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Embracing ambiguity in climate change adaptation for more effective responses to new uncertain shorescapes conditions

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ABSTRACT

Nature Based Solutions (NbS) are mainstreamed as an innovative and adequate approach to climate change. Combining natural dynamics and materials with technical knowledge, NbS are seen as a promising venue for coastal adaptation. However, little still is known about the role that the many uncertainties associated with such projects play in the effectiveness of these solutions, and about how to cope with these uncertainties, considering both positive and negative impacts that NbS may have for our society. Here, we investigate, if and how, managing uncertainties via the *cascades of interrelated uncertainties* conceptual framework improves the governance capacity for implementing NbS coastal management projects. To this end, we conduct an ex-post analysis of the uncertainties in two NbS study cases (Sand Engine and Safety Buffer Oyster Dam BwN projects in The Netherlands), critically analyzing through the conceptual framework, how uncertainties were addressed and proposing better fit supporting alternatives. Our results indicate major benefits for uncertainty management, supporting project development and implementation: generating more flexibility in managing under unknown conditions, being able to anticipate conflict and maladaptations, providing opportunities of creating new supporting relationships and alternative solutions.

1. Introduction

Adapting to climate change has become an inescapable fact, one that has tremendous repercussions for how we manage our coasts (IPCC AR6 WGII, Chapter 17 [25]). Even when future predictions can appear to reflect rough estimates, the presence of sea level rise, increases in sand erosion, biodiversity loss, changing temperatures and extreme events unequivocally constitute an inevitable reality for managers and decision-makers. A new normal is established that challenges and conditions how our coasts must be managed. Here, the command and control approaches combined with hard engineering solutions, exceptionally preferred during the past decades, no longer serve us [12,36,38]. Instead, more inclusive and adaptive solutions that are better equipped to cope with the great complexity, uncertainty and multiplicity of risks of an anthropogenic evolving coast are needed [2,19,27,28].

Paralleling its urgency, and with the double aim of finding successful measures while avoiding maladaptation [23,32,33] a concern for climate change adaptation has increasingly taken traction in policy and decision-making arenas. Expanding from local to regional and national scales, in the recent past, devising adaptation plans for climate change is inherent to the design of formal institutions. In Europe, for example, the new EU Climate Adaptation Strategy was launched [14] setting out how the European Union can adapt to the impacts of climate change and become climate resilient by 2050. Within this strategy, EU member-countries have the task of individually creating their own action plans.

In these institutional proposals, Nature Based Solutions (NbS) are mainstreamed as an innovative and systemic approach to climate change adaptation [35]. Under the rationale of letting the working of nature do the job of adapting, instead of forcing nature through the use of hard engineering solutions, NbS aims at utilizing natural dynamics (e.

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g., wind and currents) and natural materials (e.g., sediment and vegetation) for the realization of effective flood defense systems, while at the same time, providing opportunities for nature development [11]. Good examples of NbS in the field of coastal protection are the Building with Nature (BwN) approach in the Netherlands, the similar Working with Nature approach of PIANC and the Engineering with Nature approach of the US Army Corps of Engineers [44].

Beyond the appeal of such multifunctional innovations and the co-benefits they have proved to offer [24,4], one question remains: will these innovations render the expected effective results under the uncertain, and ever changing, conditions of climate change? Here we argue that when adopting NbS, the uncertainties - and the risks these uncertainties pose - are potentiated, since the inherent uncertainties in climate change nest the uncertainties associated with the natural (e.g., will the wind bring the sand to the shore?) and social dynamics (e.g., will people accept this innovation?). Further, the complexity of this situation is increased even more as the effectiveness of NbS depends on societal acceptance and the response capacity and opportunity of the people affected by them, bringing along the adverse possibility of maladaptation and failure to cope with the impacts of climate change [23].

Innovations, such as NbS, are foreseeable to have consequences in terms of coastal geo-morphodynamics and ecology, as well as in terms of behaviors, organizations, routines, policies and institutions. Therefore, in addition to technical capacities, the successful implementation of such novel approaches requires the governance capacity for assessing and changing common practices and policies as well as of sustaining these developments in the short-medium and long term [34,37]. Doing so requires recognizing the social, organizational and political dimensions of these innovations, and acknowledging that the extent to which an innovation is successful is contingent on how humans respond to these innovations, on how different actors' perspectives and interests are considered, and on how uncertain and ambiguous issues are addressed [16,21].

An extensive body of scholarly work has made clear that the adoption of a new technology induces fundamental changes in the societal system in which the technology is being introduced ([39], Heller 1989). Associated with technological innovations there are particular user practices, norms, regulations, time-spatial scales and networks of maintenance that support the technology in fulfilling a societal function [18]. Scholarly work in the field of transition research has clearly indicated that technological transitions are always paralleled with transformations in the way in which society functions. As stated by Geels: "technological transitions do not only involve technological changes, but also changes in elements such as user practices, regulation, industrial networks, infrastructure, and symbolic meaning" ([15], pp 1257).

Here, we investigate how managing uncertainties via the *cascades of interrelated uncertainties* conceptual framework [42] could improve the governance capacity in supporting the implementation of BwN innovative processes of coastal management. Our goal is twofold: 1. To understand the role that the different types of uncertainty, being interrelated, have in settling project's societal acceptability. 2. To identify possibilities for managing uncertainties that are aligned with what society wants and how it functions. To this end, and building on our previous work and findings [42], we conducted an ex-post analysis of the uncertainties in two NbS study cases: Sand Engine and Safety Buffer Oyster Dam BwN projects, critically evaluating the shortcomings of how uncertainties were addressed and proposing better fit supporting alternatives.

2. Methods

2.1. Analytical framework

We adopt the *cascades of interrelated uncertainties* conceptual framework developed by Van den Hoek et al. [42]. This framework builds on the relational approach to uncertainty brought forward by Brugnach et al. [7], where uncertainty is conceptualized as a knowledge relationship: a relationship established between one or more knowing subjects (e.g., decision-makers) and an object of knowledge (e.g., socio-techno-environmental system upon which decisions need to be made). We chose this framework because it enables us to identify uncertainties from the perspective and context of decision-makers, taking into account the different, and occasionally contentious, framings held by those involved in the decision-making process.

Under this framework uncertainty is defined as the situation in which there is not a unique, nor complete, understanding about how a system on which decisions need to be made works (Brugnach at al 2008). A system is thought of as three interconnected subsystems, namely the natural, technical and social. For example, in a coastal system, the natural system comprises the land, the sea and the atmosphere (e.g., shore, weather, waves, tides, biota, etc.)., the social system its people and institutions (e.g., beach users, administrators, etc.) and the technical system the infrastructures, technologies used to manage it (e.g., see walls, beach nourishments, etc.).

The framework distinguishes three types of uncertain knowledge relationships, namely incomplete knowledge, unpredictability and multiple knowledge frames (ambiguity), which even though distinct, can be simultaneously present in decision-making. Incomplete knowledge refers to the lack of knowledge about the present or future state of the system and its functioning, concerning what we do not know at this moment, but might know in the future if sufficient time and resources are available to perform additional research in order to collect more data (e.g., water quality, water level). Unpredictability refers to what we cannot know about a system due to its inherent chaotic or variable behavior of e.g. natural processes, human beings or social processes. Differently from incomplete knowledge, unpredictability cannot be fully reduced by doing more research or collecting more data (e.g., future weather conditions).

Ambiguity is considered an uncertainty of a different kind, as it does not attend to how much, or how well, actors know a system, but to the different ways of knowing about it and of framing concerning issues. Thus, ambiguity refers to the situation in which in a group there are different, and sometimes non-overlapping or conflicting knowledge frames, raising questions regarding what the main concerns are, if there are any, or what are appropriate ways to cope with them [13,30,7,41]. As the two study cases will demonstrate, ambiguity speaks for the needs and views of society, having a primordial role in determining the acceptability of a project. E.g., would the groundwater be affected by the sand dynamics, and if so, what do we do about it?

Furthermore, uncertainties are not conceptualized in isolation but in relation to other uncertainties, influencing each other, where the impact of a particular uncertainty may be created or enlarged through the cascading effects of other uncertainties. So, based on this framework, different uncertainties, which might have a fundamentally different nature and could be associated with different aspects of the system under study, are directly related in *cascades of interrelated uncertainties*. One unique feature of this framework is the consideration of ambiguity capturing the perspective of the actors, regarding what they care about and what they perceive to be problematic. Fig. 1 presents a brief description to the reader of the cascades and its elements.

2.2. Ex-post analysis of uncertainties

Adopting the *cascades of interrelated uncertainties* conceptual framework described above, the ex-post analysis of uncertainty conducted in the two study cases follows the four steps procedure indicated below:

Step 1: Identification of main issues of concern: Identify the main societal issues of concern associated with the implementation of the BwN project, which emerge in relation to what is known, or not known, about the project and the multiple, and sometimes contested, framings held by the various involved actors. The work of Van den Hoek et al.

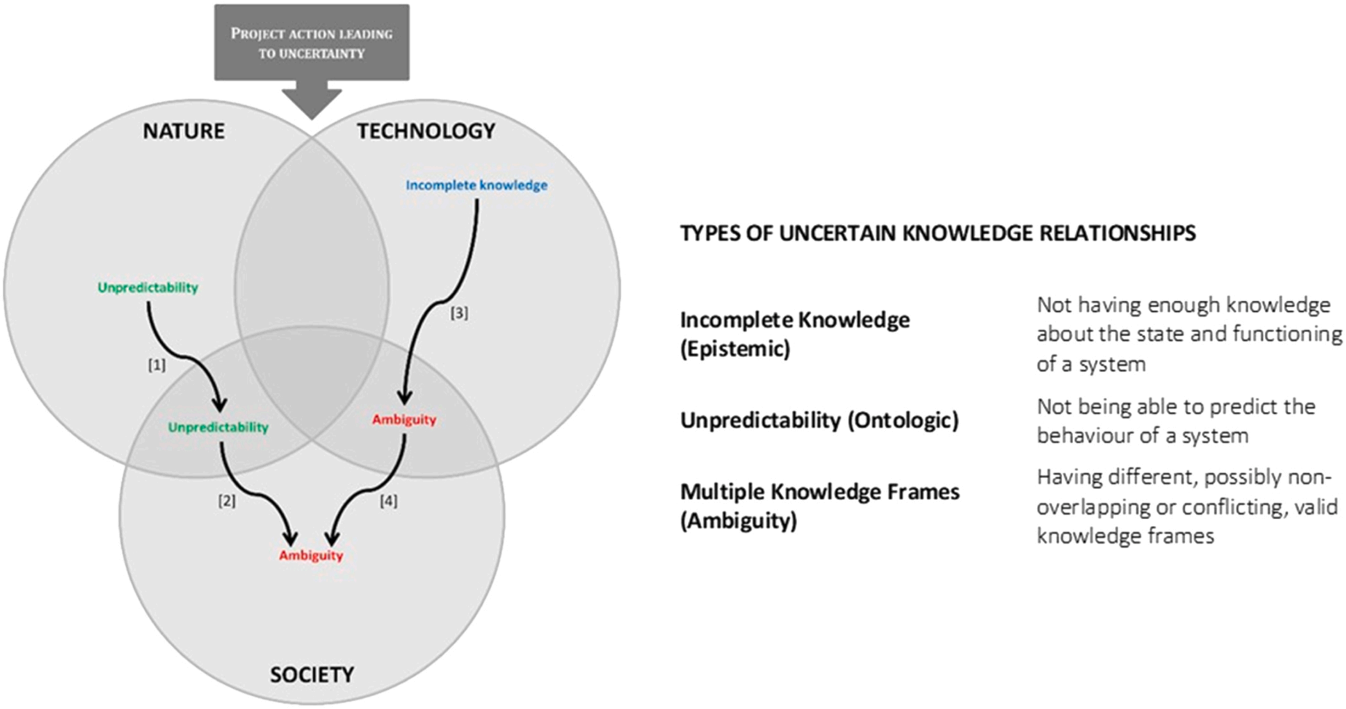

Fig. 1. Black arrows express that an uncertainty is related to another uncertainty. For each uncertainty, colors indicate which of the three uncertain types; green for unpredictability, blue for incomplete knowledge and red for ambiguity. At the top of each figure, it is indicated which project action or aspect the cascade concerns. Adopted from Van den Hoek et al. [42].

[42] is used as the baseline in this identification process. The questionnaires used in interviewing the actors are found in Supplementary Information C.

Step 2: Per issue of concern, identification of uncertainty cascades associated and their impact: Elicit and classify different uncertainty types (incomplete knowledge, unpredictability and multiple knowledge frames (ambiguity)) and their cascading effects. Assess the relevance of each uncertainty cascade by considering two aspects: **its potential impact to the project implementation** ("can it lead to substantial cost overrun, a substantial delay or even project cancellation?") and **the**

Fig. 2. Case studies location.

actors perceived project-wide relevance ("is this uncertainty considered important by multiple interviewees and project's actors?").

Step 3: Identification of coping strategies: In each uncertainty cascades, identify the coping strategies that were opted or applied by the project team to address the uncertainties and avoid potential negative impacts. Strategies relate to the implementation phase in which the project is in, being preventive in pre-implementation phases and reactive in implementation and post-implementation ones.

Step 4: Evaluation of coping strategy: Determine how successful the identified coping strategies were in preventing the potential negative impact of the uncertainty (e.g., substantial cost overrun, delay or project cancellation). Discuss whether the applied coping strategies provide a *sustainable* solution: the strategies should not only offer a solution in the short term, but should also prevent the uncertainty from re-intensifying at a later stage in the project's development process.

2.3. Case studies and data collection

The analysis is based on two Dutch BwN projects: Sand Engine and Safety Buffer Oyster Dam (Fig. 2).

2.3.1. Sand engine delfland

The continuing coastal erosion, on-going land subsidence and sea level rise, made the sandy Holland coast increasingly vulnerable to flooding. Therefore, the Dutch government implemented the so-called Dynamic Preservation policy: Holland's coastline had to be maintained at its 1990 position by performing periodic, relatively small-scale, sand nourishments [17]. But how to do so? Would one major nourishment done at once, instead of several small ones over the years, have similar, or even increased impacts on the coastline? To explore the answer, the Sand Engine Delfland – a mega-sand nourishment of 21.5 million m3 – was proposed to be constructed in 2011 (Fig. 2). The Sand Engine constituted the first large-scale pilot project based on BwN design principles, and was supported by public authorities, private companies and research institutes [11]. The end goal was to stimulate natural dune development concomitantly with opportunities for nature and recreational development over an expected period of 20–50 years. One key objective of the project was to learn about the applicability and efficiency of the mega-nourishment concept (for an overview of the results so far, see [1]).

2.3.2. Safety Buffer Oyster Dam

The Sand Hunger is an erosion problem suffered in the Eastern Scheldt that originates from the construction of a large Eastern Scheldt storm surge barrier in the 1980s (Fig. 2). It refers to the on-going erosion of existing tidal flats – important bird habitats and natural flood defenses – due to the disturbance of the sediment balance caused by the estuary's closure. The Safety Buffer Oyster Dam project constituted a practical and local response to the effects of the Sand Hunger problem. This pilot project – performed in November 2013 – consisted of a sand nourishment of 350,000 m^3 in front of the Oyster Dam (which is actually the largest dam of the Delta Works). The goals of the Safety Buffer project was to reconstruct one of the eroded tidal flats in the Eastern Scheldt estuary, as well as the construction of an artificial oyster reef to slow down the tidal flat's erosion. While one of the project's goals was to gain knowledge about dealing with the effects of the Sand Hunger problem, the main objective was to develop a sustainable flood safety situation and a restored tidal flat landscape at the Oyster Dam for the next 50 years. The preferred design alternative was the nourishment of half of the existing tidal flat, while letting the sand of the other half to be redistributed through natural dynamics. At that time, no studies regarding the nourishment's future development were commissioned by those responsible for the initiative (for an overview of the results of the pilot project, see Boersema et al. [3]).

2.4. Data collection methods

Sand Engine Delfland. We used two main data collection methods. First, three public information meetings were attended, during which stakeholders and the general public had the opportunity to pose critical questions, express their appreciation or concerns about the project and to file complaints. Minutes of these meetings were made and studied to identify important uncertainties and to understand the diverging viewpoints regarding the project. Second, we performed nine interviews with individuals that were or are involved in the Sand Engine's development process or its maintenance after implementation. In April and May 2011, we interviewed three (former) members of the project team, one member of the project steering group and two experts – involved in the Environmental Impact Assessment (EIA) and modeling – about the most important uncertainties encountered during project development, how these could have hampered the project and how the uncertainties were coped with. In the period from May until November 2012, we performed three additional interviews to acquire specific information about the Sand Engine's recreational safety situation. The interviewees were invited to elaborate on the safety measures regarding recreation, the reasons why measures were changed and which specific uncertainties were coped with. The semi-structured interviews were conducted in the Dutch language, took between one and two hours, and were recorded and transcribed. Standardized interview protocols with several open-ended main questions and follow-up questions were used during both interview series.

Safety Buffer Oyster Dam. First, we attended meetings of the project's knowledge development team in March 2012 and the stakeholder sounding board in April 2012. Whereas the meeting of the knowledge team was recorded and transcribed, the sounding board meeting could not be recorded but minutes were made. We studied the data of both meetings to identify important uncertainties, discussion themes and stakeholder issues in the Safety Buffer Oyster Dam project. Second, we conducted four interviews with actors related to the project team (performed by two interviewers) and nine interviews with stakeholders (performed by one interviewer) in July, August and September 2012. During three of these interviews, two respondents were interviewed instead of one. Thus, in total, we spoke to six project team associates (three at the executive and three at the project level) and ten stakeholders. The interviewees were invited to elaborate on those project topics that were most important for them, but that also caused the hardest discussions due to the existence of uncertainty and diverging viewpoints. For each of these uncertainties, it was discussed how the project team aimed to cope with it. The semi-structured interviews were conducted in the Dutch language, took about one hour, and were recorded and transcribed. Two standardized interview protocols (one for the project actors and one for the stakeholders) with up to fourteen open-ended main questions were used.

In both cases, we studied project documentation and communication as additional research material. These documents indicate whether a particular uncertainty was coped with by acquiring more information (e.g., a research report on the topic is present) or by addressing the different viewpoints of particular stakeholders' issues (e.g., there are emails in which stakeholders are invited to participate during a meeting). Furthermore, we consulted interviewees or other project actors to acquire additional information on specific uncertainties if needed.

3. Results

3.1. Sand engine delfland

3.1.1. Identification of main concerning issues

Initially, the Sand Engine was expected to redistribute sand along the coast over a period of 20–50 years, through natural dynamics such as waves and wind. This was thought to result in a beach area and dunes fairly naturally built (see Luijendijk, van Oudenhoven [1] for an overview of project results). However, unpredictable weather conditions over long time scales, plus highly uncertain predictions regarding the nourishment's distribution, soon triggered major concerns regarding: **A. swimming safety, B. drinking water quality, C. harbor accessibility and D. project's economic attractiveness** [40]. Here below we address the issues of swimming safety and drinking water quality. The reader can learn about the concerns about the harbor accessibility and the project's economic attractiveness in Supplementary Information A1 and A2 respectively.

3.1.1.1. Swimming safety. ***Uncertainty cascade associated with swimming safety, and their impact.*** Early on during the Sand Engine's development process, experts carried out a modeling exercise to study the project's morphological development. The results indicated that the *water conditions* in the vicinity of the Sand Engine were expected to be unpredictable. Consequently, it was acknowledged that the effects of the nourishment on *swimming conditions* were also highly unpredictable – an uncertainty associated with the physical aspect of the natural processes. This in turn led to ambiguity regarding *recreational safety* – an uncertainty associated with the social system – calling into question the acceptability of the whole project, and, in consequence, with potentially negative impacts to the project implementation.

Coping strategies. The project team initially approached *recreational safety* as an isolated – and rather deterministic – issue, focusing on strategies that created a robust management plan consisting of measures such as a swimming prohibition, do-not-swim signs and professionalizing the local life guard brigades (Fig. 3). The project team was convinced that their swimming safety management plan was sufficient to assure a safe situation, but seemingly failed to adequately assess the social dimension of the problem.

A group of local inhabitants – supported by a large political party – had a different view regarding *recreational safety*, fearing that the Sand Engine would create a highly unsafe recreational situation. They claimed that the project was *unacceptable* due to safety risks. They formed an action committee to oppose the initiative on the internet and in public meetings. The supporting political party officially requested the project's cancellation in the Dutch parliament.

The project team addressed the claims on *recreational safe*ty, and the ambiguity emerging between local inhabitants and them, by acquiring more knowledge regarding *swimming conditions*. They commissioned high-quality modeling studies in order to develop detailed scenarios of the 20-year morphological development of four Sand Engine design alternatives. Furthermore, they proposed an extensive monitoring and evaluation program to assess the development of the nourishment and its impacts.

These new studies proved to be partially accurate, predicting the shape of the Sand Engine as it developed; however, they underestimated

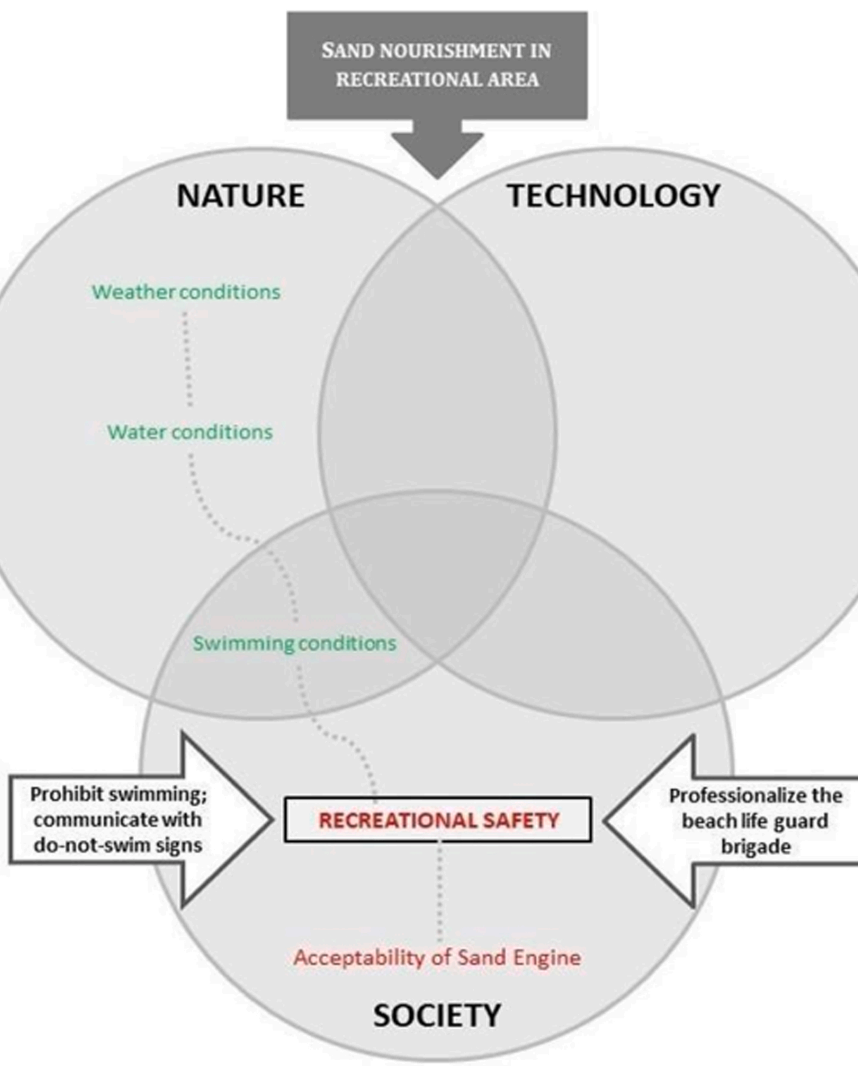

Fig. 3. Uncertainty cascade associated with swimming safety.

the *speed* of the initial morphological development, which was higher than expected, probably because of the many storms that happened during the Sand Engine's first winter. Over time, the opposition generated by these miscalculations gradually reduced, partly because only few incidents with recreants with no major injuries were experienced (to the authors' knowledge), and the project was eventually able to be successfully implemented without significant time overrun or budgetary problems.

Reflection on coping strategy. Despite its potential impact, the project team did not account for the cascading effects of unpredictable *water conditions* into *recreation safety*. The team was confident about their management plans and convinced that the body of additional knowledge could suffice for addressing the safety concerns and the ambiguity that *swimming safety* raised among different actors. By ignoring this uncertainty cascade, the Sand Engine opponents' viewpoints were not attended to, and the ambiguity about *recreational safety* remained a potentially hampering factor during the whole developmental process. Another, more inclusive, and probably less risky response to uncertainty would have been to meet the opponents and jointly discuss actions on how to reach a sustainable solution with regard to the issue [8].

3.1.1.2. Drinking water quality. ***Uncertainty cascade associated with drinking water quality, and their impact.*** An important uncertainty cascade emerged from the lack of knowledge about how the construction of a major sand peninsula at a coastline could affect *groundwater levels* and *groundwater transport processes*, and eventually *drinking water quality*. As such, posing major concerns to the drinking water company, since the drinking water supply nearby could come in contact with non-potable saltwater or might even become polluted with waste (e.g., debris, ruble) present in the local dunes. This uncertainty cascade resulted in ambiguity between the drinking water company and the project team regarding the *manageability of drinking water quality*.

Being aware of a potential water quality problem, and based on the Environmental Impact Assessment, the project team was confident that the effects of the Sand Engine project on drinking water quality was manageable, if some minor mitigating measures were taken. However, the local drinking water company anticipated problems with the drinking water supply and demanded additional research, claiming that otherwise, they would file an official complaint – as the project would be unacceptable for them – which would cause significant delays.

Coping strategies. Initially, the project team unsuccessfully attempted to address the ambiguity emerging with the drinking water company, proceeding as follows:

> *"We gave proper answers [to the drinking water company]. Then [we made] the draft permit and exactly the same questions popped up again from [the drinking water company]. And I really thought: 'how come?' [Our experts] tell me that everything is fine… [However, it turned out that] the engineering company's and our knowledge just wasn't sufficiently accurate."*

Because the ambiguity between the two actors (project team and water company) remained troublesome when the project needed to be completed, the project team eventually had to commission the research

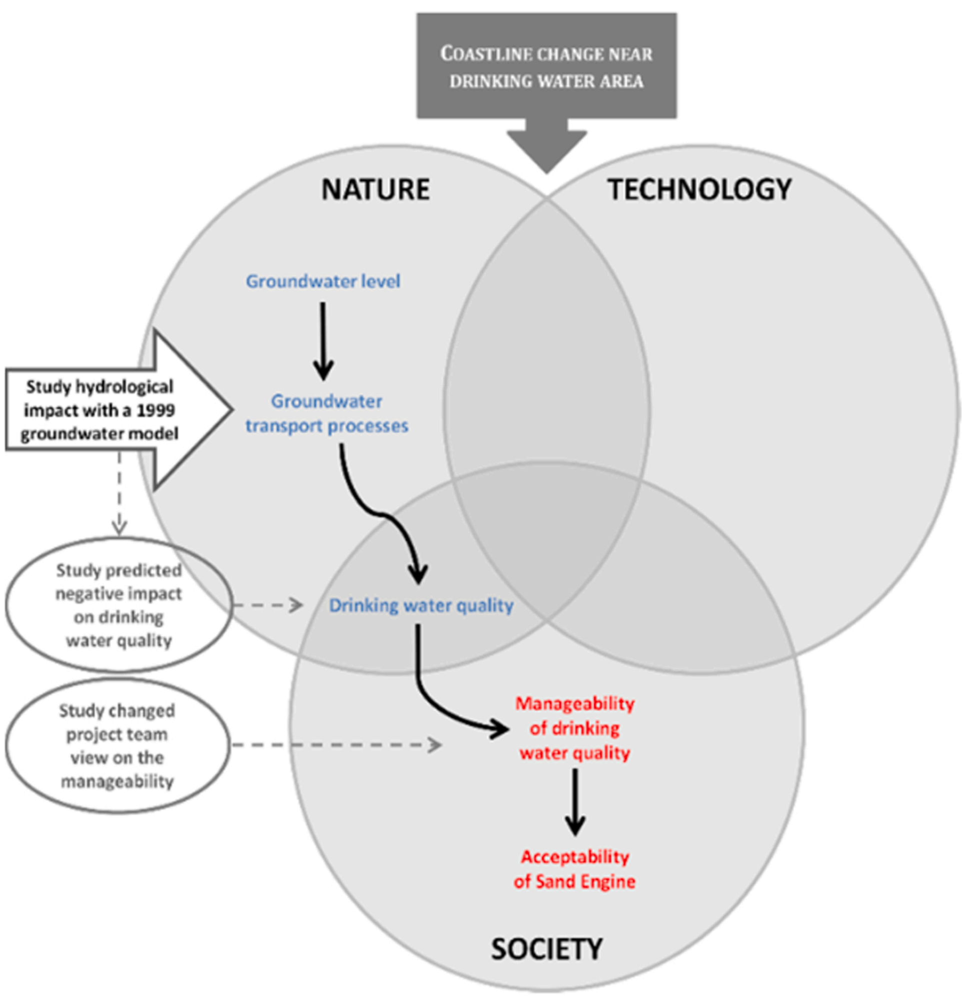

Fig. 4. Uncertainty cascade associated with drinking water quality.

requested by the drinking water company to avoid potential delays. Based on the information acquired from this research, it was found that the concerns of the drinking company were legitimate and that additional mitigating measures were needed (i.e., a drainage pipe with a pumping station). Ultimately, the project team acknowledged that the view of the drinking water company was the correct one (Fig. 4).

Reflection on coping strategy. The initial passive response from the project team in addressing the eventual impacts of the Sand Engine in water quality, was followed by the urgent need for addressing the controversial demands of the water company, which in this case was met by gathering more and better information and finding engineering solutions. Although these strategies allowed to successfully address the ambiguity (to the authors' knowledge, no impact on the drinking water quality occurred), it nearly led to the cancellation of the project. In fact, the late involvement of the drinking water stakeholder was pointed out as one of the main reasons that the ambiguity eventually emerged:

> *"The drinking water [stakeholder] in fact also didn't want the [Sand Engine] because they weren't involved in the project team… [The groundwater issues] could have influenced the design if it had surfaced [earlier]. Very late in the process, it was acknowledged that [we] should take a closer look at it. In fact, for two reasons I think. [The drinking water stakeholder] was never fully involved in the project team. And the other reason is: at some point, we once had some workshop about monitoring and [the drinking water issue] was not mentioned [at that occasion]."*

To avoid the potential negative effects of this ambiguity, a more inclusive, and less risky, coping strategy, would have been to recognize the importance that water quality may have for the drinking water company and actively involve this stakeholder at an early stage in the process, instead of doing so as the belated response to an Environmental Impact Assessment stating that ̈agreements with this stakeholder need to be madë.

3.2. Safety Buffer Oyster Dam

A few years before the launch of the Safety Buffer Oyster Dam project, a coalition of governmental parties and local stakeholders worked out some initial ideas about the Oyster Dam's future through small-scale projects. This preliminary work, carried out by an unusual coalition formed by two Dutch governmental agencies and a non-governmental environmental interest organization, not only served as a basis of the 2013 project, but also as a stimulus for stakeholders to actively participate in the initiative. The project commenced with a major stakeholder meeting, intended to come up with a list of stakeholder requirements that need to be taken into account as much as possible. Moreover, the project team formulated boundary conditions to protect stakeholders' interests: the Safety Buffer Oyster Dam project was not allowed to adversely impact stakeholders and all unforeseen damage had to be fully compensated. The major concerns regarding the project's impact were associated with: **A. the sand mining location**, **B. shellfish health at the nourishment site, C. benthic organism health, from a nature conservationist and a fishermen's perspective,** and **D. fishing grounds at the nourishment site** [41]. Below, we zoom in on the concern with regard to the sand mining location; the other three issues of concern are presented in the Supplementary Information B.

3.2.1. Sand mining location

Uncertainty cascade associated with sand mining location, and their impact. For a nourishment as large as the Safety Buffer Oyster Dam, a considerable amount of sand is required. This sand is harvested through a process called 'sand mining', which consists of taking sand from an external sand mining location and then transporting it over several kilometers to the nourishment's site, in this particular case the Oyster Dam. These sand mining activities can potentially impact local fish and shellfish populations at the sand mining location (so at the spot where the sand is extracted before transportation to to the Oyster Dam), directly affecting two stakeholder parties, small-scale professional fishermen and the shellfish industry, triggering two different uncertainty cascades (Fig. 5).

For small-scale professional fishermen, the particular spot within the Eastern Scheldt estuary where sand was mined could (temporarily) loose economic attractiveness due to the disturbance of the local fish habitat: the *profitability of the fishery sector* rests on the *number of fish* and so, on the *nutrients supply available for fish* which is affected by sand mining. A large part of the nutrients in the upper layer of the estuary bed was to be removed due to the mining activities. Although the impact on the fish habitat was presumed to be low, the extent to which the fish population would be influenced was highly uncertain.

Instead, for the shellfish sector, the impact of the sand mining activities were different. Dredging usually causes the formation of a plume of suspended sediment, under specific *weather and tidal conditions*, the *amount and direction of this sediment plume* might drift off towards commercially cultivated shellfish beds and cover oysters or mussels under a suffocating layer of sediment, affecting the *number of healthy cultivated selfish* as well as the nutrient-rich upper layer of a highly populated fish habitat near the mining area. The cascading effects of the uncertainty associated with sand mining in uncertain weather conditions can have a great financial impact on the *profitability of the shellfish sector*.

Coping strategy. The shellfish and fishing sectors had a specific view regarding the sand mining activities and preferred a sand mining location with only a minor probability of undesired suspended sediment transport towards their (shell)fish areas. Furthermore, they demanded mining activities to only take place during low tide. The project team acknowledged the stakeholder concerns and invited both sectors to participate in the search for an appropriate sand mining location. During this process, several alternative locations were proposed and rejected. Finally, a consensus was reached between participants on the locations Wemeldinge and Lodijksche Gat. Furthermore, it was agreed that the sand mining activities will only take place during favorable tidal and weather conditions and impacts will be monitored extensively.

Reflection on coping strategy. Differently than in the Sand Engine, uncertainty coping strategies relied on stakeholder participation and consensus seeking, namely: early involvement of stakeholders in a meeting to determine stakeholder demands and preferences, and dialogues to find optimal sand mining location. All actors involved agreed on the preferred sand mining location.

4. Discussion

Here, we have used the *cascades of interrelated uncertainties* conceptual framework to analyze the role played by uncertainty in the development and implementation of two BwN projects in coastal management. Building on the framework`s central premise which states that uncertainties are not independent but interrelated and influencing one another generating cascading effects, we reflect on the coping strategies chosen, identify alternative possibilities and explore the ways in which the management of uncertainty can improve the implementation of BwN innovations. Our results indicate that project teams can benefit from the information that a cascade of interrelated uncertainties provides, supporting the development of timely coping strategies, through the identification of (diverse and substitutive) strategic alternatives, and the anticipation of undesirable effects. Below we discuss our findings based on the two BwN projects we used as examples.

4.1. Diversifying the possibilities of action for coping with uncertainty through interrelatedness and cascading effects

In the *cascades of interrelated uncertainties* conceptual framework, each identified uncertainty within a cascade represents a potential point of intervention or facilitation for managing uncertainty. Here,

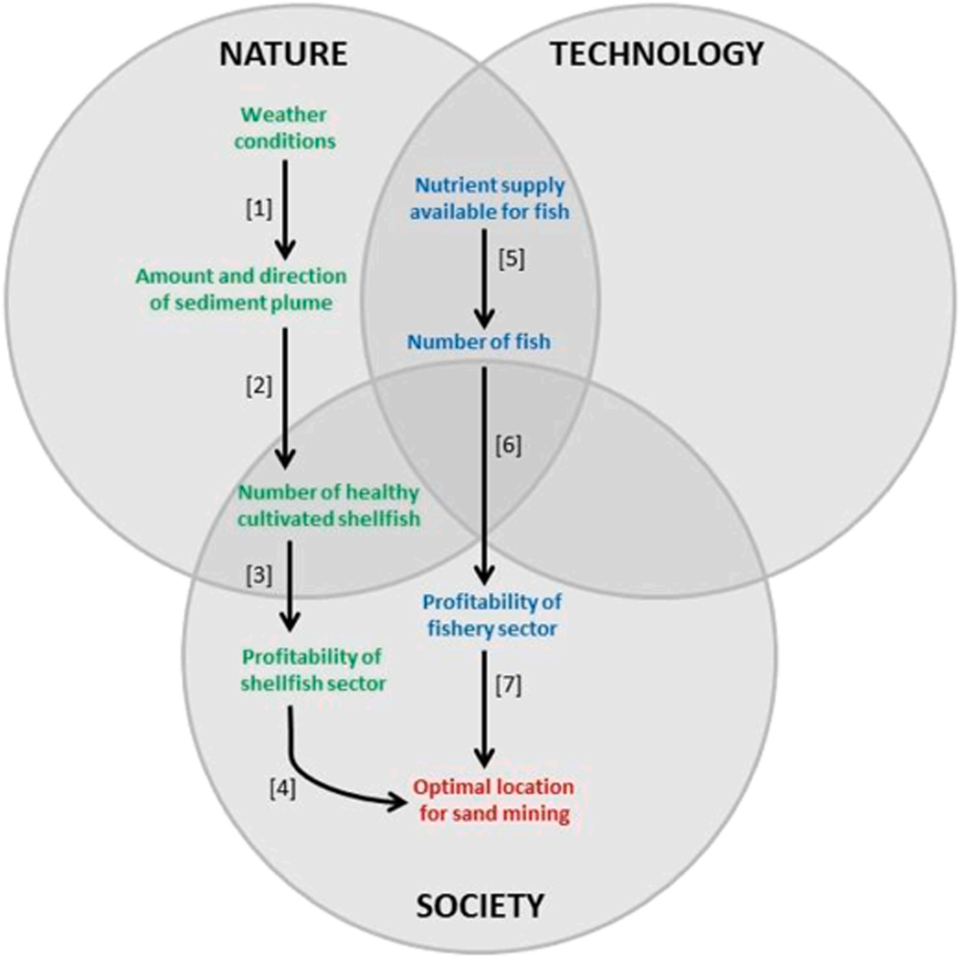

Fig. 5. Uncertainty cascade associated with sand mining location.
Adopted from Van den Hoek et al. [42].

uncertainties are conceived as interdependent from one another, with their effects branching out through the cascade. For coping with uncertainty, these cascading effects and the chain impacts they can generate, can constitute an advantage, since alternative possibilities of intervention can be made available, increasing the opportunities of intervention and strategy repertoire.

In the Sand Engine project, the issue of swimmer safety provides an ideal example of how the cascades of interrelated uncertainties could have contributed to better uncertainty management during the project. While the unpredictability associated with swimming safety was handled by carrying out additional studies regarding the sea's physical swimming conditions, an early assessment of the cascades could have, instead, led to a better understanding of the problem at hand, and thus to the identification of more effective strategies for coping with uncertainties and their impact in project development. For example, in addition to the development of a swimming water prediction model, early stakeholder involvement for the development of inclusive solutions able to take into account swimmers views and needs (e.g., invite stakeholders to share their concerns, jointly set up a life guard brigade with stakeholders instead of communicating swimming prohibition, etc.) would have helped to cope with the rising ambiguity about the safety situation between swimmers and the project team (Fig. 6).

An early assessment of the cascade of interrelated uncertainty would also have expanded the strategy repertoire by exposing the relationships between the different uncertainties at an early project's stage, providing insights about the social implications of swimming safety within the socio-political context in which the project was running. Unpredictable swimming conditions were likely to affect stakeholders' views on safety, a priority issue for managing the Dutch coast, one that could have potentially eroded the *acceptability* of the project to a point of risking stopping the project for contributing to human unsafety.

4.2. Anticipating and preventing undesirable outcomes

One undeniable aspect within these cascades of interrelated uncertainties is ambiguity. It speaks for the different meanings that social actors attribute to the project and its impacts [6]. Ambiguity makes visible the differences in understanding and interests among stakeholders, shedding a light on the pros and cons faced by those that are affected by it, and the potential social implications and maladaptations of a BwN intervention. Knowing what ambiguities are present or expected, gives essential information for supporting the successful development of a BwN project. Through our two case studies we learned that paying attention to ambiguity can help anticipate and prevent potential obstructive differences, as well as being prepared to face surprises. This, our results suggest, is better done proactively and at an early stage of the project, before the effects of ambiguity become controversial and potentially negative and maladaptive [33].

For a project's development, ambiguity can be both a blessing and a curse. On the one hand, being aware of the multiplicity of valid meanings can help to understand an issue in its full complexity (e.g., what people really care about) and plan accordingly. As the following Sand Engine interviewee statement exemplifies for the case of swimming safety in the Sand Engine:

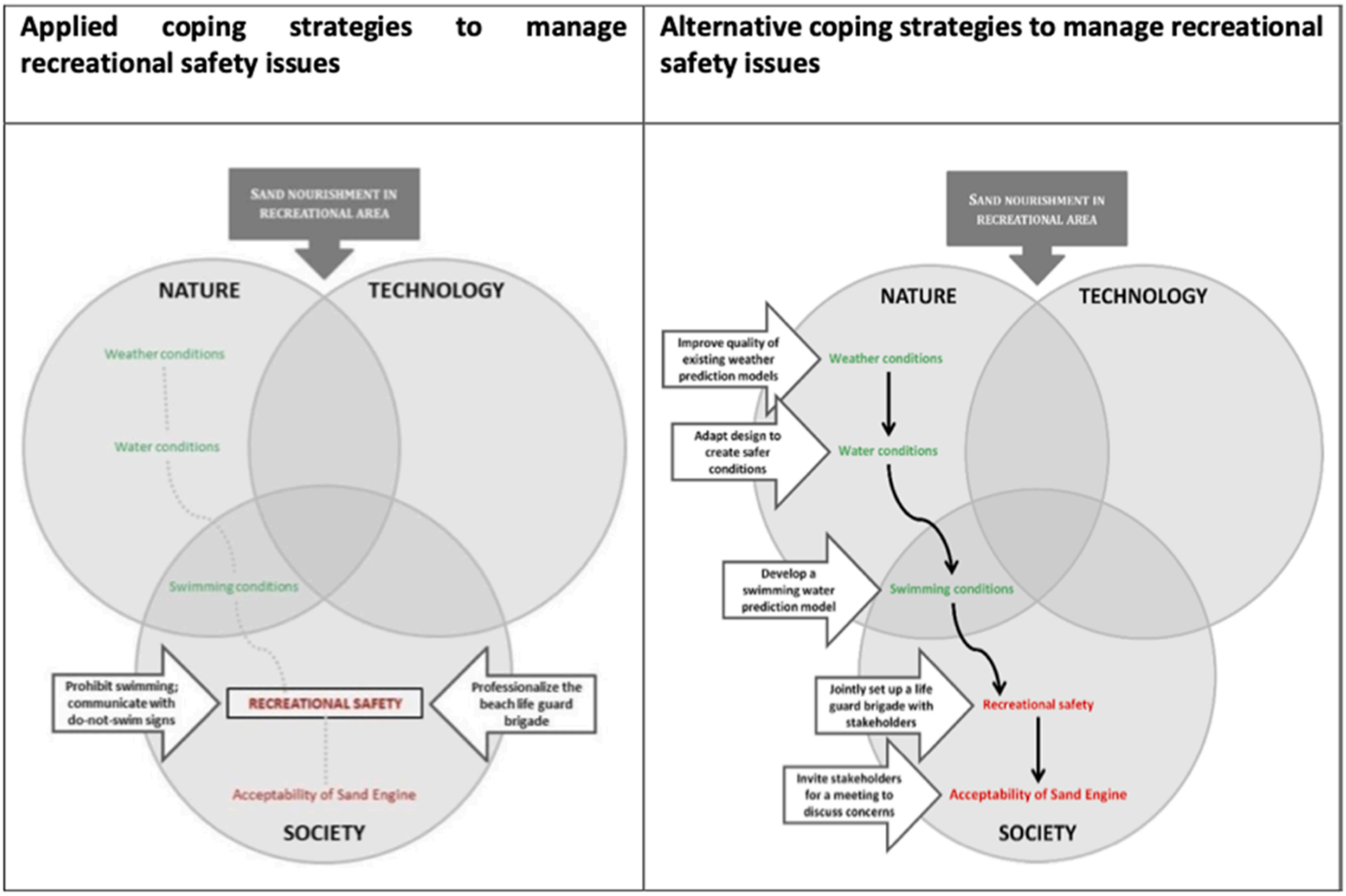

Fig. 6. Applied and alternative coping strategies for recreational safety.

"I think that [the action committee] helped us to sharply define the subject of swimmer safety… Due to them, it was put high on our agenda… I am not sure if we would have done so well without that group. I actually do not know that. Safety is always on top. Always. But such a group helps you to give it additional [attention]." On the other hand, ambiguity can point to lack of agreements or conflicts, which if not timely addressed, can become a hampering factor for the implementation of a BwN project [40].

In the Sand Engine project, ambiguities regarding swimming safety and water quality, at first instance unnoticed by the project team, posed major threats to the project's implementation. Whereas an early assessment of the cascades of interrelated uncertainties could have been very valuable, in aligning the project development with people's views and needs, in practice the project team did not fully understand the subject until the opposition had already emerged, losing the possibility of preventing potential severe conflict. Differently, the project team invested great effort in addressing the ambiguities regarding *shape and location of the Sand Engine* concerning the issue of harbor accessibility (explained in Supplementary Information A1), and *project's attractiveness for constructors* concerning economic attractiveness (explained in Supplementary Information A2), as they considered them to be an imminent risk to the implementation of the project. In doing so, undermining the power of small stakeholders.

In the Safety Buffer Oyster Dam project, ambiguities were addressed very differently. From an initial stage, the project team took an inclusive and dialogical approach in bringing different sectors and interest groups, which influenced how they were able to cope with the emerging ambiguities. This is reflected, for example, in the agreements reached with the shellfish and fishing sectors regarding the preferred sand mining location, and the conditions for mining (see concern 1: sand mining location). Or, in how they tackled the unexpected opposition of the oyster sector concerning the eventual impacts of sediment transport in shellfish health (explained in Supplementary Information B1). Or, in how the project team resolved the discontent regarding the potential lost benthic organisms, raised by local amateur environmental interest groups and fishermen, going beyond what they legally obliged to do to maintain good quality relationships (explained in Supplementary Information B2). Or, in how the team compensated the fisherman that just wanted to fish (explained in Supplementary Information B3). So, even though ambiguities could have risked the project development in any of these cases, the project team had the capacity to integrate them as part of the project design and openly and collectively cope with and learn from them. As one representative of the fishermen sector stated:

"[The state water authority] just took that up very well at the Oyster Dam and figured prudently that we again had a major interest there. And [they] just called us for consultation in the initial stages… You can oppose the project and just try to stop it. Insist [that you have] your permit and say: '[look], we just don't want it'… Or you could indeed think along from the beginning to come to a joint solution. And then we always prefer the latter."

4.3. Adapting strategies: from knowledge gathering to learning to agree

The two cases studied showed distinct ways of addressing ambiguity. In the Sand Engine, those responsible for the project mainly relied on strategies that aimed at gathering more knowledge. For instance, to address the concerns and ambiguity associated with swimming safety, the project team commissioned high-quality model studies in order to develop detailed scenarios of the 20-year morphological development of four Sand Engine design alternatives. Furthermore, an extensive monitoring and evaluation program was set up to assess the development of the nourishment and its impacts. Similarly, to address the differences in views with the drinking company about potential water pollution, the project team had to commission more research. In both situations, the project team mediated actors' differences by improving the factual knowledge base. While the strategy of gaining more or better knowledge (to reduce uncertainty) worked well in these two situations, predicting the behavior of such complex systems may not always render good results, particularly under the presence of ambiguity [8].

As BwN projects are driven by unpredictable natural dynamics, system conditions can change at any time – even after project implementation – and an uncertainty management approach that proved to be very effective might eventually fall short due to an unanticipated surprise. Thus, this suggests that it is important that those responsible for the development of a BwN project have the capacity to adapt their uncertainty management approach if needed. In the Sand Engine project, the best models and experts available were used to formulate trustworthy forecasts regarding the project's future developments and impacts. This resulted in adequate predictions of the development of the Sand Engine's shape, forecasts needed for applying swimmer safety measures and essential information about the impacts of the project on the drinking water supply. However, the future can never be forecasted flawlessly in BwN projects. An interviewed expert stated the following regarding this issue:

> *"Now, the Sand Engine was calculated using a coastal morphology model. But I think, off the cuff, that there are like 10 reasons why that model is not [accurate]. That is, among other things, because you model on the very long term. So inevitably you have to simplify particular things… you take a sort of annual average as model input… run [the model] for 20 years and get an outcome. [But] particular things are modeled less accurately. Storms that occur once in a while… So the expectation is just simply that processes could go much faster than we predicted using those coastal morphology models… What does [the Sand Engine] do in case of a storm? Then you observe, of course, that it goes much faster."*

As a flood protection solution, the nourishment still develops in a promising way and it continues to be scientifically studied. Furthermore, the concept of the Sand Engine has been adopted in other places, like for example, by the Bacton to Walcott coast sandscaping scheme in the UK in 2019 [31].

Differently, in the Safety Buffer Oyster Dam project, the focus for coping with uncertainty was on addressing ambiguity (e.g., ambiguity about the impacts on the shellfish and fishermen sector) via participatory processes, instead of improving the scientific knowledge base. The project team sought the agreement among actors about the best course of action and, as a result, reduced the urgency to acquire more knowledge about the speed and extent of the benthos recovery during project development. In this case, differences in understanding and interests among the actors were discussed, negotiated, and agreed, with no further need of additional research. To this end, the project team purposely invested in closely engaging with the pertinent actors, an inclusive strategy that improved their relationships and mutual understanding, increasing the acceptability of the project as well as avoiding present conflicts and becoming prepared to avoid future ones. Interpreting this situation via the cascades of interrelated uncertainties, the initial need for improving the incomplete knowledge of the shellfish and fishermen sector was addressed through reframing what actors considered to be important about the project: a learning opportunity that may have initial adverse impact on the benthos, where no more knowledge was needed on beforehand.

Many are the scholars that advocate early and active participation of a diversity of actors as an important means to cope with uncertainty and ambiguity leading to better and more legitimate decisions in the end (e.g., [26,43,30,5,20]). However, actor engagement in itself is not a magic bullet for improving decision making [45]. This is an activity that requires a thorough inquiry regarding who participates and in which role [29] and how these processes of participation are organized [22,9], considering that participation may bring strategic and controversial behaviors (e.g., the oyster sector in the Safety Buffer Oyster Dam, Supplementary Information B, case B1) that may influence project development [6,10]. Compared to existing uncertainty conceptualizations, using the concept of *cascades of interrelated uncertainties* adds to the analytical tool kit, supporting the identification of wider uncertainties such as ambiguities that emerge from deep engagement within different parties in society. Assessing a cascade of interrelated uncertainties at an early stage in a project provides the insight to proactively anticipate potential ambiguity. If it is clear which ambiguities can be expected to arise, based on genuine concerns or strategically motivated actions, a cascade of interrelated uncertainty provides essential insight into which actors to actively involve during a project's development process.

5. Conclusion

Here, we have investigated, if and how, managing uncertainties via the *cascades of interrelated uncertainties* conceptual framework improves the governance capacity for implementing coastal management projects based on BwN design principles. At its very core, the cascades of interrelated uncertainties bring the science of nature-based solutions and stakeholder experiences together, and our results indicate that doing so yields major benefits for uncertainty management, supporting project development and its successful implementation: generating more flexibility in managing under unknown conditions, being able to anticipate conflict, providing opportunities of creating new supporting relationships and alternative solutions.

Based on the two case studies analyzed here, we have identified different ways in which the *cascades of interrelated uncertainties* conceptual framework can help policy- and decision-makers strategizing coping mechanism for dealing with the uncertainty and associated risks of these complex solutions:

- Taking advantage of the multiplicity of uncertainty types associated with a concerning issue or problem, their relationships and their cascading societal effect, widens the strategies available to manage uncertainty within a BwN project, and can assist those responsible to adaptively anticipate any development that occurs over time, acknowledging the evolution of maladaptation in an increasingly timely fashion.
- The uncertainty cascades can, already at an early stage of a project's development, provide an overview of the many potential coping strategies, where each uncertainty in the cascade represents a potential node of intervention or facilitation.
- Acknowledging that there are multiple fundamentally different, yet interrelated, uncertainties associated with a problem or issue of concern, means that coping with a particular uncertainty will influence also those to which it is related.
- If a particular strategy for coping with uncertainty fails or predictions turn out to be incorrect, the other uncertainties in the cascade can provide alternative opportunities of intervention, offering the chance to adapt the uncertainty management approach.
- Under this framework, not only what is factually known (or not known) counts, but also people's interests, beliefs and knowledge, and the discrepancies that differences in views may trigger.
- Ambiguities are a distinct type of uncertainty considered in this conceptual framework. Explicitly addressing them enables a proactive inclusive approach towards the development of strategies and the creation of mutually beneficial opportunities, with the long term benefit of community building. In collective decision-making settings, ambiguity can help anticipate and prevent conflicts.
- Resolving ambiguity can also help reduce the importance of other uncertainties, opening new ways for addressing uncertainty, like for example, via participatory processes instead of doing so through

more data collection. Early involvement, listening to and recognizing others can be potent tools to cope with ambiguity.

When compared to current conceptualizations of uncertainty, this framework brings forward significant advancement in our understanding of how uncertainties in BwN (or other NbS that match unpredictable dynamics) work, their cascading effects, and the potentially hindering impacts they may have on the projects and society, having large implications for policy and the implementation of adaptation measures. Through the application of this framework in both BwN cases, we learned that the early, active and sustained involvement of societal actors into the definition and resolution of the issues being faced allow for a much more inclusive and adaptive approach to problem-solving. It allowed the actors to thoroughly understand the issues being faced, the diverse views, needs and constraints, and the fundamentally different ways in which these issues could be addressed. It also opens a door to being explicit and transparent about controversies and conflicts among actors, bringing to the fore the potentially negative impacts of unaddressed ambiguity. Involving actors as part of the project helped forge a collaborative social force that worked together through these differences as the project progressed. Not only could problems be anticipated in the beginning stages of the project this way, but the measures needed to sustain their solutions could become collectively, systematically and sustainably approachable, preventing maladaptation and an unwillingness to change issues being faced.

Overall, the cascades of interrelated uncertainties acknowledge that our knowledge, no matter how good it is, is inseparable from the multiplicity of people that are involved in decision-making. A particularly important point, if we want NbS that are technically sound and socially inclusive for adaptations to climate change. The most fundamental insight we find this project prompts being that embracing ambiguity in climate change adaptation offers the potential to generate more effective responses to new and uncertain shorescape conditions.

Author statement

Marcela Brugnach and Ronald van den Hoek conceptualized the idea and made the analysis. Brugnach led the writing of the manuscript. Both authors contributed critically to the draft and consent to its content.

Declaration of interest

The authors declare no competing interests.

Data Availability

The data that has been used is confidential.

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Appendices A–C. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2023.105626.

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