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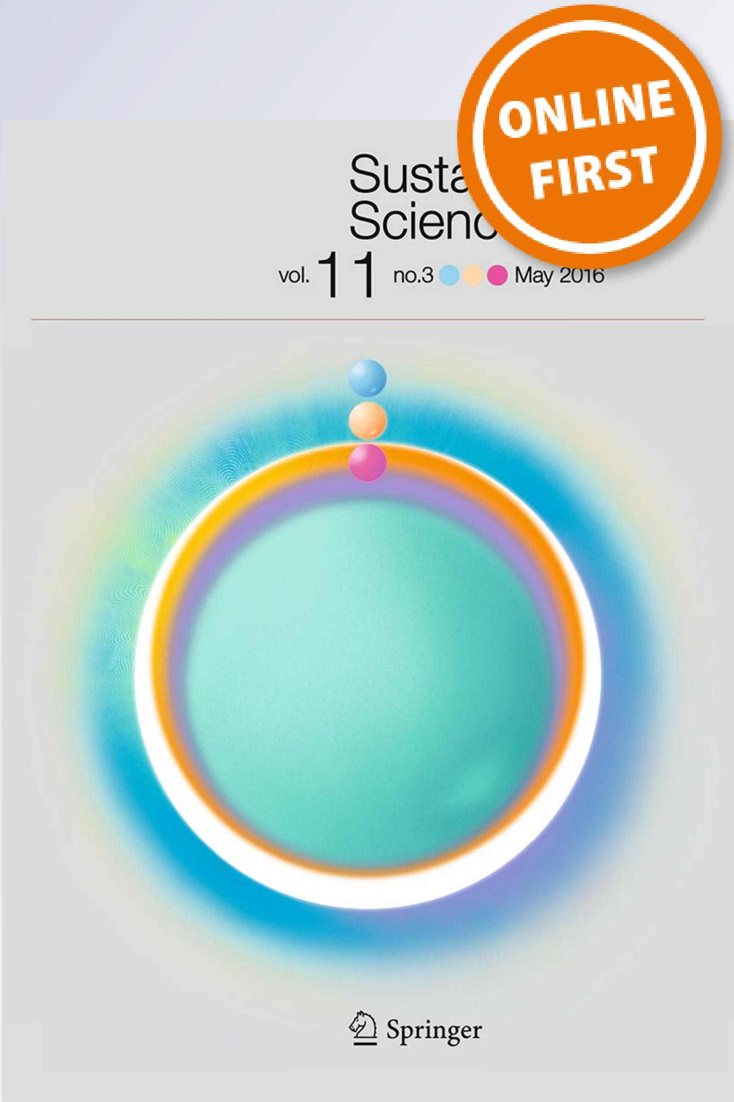

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ORIGINAL ARTICLE

Decision makers' barriers to climate and extreme weather adaptation: a study of North Atlantic high- and medium-use seaports

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Abstract

Decision-making barriers challenge port administrators to adapt and build resilience to natural hazards. Heavy rains, storms, sea level rise (SLR), and extreme heat can damage the critical coastal infrastructure upon which coastal communities depend. There is limited understanding of what impedes port decision makers from investing resources in climate and extreme weather adaptations. Through semi-structured interviews of 30 port directors/managers, environmental specialists, and safety planners at 15 medium- and high-use ports of the U.S. North Atlantic, this paper contributes a typology of seven key adaptation barriers. We measured shared knowledge of the identified barriers using a cultural consensus model (CCM). Knowledge of the barriers that prevent or delay resilience investments can help the decision makers direct their resources to help reduce coastal vulnerability and support safe and sustainable operations of U.S. ports. Such actions also serve to help prepare the marine transportation system for future climate and extreme weather events.

Keywords Barriers to adaptation · Climate change adaptation · Decision makers · Extreme weather · Seaports · Resilience

Introduction

Port decision makers need to plan for adaptation to storms and extreme weather events to reduce risks of disaster and increase the ports' resilience (NRC 2009; Biesbroek et al. 2011). Active planning, as opposed to reactive planning (Kretsch 2016), can help ports ensure long-term sustainability. Coastal infrastructures are adapted to climate change by protecting their coastlines, elevating their piers, designing for submersion or abandoning when the cost of adaptation is not worth the investment (Becker et al. 2018). In 2012, the Intergovernmental Panel on Climate Change (IPCC) describes how adaptations require "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploit beneficial opportunities" (IPCC 2012, p. 5, Taylor 2019). Furthermore, the IPCC warned that researchers would face challenges in understanding the processes by which adaptation is occurring and will occur in the future (Adger et al. 2007; IPCC 2007). They highlighted that the first step in addressing climate change adaptation is to understand the barriers that exist and their context to plan strategies to overcome them. In response to these concerns, social-scientists started studying barriers to climate change (Moser and Ekstrom 2010).

Some progress is being made: in the U.S., projects regulated by the Army Corp of Engineers (USACE) are incorporating sea level rise (SLR) into their design specifications (USACE 2014). Recent studies suggest that some ports are addressing climate change risks (Scott et al. 2013; Ng et al. 2018; McEvoy and Mullett 2013; McEvoy and Mullett 2013; Diego 2018; Stenek et al. 2011; Zeppie) or responding to Hurricane impacts (Becker 2016b). But, coastal communities have experienced and continue to experience worsening impacts from climate change-related natural hazards (Melillo et al. 2014). Although these changes are inevitable (IPCC 2012; Melillo et al. 2014) damages to critical infrastructure can be reduced through the implementation

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of adaptations that build natural hazard resilience (Füssel 2007).

The purpose of this study is to understand barriers to climate and extreme weather adaptation for one critical sector of coastal infrastructure: seaports. Using empirical data collected from port administrators, we explore how seaport decision makers perceived barriers, and whether there was a shared agreement in the identified types of barriers that port directors/managers, environmental specialists and safety planners face. Interviewees answered questions about the barriers to climate and extreme weather adaptation (e.g., 'What are some of the challenges to implementing extreme weather adaptation actions at your port?') and their perceptions of the port's vulnerability. Through analysis of the interviews and a literature review on barriers to climate and extreme weather adaptation, researchers developed a port-specific typology of barriers to climate and extreme weather adaptation.

Barriers are defined as "… obstacles that can be overcome with concerted effort, creative management, change of thinking, and the related shift in resources, land uses, institutions, etc." (Moser and Ekstrom 2010, p. 22027). Building natural hazard resilience depends on decision makers overcoming these barriers, so that systems can bounce back quickly following a storm event. Several studies identify barriers or propose frameworks to identify and analyze them (Moser and Ekstrom 2010; Biesbroek et al. 2013). Fewer studies present guidance for interventions (Moser and Ekstrom 2010), or their context (Biesbroek et al. 2013), or how to build the adaptive capacity necessary to overcome such barriers (Siders 2019). In 2010, Moser and Ekstrom addressed these limitations in a comprehensive policy framework for identifying and analyzing barriers that also provided guidance for capacity-building interventions (Moser and Ekstrom 2010).

Barriers to adaptation can be institutional (Adger et al. 2007; Barnett et al. 2013), or socio-cultural (Burch 2010); these can also be informational, financial, and cognitive (Adger et al. 2007). Differences and subjectivity arise when trying to categorizing barriers (Jones and Boyd 2011), but typologies such as the one proposed here increase our general understanding of where opportunities lie for overcoming such challenges. Barriers to adaptation in the spheres of governance can be explained (Adger and Barnett 2009; Adger et al. 2009; Moser and Ekstrom 2010; Barnett et al. 2013) as challenges in leadership, caused by uncertainty in the roles and responsibilities across different levels of governance (Moser and Ekstrom 2010; Barnett et al. 2013). These challenges are also reflected in barriers reported in policy initiatives (Tompkins et al. 2010), many of which are intensified by the uncertainty in climate change projections (Barnett et al. 2013). In a study on barriers conducted in Australia, Barnett et al. described five main barriers to adaptation for coastal communities, these are: governance, policy, uncertainty, resources, and psychosocial factors. The study also recognized the shared responsibility of key actors in adapting to sea level rise, and the role played by different levels of governance (Barnett et al. 2013).

Biesbroek et al.'s studies highlight that while some barriers to climate and extreme weather adaptation are not necessarily climate change-specific (2013), others stem from the "long term impacts of climate change versus the short-term dynamics of politics and decision-making; the reliance on scientific models to identify, understand and communicate problem and propose solutions, and the inherent uncertainty and ambiguities of climate change" (Biesbroek et al. 2013, p. 1124).

Similar to general barriers to adaptation mentioned earlier, ports are also challenged by the complexity of their governance and leadership (Becker and Caldwell 2015), as well as by a lack of communication between key stakeholders (Ng et al. 2018). As the National Research Council (NRC) notes, effective climate adaptation will require all types of decision makers and stakeholders to participate (NRC 2010). Others emphasize on the importance of adopting an 'adaptation pathways', a process for planning that enables decision makers to assess climate changes within broader context that address societal transitions and transformations (Wise et al. 2014).

In the following sections, we present the methods of our study, the study sites, and analysis, followed by the results on decision makers' perceptions of barriers to climate and extreme weather adaptation in 15 ports of the North Atlantic. Port directors, environmental specialists and safety officers' perceptions on the barriers to climate and extreme weather adaptation are presented, along with the context in which they were discussed during the interviews. In the discussion, we expand on the implications of these findings. Improving decision-making to adapt ports to climate and extreme weather events can only decrease future risks and increase a seaports resilience to these impacts. In the long term, coastal cities face dramatic changes from sea level rise and eventually many ports may no longer be viable due to inundation. However, assessing where federal resources should be directed, and where future key investments can be made sustain operations of major ports is an essential step towards increasing resilience of the maritime transportation system (Hsieh 2014; Becker et al. 2014; Chhetri et al. 2014).

Methods

This study investigates seaport-specific barriers to climate and extreme weather adaptation for 15 medium and high-use ports in the North Atlantic. Between November 2017 and February 2018, our research team interviewed 30 decision

Table 1 Description of responsibilities of port decision maker positions

Position	Number interviewed	Responsibilities
Directors or managers *Common titles:* Executive director Director of operations Project manager	17	Run port operations and systems (short or long term) Perform maintenance of vessels and facilities Supervise employees Manage specific functions of port facilities Plan efficient use of port resources, with attention to security, safety, and health of personnel
Environmental specialists *Common titles:* Marine environment and civil engineering consultant Manager of strategic planning Harbor master Environmental manager Project manager Climate mitigation and resilience manager	8	Monitor related environmental regulations Oversee environmental protection and other social responsibility functions
Safety planners *Common titles:* Vice president of sustainability (consultant) Chief harbor safety strategist and operations assistant	5	Monitor and assess hazardous and unsafe situations Develop guidelines for personnel safety

makers to develop a framework for perceptions of the barriers[1] to climate and extreme weather adaptation. The data were also used to develop a cultural consensus model to measure the decision makers' consensus on the barriers. Port decision makers in this study are defined as port directors/managers, environmental specialists and safety planners who have responsibility for decision making related to climate and extreme weather resilience. Not all ports have representatives for these positions. For some ports, aspects of these roles are outsourced to private consultants. In most areas, harbor masters and the U.S. Coast Guard have additional responsibility for the safety planning of coastal infrastructure in a region. However, this study was limited to employees of the ports who are charged with leadership and decision making within the studied ports. The responsibilities of each group are described in Table 1.

Management and governance structures vary across the ports. Those without a port authority are privately owned or managed by a private entity in the name of the state (Table 2). Because the number of decision makers and their years' experience can influence perceptions, these data are also included in Table 2.

[1] Interview protocol and procedures were approved by the Institute of Review Board at the University of Rhode Island (IRB Approved 894694-8). Interviewees were informed of the purpose of the study and that they give a written or oral consent to being interviewed and being recorded (for transcription purposes only). The majority of interviews (73%, 22/30) were conducted in person, 27% were conducted over the phone, 10 of the ports were visited.

Data collection

Interviews were conducted at 15 out of 22 medium- and high-use ports of the United States Army Corps of Engineers (USACE) North Atlantic Division (CENAD) (S 1). The ports were selected in consultation with the U.S. Army Engineer Research and Development Center (ERDC) to represent ports with a varying degree of risk to major hurricanes.

There were two sections of the semi-structured interviews, with nine and eight questions, respectively (S 2). The

Table 2 Demographics representing the study's participating decision makers

Number of participating ports	15/22
Ports with port authority	9/15
Number of interviews	30
Types of decision makers	
Directors and managers	17
Safety planners	8
Environmental specialists	5
Years of experience	
<5	7
5–10	7
11–20	8
>20	8
Range of experience	1–46 (years)
Gender of decision makers	
Female	8/30
Male	22/30

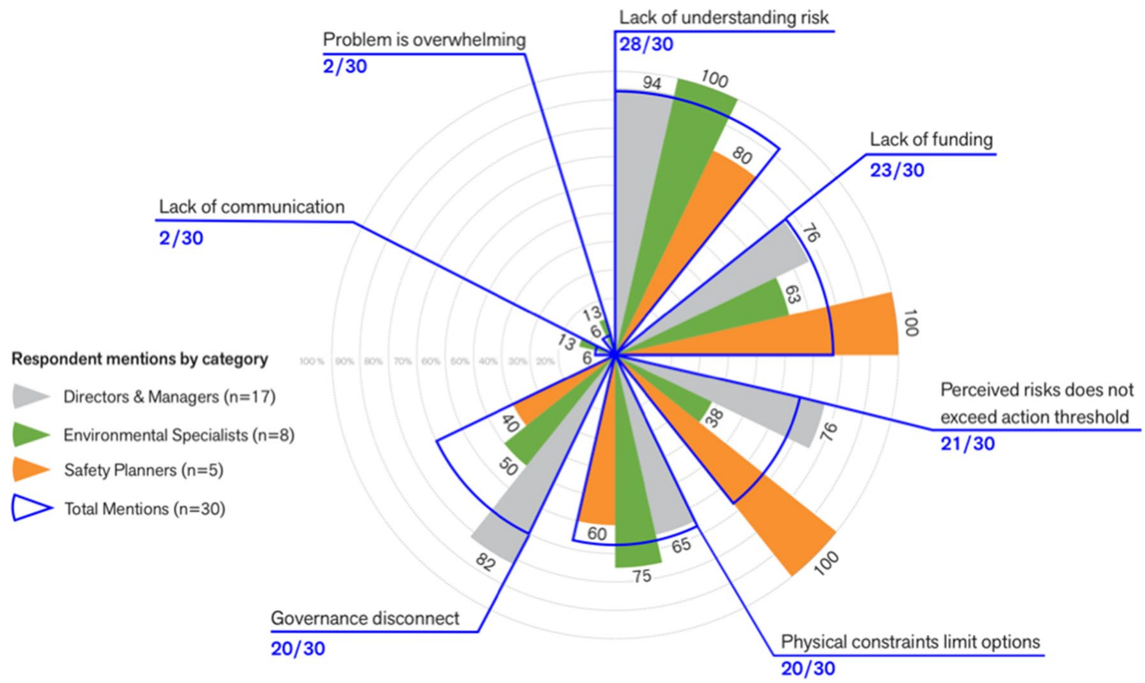

Fig. 1 Seven barriers to climate and extreme weather adaptations resulted from 30 interviews in 15 North Atlantic ports. The value above each colored pie is the percentage of respondents who mentioned that barrier within the decision maker type (directors/managers, environmental specialists, safety planners). Blue numbers are the total frequency of the responses. The blue-outlined pie is the overall percentage of responses for a barrier

first section sought to understand perceptions of barriers to climate and extreme weather adaptation, and the second to understand perceptions of port vulnerability. Questions were open-ended, hence, the absence of a mention of a barrier does not mean that the port is not challenged by it, but that other challenges were more palpable to interviewee (S 2).

Data analysis

The analysis was divided into three steps. First, we coded responses to identify the major barriers as perceived by respondents. Second, we ran the cultural consensus model (CCM) using ANTHROPAC 6.46 software (Borgatti 1996) to assess agreement between different respondents. The CCM assumes that there is a shared cultural knowledge and aggregates individual "culturally correct responses" to measure the level of agreement between individuals (Weller 2007; Romneyet al. 1987). A Pearson correlation coefficient value indicates if there is an association between two variables' measures' associations or agreement between the subjects. Third, we compared the responses across the categories to identify patterns or variation in the responses across the different decision makers groups.

After the transcription of the interviews, we coded the transcripts line-by-line using the *NVivo* qualitative data analysis software package (NVivo 2014). Reviewing the transcripts, we identified and classified the barriers, and resolved coding differences between researchers' assessments where necessary,[2] following the process laid out by Ekstrom and Moser (2014). The coding scheme used an iterative process based on grounded theory (Charmaz 2006; Glaser and Strauss 2017). Statements characterized as a constraint, a challenge, or a limitation to the adaptation process, were coded as a potential barrier. This process allowed for views and concepts to emerge and be grouped into unique categories.

Results

The analysis of the 30 decision makers interviews from 15 ports in the North Atlantic resulted in the identification of seven perceived barriers to climate and extreme weather adaptation (Fig. 1). Barriers include: the lack of understanding of the risks (mentioned by 93% of responses), lack of funding (77%), perceived levels of risks do not exceed the action threshold (70%), governance disconnect (67%),

[2] NVivo Coding comparison between coders; in the initial coding phase, yielded a 0.696 Kappa value (Values between 0.40 - 0.75 = fair to good agreement).

Table 3 Cultural consensus model analysis: consensus for 30 port decision makers on the perceived barriers to climate and extreme weather adaptation

	First Factor	Second Factor	First to second factor ratio	Average "competency"
Sample ($n=30$)	14.282	4.905	2.912	0.598 (st. dev 0.25)

Factor loading one, accounts for the variability in the data, factor two accounts for as much of the remaining variability

physical constraints (67%), lack of communication amongst individuals (7%), and the problem (of adaptation) is overwhelming (7%). Figure 1 shows the number of respondents that mentioned at least one barrier from each of the seven categories at least one time during the interview.

The following section presents the results of the cultural consensus model (CCM) and then explains each of the seven major categories of the identified barriers.

The cultural consensus model results

Fit to the cultural consensus model (CCM) is given by the factor ratio of 3 to 1 or greater, that is a standard indication of clustering. We deemed eigenvalue ratio of 2.91 as sufficient evidence of conditional independence between factor 1 and 2, and evidence of shared knowledge (Borgatti 1996). The percentages of the responses in our data show a strong cultural pattern, meaning that respondents have a high agreement in their responses. When the factor ratio is smaller than 3 this indicates that respondents divide into 'two' or 'more' populations—meaning that their views are not homogeneous.

The competence score in the CCM represents a measure of respondents' shared knowledge. For the studied group, the average competence score is 0.598, and the values range from 0.981 (highest agreement) to 0.067 (low or absence of agreement) (Table 3). As an example, when two respondents answered that barrier #1 and barrier #2 were the main challenges, their competence score could be closer to '1', or 0.981. But when a third respondent who mentioned barrier #3 to be most important, its competence score could be closer to 0.598. The closer their competence score is closer to '1', the higher is their agreement with the mean, and the closer the competence score is to '0', the lesser is their agreement.

Typology of seven key barriers to climate and extreme weather adaptation for seaports

This section describes the seven categories of barriers, and how decision makers in different categories perceived them. Each barrier is explained within the context in which it was mentioned by the respondent, and some examples are provided. For example, the barrier lack of understanding of risks was mentioned in the context of confusion over the level of risk and the difficulty of predicting where (or if) impacts will be (For further details on the context in which each barrier is mentioned see S 3). Distinct responses and differences in viewpoints of given groups were also highlighted. In parenthesis, the respondent category is noted, as follows: DIR = Port Director, ES = Environmental Specialist, SP = Safety Planner.

The respondents not only mentioned one barrier to adaptation, but multiple ones when being interviewed, we illustrate this complexity in Fig. 2. For example, seven directors/managers are represented in A. One director could have mentioned up to five of the seven adaptation barriers during the interview. Similarly, in part B all the safety officers that participated mentioned from two to five barriers (Fig. 2).

The distribution of responses across all decision makers categories illustrates how barriers are perceived by type of decision maker, with further context provided (Fig. 3, S 3). To illustrate these differences, the 15 ports (labeled ports A–N) are organized by the number of decision maker categories who participated. First, the ports where only directors/managers participated are presented, then ports where port directors/managers and either environmental specialist or safety officers participated are presented, and lastly, ports where all of them participated. Agreement on a barrier category is coded in green, and absence of agreement, in grey. The columns represent the decision makers categories for the 15 different ports, and the rows indicate whether or not they mentioned a given barrier to adaptation. In descending order of frequency (1 > 7), the barriers mentioned most frequently also present highest agreement level for the decision makers categories. Secondly, in ports where all decision makers participated (Ports D, H & L), almost all of the respondents agreed that lack of understanding of risks was a barrier, but one environmental specialist—out of a team of two—mentioned lack of funding, and perceived risks do not meet action threshold.

Barrier 1: lack of understanding of risks

The lack of understanding of risks was mentioned by 28 of 30 respondents (Fig. 3), representing 13 of 15 ports. Many of the decision makers mentioned lack of understanding of risks as it related to the difficulty in predicting impacts or if the hazard will occur, like where at their port the flooding might occur (S 3). Many felt that severe weather events in the past (if there were any) did not serve as predictions for the future. As an example, one respondent said "… The storm was over 50 miles/hours gusts, but we typically don't see a whole lot of these [level of the storm]" (DIR). Sometimes,

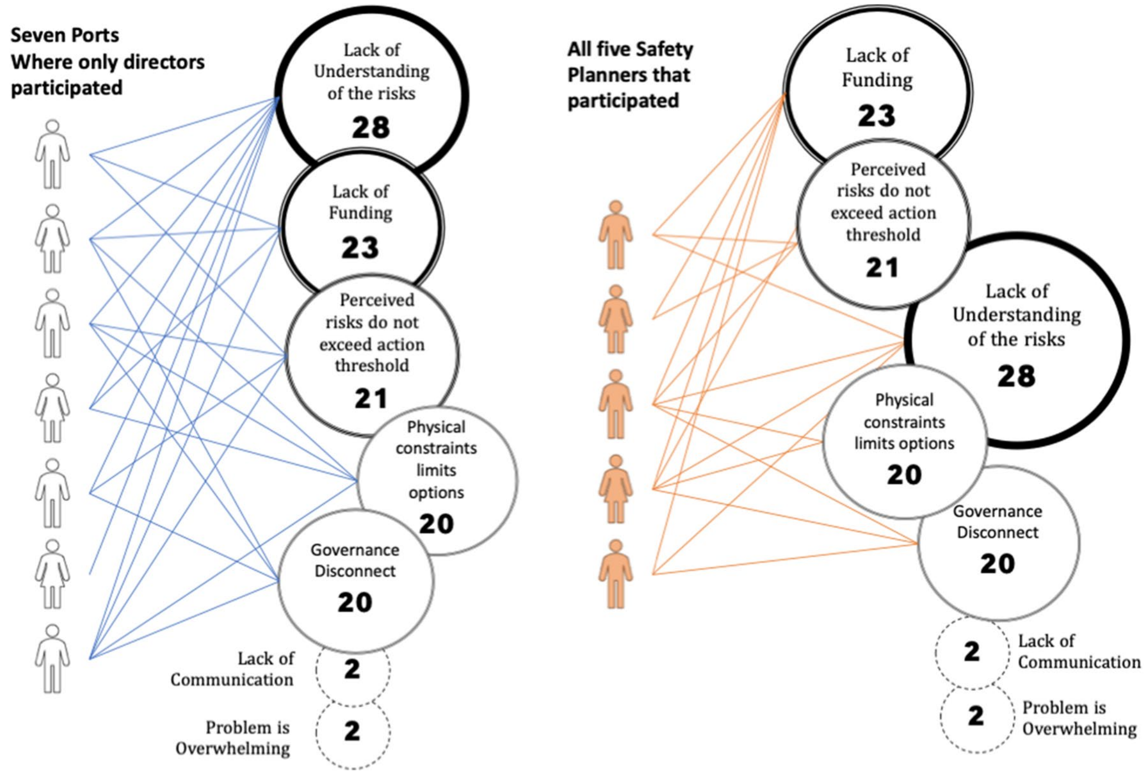

Fig. 2 The complexity of the responses: one respondent can mention one to five different barriers. **a** Ports at which directors mentioned up to five of the identified adaptation barriers. **b** The five interviewed safety officers also mentioned the same five barriers

expected damages do not occur or require an unanticipated response. In another example, one decision maker said: "… the flooding was coming from the *other* way… from a direction people were *not* expecting it…" (ES).

Respondents described resilience planning as often being reactionary and myopic, with ports engaging in mitigation planning only after a natural hazard and then preparing to respond to similar hazards in the future based on the latest experience, rather than for the full range of plausible events. As one decision maker said, "I think that we have done enough… measure[ing] ourselves up against the next Hurricane Sandy… But unfortunately, the reality is Sandy was not nearly as bad as it could have been." (DIR). Another explained, "… because we got hit with flooding and surge, we… react [only] to flooding and surge… there is not really a focus on the other hazards we are facing." (SP). Others emphasized the need to understand the full suite of risk, not just the risk at the terminal itself, stating, "Even if our terminals are resilient, getting goods and services off the terminal and over the transportation network might pose challenges if… networks are not adequately resilient." (ES). Environmental specialists emphasized the need to conduct regular risks assessments to help overcome this barrier.

Barrier 2: lack of funding

Twenty-three of 30 respondents *mentioned lack of funding* (Fig. 1), defined here as the absence of financial resources or the absence of trained human resources to implement the needed adaptations (Fig. 3, S 3). In Fig. 3, the levels of agreement are represented by their percentages, along with the number of mentions per decision maker category. Lack of funding referred to both capital costs and maintenance costs, as well as costs related to planning and assessment. Maintenance, for example, provides an opportunity to make improvements that integrate resilience to climate and extreme weather considerations. However, planning for smarter, longer-term resilience also adds cost. One director explained, "We inherited some old facilities at the port and are… rehabilitating our main pier… built in 1956…" But, as the words of another director at the port made clear, building in resilience measures on these projects "… comes down to money." (DIR).

Decision makers explained how funding for resilience was in competition with other pressing needs. As ships get larger, waterways become too narrow or shallow to accommodate them. This issue often trumps resilience challenges, as ports must keep pace and spend capital on dredging

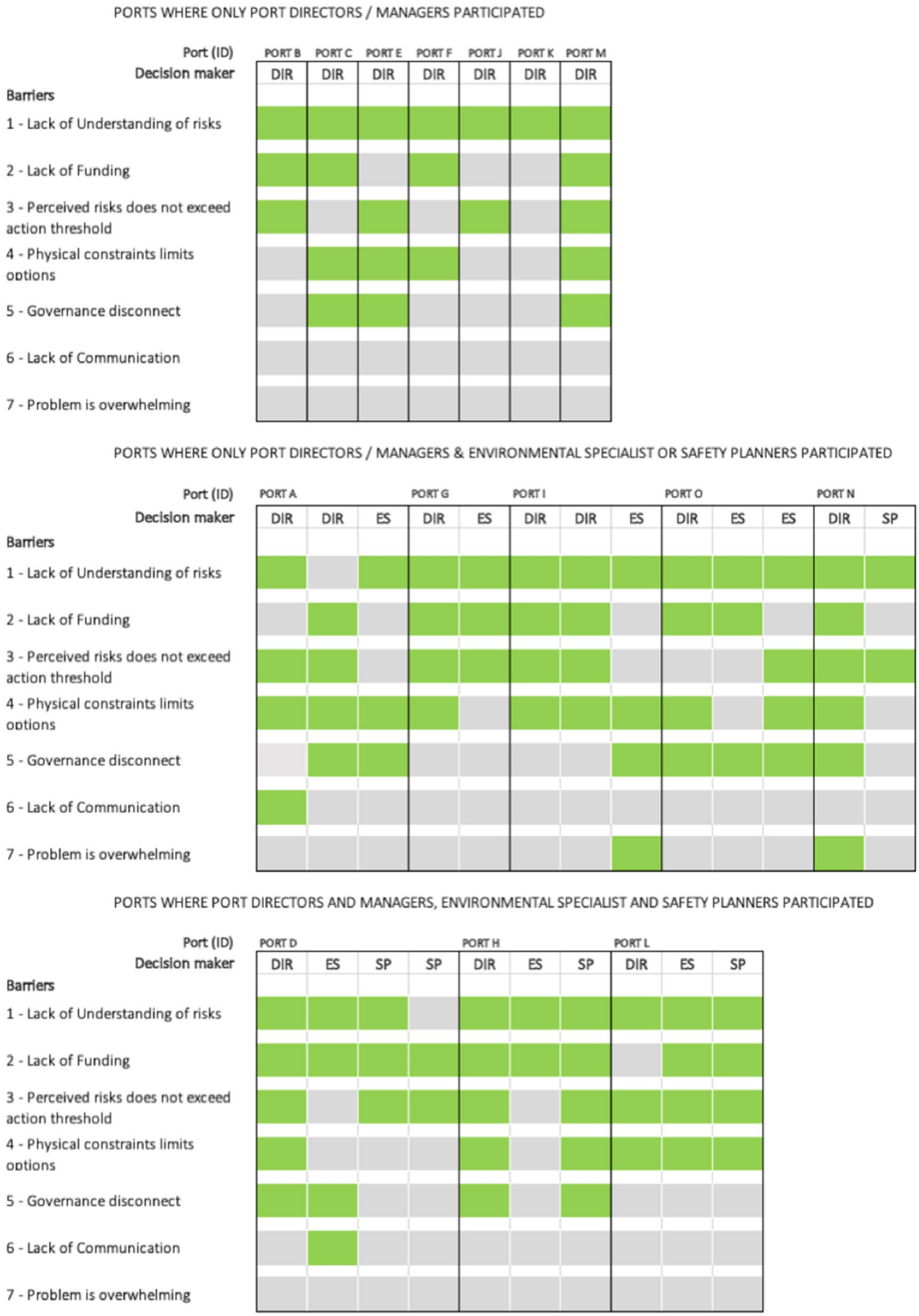

Fig. 3 Barriers and the responses by ports and the participating decision makers. The colors in each box denote when respondents in each decision maker group that mentioned the barrier at least one time. The color denotes agreement (green), or absence of agreement (grey)

channels or purchasing larger cranes. Compliance with environmental regulations was also perceived as diverting monies away from resilience. As respondent stated, "… the commercial fishing industry, with all the regulatory problems that they have, can't bear the financial burden [of resilience investment]." (DIR) Compliance other regulations, such as the American Disabilities Act (ADA), can increase the costs of adaptation, especially when space is limited. An environmental specialist mentioned the port's electrical components' exposure to climate and extreme weather events, noting that newer technology does not always perform under extreme weather conditions. Another noted that "electrical substations are very low and not elevated sufficiently… they could be elevated, but it is a huge expense." (ES). All of these financial challenges are further complicated by limited available funding and the complexity of retrofitting a port.

Barrier 3: perceived risks do not exceed an action threshold

Twenty-one of 30 respondents mentioned perceived risks do not exceed an action threshold (Fig. 1). Here, there is risk awareness, but the risk has not exceeded a magnitude or intensity to prompt an action. It is related to barrier two (a lack of understanding of the risks) but was discussed in the context of ports being unwilling to invest in the unknown. In the words of one environmental specialist, "It is a cost–benefit risk management decision to say how much are you willing to spend for an event that may—or may not ever—take place.." (ES). Disruptions challenge port operations and reconstruction affects the ability to keep up with operations, given that ports often operate at near-capacity. Decision makers emphasized that the mission of terminals is to serve their customers, which means, "… get more product in and get it out of the gate." (DIR). Although they acknowledged the need for adaptation to natural hazards, they prioritize immediate tasks related to standard operations, maintenance, and replacement of equipment. The safety planners mentioned that decision makers lack the will to invest due to this difficulty in predicting the future. Resilience investment is especially difficult for ports that have little or no experience with severe storms or flooding events. "We need to change the culture and start to think… forward… get in the right mindset of 'this is… real'… we need to face it." (SP).

Some directors and safety officers perceived that agency culture is not forward thinking or that the science was not sound. "I am not convinced that there is climate change." (DIR). In the opinion of a safety planner "You know, the weather fluctuates! I am trained to look at facts and in some cases statistics and evidence." (SAF).

Barrier 4: physical constraints limit adaptation options

Twenty out of 30 respondents mentioned physical constraints limit options, including 14 directors, four environmental specialists, and two safety planners (Fig. 1). These location-specific factors or physical/geographical-specific characteristics limit the options for the port's infrastructure adaptation. Many noted that facilities were under-designed for present and future conditions, but expansion of ports into nearby areas, or adaptations along the river that could allow floodwaters to escape, were impossible—simply because the coastline was already developed.

Both the directors and the environmental specialists explained this barrier in similar terms (Fig. 3), explaining that refitting ports is both a challenge and an opportunity. Extensive yard areas would need to be elevated, but "… every time you invest, it is an opportunity to give it [the port/port infrastructure] more lifespan." (ES).

Safety planners mentioned that current facilities are under-designed and practical solutions are lacking, in his words, "Right here [around the port authority headquarters], the challenge is to keep the water from coming up into the side. So, if you had that wall in place [to protect from storm surge, you risk] trapping the rainfall water in." (SP) (see S 3).

Barrier 5: governance disconnect

Governance disconnect was mentioned by 20 of 30 respondents (Fig. 1): 11 port directors, six environmental specialists, and three safety planners (Fig. 1, S 2). For directors, this barrier ranked second after the lack of understanding of the risks. Ineffective governance can result from lack of coordination across sectors, or across levels of organization, or both. Sometimes, governance is complex for a multi-entity system, challenged by an absence of coordination or direction. This leads to a lack of clarity on who decides on infrastructure resilience investment priorities. Nine of the 15 participating ports in the study were governed by a municipal or regional port authority (Table 2). The remaining six were either privately owned or had an agency acting as a corporate trust on behalf of the port owners. In addition, "There are multiple terminals that operate within the port that are private" (ES). In regard to deciding on the needed investments, one safety planner asked, "Who is going to pay for adaptations?… to control it?… to maintain it?" (SP). Respondents saw the complexity of multi-entity planning as a limiting factor (Fig. 3), with one stating, "I think that as the port operators, we are probably not looking to make those investments." Asked if the port has a management plan that considers climate and extreme weather resilience, this environmental specialist said he was not aware of one. "We haven't been asked to develop one, so I don't think that [we] have one specific for natural hazards." (ES).

Directors also spoke of the challenges of being a multi-entity organization where facilities and terminals under the port's authority had different landlords and different management frameworks. Respondents often described the administration of ports as being fragmented. "Long-term, [making a decision to] raise the land would be extremely challenging with how fragmented everything is down here." (DIR). Another said that while he had a good relationship with the private owners of the port facility, he was not aware of their climate adaptation plans.

Respondents also explained that the Federal Emergency Management Agency (FEMA) only compensates for the costs of bringing the port back up to the required basic code after a disaster. This gives ports little incentive to elevate their infrastructure beyond the minimum required, as some respondents mentioned:

> FEMA will give you a reimbursement to put a set of offices (like an office trailer) back where it was, and you don't have to elevate it. The code may require you to elevate, but FEMA doesn't necessarily give you any additional compensation beyond what the basic code requirement is.' (DIR)

Safety planners highlighted this barrier as driven by political decisions, "… we got to play politics to get the finances." (SP). Or they believed a cause was a lack of direction from above or the result of ports not being prioritized in large-scale regional planning.

Barrier 6: lack of communication amongst individuals

Lack of communication amongst individuals was mentioned by only one director and one environmental specialist (Figs. 1, 3). This barrier relates to keeping staff and stakeholders informed of changes in climate and weather events, as well as adaptation strategies, to be prepared to sustain port operations. The director noted, "Communication is always the key, making sure that our staff is informed about our plans moving forward to adapt to the changing weather patterns, communicating with the captains of the vessels." (DIR). The environmental specialist saw recent improvements in communications but added, "But, that [communications] can definitely be an issue from time to time." (ES)

Barrier 7: the problem is overwhelming

The problem is overwhelming was mentioned by one director and one environmental specialist (Fig. 3, Table 4). This barrier relates to the enormity of the climate change problem and humans' inability to reverse course on global warming.

Table 4 Other recommended actions that port decision makers can take in function of their positions at the ports

Port directors and managers	Environmental specialists	Safety planners
(1) Work with regulatory agencies to develop regulatory changes that encourage resilience and provide financial incentives	(1) Integrate climate risks assessments into the port management plan	(1) Integrate climate risks assessment into the port management plan
(2) Lead managers, port operators, and others in organizing and establishing working groups and developing emergency response strategies (flood barriers, etc.)	(2) Organize working groups to address climate risk	(2) Organize working groups to address climate risk
(3) Promote learning opportunities, acquisition of data and communication tools, to enhance understanding of risks, i.e., encourage a multi-way communication model of communication to downscale climate risk and uncertainty data, connecting direct plans and actions among stakeholders and the authorities	(3) Acquire and provide information on environmental risks and climate change uncertainty as it pertains to environmental concerns	(3) Organize drill exercises to enhance the ability of port personnel to respond to natural disasters Outline port safety risks and uncertainties and plans/actions needed to reduce them
(4) Direct working groups to update port master plans to include relevant SLR projections, and/or to develop risk assessments		

These two respondents felt that regardless of how much the port prepares, it will always be vulnerable:

> "… you cannot control mother nature, the severity of it. For a hurricane to come through, there is only so much you can do. You are never going to come out of it unscathed. So, obviously, there are challenges with all that. Although you can prepare,… you are always vulnerable at some of these extreme weather changes." (DIR)

Discussion

In this section, we discuss the implications of these findings in the context of other barriers to adaptation studies. Results outline a typology of adaptation barriers and conditions as perceived by port decision makers in 15 ports. The consensus in decision makers' perceptions was measured to identify gaps and trends in their knowledge (Romney et al. 1987). The high level of agreement shared by port decision makers –as well as their understanding of the port's vulnerability (S 4)—can be used to inform conversations and collaborations to build port resilience in the North Atlantic region.

The barrier lack of understanding of risk by governance, or leadership, can explain the lack of will to invest (Barnett et al. 2013); an outcome that is closely linked to perceived risks do not exceed an action threshold, and/or to lack of funding. Rational decision making depends on an individual's understanding of risks, to plan an adaptation action, and to manage the implementation of strategies (Moser and Ekstrom 2010). Some of the challenges in understanding the risks, are related to differences between long-term impacts of barriers to climate and extreme weather adaptation and the short-term [societal] dynamics that makes adaptation planning difficult (Biesbroek et al. 2013). Sometimes, the most effective motive leading to adaptive behavior is having experienced recent extreme weather events (Whitmarsh 2008; Cahoon et al. 2013; Smythe 2015). To solve for the lack of understanding of the risks, ports could conduct regular risk or vulnerability assessment that consider plausible scenarios under various climate futures (USDOT 2013; Scott et al. 2013; IPCC 2014; Melillo et al. 2014); or, similar to this study, they could assess ports stakeholders' barrier to adaptation perceptions, or their perceptions of risks posed by climate change (Yang et al. 2016). Furthermore, proactively analyzing societal constrains to adaptation as they relate to values, rules and knowledge would provide needed decision-makers additional information and context (Gorddard et al. 2012).

Improving infrastructure to withstand more frequent extreme events is often delayed due to the lack of financial resources (Eisenack et al. 2014). This barrier of lack of funding is explained in other studies in the context of a governance void (Hajer 2003), absence of leadership (Becker et al. 2014; Kretsch 2016; Becker and Kretsch 2019) or lack of will to invest (Vine 2012; Barnett et al. 2013). Such delays can also be explained by misaligned short-term dynamics of politics and the long-term changes of climate and extreme events (Biesbroek et al. 2013). As an example, an elected city mayor often makes decisions that promote him/her during their 4–5 years appointment without considering the enduring consequences of these decisions on climate change impacts. To address the lack of funding, decision makers mentioned that a change of culture is needed, after all, ports need to keep their competitive edge—looking into the future, the investments of today depended on the investments of the past (Crabbé and Robin 2006; Hallegatte 2009; Pechan 2014).

The physical constraints limit options to adaptation included aging infrastructure, geophysical restraints and the ports physical exposure. Port facilities were described as being presently under-designed, for present day and future conditions. However, both the directors and the environmental specialist saw refitting of the ports as both a challenge and an opportunity to give the port, and its infrastructure, more lifespan.

Governance disconnect may simply result in the lack of a management plan for climate and extreme weather adaptation (Moser and Ekstrom 2010). Decision makers in this study described the complexity of planning within a multi-entity organization. This disconnect is described by others in the context of institutional crowdedness and institutional void, or in the context of institutional or governance fragmentation (Biesbroek et al. 2011; Ekstrom and Moser 2014), explained by a lack of clarity of responsibilities for adaptation at local levels (Huitema et al. 2008; Ekstrom et al. 2011; Mukheibir et al. 2013; Ekstrom and Moser 2014). Others have emphasized on the importance of understanding the interdependencies that exist between institutions, values, rules, and knowledge to facilitate an make needed changes in decision-making and adaptation (Stern et al. 1999; Head 2010; Gorddard et al. 2012). This barrier is not singular to climate and extreme weather adaptation, but present in many types of governance dealing with a complex problem (Eisenack et al. 2014). It can be political—because of costs; in some cases, an elected official will defer adaptation because of the high costs (Vine 2012). When considering local, state and federal governance, different governance levels would be best suited to address different responsibilities (Mukheibir et al. 2013). One of the most important steps an organization can take to overcome problems with governance disconnects is "the inclusion of adaptation and mitigation in their annual operative plans and budget allocations" (Zambrano-Barragán et al. 2010, p. 1).

Climate and extreme weather adaptation will always be affected by political interest contesting for support from municipalities (Keen et al. 2006); it is said that climate adaptation policies as strategies are at a level of infancy (Cusano et al. 2016). Regulatory change is often long-term in scope, and political agendas are short-term in scope, making alignment of agendas challenging (Stocker 2013).

Others propose an incremental approach of "extensions of actions and behaviors that already reduce the losses that can enhance the benefits of natural variations in climate and extreme events." (Kates et al. 2001, p. 641). In this regard, to promote pro-active actions towards strategic adaptation, both environmental specialists and safety planners interviewed in this study favored regulatory changes. Regulatory changes that align with a resilience mandate requires an active leadership in ports that is preoccupied with adaptations. This type of leadership could influence the allocation of resources to both safeguard the port and serve the surrounding areas and communities. The role of the responsible actors that are actively engaged in decision making and climate change adaptations, cannot be underestimated, and although the decision makers can be informed of many positive benefits and social-economic outcomes to prioritize on needed adaptations –without a regulatory mandate—their governance will continue be constrained by short-term budgetary cycles (Burch 2010) or outdated constructions standards.

Decision makers mentioned the governance disconnects that arise when collaborating with other agencies. The Federal Emergency Management Agency (FEMA) might favor investment in preparation, response, and recovery for disaster (FEMA 2015) and provide less funding for mitigation activities (Becker and Caldwell 2015).

Lack of communication related to the need to keep port stakeholders informed of risks, as well as of adaptation strategies. In 2011, Biesbroek et al. also identified lack of awareness and lack of communication as a barrier to climate change adaptations. In their study, lack of awareness, or media misinformation influenced public and government support needed for climate adaptation (Biesbroek et al. 2011). Also, Ng et al. in their study of ports in Canada, found communication to be a constrained; here stakeholders outlined the port's inefficient 'go at it alone' model with inadequate information between port authorities and port operators (Ng et al. 2018). One way in which ports can address barriers to climate and extreme weather adaptation is through the establishment of a partnership approach that integrates multiple stakeholders (Becker 2016a). Cone et al. highlight the importance of bringing more people into the conversation, as interactions between planners and stakeholders raise the mutual understanding of potential resilience strategies (Cone et al. 2013).

Misinformation or misinterpretation of available data further challenges decision makers (Cone et al. 2013). More work is needed to integrate a larger number of port stakeholders in the conversation, to identify and overcome barriers (Biesbroek et al. 2013). Efforts should expand to understand risks both at the port and their neighboring communities through, for example, promoting a multi-way communication model (McQuail 1987) that helps rationalize climate risk and uncertainty data in a way that best connects effective plans and actions among stakeholders and port decision makers. Such an approach can reduce barriers of communication by enhancing monitoring and learning processes that integrate research, tools and best available data.

In the table below, additional recommendation actions are outlined for each the different decision maker type (Table 4).

Conclusions

The results of this study suggest that North Atlantic medium and high-use port decision makers' perceived barriers to climate and extreme weather adaptation fall into seven categories. The 30 interviewed port decision makers have consensus on the barriers that prevent them from implementing resilient adaptations to address risks from storms and extreme weather events. Port authorities and port administrators, together with state, federal, and private agencies, can help port decision makers in planning actions to reduce or remove the barriers to increase the resilience of their ports in a holistic manner. Directors, environmental specialists, and safety planners, together with other port administrators and informed stakeholders can implement the adaptation processes: understanding the barriers, evaluating strategies and carrying out their implementation and evaluation. Together with collaborative approaches and better communication flows, adaptation should be facilitated and supported at the state and national levels. Greater involvement of port tenants and diverse port stakeholders would also increase the understanding of the risks and generate a greater sense of responsibility.

While some barriers identified here can be overcome through political will, broader conceptualization of practices that allow for adaptation practices need to be considered. Furthermore, researchers and decision makers need to develop a deeper understanding of the interdependencies that exist between institutions, their values, rules, and the knowledge, beliefs and values of port stakeholders. Analyzing societal constraints to adaptation can provide context that enables decision makers to take steps and plan strategic actions to address the challenges they face.

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