J Coast Conserv (2018) 22:145–156
DOI 10.1007/s11852-016-0454-8

Multi-risk, multi-scale and multi-stakeholder – the contribution of a bow-tie analysis for risk management in the trilateral Wadden Sea Region

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Received: 16 February 2016 / Revised: 14 July 2016 / Accepted: 16 August 2016 / Published online: 2 September 2016

Abstract Risk management processes increasingly call for enhanced stakeholder participation, and aim to integrate different risk perceptions, concerns and interests. Frequently, this goal is driven by the increased complexity of risk management processes, as risk management processes continuously have to deal with multi-risk situations including impacts resulting from risks of natural hazards and risks caused by misguided social or economic development. Although stakeholder participation is required by different policies, major challenges still arise from the question of how to perform multi-stakeholder participation in practice. In order to find answers, we tested the so-called 'bow-tie analysis' as a potential tool to facilitate multi-stakeholder participation with a major effort on integrating stakeholders risk perceptions and interest in the risk management processes. The bow-tie analysis is a commonly used risk assessment technique (IEC 2009) to analyse cause-and-effect pathways of risks, but its application in multi-stakeholder processes in risk management of natural hazards, especially in a European context, is rather new. Using practical experiences from the trilateral Wadden Sea Region we demonstrate the bow-tie analysis' contribution to coastal risk management processes in this coastal area by facilitating collaborative identification, comprehension and analysis of the management system. The use of a modified bow-tie analysis in collaboration with stakeholders from the Wadden Sea Region proved to be an appropriate framework for enhancing the understanding of risk management processes and fostered disclosure of different perceptions and concerns of multi-risk problematics. The bow-tie can be beneficial as a communication and co-construction tool in risk management processes in a multi-risk context.

Keywords Bow-tie analysis · Risk management · Multi-stakeholder participation · Wadden Sea Region

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Introduction

The world is becoming increasingly complicated. A risk is no longer only a risk; it can have multifarious forms and can have impacts in multiple sectors on multiple scales. In the context of a *world risk society* Ulrich Beck identifies such situations of accumulated risks[1] and the increased uncertainties evolving out a state of not knowing about the impacts and consequences as a key theme of contemporary society (Beck 2007, 2009). In this regard, dealing with natural hazards and environmental risks nowadays becomes a considerable challenge for risk managers, sectoral interests and authorities as much as for the society at large. These multi-faceted hazardous risk situations are often characterized by highly interlinked risks, unexposed differences between the causes and the consequences of threatening risks and a multitude of actors that affect or are affected by the risk management processes. There is growing awareness in risk management communities that these situations are no longer manageable by a single actor, such as the government (Evans 2012) – but

[1] Beck is referring to an accumulation of ecological, terrorist, military, financial, biomedical and informational risks that has an overwhelming presence in our world today (Beck 2009)

require rather an enhanced involvement of multiple stakeholders in risk management processes to cope with these challenges.

The call for stakeholder involvement is however nothing new in risk management processes – moreover, the growing awareness of multi-risk situations adds weight this call. Risks are understood from a sociological perspective, as mental constructs which originate in the human mind and emerge within societal frames[2] (Luhmann 1993; Renn 2008). In this understanding risk is bounded and influenced by perception, interests and political will and depends on social, political, economic and cultural contexts and judgments (Luhmann 1993; IRGC 2005). In consequence, risk management is not only a technical issue, but a social process taking place within a societal frame of constantly changing and uncertain boundary conditions. In this context different perceptions and understanding of risks are essential elements shaping these boundary conditions. It is crucial to consider what the single system's "agents" perceive as risk and consider as the appropriate response at the individual level, especially in the context of multifaceted risk situations. From a complexity theory perspective, dealing with multi-facetted risk situations within society requires consideration of the non-linear behaviour of the system where emergent behaviour and surprises inherent to the system's trajectory (Ratter 2012). Understanding society as a dynamic and non-linear system, multifaceted risk perceptions must be discussed and negotiated within the society in order to set the scene for public-policy and management objectives as well as to cope with multi-facetted, highly interlinked and non-linear risk situations.

On this basis, risk perception represents an essential element of risk management activities as much as multi-stakeholder participation to facilitate integration of risk perceptions. Although these issues are discussed in, often scientific, literature (e.g. in a governance context, Gall et al. 2014; Renn 2008; IRGC 2005; Wanczura et al. 2007; Greiving and Glade 2013), implementation in practice is proceeding rather slow for risk management processes. This is particularly true for coastal risk management processes where technical understandings of risk continue to dominate (Ballinger 2015). Cross-national strategies and polices, like the EU-Flood Risk Directive, the EU-Water Framework Directive or the recently updated Sendai Framework for Disaster Risk Reduction 2015–2030 are important steps in this context. However, practical guidance on how to perform effective stakeholder participation, are rare in these strategies, too. Available practical frameworks like the Standard 31000 of the International Organization for Standardization (ISO) could help remedy this situation, but are not applied or used as reference in the context of multi-risk situations in risk management, due to our knowledge.

The aim of this paper is orientated towards these challenges in coastal risk management and the following open questions: 1) how can risk perceptions as well as societal concerns and needs be made accessible to the risk management process in a multi-stakeholder participatory manner? 2) Which benefits and contributions could be expected by a multi-stakeholder involvement and which obstacles are arising?

We discuss these questions from the perspective of our practical experiences from supporting participatory activities in coastal risk management processes in the international Wadden Sea Region (WSR). In the context of the overall aim to facilitate enhanced stakeholder participation in trilateral risk management processes in the WSR we tested the so-called 'bow-tie analysis' as a tool to facilitate involvement of different stakeholders' perceptions and foster multi-stakeholder participation in the risk management processes. Our discussions reflect upon the applicability, feasibility and effectiveness of the "bow-tie-analysis" contributing to the conceptual questions regarding the potential benefits of multi-stakeholder participation.

The Wadden Sea Region's multi risk and multi-scale situation

Risk management in the WSR faces the challenge of a multi-facetted, highly interlinked risk situation. The case study of the WSR is particularly suitable to discuss the challenges of including risk perceptions and of opening the process of risk management to a broader audience. Within this situation multiple stakeholders of different sectoral affiliation, involved in risk management processes at different scales, are confronted with the common task to cope with risks and impacts, affecting the local, regional and national scale.

The trilateral WSR comprises the coastal area along the European North Sea coast including the seaward areas of the Wadden Sea and the low-lying, tidal coastal regions behind the dykes along the North Sea coastline of the Netherlands, Germany and Denmark. At the seaward side, the WSR represents a coherent intertidal ecosystem characterized by a shallow body of water, tidal flats and wetlands (Enemark 2005). At the landward side the WSR can be characterized as a largely rural area, encompassing several important small- and medium-sized towns. For the work presented here we refer to the WSR defined as the Wadden Sea with its islands and sands and the relevant parts of the Exclusive Economic Zones of the three countries, as well as the landward side the three Dutch Wadden Sea provinces, the German counties along the coast and the Danish Wadden Sea municipalities (Wadden Sea 2013). Due to its similar ecological characteristics as well as similar social and economic structures within the Dutch,

[2] In contrast to a technological perspective, in which risks are defined as the algorithmic calculation: risk = threat x vulnerability x cost (c.f. Ratter 2013).

German and Danish parts of the WSR the entire Wadden Sea coast is affected by similar risks in a similar way. Periodic storm surge events of different levels of destructiveness have caused huge losses of live and goods in all three countries over the centuries. Since the last hazardous storm surge events in 1953 and 1962, significant transformations in storm surge management has been conducted, especially in the Netherlands and in Germany (von Storch et al. 2008; Gerritsen 2005, FAK 2009), underlined by a technical superiority of coastal protection measures. Beside the high water level, the WSR is exposed to storm events, causing major damages to settlements, infrastructure and economic sectors (e.g. winter storms "Lothar" in 1999 and "Kyrill" in 2007). Increase in mean sea level during the last decades on a global (Church et al. 2001) and on a regional scale (Wahl et al. 2011) as much as a projected on-going increase for the coming decades (Church et al. 2001; Katsman et al. 2008; IPCC 2013; Katsman et al. 2011) will have an effect along the entire coastline of the WSR. It is expected that effects of storm surge events in the WSR are intensifying (Woth et al. 2006; Weisse et al. 2014) and additionally hydrological risks result from inland flooding events. In the WSR different rivers run into the North Sea[3] which temporarily cause flooding as a result from extensive inland run-offs. With regard to climate change, heavy rainfall events are projected to increase in Northern Europe (IPCC 2007).

However, risks and challenges in the WSR do not only result from natural hazards and hydrological threats; furthermore, additional socio-economic challenges in the region lead to a multi-facetted risk situation. Different concentrations of population (densely populated cities, sparsely populated rural areas) and a diverse accumulation of economic values (high accumulation e.g. in harbour areas, areas of industrial use) create different levels of vulnerability since large parts of the WSR lie at sea level or even below. At present, an estimated 3 million inhabitants live in the WSR (Kabat et al. 2012). Traditionally, the WSR has been an important agricultural area (Kabat et al. 2012); today additional important economic sectors in the WSR are tourism, the energy sector (on-shore, off-shore wind and solar energy) as well as fishery and port industry and management (Wadden Sea Forum 2004; van Dijk et al. 2016). These sectors are directly or indirectly affected by risks from natural hazard events as much as by socio-economic risks such as demographic change. All three countries suffer in large parts from population decline and an aging society (van Dijk et al. 2016) and this declining trend is projected to continue in the next decades (Wadden Sea Long-Term Ecosystem Research et al. 2014). These demographic developments create urgent needs for enhanced management strategies to cope with these changing conditions.

Current risk management processes of these risks and challenges discussed above are bounded to national, regional and local, mostly administrative scales, with multiple institutions assuming partial responsibility. The existing structures underline the fact that impacts occur and are managed according to their impacts within rather than across different scales in the WSR. Even if risk management processes necessarily relay on responsibilities and activities taken on several levels, these structures have nevertheless led to the development of a 'silo mentality' as sectoral administrations operate in relative isolation from each other (Ballinger 2015, 1999). Within these structures, the multi-risk problematic is difficult to address. Without undermining existing multi-scale management processes we see a need to address the integration of stakeholders and their perception on this multi-risk situation on a cross-national, trilateral level. The trilateral level is the scale where the interlinkages become more easily apparent. In the following we will describe the already existing multi-stakeholder setting in the WSR in order to further discuss how multi-stakeholder participation as much as the involvements of their different risk perceptions was facilitated with the bow-tie analysis in the trilateral context.

Facilitating stakeholder participation in the risk management process

A basis for a multi-stakeholder collaboration on the trilateral level in the WSR is already given since 1978 by the Trilateral Wadden Sea Cooperation (TWSC) (Kabat et al. 2012) as much as by the multi-stakeholder platform Wadden Sea Forum (WSF) founded in 2002. The latter is an independent, voluntary multi-stakeholder platform, serving as a trilateral advisory and consultation body to the TWSC (Wadden Sea Forum 2013). It brings together stakeholders from Denmark, Germany and the Netherlands, representing the private economic sectors of agriculture, energy, fisheries, industry and harbour, and tourism, non-governmental organisation of nature and environmental protection as well as representatives from local and regional governments of the three Wadden Sea countries. National governments are represented as observers (Wadden Sea Forum 2005; 2010). Originally the focus of the WSF was on sustainable development, but since the TWSC agenda has incorporated the new topic of risk management (CWSS 2014), the WSF has correspondingly extended its activities. This paper presents the collaborative research and experience gathered in the context of the EU-funded research project ENHANCE – Enhancing risk management partnerships for catastrophic natural hazards in Europe (see http://www.enhanceproject.eu/). The focus was to support

[3] In the Netherlands, there are the Ijssel and the Reitdiep, the river Ems at the border between the Netherlands and Germany, in Germany the Weser, Elbe and Eider rivers and in Denmark, the river Ribe Å has already caused some flooding events in the past.

the WSF's endeavour in developing its newly declared objective and strategy as a multi-stakeholder platform for coastal risk management processes on a trilateral level.

The support of the WSF was put into practice as a series of three collaborative workshops with the WSF members. The workshops were conducted as one and a half day meetings, stimulating active stakeholder involvement in form of a combination of working in small groups and exchange and feedbacks in plenary discussions. Between 15 and 20 stakeholders participated in each of the three workshops, portraying a broad and balanced picture of most of the sectors and administrative levels from the three countries represented in the WSF. Within the workshop series the 'bow-tie analysis' was a major element, applied as a methodical tool to involve and discuss stakeholders perceptions of the multi-risk problematic in the WSR as much as to further facilitate multi-stakeholder participation. We chose the bow-tie analysis due to its capabilities to support an improved understanding of risk management, to differentiate between the system's elements and increased awareness of interlinkages between different risks. Furthermore, we appreciate the bow-tie's capability to integrate multiple causes and consequences in relation to a central event, and to assess a given system of management control.[4]

By focussing on the bow-tie capacities described above, we are aware of the fact that our activities of the collaborative bow-tie exercise address just a part of the entire process understood by the term risk management in a technical sense. In general, risk management is understood as "coordinated activities to direct and control an organization with regard to risk" (ISO 2009). Following the definition of ISO 31000,[5] the process of risk management includes the "systematic application of management policies, procedures and practices to the activities of [related to the essential elements of] communicating, consulting, establishing the context, and identifying, analyzing, evaluating, treating, monitoring and reviewing risk" (ISO 2009). The activities supported by the bow-tie analysis address predominantly the elements of establishing the context, identifying risk and priorities, as well as supporting activities of risk analysis and evaluation. The addressed stakeholder perceptions are part of a comprehensive risk analysis together with an additional qualitative and quantitative analysis. The presented bow-tie exercise is considered as a contribution to facilitate the inclusion of stakeholders' risk perception into the risk analyses beside other available data.

The bow-tie analysis

The bow-tie analysis is a commonly-used risk assessment method. It is listed by the International Organization for Standardization (IEC 31010 risk assessment techniques) as an appropriate risk management technique to implement risk management processes following the ISO 31000 framework facilitating the analysis, assessment and evaluation of risks. More in detail, the bow-tie analysis facilitates and supports the differentiation between the causes of a risk, the damaging event, and its resulting consequences. The bow-tie is used to visualize causes and effect pathways of risks (IEC 2009). This in turn provides the basis to analyse the system of management controls as much as identifying gaps and areas for an improved management. Existing experiences with the bow-tie analyses demonstrated that in most cases a multidisciplinary team is required for its proper implementation (Rausand 2011).

The origin of this method dates back to cause-and-consequence diagrams developed in the 1970s. Since the early 1990s the oil company Shell has made significant contributions to enhancing the use of the method and the visualisation in the bow-tie diagrams have been actively used in safety reports for the petrochemical industry in the UK and later in the US (Salvi and Debray 2006). Over the last decade, the approach has spread outside of the oil and gas industry to aviation, mining, maritime safety, chemical and health care. Application of the ISO standard in environmental management is still in its early stages (Creed et al. 2016). This is particularly the case for risk management of natural hazards with few existing examples in Europe.

In practice, the bow-tie analysis is particularly beneficial due to its capability to structure and visualize the essential elements of risk (events) in the bow-tie diagram: causes and consequences as much as the measures in place to adapt to the cause and to mitigate the consequences (see Fig. 1). The resultant structuring supports stakeholders in achieving an overview of the risks, their causes and consequences; in gaining an understanding of risk pathways and their interrelations; as well providing a basis to discuss management actions. The bow-tie diagram facilitates the visualization of the complexity of risks in one image in a schematic, clearly structured manner. Within a setting of a multidisciplinary multi-stakeholder team, bringing together different perspectives, interests and risk perceptions on a multi-facetted risk situation the (visual) differentiation between different system elements as much as the traceability of risk pathways

[4] In IEC 31010 the bow-tie analysis is highlighted as one of two tools (out of more than 30 risk assessment tools), which is able to assess a given system of management control; and it is highlighted as the only method which is able to integrate multiple causes and consequences in relation to a central event: the bow-tie analysis (IEC 2009)

[5] The Standard 31000 of the International Organization for Standardization (ISO) provide a framework for management of any risk characterized by a strong focus on practical implementation of risk management processes (Creed et al. 2016, p. 410).

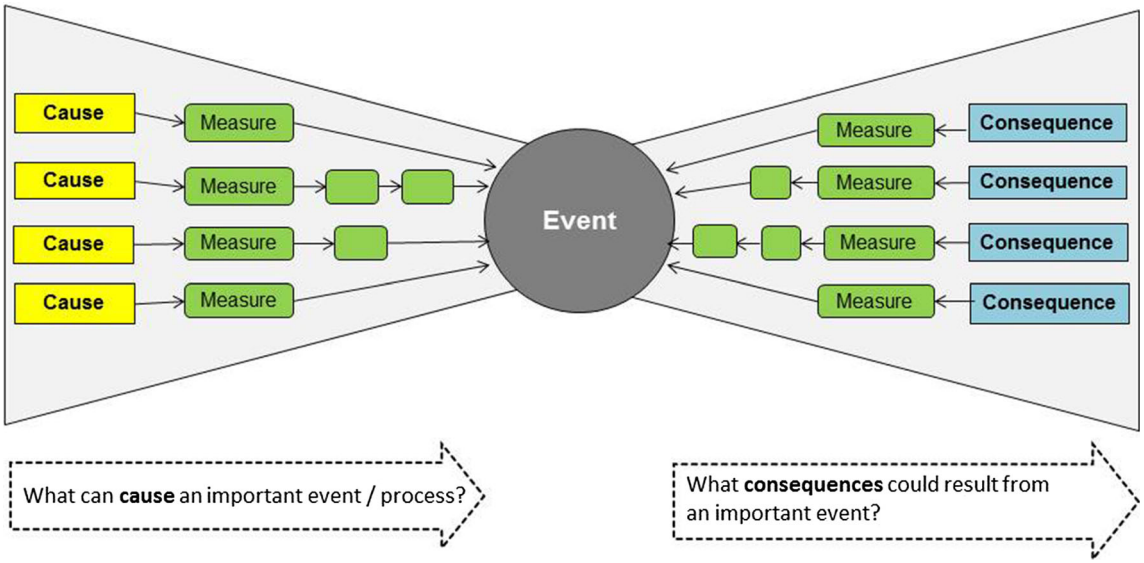

Fig. 1 Schematic overview about the essential elements of the bow-tie diagram (based on IEC 2009). The centre represents the event/challenge (e.g. a storm surge) society has to cope with and which has the potential to cause damage to society or the environment. Causes of the event are described in the yellow boxes on the left side of the diagram; measures to adapt to these causes are included in a 'barrier-position' (green box) between the cause and the event. The right side of the diagram depicts the consequences of the event (blue boxes), mitigating measures minimizing or preventing the consequences from occurring are included as a 'barrier' between the event and the consequences

are essential contributions of the bow-tie analysis to an enhanced understanding of system structure in risk management.

Framework for the Wadden Sea Region

Usually the bow-tie-analysis is applied to analyse the management control system in place for a well-known risk. In this case the risk is predefined as a starting point, causes and consequences due to the existing knowledge from technical risk assessment as much as existing strategies and measures are added to the diagram as a means to detect potential lacks and room for improvement in the management control system.

For the Wadden Sea context we adapted the procedure to complete the diagram and facilitated a transformation of the bow-tie analysis into a bow-tie process: We adapted the original procedure to our needs by filling the diagram *exclusively* with input from stakeholder *perceptions* on the multi-risk situation – which of course include their individual level of knowledge and experience. In addition, no further results of qualitative or quantitative analysis were introduced at this stage, since the exercise is explicitly focused on disclosing, integrating and structuring stakeholders' perceptions. We used the structuring capacity of the bow-tie analysis to order the stakeholders perceptions and to visualize risk pathways by distinguishing the stakeholder inputs between risks, causes and consequences of risks. In this process the risk event (centre of the diagram) is not predefined at the beginning. Furthermore, the structuring capacity of the bow-tie facilitates joint identification of the central challenge (s) for risk management in the trilateral WSR. In this form the bow-tie offers valuable insights into stakeholders' understanding and interpretation of the risk situation and pathways. In this exercise it is not the aim to evaluate whether the arguments and interlinkages between causes and consequences are logical or factually correct or wrong. The bow-tie process facilitates societal understanding of the multi-risk situation, from which current processes and measures could be evaluated as much as suggestions for improvements could be identified. In this manner, we transformed the bow-tie analysis into a bow-tie process. This bow-tie process underlines our understanding of risk management as an iterative, continuous process dependent on continuous stakeholder participation.

The bow-tie process in the Wadden Sea Region

In practice, the bow-tie exercise with the WSF was part of a series of three collaborative workshops. In this setting, the first workshop created the basis for the bow-tie process. The first workshop was focused on bringing together stakeholder perceptions of risks that are threatening the coastal communities and the environment in the WSR and delivers an overview of their level of urgency for the trilateral stakeholder group. As a result a list of perceived risks threatening the coastal communities was put together and subsequently ranked by the WSF's members. In a descending order the risks are a) storm surges and changes in climatic conditions, b) demographic change, c) risks resulting from imbalanced development and d)

conflicting spatial uses between different user interests in the WSR, e) economic and ecological risks (e.g. shipping and oil tanker accidents), f) economic crises on global and regional level, g) risks and uncertainties with regard to emissions (especially CO_2), h) pollution of rivers and the North Sea, i) loss of biodiversity and increase of alien species in the WSR. The subsequent discussions in the first workshop indicated the most urgent needs for improved management processes with regard to b) demographic changes (aging society, emigration of young and qualified people) and d) conflicting spatial uses.

The first workshop, therefore, created an overview about the most challenging risks and the identified potential ways to deal with them. For the achievement of the goal to comprehensively embed stakeholder perceptions as an essential element in the risk management process, we further facilitated an exchange about the detailed stakeholders' concerns, perspectives and personal assessment. Intensive discussions about their perspective and understanding of risk pathways have been facilitated by applying the bow-tie process. Based on the first workshop results, three bow-tie diagrams have been developed and discussed with the WSF members. The bow-tie diagrams are concentrated on the major challenges of 'demographic change', 'climate change resulting in environmental changes' and 'imbalanced development in the WSR' which represent the central event in each diagram (see Figs. 2, 3, and 4). Each diagram visualizes a breakdown of the stakeholders' input for the causes, consequences and adaptive or mitigating measures related to each challenge, as much as they visualise the identified links between the bow-ties at the decisive points. Figures 2, 3, and 4 visualizes the resulting bow-tie diagrams produced with the software Bow-tie XP CGE Risk Management Solutions. Stakeholders' input on adaptive and mitigating measures are included but hidden in these figures for readability reasons.

In the following we discuss the WSR bow-tie diagrams based on the results of the WSF workshops. The focus here lies on the methodical benefit of the bow-tie process. The examples underline the bow-tie's capabilities to disclose the most urgent risks to be addressed by risk management processes, to detect the current availability and needs of measures and enable stakeholders to detect obstacles in the existing risk management process.

Demographic change – detect and unravel the most urgent risk

The first bow-tie addresses the risk of demographic change in the WSR (Fig. 2). It provides a good example how the bow-tie facilitates and support the disclosure of most urgent risks. The bow-tie diagram reflect stakeholders concerns of a lack of balanced development as a major driving force of demographic change affecting coastal communities in all three countries in a similar, mostly negative way (see Fig. 2). The risk pathway of demographic change makes clear that mainly societal processes cause demographic change in the WSR. The stakeholders perceived an increased NIMBY mentality (Not In My Back Yard), increased individualism, as well as limited and egoistic thinking as essential elements of these social processes. Several different issues were identified as consequences – including increased unemployment, out-migration especially of young and highly qualified people, an ageing society and increased social disintegration. Unravelling the risk pathway for the risk of demographic change expressed the different societal processes which lead to stagnating development and increasing concerns in coastal communities. In this context, risk management means more than merely implementing technical measures. Dealing with processes of societal change is an important part of comprehensive risk management in order to successfully manage risks and uncertainties.

Regarding the capabilities of a bow-tie process, the bow-tie on demographic change highlighted its benefit as a structuring as much as a communication tool. By structuring the stakeholders' input as causes and consequences, the resulting picture supports an understanding of risk pathways and provides a basis for discussion on risk management strategies and measures.

Environmental changes – assess availability and identify needs of measures

The second bow-tie reflects the stakeholder concerns about the threat of climate change in the WSR which might result in environmental changes affecting the WSR communities (see Fig. 3). By focussing on the issue of storm surge management, this bow-tie process presents an example how the bow-tie supports the stakeholders in taking stock of current existing measures and identifying requirements for new measures in the future.

As a general result, the bow-tie process underlines stakeholders' concerns about changed environmental conditions due to climate change, since they might (negatively) influence social, economic and natural development in the WSR. The stakeholders identified increased frequency and amplitude in storm surge events, increased precipitation and rising sea levels as causes hampering the development in the WSR. Consequences resulting from these negative changes are perceived as increased coastal erosion, rising ground water levels and potential change of the WSR into a lagoon if the water level rises too high, flooding events, impacts on business activities in the area (e.g. agriculture, tourism, etc.) as well as a perceived decrease in the ecological and cultural quality of the WSR. Taking a closer look at the stakeholders' input on storm surge management, the bow-tie visualizes the fact that dealing with the causes of storm surge risks means applying mainly

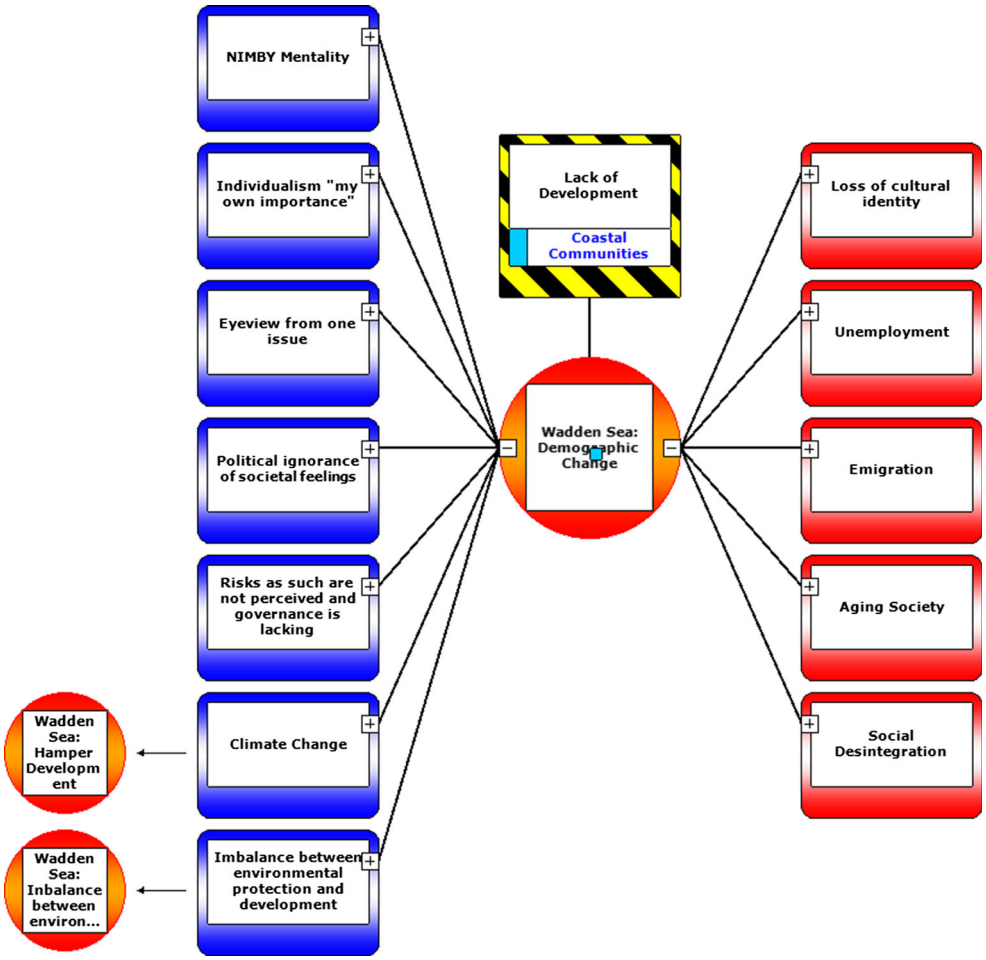

Fig. 2 Bow-tie diagram dealing with stakeholders concerns about demographic changes in the WSR; information on adaptive and mitigating measures are hidden; diagrams were produced with the software Bow-tie XP CGE Risk Management Solutions

adaptive measures. These adaptive measures have already been implemented in terms of technical coastal protection measures. The discussions with the WSF and other studies (comp. Gonzalez-Riancho et al. 2015; Ratter and Sobiech 2011) made clear that there is consensus and deep-seated trust in traditional engineering measures (such as dykes, flood barriers etc.) representing an adequate defence against disastrous storm surge events as well for the decades to come. In this context the bow-tie process further underlined the main challenges in storm surge risk management result from the consequences of storm surge events, under current and future climate conditions. Different measures are already in place for mitigating these consequences, but within the bow-tie process discussions with the stakeholders clearly emphasized the need for improved and additional measures.

The example of storm surge management highlighted the bow-tie's capacity to detect the availability and the needs of measures in currently applied risk management processes. The visualizing capacity of the bow-tie process highlighted the imbalance between applied measures (many adaptive, fewer mitigating measures). The structured overview provides a sound basis through which new or improved measures and strategies can be discussed and evaluated and potential barriers in the current management processes can be detected.

Imbalanced development – detect obstacles in current management processes

The third bow-tie discloses risk pathways of the major challenge 'imbalanced development in the WSR', mainly referring to the prospect of uncoordinated, unsustainable development in the region (see Fig. 4). This bow-tie is a good example to demonstrate the bow-tie's capacity to examine existing strategies and measures as much as to detect obstacles in the current risk management process.

The bow-tie process highlighted stakeholders' concerns regarding an imbalance between different lines of development, including social, economic and ecological development. The causes of imbalanced development are related to intensified sectoral activities, e.g. in the energy, fishing, or tourism sector. Furthermore, different sources of pollution, e.g. oil spills, shipping accidents, emissions and marine pollution concerned the WSF members. As a consequence, loss

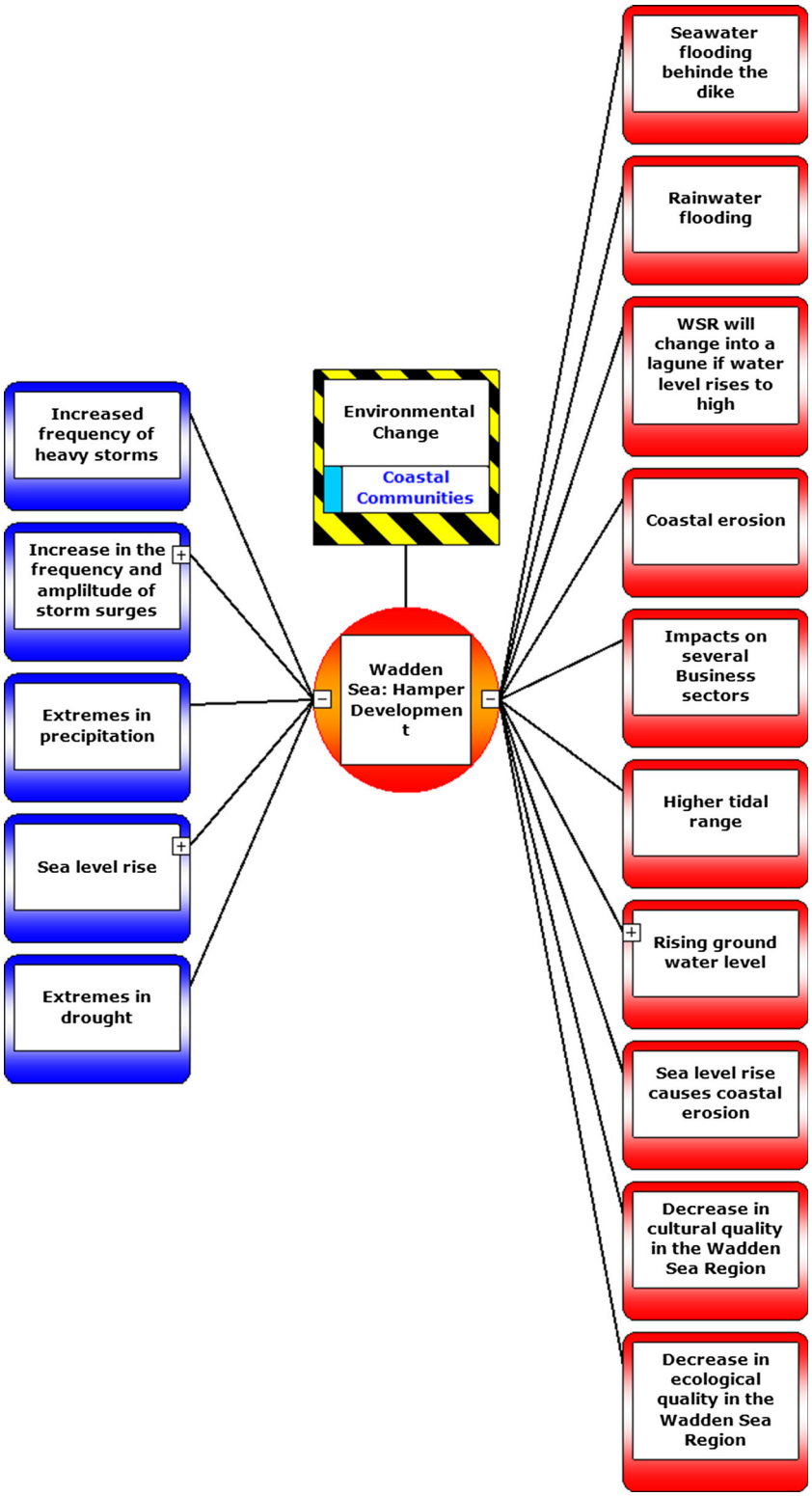

Fig. 3 Bow-tie diagram representing causes (left) and consequences (right) concerning the threat of environmental changes due to climate change affecting the coastal communities in the WSR, information on adaptive and mitigating measures are hidden; diagrams were produced with the software Bow-tie XP CGE Risk Management Solutions

of productivity and biodiversity as well as an increase in alien species in the WSR are suspected. Increased ship traffic and greater risks of oil spills were also feared.

Concerns regarding an imbalanced development are closely linked with the WSF's endeavour to facilitate sustainable development in the WSR, in which "economic activity supports social development and safeguards healthy ecosystems and cultural landscapes throughout the WSR" (WSF 2013, p.12). In this context the WSF developed an Integrated Coastal Zone Management (ICZM) strategy to foster

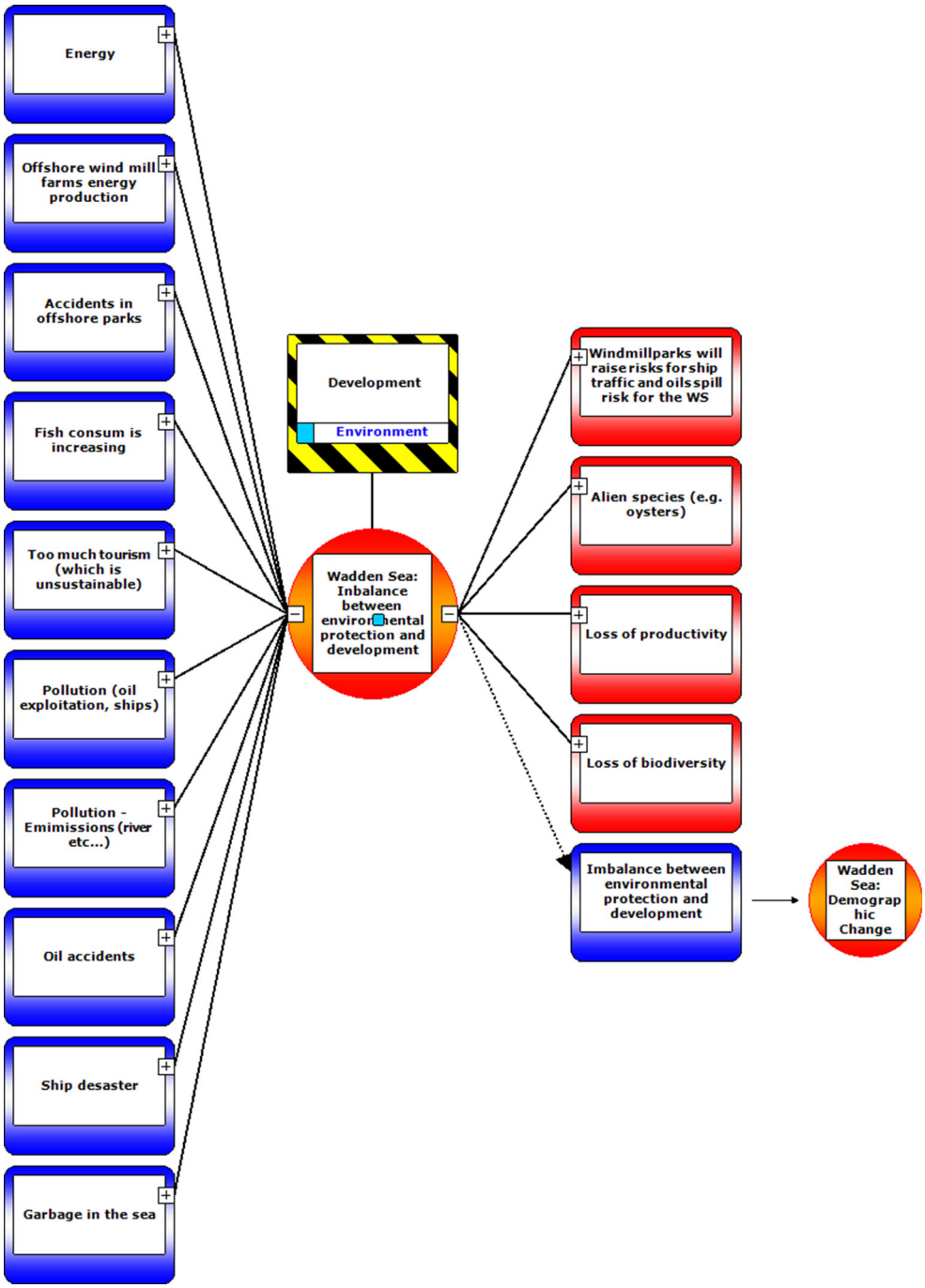

Fig. 4 Bow-tie diagram evolving around the worries of an imbalanced development and conflicting social, economic and environmental interests; information on adaptive and mitigating measures are hidden; diagrams were produced with the software Bow-tie XP CGE Risk Management Solutions

sustainable development by defining objectives for overarching issues for all sectors in the WSR as well as for some specific developments (WSF 2013).

The bow-tie diagram (Fig. 4) shows most of the risk pathways as the issues addressed by the already existing ICZM-strategy of the WSF. This obviously close link enabled the participants to distinguish between measures already in place and measures which need to be elaborated. The bow-tie process helped the WSF to examine their existing ICZM-strategy with regard to the status of the strategy's implementation and effectiveness. The workshop highlighted an increased need to transform the recorded goals into practice. Furthermore, the bow-tie process made clear that the ICZM strategy is not sufficiently known and visible in the different sectors in order to be considered for practical implementation of risk management measures. This example demonstrated how the bow-tie process is supportive in detecting whether already existing strategies and measures are sufficiently established and

efficient or neither of the two. This might help the WSF to detect further action points as well as obstacles hampering the implementation process of existing strategies.

The WSF exercise is able to demonstrate the methodical benefits of the bow-tie process. In general, the bow-tie process supports an understanding of the complexity of the multi-risk situation. The bow-tie process supports a global overview on a complex multifaceted risk situation as well as at the same time enabling the participants to disclose risk pathways at the specific (local) level. The bow-tie process steered the stakeholders' focus on the fact that risks are interlinked and interdependent. Cascading effects between the different risk clusters can influence the risk management performance and have to be taken into account in risk management processes. The latter was visualized in the bow-tie diagram by the linkages and connections between the three bow-ties, e.g. the bow-tie diagram on imbalanced development highlights several interlinkages and feedback to consequences mentioned in the cluster of demographic change. In addition to the global view on the multi-risk situation the bow-tie process allows a more detailed look at the measures and activities in place at different levels. In the WSR we made use of this fact by identifying and determining current responsibilities for different risk management tasks together with the WSF stakeholders. The discussions helped to identify the potential role of the WSF in risk management on the trilateral level.

Discussion on the use of the bow-tie analysis

The call for enhanced stakeholder participation is not only part of a democratic process it also includes the enhanced consideration of multiple differences, perceptions and interpretations of risks and their impacts on different actors, sectors or institutions. Our experience with the WSF demonstrated the advantages of a bow-tie process, as a beneficial framework to facilitate stakeholder involvement. The bow-tie process, as presented for the WSR, underlined the method's potential to support communication and co-construction in a multi-stakeholder context. In this context the bow-tie process supports the structuring of risks by a systematic identification of risks, causes and consequences and significantly enhances communication about awareness of risks and their management in the stakeholder group (compare IEC 2009). The structured discussions facilitate stakeholders to gain enhanced understanding of the complexity and interrelationships of different risks, causes and consequences, facilitate an overview about the current state of management measures and enable stakeholders to detect needs from improved measures as much as to detect obstacles in the current risk management process. In this context, the bow-tie exercise with the WSF demonstrated the beneficial contribution for risk analysis and risk evaluation (following ISO 2009).

Nevertheless, the schematic visualization of the structuring processes within the bow-tie diagram also gave room for critique and showed some limitations. The complicated structures of risk pathways the bow-tie diagram allows to a limited extent only the visualization of feedback effects between the different elements. Feedback and feedback loops, however, are important for the examination of complex and highly interlinked processed between different risks. The WSF stakeholders also criticised the scientific-look and model-like character of the bow-tie diagram, which requires intensive dedication and demands flexibility on the part of the stakeholders towards new ways of thinking as well as their willingness to invest time and mental training. These reservations notwithstanding the WSF stakeholders were willing to invest time and dedication in the bow-tie process. Such a comprehensive commitment of the stakeholders we would argue is an essential precondition for the bow-tie process and a driver for successful stakeholder participation. The interactive bow-tie process supports stakeholders to communicate their perspectives to others in a structured way as well as to learn about other perspectives. Discussions in the bow-tie process make the whole risk management cycle and its single elements more transparent and comprehensible for the stakeholders.

Based on the presented experience in the WSR we encourage actors in coastal risk management to take up the bow-tie process as a communication tool supporting disclosure of the variety of perceptions and perceived cause-effect-relationships, which is an essential part of a comprehensive, complementary and widely-accepted grounding for risk management processes.

Conclusion

The aim of the paper was to methodologically contribute to the rising demand for multi-stakeholder involvement in coastal risk management processes and to demonstrate the applicability of stakeholder involvement in risk management. We addressed the question as to how risk perceptions as well as societal concerns and needs can be made accessible to the risk management process in a multi-stakeholder participatory manner. The case study of the trilateral WSR instructively demonstrated how the bow-tie analysis, performed as a bow-tie process, was put into practice. This process supported the structuring of the multi-risk situation in the WSR was clustered around the challenges of 'demographic change', 'climate change resulting in environmental changes' and 'imbalanced development in the WSR'. The bow-tie process in the WSR supported the detection of urgent management needs to improve existing risk management and of obstacles in current risk management processes.

We were able to underline the bow-tie process capacities to enhance stakeholders' understanding of risks and risk

management processes, fostered structured discussion on risk pathways, to pave the way for stakeholders to give feedback about the performance and efficiency of actual management processes as much as to strengthen stakeholders' commitment in risk management processes. Enhanced understanding and rethinking of risk management processes are emphasised as one of the positive implications that multi-stakeholder participation might contribute in enhanced risk management. And at the same time, enhanced understanding of risk management processes facilitates clearly structured discussions to continuously define and verify the role and contribution of multi-stakeholder involvement in these processes. The inclusion of multiple stakeholder perceptions can stimulate communication and discussion which in themselves are main benefits of multi-stakeholder involvement in risk management processes. Negotiations are as much a learning process for stakeholders as for the decision-makers involved – enhancing awareness and acceptance of risk management measures and policies within the stakeholder community. Our findings emphasize that making stakeholders' voices heard and including their perspectives and concerns in a risk management process is an essential contribution of multi stakeholder involvement to facilitate decision-making for successful risk management processes. In the sense of the guiding principles of the Sendai Declaration, stating that "disaster risk reduction and managements depends on coordination mechanisms within and across sectors and with relevant stakeholders at all levels […] and a clear articulation of responsibilities across public and private stakeholders" (United Nations ISDR 2015, p. 8), we demonstrated with the WSR case that such strategic principles can be put into practice.

Acknowledgments The research underlying this paper has received funding from the EU's Seventh Framework Programme (FP7/2007–2013) under grant agreement No. 308438 (ENHANCE: Enhancing risk management partnerships for catastrophic natural hazards in Europe). We thank all the participating Wadden Sea Forum members for their contribution as well as fruitful and inspiring discussions during the stakeholder workshops. We would also like to thank Roland Cormier, Cormac Walsh and our anonymous reviewers for the very helpful and supportive comments on earlier versions of the paper.

References

Ballinger R (2014) On the edge: coastal governance and risk. In: Fra Paleo U (ed) Risk governance - the articulation of hazard, politic and ecology. Springer, Dordrecht Heidelberg New York London

Beck U (2007) Weltrisikogesellschaft, 3rd edn. Suhrkamp, Frankfurt am Main

Beck U, (2009) World Risk Society and Manufactured Uncertainties, European Journal of Philosophy and Policy Debates, p. 291–299. <http://www.fupress.net/index.php/iris/article/view/3304>. Accessed 15 December 2015

Church J, Gregory J, Huybrechts P, Kuhn M, Lambeck K, Nhuan M, Qin D, Woodworth P (2001) Changes in sea level. In: Houghton J, Ding Y, Griggs D, Noguer M, van der Linden P, Dai X, Maskell K, Johnson C (eds) Climate change 2001: working group I: the scientific basis. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Creed IF, Cormier R, Laurent KL, Accitino F, Igras J, Henley P, Friedman KB, Johnson LB, Crssman J, Dillon PJ, Trick CG (2016) Formal integration of science and management systems needed to achieve thriving and prosperous great lakes. Biogeosciences 66(5):408–418

CWSS; Common Wadden Sea Secretariat, (2014) Toender Declaration. Ministerial Council Declaration of the 12th Trilateral Governmental Conference on the Protection of the Wadden Sea. Common Wadden Sea Secretariat, Wilhelmshaven, Germany.

Enemark J (2005) The wadden Sea protection and management scheme – towards an integrated coastal management approach? Ocean Coast Manag 48:996–1015

Evans JP (2012) Environmental governance. Routledge, London

FAK, Fachausschuss für Küstenschutzbauwerke (2009) Küstenschutzstrategien bericht der FAK-arbeitsgruppe. Die Küste 76:1–74

Gall M, Cutter SL, Nguyen K (2014) Governance in Disaster Risk Management. IRDR AIRDR Publication No. 3, Beijing: Integrated Research on Disaster Risk. http://www.irdrinternational.org/wp-content/uploads/2015/01/AIRDR-Project-Report-No.-3-WEB-6MB.pdf. Accessed 20 Aug 2015

Gerritsen H (2005) What happened in 1953? the big flood in the Netherlands. Phil Trans R Soc A. doi:10.1098/rsta.2005.1568

González-Riancho P, Gerkensmeier B, Ratter B, Gonzalez M, Medina R (2015) Storm surge risk perception and resilience: a pilot study in the German North Sea coast. Ocean Coast Manag 112:40–60

Greiving S, Glade T (2013) Risk governance. In: Bobrowsky PT (ed.) Encyclopedia of Natural Hazards, pp 804–806.

IEC; International Electrotechnical Commission International Organization for Standardization (2009) Risk Assessment Techniques. ISO. IEC/ISO 31010:2009

IPCC; Intergovernmental Panel on Climate Change (2007) The physical science basis. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

IPCC, Intergovernmental Panel on Climate Change (2013) Summary for policymakers. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Climate change 2013: the physical science basis contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

IRGC; International Risk Governance Council (2005) Risk governance: Towards an integrative approach. White paper No 1, Author O. Renn with Annex by P. Graham. Geneva.

ISO, International Organization for Standardization (2009) Risk management - Principles and guidelines. ISO

Kabat P, Bazelmans J, van Dijk J, Herman PMJ, van Oijen T, Pejrup M, Reise K, Speelman H, Wolff WJ (2012) The wadden Sea region: towards a science for sustainable development. Ocean & Coastal Manag 68:4–17

Katsman C, Hazeleger W, Drijfhout S, van Oldenborgh G, Burgers G (2008) Climate scenarios of sea level rise for the northeast Atlantic ocean: a study including the effects of ocean dynamics and gravity changes induced by ice melt. Climate Change. doi:10.1007/s10584e008e9442e9

Katsman CA, Sterl A, Beersma JJ, van den Brink HW, Church JA, Hazeleger W, Kopp RE, Kroon D, Kwadijk J, Lammersen R, Lowe J, Oppenheimer M, Plag HP, Ridley J, von Storch H, Vaughan DG, Vellinga P, Vermerrsen LLA, van de Wal RSW, Weisse R (2011) Exploring high end scenarios for local sea level

rise to develop flood protection strategies for a low lying delta – the Netherlands as an example. Clim Chang 109(3–4):617–645

Luhmann N (1993) Risk: a sociological theory. Walter de Gruyter, Berlin

Ratter BMW (2012) Complexity and emergence - Key concepts in non-linear dynamic systems. In: Glaser M, Krause G, Ratter BMW, Welp M (ed) Human-nature interactions in the anthropocene. Potentials of social-ecological systems analysis. New York, pp 90–104

Ratter BMW, Sobiech C (2011) Heimat, Umwelt und Gefahren - Wahrnehmungen der Bevölkerung an der deutschen Nordseeküste. In: Fischer L, Reise K (eds) Küstenmentalität und Klimawandel - Küstenwandel als kulturelle und soziale Herausforderung. Ökom, Munich, pp 181–196

Rausand M (2011) Risk assessment – theory, methods, and applications. Wiley, Hoboken

Renn O (2008) Risk governance. Coping with uncertainty in a complex world. Earthscan, London

Salvi O, Debray B (2006) A global view on ARAMIS, a risk assessment methodology for industries in the framework of the SEVESO II directive. J Hazard Mater 130(3):187–99

United Nations ISDR; International Strategy for Disaster Reduction (2015) Sendai Framework for Disaster Risk Reduction 2015–2030. Geneva, Switzerland available at: http://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf. Accessed 10 Dec 2015

van Dijk J, Broersma L, Mehnen N (2016) Options for socioeconomic developments in ICZM for the tri-national wadden area. Ocean Coast Manag 119:76–92

von Storch H, Gönnert G, Meine M (2008) Storm surge - an option for Hamburg, Germany to mitigate expected future aggravation of risk. Environ Sci Pol 11:735–742

Wadden Sea Forum (2004), Sector-specific analysis and perspectives for the Wadden Sea Region, available at: http://www.waddensea-forum.org/images/archive/studies/waddensearegional-analysis-en.pdf

Wadden Sea Forum (2005) Breaking the Ice. Wilhelmshaven. http://www.waddensea-forum.org/strategy/breaking-the-ice Accesse 07 June 2016

Wadden Sea Forum (2010) Without Frontiers – achievements in cross-border, cross-sector, communication and cooperation.Wilhelmshaven. http://www.waddensea-forum.org/strategy/without-frontiers Accessed 07 June 2016

Wadden Sea Forum (2013) ICZM Strategy for the Wadden Sea Region. Wilhelmshaven. http://www.waddensea-forum.org/strategy/iczm-strategy Accessed 07 June 2016

Wadden Sea Long-Term Ecosystem Research (WaLTER), Waddenacademie KNAW, Common Wadden Sea Secretariat (CWSS) (eds.) (2014) Wadden monitoring in the spotlight. http://www.waddenacademie.nl/fileadmin/inhoud/pdf/04-bibliotheek/2014Waddenmonitoring_in_the_spotlight.pdf Accessed 06 June 2016

Wanczura S, Fleischhauer M, Greiving S, Fourman M, Sucker K, d'Andrea A (2007) Analysis of recent EU, international and national research and policy activities in the field of risk governance. Del. 1.1 MIDIR ProjectWard.

Weisse R, Bellafiore D, Menendez M, Mendez F, Nicholls R, Umgiesser G, Willems P (2014) Changing extreme sea levels along European Coasts. Coast Eng 87:4–14

Woth K, Weisse R, von Storch H (2006) Climate change and North Sea storm surge extremes: an ensemble study of storm surge extremes expected in a changed climate projected by four different regional climate models. Ocean Dyn 56:3–15