Tran et al., 2018). National policies prioritise hard, infrastructural strategies such as dike building in the Mekong delta, at the expense of developing a diverse suite of adaptation strategies at lower levels that consider local circumstances (Smith, Thomsen, Gould, Schmitt & Schlegel, 2013). This may explain why reflexive law is currently lacking from the Mekong delta plan.

Stakeholder participation enhances conditions for creativity, innovation and information sharing which is essential for the successful implementation of NbA (Folke et al., 2005; Wamsler, 2015). In this context, internal enforcement is important to monitor the behaviour of those stakeholders and enforce compliance with rules (DeCaro et al., 2017a). Monitoring also makes those who do not comply with rules visible to the community, which, in turn, increases the effectiveness of rule enforcement mechanisms (Cox, Arnold & Tomás, 2010). Therefore, the lack of internal enforcement in the Mekong delta plan is a constraint on the policy feasibility of NbA in the Mekong delta (Figure 12). Currently there is no way specified in the delta plan in which stakeholders are monitored to ensure that NbA strategies are implemented effectively. Ha et al. (2018) also found that policies in the Mekong delta are often poorly enforced. This is attributed to a lack of manpower at district and commune governments to monitor stakeholders and enforce their compliance. Taxes are sometimes used as an enforcement mechanism but local households in the Mekong delta are often too poor to pay these taxes (Ha et al., 2018). This may explain why internal enforcement is currently absent from the Mekong delta plan. Essential for effective internal enforcement in the Mekong delta is that the monitors are members of the community they are monitoring or that they are accountable to members of the community (Cox, Arnold & Tomás, 2010).

6.4. Implications of constraints on NbA

Although the Rhine and Mekong deltas are two highly contrasting cases, interestingly the feasibility of NbA to address anthropogenic stress in the deltas is similar. The Rhine and Mekong delta plans are sufficiently based on principles for adaptive governance. Therefore, from a policy perspective, there are opportunities for NbA in both deltas. However, the environmental feasibility of NbA is highly constrained. At present, the only two nature-based strategies that could be easily implemented (i.e. without environmental constraints) by delta managers in the Rhine and Mekong deltas are (re)construction of biogenic reefs and ecological enhancement of dikes. However, these two strategies are likely insufficient to deal with the full range of challenges that currently threaten the inhabitants of the Rhine and Mekong deltas. In addition, although studies have experimented with NbA strategies at the local scale (Cohen-Shacham et al., 2019), it is very difficult to scale these strategies up to regional or even global levels (Temmerman et al., 2013). Therefore, NbA may not be feasible to fully address anthropogenic stress to the Rhine and Mekong deltas. This may also be true for other deltas worldwide. Other approaches, or combined approaches, are thus required.

There is an urgent need for hybrid solutions that combine strong mitigation measures, with various adaptation strategies and strategies to deal with the residual loss & damage. Examples of such strategies are presented in Figure 13, which zooms in on the 'contributions of this thesis' section of the original mitigation, adaptation and loss & damage framework in Figure 2.

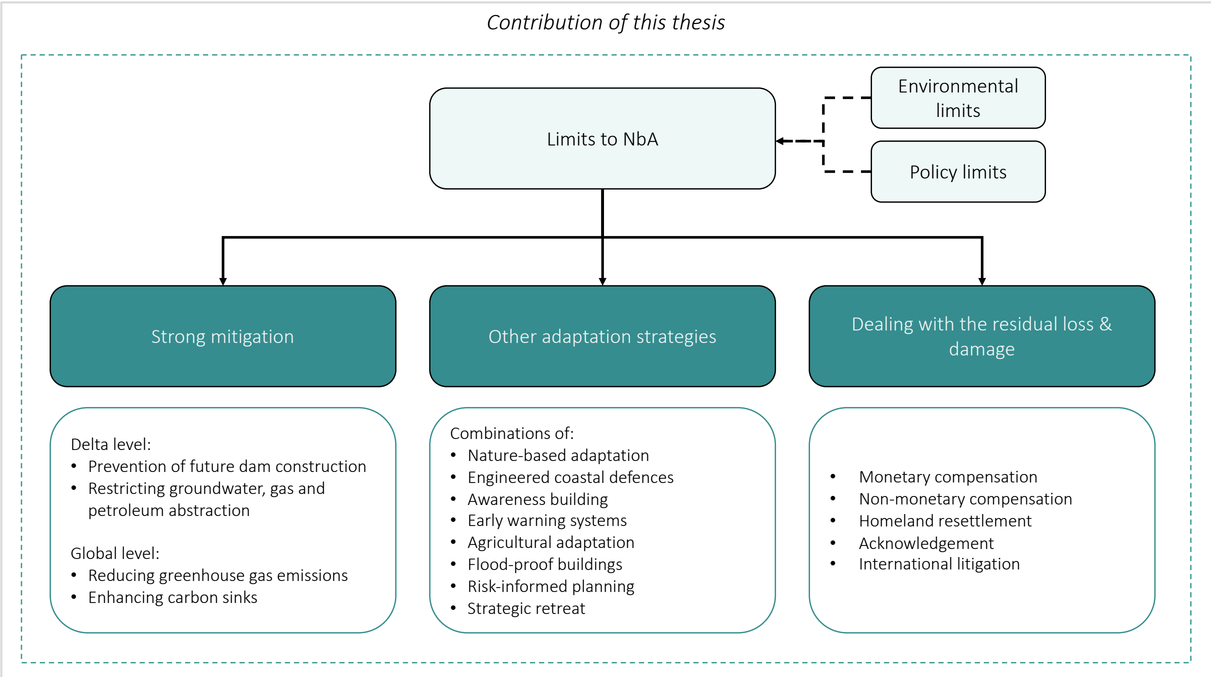

Figure 13. Implications of constraints on NbA. As NbA is highly constrained in the Rhine and Mekong deltas from an environmental perspective, there is an urgent need for strong mitigation, other adaptation strategies, and dealing with loss & damage. This figure zooms in on the 'contributions of this thesis' section in Figure 2.

6.4.1. Need for hybrid solutions

6.4.1.1. Strong mitigation

To prevent the projections of environmental change in the Rhine and Mekong deltas from becoming reality, strong mitigation measures are required at the delta level and the global level (Figure 13). At the delta level, a potential mitigation measure to ensure a continued supply of sediments to the deltas is preventing future dam construction (Dunn et al., 2019). The trapping of sediments behind dams makes deltas increasingly vulnerable to subsidence, erosion and sea-level rise and threatens their long-term sustainability (Anthony et al., 2015; Dunn et al., 2019). Another example of a mitigation measure at the delta level is restricting the abstraction of groundwater, gas and petroleum. This can cause accelerated land subsidence, which increases the vulnerability of the Rhine and Mekong deltas to flooding, salinization and coastal erosion (Minderhoud et al., 2020). Groundwater abstraction is one of the main causes of subsidence in the Mekong delta (Erban, Gorelick & Zebker, 2014; Minderhoud et al., 2017).

Mitigation efforts at the global level are required to halt the rate of global warming and thus sea-level rise. This reduces the threat of permanent inundation in the Rhine and Mekong deltas, but also in other deltas across the globe. Two potential strategies are reducing the sources of greenhouse gas emissions and enhancing carbon sinks. Greenhouse gas emissions can be reduced for example through switching to renewable energy technologies such as wind, solar, geothermal, biomass and hydropower (Arent, Wise & Gelman, 2011). Emissions can also be reduced through dietary changes. Greenhouse gas savings could be up to 22% and 26% for vegetarian and vegan diets respectively (Berners-Lee, Hoolohan, Cammack & Hewitt, 2012). In addition to reducing the sources of greenhouse gases, enhancing carbon sinks is an important strategy. This can be done through for example afforestation, reforestation and avoiding deforestation (Reyer, Guericke & Ibisch, 2009).

6.4.1.2. Other adaptation strategies

The environmental data analysis shows that the feasibility of many of the NbA strategies are constrained because they require a lot of space. This is space may not be available in the Rhine and Mekong deltas, because urban land-uses and croplands are concentrated in coastal areas and along river banks. Hard, infrastructural adaptation, such as embankments and storm surge barriers, takes up less space (Temmerman et al., 2013). However, infrastructural adaptation negatively impacts surrounding ecosystems and disadvantages communities that depend on the services provided by these ecosystems (Borsje et al., 2011; Reguero et al., 2014).

Combining infrastructural adaptation with small-scale nature-based solutions may be a very suitable alternative to protect the Rhine and Mekong deltas from flooding while simultaneously providing benefits to communities and nature by restoring natural ecosystems (Figure 13) (Jongman, 2018). Combining engineered defences with natural ecosystems is much more adaptive and sustainable than solely relying on infrastructural adaptation (Temmerman et al., 2013; Van Wesenbeeck et al., 2014; Temmerman & Kirwan, 2015). For example, combining mangrove restoration with dikes reduces construction and maintenance costs of dikes, because wave action on the dike is reduced, while simultaneously providing effective protection against flooding and ecosystem benefits from the mangrove restoration (Jongman, 2018). Besides, the NbA strategies that currently have no environmental constraints in the Rhine and Mekong deltas can create enabling conditions for other NbA strategies. For example, (re)construction of biogenic reefs has been shown to reduce coastal erosion, which enhances the feasibility of beach nourishment and the restoration of dynamic dune systems. Biogenic reefs can also trap seawater like a dam which increases sediment deposition. This enhances the feasibility of the restoration of coastal wetlands such as mangroves and saltmarshes.

In addition to protective adaptation approaches, such as awareness building, early warning systems, and combining infrastructural adaptation with NbA, accommodative approaches are required (Nicholls, 2015). Accommodation strategies encourage people to adapt to the new reality that lands can often flood. Large parts of the Rhine and Mekong deltas are used for agriculture, which requires agricultural adaptation strategies (Figure 13). Examples include switching to saline tolerant crops to deal with salt intrusion, floating agriculture, switching from agriculture to aquaculture or combinations of agriculture and aquaculture, such as rice-fish mixed farming (Islam, Shitangsu & Hassan, 2015; Van Staveren, Warner & Khan, 2017). In addition, the Rhine and Mekong deltas are densely populated. Buildings can be redesigned to better sustain floodings, for example by building houses on stilts or floating houses (Figure 13) (Nicholls, 2015).

Strategic retreat and risk-informed planning are also required (Figure 13) (Cheong et al., 2013; Van Wesenbeeck et al., 2014; Nicholls, 2015; Jongman, 2018). Strategic retreat and preventing development in areas that are threatened by erosion and flooding are important strategies to deal with flood risks in the Rhine and Mekong deltas (Nicholls, 2015). Strategic retreat has been argued to be the best response to relative sea-level rise (Pilkey & Young, 2015). However, the implementation of this strategy is likely problematic, considering all the social issues around relocating people and having to live with a growing population on an even smaller land area. The optimal mix of different adaptation measures will vary from place to place, as it depends on the level of risk, funding and political will (Jongman, 2018).

6.4.1.3. Dealing with residual risks and loss & damage

Unfortunately, even strong mitigation and adaptation efforts in the Rhine and Mekong deltas may not be sufficient to fully prevent all the negative impacts from anthropogenic stress. Worldwide, threats to deltas remain even after mitigation and adaptation measures have been implemented, which affects hundreds of millions of people, buildings and infrastructure, and tourism, and may result in significant economic losses and damaged livelihoods (Reguero et al., 2014; James et al., 2014). Strategies to deal with the residual loss & damage from climate change and other human-driven stresses are therefore required, for example in the form of compensation (Figure 13) (Burkett, 2014). Risk transfers allow a country to pay a fee to an insurer or another pool of countries that in turn would compensate affected areas for the loss & damage incurred. This allows for the rapid provision of funds to areas after a disaster has occurred (Burkett, 2014). Compensation can also be non-monetary (Boyd et al., 2017), for example in the form of food or other basic necessities. Other potential measures to deal with loss & damage are homeland resettlement, acknowledgement and international litigation (Figure 13) (Boyd et al., 2017).

6.4.2. Implications of environmental change for governance

6.4.2.1. Limited agency

Although NbA in the Rhine and Mekong deltas is mostly constrained by the environmental variables, the agency of the Netherlands and Vietnam in changing these environmental variables is limited. In other words, it is difficult for the Netherlands and Vietnam to enhance conditions for NbA in the Rhine and Mekong deltas. This is especially true for sea-level rise and sediment availability. Climate change, and thus sea-level rise, is a global issue in which all countries have a share. Therefore, the impact of climate change mitigation efforts taken in the Netherlands and Vietnam is small, although mitigation efforts in the Netherlands would have a bigger effect than similar efforts in Vietnam as the Netherlands emits more greenhouse gases (World Bank, 2014). Effectively slowing down climate change-induced sea-level rise would require strong international agreements and enforcement. The same is true to a certain extent for sediment availability. Although sediment availability is a regional issue, ensuring a continued supply of sediments to the Rhine and Mekong deltas would also inherently involve international agreements and collaboration with upstream countries, which often have diverging preferences. Compromises have to be made, which reduces the capacity of the Netherlands and Vietnam in ensuring the supply of sufficient sediments to the Rhine and Mekong deltas.

The only two environmental variables that can be altered by governance efforts in the Netherlands and Vietnam are land-use and subsidence, as these are mostly local issues. This is therefore where trade-offs between different governance systems become important. Due to the constraints on NbA, adaptive governance may be insufficient to sustainably manage the Rhine and Mekong deltas.

6.4.2.2. Combining governance systems

Although the adaptive governance framework is important for the feasibility of NbA, the results of this thesis have shown that NbA is constrained by various environmental variables and it may be insufficient to protect the Rhine and Mekong deltas from anthropogenic stress. Many environmental processes in deltas are changing too quickly for society to mitigate or adapt. As a result, the long-term sustainability of deltas is compromised and there may be a fundamental need for sustainability transitions (Chaffin et al., 2016). When a socio-ecological system, such as a delta, has eroded to a point where it is no longer sustainable, regime shifts are necessary. However, such shifts cannot be facilitated by the adaptive governance framework (Chaffin et al., 2016). Instead, transformative governance aims to actively shift a socio-ecological system to "an alternative and inherently more desirable regime by altering the structures and processes that define the system" (Chaffin et al., 2016; p. 400). Where adaptive governance aims to preserve socio-ecological systems in their most natural and dynamic state, transformative governance aims to fundamentally transform socio-ecological systems when they are no longer sustainable. Transformative governance requires elements of governance that exceed those required for adaptive governance because instead of trying to maintain a system, governance systems need to have the capacity to shape sustainable change in socio-ecological systems (Chaffin et al., 2016). However, the institutionalisation of adaptive governance does provide an opportunity for the emergence of transformative governance, because actors and networks involved in adaptive governance build capacity for adaptive change and produce narratives of change that can be used to frame the need for sustainability transformations (Chaffin et al., 2016). As most of the design principles for adaptive governance are present in the Rhine and Mekong delta plans, there are opportunities for the development of transformative governance.

The adaptive and transformative governance frameworks both underline the importance of interaction and stakeholder participation for enhancing flexibility and driving change (Chaffin et al., 2016). However, the extent to which participation actually positively contributes to the quality of decisions depends on the participation processes leading up to those decisions (Reed, 2008). If participatory processes are not well run, stakeholders may feel like their influence on decisions is limited (Burton et al., 2014). It is not enough to facilitate participation if stakeholders cannot actually participate, for example, if decisions are too technical and stakeholders do not have the required knowledge (Weber & Christopherson, 2002). Such issues are not emphasised in the adaptive and transformative governance frameworks. This is where the interactive governance framework comes in. According to interactive governance, it is not only the extent of stakeholder participation, but the quality that determines the performance of governance systems (Chuenpagdee, 2011). Interactive governance underlines that participation groups should reflect the broader interest of society. Concepts such as equity and empowerment are highly valued, whereas this lacks in the other governance frameworks. These values are, however, especially important in the face of current and future threats to deltas. Currently, more than 500 million people live in deltas. Therefore, rising relative sea-levels may result in significant economic losses and damaged livelihoods, which often hits vulnerable communities the hardest. Interactive governance assumes that broad societal participation is desirable because it is an expression of democracy and it stimulates the formulation of common, inclusive objectives and policies (Bavinck, Chuenpagdee, Mahon & Pullin, 2008; Torfing, Peters, Pierre & Sørensen, 2012). Interactions between different public and private stakeholders, all with their own resources and strategies, is assumed to be important to solve complex issues associated with dynamic ecosystems such as deltas (Kooiman, Bavinck, Chuenpagdee, Mahon & Pullin, 2008; Chuenpagdee, 2011; Torfing et al., 2012).

A one-size-fits-all governance solution is likely to fail (Ostrom, 2007). Different governance frameworks have their strengths and weaknesses. Therefore, I contend that the best way to manage the challenges resulting from anthropogenic stress in the Rhine and Mekong deltas is combining the three frameworks above. Combining the flexibility of the adaptive governance framework, with the aim for sustainability transitions of the transformative governance framework, and inclusive societal participation from the interactive governance framework, may result in more robust, sustainable and inclusive solutions to environmental problems.

6.5. Limitations of this thesis

Due to the relatively small scope and short time-period of this thesis, the methods employed have some unavoidable limitations, which are briefly discussed here. These limitations relate to the reliability and validity of the methods and other important factors that were not analysed in this thesis. However, the limitations do not compromise the relevance of the results.

First of all, the process of conducting the research and writing this thesis inherently involved making assumptions. Assumptions were made both in the quantitative part of this thesis, which involved linking the projections of environmental change to requirements for delta-specific NbA strategies, and in the qualitative part of this thesis, which involved identifying legal and institutional design principals for adaptive governance in the Rhine and Mekong delta plans. Assumptions are subjective and other researchers may have assumed some things differently. This reduces the reliability of the methods.

The second limitation is that this thesis included a limited set of environmental variables. I assumed that sea-level rise, subsidence, sediment availability and land-use are the most important environmental variables in the context of NbA in deltas. However, one may argue that including four environmental variables is limited. In reality, other factors can be identified that may also be important in determining the success of NbA strategies, such as climate, soil characteristics or hydraulic conditions. Besides, this thesis employed fixed land-use as a fraction of total land-use to assess the available space for NbA in the Rhine and Mekong deltas. This, however, does not tell us anything about the exact spatial location of the land-uses. Although various sources were cited to support the argument that fixed land-uses are concentrated along rivers and the coast in the Rhine and Mekong deltas, this is insufficient to conclude with certainty on the available space for NbA.

This thesis also included a limited set of policy documents, which is the third limitation. Only delta plans were analysed using the framework for adaptive governance by DeCaro et al. (2017a). In addition, this framework provides legal and institutional design principles, whereas delta plans are policy documents and are therefore neither fully legal nor institutional. Other documents need to be analysed to assess the policy feasibility of NbA, such as laws, regulations and institutional documents.

The fourth limitation is that the adaptive governance framework is the only framework used in this thesis to assess the delta plans. Although the adaptive governance framework facilitates conditions for flexibility and adaptability, which is especially important in the context of NbA, there may be other aspects to consider to sustainably manage deltas in the future such as illustrated by the transformative and interactive governance frameworks. Therefore, using only the adaptive governance framework by DeCaro et al. (2017a) to assess the Rhine and Mekong delta plans is likely insufficient.

The fifth limitation of this thesis is that the Mekong delta plan does not have the same formal status as the Rhine delta plan. The Mekong delta plan functions as a guideline for the Vietnamese government. Therefore, it was assumed here that all measures proposed in the 2013 Mekong delta plan were actually implemented. This is of course not necessarily the case. If the opposite is true and the proposed measures were not implemented in the Mekong delta, the policy feasibility of NbA in the Mekong delta might be lower than indicated by this thesis.

The final limitation of this thesis is that, in addition to environmental and policy limits, there may be other factors that constrain NbA, such as technological and economic limits. These were not included in this thesis because I assumed here that technological and economic dimensions are more important for infrastructural adaptation. Building hard infrastructures requires elaborate engineering plans and is often costlier. In contrast, I assumed that policy and environmental constraints are more important for NbA. The success of NbA depends on the health of ecosystems, which is strongly influenced by environmental change. Besides, policies play an important role in fostering trust in new, adaptive approaches.

6.6. Recommendations for future research

Our current understanding of the feasibility of NbA at regional or even global scales is still in its infancy. This is illustrated by the fact that only nine NbA strategies for deltas and coasts exist in the current literature and that the majority of the publications focus on coastal wetland restoration. As a result, hard environmental limitations, or thresholds, to NbA are only identified for coastal wetlands. We currently do not know, for example, how much sediment is exactly needed for riverine wetlands to be restored, or how much space is required for dynamic dune systems. Therefore, further research is needed to identify and quantify such thresholds for all delta-specific NbA strategies.

The results of this thesis have shown that seven of the nine NbA strategies are likely to be constrained in the Rhine and Mekong deltas by environmental change. This conclusion may also apply to other deltas worldwide. However, deltas are unique, dynamic systems. There are no blueprints of nature-based solutions that can be applied everywhere. To find out what actually works in practice, action-oriented research is needed to experiment with different NbA strategies at larger scales and in different contexts. If NbA is indeed highly limited in deltas across the globe, then detailed analyses are needed that evaluate the range of other potential adaptation options in various locations. This allows for designing flood management strategies that effectively combine natural, infrastructural and policy instruments. Further research should also evaluate different potential governance systems and identify the most optimal combination depending on the local context.

Important for future research is to consider the limitations of this thesis and to account for them in further studies. Here, only four environmental variables were included. Other environmental factors may also constrain the feasibility of NbA in deltas and should, therefore, be included in future research. This thesis also only included fixed land-use as a fraction of total land-use, which is insufficient to conclude on the available space for NbA in deltas. Detailed spatial analyses should be conducted to determine the spatial distribution of different types of fixed and non-fixed land-uses. In this way, we can conclude with more certainty on the available space for NbA. Future studies should also include a large variety of legal and institutional documents. Governance systems are extremely important in determining the adaptive capacity of a region. Therefore, detailed analyses of legal and governance structures in the Rhine and Mekong deltas, but also in other deltas, are crucial to gain a better understanding of the enabling and constraining conditions for different adaptation strategies.

7. Conclusion

NbA is increasingly portrayed as the ultimate solution to deal with flood risks in deltas. It has been argued to be more sustainable and cost-effective in the long run than engineering adaptation, and it provides a multitude of positive side effects to surrounding ecosystems and communities. However, until now, NbA has mostly been applied at the local scale and scaling up to regional or global levels may prove to be difficult. Besides, although from a policy perspective there are opportunities for the incorporation of NbA in the Rhine and Mekong deltas, from an environmental perspective most of the NbA strategies identified in the literature are highly constrained in both deltas. This may also be true for other deltas worldwide. Therefore, there is an urgent need for hybrid solutions. All strategies, either for mitigation, adaptation or dealing with loss & damage, inherently have strengths and weaknesses. It is therefore important to combine different strategies to effectively deal with flood risks in deltas. The same is true for governance systems. Due to the constraints on NbA in deltas, adaptive governance may be insufficient to deal with future threats. Transitions may be necessary if socio-ecological systems are no longer sustainable. This is where transformative governance comes in. Additionally, fully preventing the occurrence of loss & damage may be impossible. Compensating for loss & damage in the most reliable and equal way is essential, which can be achieved through interactive governance. Therefore, combining adaptive, transformative and interactive governance could be the way to go. The results of this thesis contribute to filling a knowledge gap in the literature and have brought to light questions for future studies. Future research needs to quantify hard limitations to NbA in different contexts. If NbA is indeed highly constrained in deltas, then detailed analyses are required to determine the range of potential mitigation and adaptation strategies in different locations and how to combine these in the most effective way to avoid the occurrence of loss & damage.

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9. Appendices

9.1. Translations of Rhine delta plan quotations

Table 3. Overview of the quotations taken from the Rhine delta plan that had to be translated from Dutch to English. The first column shows the quotations in Dutch and the references to the pages in the Rhine delta plan. The second column shows the translations into English. The quotations in the table follow the order in which they are given in section 5.3.1. in the text.

Quote in Dutch	English translation
"De voorkeursstrategieën van DP2015 [het Deltaprogramma uit 2015] zijn adaptief ontworpen, waardoor ze kunnen worden aangepast als veranderende omstandigheden daartoe aanleiding geven" (Deltaprogramma, 2020 p.13).	The preferred strategies of DP2015 [the 2015 delta plan] are designed adaptively, so that they can be adapted if required by changing circumstances.
"In het Deltaprogramma is gekozen voor een adaptieve aanpak: nieuwe ontwikkelingen en inzichten kunnen aanleiding zijn om eerder vastgestelde voorkeursstrategieën en (delta)beslissingen aan te passen. Dat kan ieder jaar als ontwikkelingen daarom vragen. De Stuurgroep Deltaprogramma heeft in 2017 besloten in aanvulling daarop iedere zes jaar een systematische herijking uit te voeren" (Deltaprogramma, 2020, p.19).	In the delta plan, the choice was made for an adaptive approach: new developments and insights can be a reason to adjust previously established preferred strategies and (delta)decisions. This can be done every year if developments require this. The steering group of the delta plan decided in 2017 to also carry out a systematic reassessment every six years
"Het Deltafonds bevat financiële middelen om investeringen in waterveiligheid, zoetwater en waterkwaliteit en beheer en onderhoud van het Rijk dat hierop betrekking heft vanuit het Rijk te financieren. Ook kan uit het Deltafonds een subsidie worden verstrekt voor maatregelen voor Waterveiligheid, zoetwater en waterkwaliteit van andere overheden" (Deltaprogramma, 2020, p.73)	The Delta Fund holds the financial resources to finance investments in water safety, freshwater and water quality, and the central governments' management and maintenance activities that pertain to this. A subsidy can also be granted from the Delta Fund to finance measures for water safety, freshwater and water quality of other governmental authorities
"Deze wijziging maakt het mogelijk om uit het Deltafonds ook bijdragen te kunnen verstrekken aan decentrale overheden voor het nemen van maatregelen tegen wateroverlast" (Deltaprogramma, 2020, p.66).	This amendment makes it possible to make financial contributions from the Delta Fund to decentralised authorities for taking measures against flooding
"Via een bijdrage van €25,000 per impactproject worden overheden die ze uitvoeren geholpen en andere overheden geïnspireerd" (Deltaprogramma, 2020, p.67).	The local governments that execute these projects can get financial help in the form of a contribution of €25,000 per impact project while other governments are inspired
"De minister van Infrastructuur en Waterstaat (IenW) heeft extra geld ter beschikking gesteld voor het stimuleren en faciliteren van klimaatadaptatie: in totaal €20 miljoen voor 2019 en 2020. [...] Het is bedoeld voor procesondersteuning, pilots and kennisontwikkeling en kennisdeling. De opgedane kennis is beschikbaar via het Kennisportaal en het platform Samen Klimaatbestendig" (Deltaprogramma, 2020, p.66).	The Minister of Infrastructure and Water Management has made extra funds available for stimulating and facilitation climate adaptation: in total €20 million for 2019 and 2020 [...] This is meant for process support, pilots, and knowledge development and knowledge sharing. The acquired knowledge is available through the Knowledge Portal (*Kennisportaal*) and the Platform Climate-proof Together (*Samen Klimaatbestendig).*
"Het platform is opgericht in 2018 en op basis van positieve ervaringen is besloten de activiteiten voort te zetten tot en met 2020. Het Ministerie van Infrastructuur en Waterstaat heeft hiervoor middelen beschikbaar gesteld vanuit de extra impuls van €20 miljoen" (Deltaprogramma, 2020, p.67).	The platform was established in 2018 and due to positive experiences, it was decided to prolong the activities until 2020. The Ministry of Infrastructure and Water Management made funds available for this from the extra €20 million impulse.

"In 2019 is extra geld beschikbaar gekomen voor onderzoek. Daardoor kregen kennisontwikkeling en kennisverspreiding een extra impuls" (Deltaprogramma, 2020, p.61).	In 2019, extra funds were made available for research. This gave an extra boost to knowledge development and knowledge distribution.
"Dat dit niet of onvoldoende gebeurt, heeft verschillende oorzaken, met name onbekendheid met de mogelijkheden van decentrale regelgeving bij klimaatadaptief bouwen en het ontbreken van urgentiegevoel en benodigde capaciteit. In 2019 wordt daarom een handreiking voor decentrale overheden opgesteld" (Deltaprogramma, 2020, p.15).	There are various reasons why this is currently not or insufficiently done, in particular municipalities' unfamiliarity with the possibilities of decentralised regulation for climate-adaptive building and lack of a sense of urgency and required capacity. Therefore, in 2019 a guide for local authorities will be established.
"Doelen en ambities voor ruimtelijke adaptatie zijn opgenomen en verbonden met plannen voor bijvoorbeeld openbare ruimte, energietransitie, bouwen […] en in de gemeentelijke verordeningen" (Deltaprogramma, 2020, p.69).	Goals and ambitions for spatial adaptation are included and connected with plans for, for example, public space, energy transition, construction and in municipal regulations.
"Vlaanderen en Nederland werken in de Vlaams-Nederlandse Scheldecommissie samen aan de agenda voor de toekomst" (Deltaprogramma, 2020, p.95).	Flanders and the Netherlands work together in the Flemish-Dutch Scheldt Commission (*Vlaams-Nederlandse Scheldecommissie*) on an agenda for the future.
"Nederland en Noordrijn-Westfalen hebben in de Arbeitsgruppe Hochwasser gezamenlijk onderzoek gedaan naar de overstromingsrisico's in het grensgebied. Dit is relevant, omdat een overstroming in het Duitse deel van het grensgebied gevolgen kan hebben in Nederland en andersom" Deltaprogramma, 2020, p.88).	The Netherlands and North Rhine-Westphalia have conducted research together in the Working Group High Water (*Arbeitsgruppe Hochwasser*) on flood risks in the border area. This is relevant, because a flood in the Germen part of the border area has consequences for the Netherlands and vice versa.
"Het programma WAVE2020 heeft als doel de crisisbeheersing bij overstromingen te verbeteren en de inspanningen daarvoor van de 25 veiligheidsregio's te coördineren" (Deltaprogramma, 2020, p.30).	The program WAVE2020 of the delta plan on water safety aims to improve flood risk management and coordinate the efforts of the 25 safety regions
"De werkregio's monitoren zelf de voortgang in hun gebied en rapporteren daarover. Zeven bestaande gebiedsoverleggen rapporteren op basis daarvan de voortgang aan de Deltacommissaris" (Deltaprogramma, 2020, p.57).	The working regions monitor the progress in their area and report about this. The existing seven bodies of consultation in turn report on the basis of this the progress to the delta commissioner
"Het Deltaprogramma is een nationaal programma. Rijksoverheid, provincies, gemeenten en waterschappen werken hierin op een vernieuwende manier samen met inbreng van maatschappelijke organisaties, kennisinstellingen, burgers en het bedrijfsleven" (Deltaprogramma, 2020, p.112).	The Rhine delta plan is a national program. The central government, provinces, municipalities and regional water authorities work together in an innovative way, based on input from civil society organisations, knowledge institutes, citizens and businesses
"De ambitie is waar mogelijk […] de participatie van overheden, bedrijven en burgers bij de voorbereiding van plannen en maatregelen te stimuleren" (Deltaprogramma, 2020, p.20).	The ambition is to, where possible, […] stimulate "the participation of [local] governments, businesses and citizens in the preparation of plans and measures.
"Het is van belang dat ook inwoners en bedrijven deelnemen […]. Immers: meer dan de helft van Nederland is in particulier bezit" (Deltaprogramma, 2020, p.63).	Participation of citizens and businesses […] is important, because more than half of the Netherlands is privately owned.
"Daarom worden stakeholders zo vroeg mogelijk betrokken" (Deltaprogramma, 2020, p.32).	Stakeholders are involved as early as possible.

"Voor participatie onderscheidt de systematiek […] vijf ambitieniveaus, in lijn met de participatieladder: informeren, raadplegen, adviseren, coproduceren en (mee)beslissen" (Deltaprogramma, 2020, p.21).	For participation, the system distinguishes between five levels of ambition, in line with the participation ladder: informing, consulting, advising, co-producing and (co-)decision-making.
"Bij de implementatie van de regionale voorkeursstrategieën is coproduceren het meest gekozen ambitieniveau" (Deltaprogramma, 2020, p.21)	Co-production is the most chosen level in the implementation of the region-specific preferred strategies.
"De inhoud van het project bepaalt voor een belangrijk deel welke invulling de participatie krijgt. De participatie op projectniveau laat dan ook een gevarieerd beeld zien" (Deltaprogramma, 2020, p.21).	The content of a project determines to a large extent the participation of stakeholders. Participation at the project level therefore shows a varied picture.
"Het Ministerie van IenW heeft samen met Deltares een methodiek ontwikkeld om meer expert- en ervaringskennis te kunnen gebruiken bij een Beoordeling op Maat" (Deltaprogramma, 2020, p.28).	The Ministry of Infrastructure and Water Management has, together with Deltares, developed a method for using more expert and experiential knowledge for a Customised Assessment (*Beoordeling op Maat*).
"De Minister van IenW heeft […] in 2018 het voornemen uitgesproken om samen met de overheden, bedrijven en maatschappelijke organisaties in het rivierengebied een programma voor Integraal Riviermanagement op te zetten" (Deltaprogramma, 2020, p.28).	In 2018, the Minister of Infrastructure and Water Management expressed the intention to set up a program for Integrated River Management together with governments, businesses and civil society organisations in the river area.
"In 2019 en 2020 werken de partijen aan een integrale visie op de toekomst van het rivierensysteem. Ook worden enkele beleidskeuzes voorbereid" (Deltaprogramma, 2020, p.28).	In 2019 and 2020, the parties work on an integrated vision for the future of the river system. Some policy choices are also prepared.
"De partijen signaleren kansen en voeren projecten uit om de dijkversterking te combineren met natuur, recreatie, toerisme en cultuurhistorie" (Deltaprogramma, 2020, p.83).	The parties identify opportunities and carry out projects to combine dike enforcements with nature conservation, recreation, tourism and cultural history.
"Gemeente Rotterdam en Havenbedrijf Rotterdam ontwikkelen samen met betrokken partijen gebiedsgerichte waterveiligheidsstrategieën voor alle buitendijkse gebieden in de regio" (Deltaprogramma, 2020, p.85).	Together with involved parties, the municipality of Rotterdam and the port of Rotterdam develop area-oriented water safety strategies for all areas outside of the embankments in the region.
"De werkregio's monitoren zelf de voortgang in hun gebied en rapporteren daarover. Zeven bestaande gebiedsoverleggen rapporteren op basis daarvan de voortgang aan de Deltacommissaris" (Deltaprogramma, 2020, p.57).	The working regions monitor the progress in their area and report about this. The existing seven bodies of consultation in turn report on the bases of this the progress to the delta commissioner.
"Financiële prikkels kunnen inwoners en bedrijven stimuleren om hun eigen terrein klimaatbestendig in te richten. Decentrale overheden hebben hier veel belangstelling voor" (Deltaprogramma, 2020, p.67).	Financial incentives can stimulate citizens and businesses to design their own lands in a climate-proof way.
"In het voorjaar van 2019 zijn vier pilots gestart […] die experimenteren met differentiatie van rioolheffing en subsidiëring van vergroening" (Deltaprogramma, 2020, p.67).	In the spring of 2019, four municipalities started a pilot […] in which they are experimenting with differentiation of sewage taxes and subsidisation of greening activities.
"De bestuurlijk vastgelegde alliantieprincipes geven een nadere invulling aan de samenwerking" (Deltaprogramma, 2020, p.34).	The administrative alliance principles provide further information about the cooperation.

“We zijn open naar elkaar; als ons individuele belang botst met het collectieve belang, dan maken we dit bespreekbaar” (Deltaprogramma, 2020, p.34).	We are open to each other; if our individual interest clashes with the collective interest, we will discuss this.
“We maken risico’s en issues vroegtijdig bespreekbaar, zodat hier op gestuurd kan worden en besluiten zorgvuldig tot stand komen” (Deltaprogramma, 2020, p.34).	We discuss risks and issues at an early stage, so that we can control them and make decisions carefully.
“We maken heldere afspraken met elkaar en komen die na” (Deltaprogramma, 2020, p.34).	We make clear agreements with each other and honour them.