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Operationalizing resilience planning, theory, and practice: Insights from U.S. seaports

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Academics and practitioners advocate climate change resilience planning to guide seaport management, business continuity planning, capital improvements, and so forth. Yet, questions of whether resilience planning interventions influence seaports' planning cultures and result in better prepared organizations remain underexplored. Through 10 cases of U.S. seaport resilience planning, this research explored the benefits and challenges of resilience planning and whether such efforts can enhance the adaptive capacity of a complex, multi-layered system such as a seaport. Results suggested that resilience planning interventions enhanced, inter alia, seaports' social capital with their internal and external stakeholders, and that seaports frequently identified and pursued infrastructure-related resilience enhancement strategies after completing resilience planning. Even when the sponsors of such studies intended an operational and business resilience purpose, they stated benefits consistent with adaptive management and resilience planning theories. Further, while key informants emphasized the strengthened relationships with stakeholders as benefits, they also frequently cited them as key challenges that require deliberative guidance and resources to help stakeholders effectively use products from resilience planning. Additional takeaways captured in this research provide valuable insights that can inform guidance materials designed to help seaports undertake their climate resilience-building endeavors.

KEYWORDS

resilience planning, adaptive capacity, seaports, climate change, natural hazards, governance

Introduction

Climate change is among myriad environmental, human, and technological hazards jeopardizing the maritime transportation system (MTS) (Abdelhafez et al., 2021) and, hence, the communities and economies that depend upon global supply chains of essential goods (Hosseini et al., 2016; Hossain et al., 2019; Wendler-Bosco and Nicholson, 2019). Academics and governments continually emphasize the need for resilience planning and adaptive management approaches to better prepare seaport infrastructure and governance systems for future climate change impacts and ensure continued social and economic prosperity.

Theoretically, resilience planning processes should enhance adaptive capacity to address change and uncertainty faced by seaports (Morris, 2020; PIANC, 2020). However, little research has investigated how resilience planning practices are realized by seaport stakeholders and how planning initiatives enhance their capacities to prepare for, sustain, recover and learn from, and adapt to climate hazards (Chhetri et al., 2020). Academic inquiry on seaports has instead focused on modeling the resilience of seaport functions and operations to various hazards (e.g., Verschuur et al., 2020; Abdelhafez et al., 2021), developing theoretical approaches to assessing seaport resilience (e.g., Morris and Sempier, 2016), or institutional barriers to seaport resilience-building (e.g., Mclean and Becker, 2019). Resilience enhancement strategies such as policy interventions and institutional arrangements are also underexplored, constituting a key knowledge gap regarding how resilience concepts are built into existing management structures to enhance seaport adaptive capacity.

This dearth in knowledge serves as the impetus of this research, which explored how seaports that have undertaken systematic approaches to identifying and planning for their climate risks have operationalized resilience concepts in management. Specifically, the objectives of this work were 3-fold: (1) to elucidate the key benefits and challenges or limitations associated with undertaking resilience planning interventions; (2) to identify the resilience-building actions that seaports pursue after completing resilience planning; and (3) to determine the extent to which such interventions enhance seaports' capacities to manage resilience to climate hazards.

Seaports provide an exemplar environment to explore the viability of resilience planning, adaptive management, and polycentric governance theories, as they constitute the complex systems of infrastructure and multi-scale governance that these theories address (Ostrom, 2010). We propose that seaport resilience can theoretically be enhanced by a collaborative planning and adaptive management approach supported by planning and assessment tools and processes. However, the academic discourses around operationalization of resilience concepts lack insight regarding the connection between resilience planning and the realization of capacities proposed to enhance system resilience. This investigation was thus guided by the following three research questions:

RQ1) What are the key benefits and challenges (or limitations) associated with undertaking resilience planning interventions (RPIs)?

RQ2) What resilience-building actions do seaports pursue after completing a RPI?

RQ3) How do such interventions enhance seaports' capacities to manage resilience to climate hazards?

The proceeding sections of this paper are as follows: first, we discuss the importance of seaports and their resilience, followed by a discussion of the challenges seaports face in building resilience and why such challenges designate seaports as exemplar environments to study resilience planning. The conversation then shifts to the resilience planning paradigm and the opportunities it offers for the climate crises seaports face, followed by the methods, results, and a discussion of interviews conducted with 26 U.S. seaport decision makers about their resilience planning initiatives.

Background

The importance of seaports and the need for seaport resilience

Seaports are key nodes in the global MTS, a fundamental component of the national transportation systems sector that is designated by the U.S. Cybersecurity and Infrastructure Security Agency (CISA) (DHS and USDOT, 2015; CMTS, 2017) as essential to U.S. health, economy, and security. While seaports' primary functions involve facilitating the transfer of cargo and/or people, they also serve as profit centers for sponsoring governments, shipping companies, energy companies, importers and exporters, and as a source of revenue for port authorities. Globally, communities, urban areas, and regional economies also depend on seaports for recreation, tourism, and the transportation of energy resources, building materials, finished products, and chemicals (Rodrigue and Notteboom, 2020; UNCTAD, 2020).

Given seaports' critical societal functions, the diverse stakeholders they serve have vested interests in their functional resilience through dynamic and ever-changing futures (de Langen, 2006). Like with other critical infrastructure, the resilience of a seaport depends on its technical resilience—the capacity to fulfill the function, at the necessary level during and after an adverse event—and its organizational resilience—the capacities of organizations to manage facilities, maintain key functions, and make decisions to improve the system after a disruptive event (Ayyub, 2014; Labaka et al., 2016; Lounis and McAllister, 2016). Collectively, a resilient seaport system effectively plans for disturbances; sustains the impacts of unforeseen disruptions while maintaining a desired level of functionality (e.g., level of throughput); quickly recovers back to pre-disturbance functionality; and/or self-organizes and learns from past experiences to adapt to emerging circumstances [Department of Homeland Security (DHS), 2013].

Building climate change resilience at seaports is a "wicked problem"

Building seaport resilience is often acknowledged as a "wicked problem," referring to a social problem that, for many reasons, is difficult or impossible to solve (Rittel

and Webber, 1973). This is due to the reality that seaports are functionally restricted to environments that are highly exposed to, *inter alia*, sea level rise (SLR), storms, and/or inland flooding (Asariotis and Benamara, 2012), yet their physical and administrative complexities present immense challenges for systemic transformations designed to enhance their resilience (Mclean and Becker, 2019). For one, from a planning perspective, identifying systems in need of resilience enhancement is a considerable undertaking given the vastness of the seaport landscape—comprising cargo handling equipment, storage facilities, navigation systems, channel maintenance systems, business systems and software responsible for procuring, tracking and distributing goods, and so on [Cybersecurity and Infrastructure Security Agency (CISA) and US Army Corps of Engineers Engineering Research and Development Center (ERDC), In Review]. Dependencies and interdependencies between infrastructure systems further complicate planning, as infrastructure networks extend outside the bounds of the seaport. Additionally, given that seaports are embedded in expansive logistics and supply chain networks (Montwiłł, 2014), charting the geographic extent of consequences of seaport disruptions is difficult, as interruptions and bottlenecks at one seaport facility can have cascading impacts that extend outward to neighboring seaports and related sectors (Thekdi and Santos, 2016). For example, energy and communications and port function disruptions in Puerto Rico after Hurricane Maria in 2017 and halted the distribution of key pharmaceutical supplies to across North America for months (Lawrence et al., 2020).

Seaport ownership and governance arrangements present additional challenges. Port authorities are classified on a spectrum from full ownership and operation of terminals and supporting facilities to acting as landlord and regulator with some or all operational functions being devolved to the private sector (Fawcett, 2006). Often, seaports' infrastructure systems operate within private and public jurisdictions (Fawcett, 2006; Nursey-Bray, 2014; Van den Berghe et al., 2018), which obscures understanding of responsibilities for implementing resilience enhancement strategies (Becker and Kretsch, 2019). Coordinating resilience in compartmentalized seaport organizations is another key barrier to resilience building (Mclean and Becker, 2019). The conflicting objectives and interests between seaports' key stakeholders (de Langen, 2006)—hailing from federal, state, and local agencies, as well as private sector entities and non-governmental organizations (Winkelmans and Notteboom, 2007)—may also lead to interorganizational information siloes that impede coordinated resilience decision-making (Shaw et al., 2017; Mclean and Becker, 2019). Tasked with balancing private sector activities that promote economic development, seaport managers may struggle to stimulate interest in long-term resilience efforts amongst their stakeholders when the future benefits of resilience investments are not easily recognizable. This, in turn, may lead decision-makers to gravitate toward more short-sighted resilience investments—for example, as (Becker et al., 2012) observed, seaport operators seldom considered time horizons beyond 10 years when planning for climate change.

The value of resilience planning for the management of complex seaport systems

Researchers and practitioners propose resilience planning and adaptive management approaches to enhance the resilience of complex social and ecological systems (Innes and Booher, 2010), like seaports, in the face of the evolving risks and deep uncertainties associated with climate change. Resilience theory acknowledges the susceptibility of systems to incremental and abrupt periods of change, and that the underlying drivers of change are non-linear and not easily identifiable (Davoudi, 2012). Hence, resilience planning offers a framework for managing uncertainties by focusing on bolstering system capacities for recovery and adaptation post-disruption (Wilkinson, 2012a; Sellberg et al., 2018). Operationalizing resilience planning requires that planners understand how system resilience is maintained and broken down, which necessitates a holistic view of the key functions driving the system's operations and how they relate to each other. The process of systematically obtaining such information and identifying opportunities for resilience enhancement, is referred to as a resilience assessment (alternatively, vulnerability assessment) (Quinlan et al., 2016). We conceive resilience assessment as being interwoven into the ongoing resilience planning process that proceeds through identification of future scenarios or threats, analysis of system characteristics and dependencies, development and evaluation of resilience enhancement alternatives, implementation by participants within their own authorities, and revision.

In a vast socio-technological landscape like a seaport, resilience planning necessitates system-wide engagement of all relevant stakeholders to develop a shared mental model of vulnerability and to evaluate alternative resilience enhancement strategies [Cybersecurity Infrastructure Security Agency (CISA), 2021; Cybersecurity and Infrastructure Security Agency (CISA) and US Army Corps of Engineers Engineering Research and Development Center (ERDC), In Review], further distinguishing resilience planning from other types of planning. Resilience planning also involves the development of inclusive data sharing processes and mechanisms for collaborative planning or decision-making; leadership for the development of agreements for shared learning and evaluation (Innes and Booher, 2010); and implementation of plans by participating authorities within their own jurisdictions (Pinel et al., 2018). These capacities are integral to resilience building, which is enabled by strong leadership within administrations, quality of data to plan for hazards, social capital amongst stakeholders, redundancy in critical infrastructure, flexibility in policies

to account for emerging realities, and collaborative and polycentric decision-making (Innes and Booher, 2010; Djalante et al., 2012; Ayyub, 2014; Ayyub and Wright, 2016; Curt and Tacnet, 2018; Murphy et al., 2020). Individual examples of seaport planning and vulnerability assessments conducted with multiple urban interests (Hein and Schubert, 2021) and by port authorities (PIANC, 2019) have even begun to ground truth such polycentric governance theories. Therefore, resilience planning should, theoretically, lead to outcomes that include new practices and norms for interactions among agents, a distributed structure of information and decision making, self-organizing system behavior, and adaptive management (Lebel et al., 2006; Innes and Booher, 2010; Sellberg et al., 2018).

Methodology

Seaport and informant selection and research design

This research employed a selected sample and qualitative interview approach, supplemented by secondary documentation and surveys, to document the perceived benefits and challenges of resilience planning, and how such efforts can enhance the adaptive capacity of a complex, multi-layered system. In consultation with a CISA and US Army Engineer Research and Development Center (ERDC) steering committee, we searched for seaports that had completed RPIs based on several criteria including geographic distribution, use of assessment methods involving multiple stakeholders, and a focus on climate change or sea level rise, and the continued availability of personnel that were involved. More information about our sample selection process can be found in Appendix A. We then contacted (*via* email and/or phone correspondence) all 115 U.S. ports within 10 miles of the coastline (Figure 1).

The research team also reviewed Regional Resiliency Assessment projects (RRAPs) conducted by CISA with the US Department of Energy Laboratories, as well as other planning initiatives, which were not included due to lack of informants (Appendix B). After a recruitment process (described in Appendix A), we chose 10 seaports (Table 1) that had completed a resilience planning approach in the following three categories:

(1) Vulnerability assessments led by a private consultant, hereon referred to as "contractor assessments";
(2) Seaport-focused Hazard Mitigation Plans, which are developed under the auspices of FEMA; and
(3) Seaports that used the Ports Resilience Index (PRI) self-assessment tool, a qualitative resilience index which was developed by colleagues at Louisiana Sea Grant.

Seaports were either Landlord, Operational, or both. With Landlord ports being those that own their wharves, but rent or lease to a terminal operator. In Operational ports, the port authority builds the wharves, owns the equipment, and hires labor and stevedores (see also https://www.epa.gov/community-port-collaboration/ports-primer-31-port-operations). From each seaport, we identified and invited two to four informants that were internal to the seaport management structure and typically make decisions related to their seaports' climate resilience endeavors—directors/managers, safety planners, engineers, and environmental specialists (Appendix C). In most cases, at least one informant was considerably involved with their seaports' RPI. Informants were invited to participate via email and/or phone and were asked to sign a consent form (URI Institutional Review Board Approval# IRB1920-244).

Although the approaches used amongst our sample differed somewhat in purpose and level of analysis, all involved a variety of stakeholders engaged in their process. Additionally, all followed the same four resilience planning objectives that can be represented as four key stages that are interconnected within an iterative framework, as follows [NIST, 2016; Environmental Protection Agency (EPA), 2018; PIANC, 2020; Cybersecurity and Infrastructure Security Agency (CISA) and US Army Corps of Engineers Engineering Research and Development Center (ERDC), In Review]:

(1) *Defining functions and characterizing the system in steady state*—This stage identified the functions performed by the seaport during normal operations, including key stakeholders and operators, governance structures, planning activities, and characteristics of port activities.
(2) *Identifying critical infrastructure and dependencies*—Key assets of the system that support its critical functions are identified and the condition and/or capabilities of assets and their locations are determined.
(3) *Understanding the impacts of disruptive events*—This step encompasses both risk and recovery assessment to ascertain how a system will perform under stress.
(4) *Developing and evaluating resilience enhancement strategies*—Lastly, system components requiring resilience enhancement are identified, screened, and evaluated, and strategies can are prepared and implemented. For seaports (and other critical systems), a resilience enhancement strategy refers to any institutional, economic, or infrastructure-related measure taken to improve a seaport's ability to reduce impacts, improve recovery times, and/or facilitate ongoing adaptation to emerging futures (e.g., incorporating climate change projections in harbor development protocols or building a protective seawall).

These approaches capture the scope of climate change resilience planning efforts completed by seaports to date, as seaport resilience initiatives in the U.S. have only begun rather recently (within the past 10 or so years). Comparisons across the three approaches also allowed for a more robust investigation of seaport resilience planning given observed variability in terms of, for example, the seaport's involvement level in the process (higher for the PRI and contractor assessment approaches;

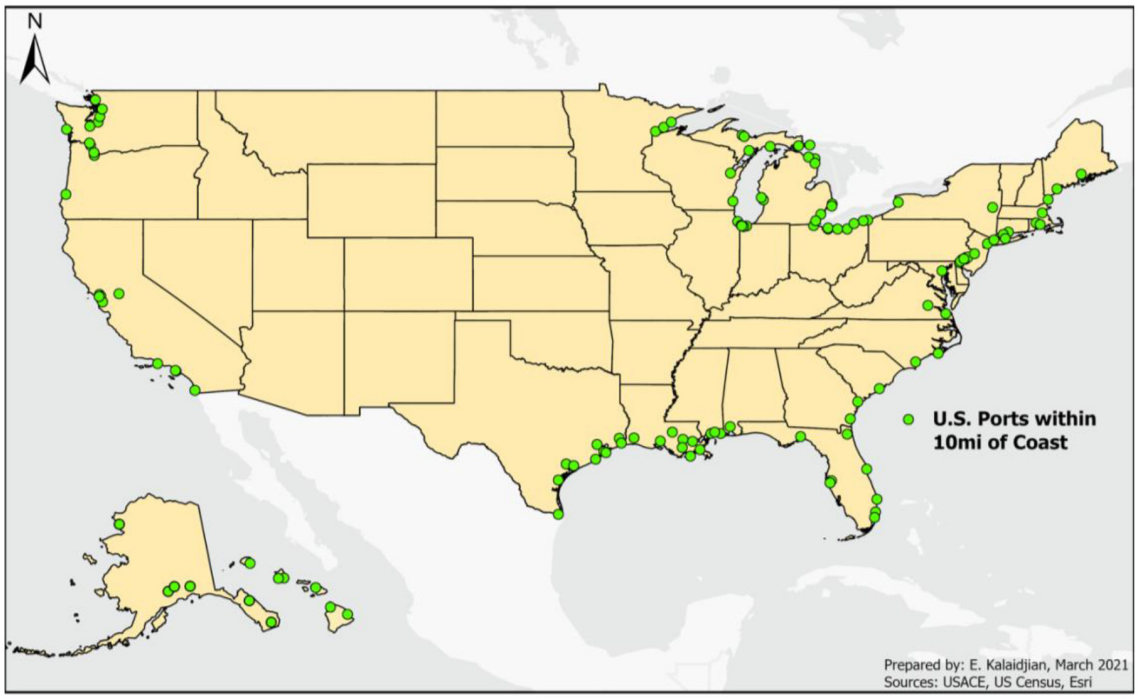


FIGURE 1
Map of all U.S. ports within 10 miles of the coastline (data from NOAA Principal Ports Database).

TABLE 1 List of participating seaports and their respective RPIs.

Resilience planning approach	Port of	Type of port	Year completed	Type(s) of hazard(s) assessed	# of pages
Contractor assessment (6)	San Diego (CA)*	Landlord	2019	SLR, storm surge	298
	Los Angeles (CA)*	Landlord	2018	SLR, storm surge	108
	Virginia (VA)*	Operational	2017	SLR, subsidence, storm surge, lightning strike frequency, karst geology	47
	Long Beach (CA)*	Landlord	2016	SLR, storm surge, extreme heat, precipitation and riverine flooding, extreme wind, ocean acidification	172
	Seattle (WA)	Landlord	2015	SLR, storm surge	26
	Baltimore (MD)*	Landlord	2010	SLR, storm surge, extreme wind, precipitation and riverine flooding	120
Hazard mitigation plan (2)	Grays Harbor (WA)	Operational and landlord	2016	Tsunami, earthquake, severe weather, flooding, extreme heat, hurricanes, hazmat release, erosion, wildfire, levee failure	10
	Freeport (TX)*	Landlord	2012	Erosion, drought, earthquake, expansive soils, severe weather, hurricanes, levee failure, land subsidence, winter storm, wildfire, hazmat release, pipeline failure	104
Port resilience index (2)	Morgan City (LA)	Landlord	2018	Coastal hazards	24
	Tampa Bay (FL)*	Landlord	2017	Coastal hazards	24

Asterisks (*) indicate that seaports have undertaken (or are in the process of undertaking) additional planning initiatives since (and/or before) the one listed. The three shades of blue simply differentiate the three categories, as seen in the first column.

lower for the Hazard Mitigation Plans, which may focus on many federal, state, and local stakeholders including the seaport); the quality and types of data each approach yields (i.e., contractor assessments and Hazard Mitigation plans usually focus on physical/infrastructure vulnerabilities and yield highly detailed, quantitative data, while the PRI explores institutional vulnerabilities to hazards and yields less detailed, qualitative data); the amount of time each process takes (i.e., contractor assessments and Hazard Mitigation Plans may take years, while the PRI approach may take less than a week); and their cost.

Data collection

We used a three-part data collection approach, which started with a systematic review of the final reports resulting from each seaport's RPI (Figure 2). The specific information collected from each document included the start and end dates of the planning effort, the methodology used, the key findings, and the resilience enhancement strategies recommended to the seaport. This information was then built into a survey and interview instrument to account for the contextual discrepancies between each seaport's approach. The interviews explored perceived benefits and challenges of resilience planning (RQ1) and changes to seaport organizations resulting from RPIs (RQ3). The survey identified the extent to which completion of RPIs led to the implementation of resilience enhancement strategies (RQ2) and measured perceived changes in seaport's adaptive capacity after RPIs were completed (RQ3).

Qualitative research is a superior approach when exploring understudied concepts or phenomena (Creswell, 2017), especially given the paucity of research on the operationalization of resilience concepts in seaport management. The decision to use surveying and focus groups interviews is justified in that it captures a more holistic picture of the phenomena under investigation (Ziervogel et al., 2006)—i.e., the institutional impact made on the case studies by the resilience planning process. This data collection format served to neutralize the limitations of each approach in isolation. Interviews are flexible and adaptable, allowing researchers to explore research questions in more depth (Robson and McCartan, 2016), while surveys require less time expenditure for informants and give the phenomena under investigation measurability. Moreover, the triangulation of survey and interview data is suggested to enhance data validity.

Online survey

A survey was administered electronically to informants prior to interviewing and was divided into two sections. One section asked informants to identify whether the resilience enhancement strategies that seaports identified through their RPIs were subsequently implemented (addressing RQ2). The other section gauged the resilience outcomes of RPIs for seaports by presenting informants with the following 10 adaptive capacity indicators (see further discussion in Appendix D) obtained from the academic literature and asking informants to rate their strength prior to and after the completion of their seaports' RPIs (addressing RQ3):

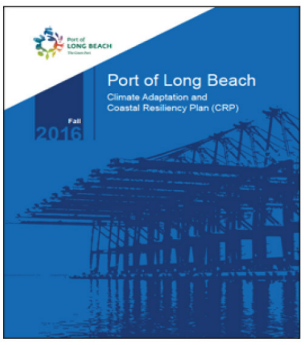
(1) the seaport's commitment to resilience-building;
(2) presence of leadership to champion the seaport's resilience-building endeavors;
(3) staff availability to work on resilience-building endeavors;
(4) data availability;
(5) data quality for resilience-building;
(6) financial resource availability;
(7) resource (staff, information, data, etc.) sharing across the seaport's departments;
(8) external stakeholder groups;
(9) collaboration with internal; and
(10) external stakeholders on resilience-building endeavors.

The change is subjective and qualitative and is based on informants' perceptions of risk and the value of assessments in enhancing resilience. Respondents rated capacities using a Likert scale from 1 to 5 with the options of Not Present, Weak, Moderate, Strong, and Very Strong.

Interviews

We held 12 Zoom interviews of roughly 45 min each, nine of which were in focus groups of two to four individuals, and three were held individually with informants of the same seaport that could not participate together due to scheduling conflicts. We chose the focus group approach over individual interviewing where possible because the use of "mini-focus groups" (i.e., groups of three or four informants) is considered advantageous when participants have specialized knowledge and/or experiences to discuss in the group (Krueger, 2014)—we felt such was the case for our sample of seaports. Further, qualitative methods literature has suggested that the internet-based focus group format overcomes some of the methodological issues arising from face-to-face focus groups. For example, Walston and Lissitz (2000) suggest that group members that participate in virtual settings are less likely to withhold viewpoints that they perceive as embarrassing or inflammatory; and are more likely to express dissent with group members of higher positions, which is frequently cited as a shortcoming of the in-person focus group approach.

All interviews were recorded and transcribed, which was made known to informants prior to interviewing. The interview instrument was divided into four sections. The first section consisted of introductory questions designed to better acquaint the researchers with the seaport's resilience planning process, such as "what drove your organization to undertake an RPI?".



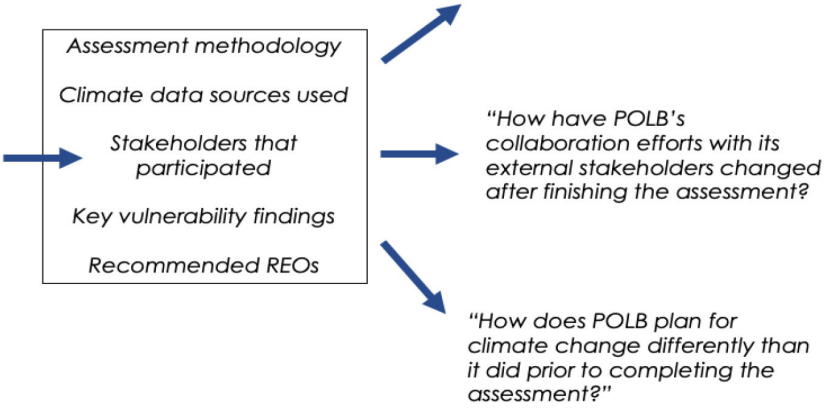


FIGURE 2
Example of the document review workflow.

The second section focused on informants' perceptions of the key benefits or utilities of their seaport's RPI, either those associated with the process itself or the findings documented in the final report. The third section addressed challenges that the organization experienced along the course of the process and any aspects of the effort that were of limited utility. The final section focused on institutional impacts, such as whether it changed the organization's climate change planning culture.

Data analysis

Survey data

We received survey responses from 19 of the 26 informants. All survey data was compiled in IBM SPSS Statistics (Version 26) and analyzed in aggregate. We categorized the strategies prescribed by each seaport's resilience planning report using six seaport-specific strategy typologies previously identified by Becker and Caldwell (2015):

(1) Building codes and land use regulations (e.g., prohibiting the use of erosive fill)
(2) Long-range planning (e.g., incorporating hazard mitigation into transportation planning)
(3) Construction and design strategies—on and off port lands (e.g., building a protective breakwater)
(4) Emergency response, preparation, and recovery (e.g., creating evacuation plan and procedures)
(5) Research (e.g., conducting risk and vulnerability assessments)
(6) Networks and new ways of thinking (e.g., establishing climate change working groups with internal and external stakeholders).

Researchers tallied the total number of reported strategies belonging to each typology, along with the total numbers of strategies that informants indicated had been or will be implemented, may be implemented, were not implemented, and those that they were unsure about. We also asked informants whether a given strategy was likely or unlikely to have been identified and implemented in the absence of the RPI, as this would allow for further evaluation of resilience planning. Lastly, data from the second section of the survey—the strengths of the 10 indicators before and after RPIs were completed—were averaged across the 19 responses (see Appendix D for further information).

Interview data

The research team coded interview transcripts line-by-line using the Atlas.ti v9 (Friese, 2019) qualitative data analysis software package to identify emerging themes regarding the useful and challenging aspects of undertaking resilience planning. The coding scheme used an iterative process based on grounded theory (Charmaz, 2006). Statements characterized as having a positive impact on or utility value to the seaport were coded as benefits of the RPI; statements evoking sentiments of difficulty or limitations were coded as challenges; and statements involving changes in the seaports' resilience planning culture (e.g., resilience becomes a budget item in a capital improvement plan) were coded as resilience enhancement strategies. This process allowed for views and concepts to emerge and be grouped into unique categories. Researchers recorded the number of times a benefit, challenge, or strategy type was mentioned and the number of seaports to which interviewees that mentioned it belonged. All benefits, challenges, or strategies, even those only mentioned once, were considered

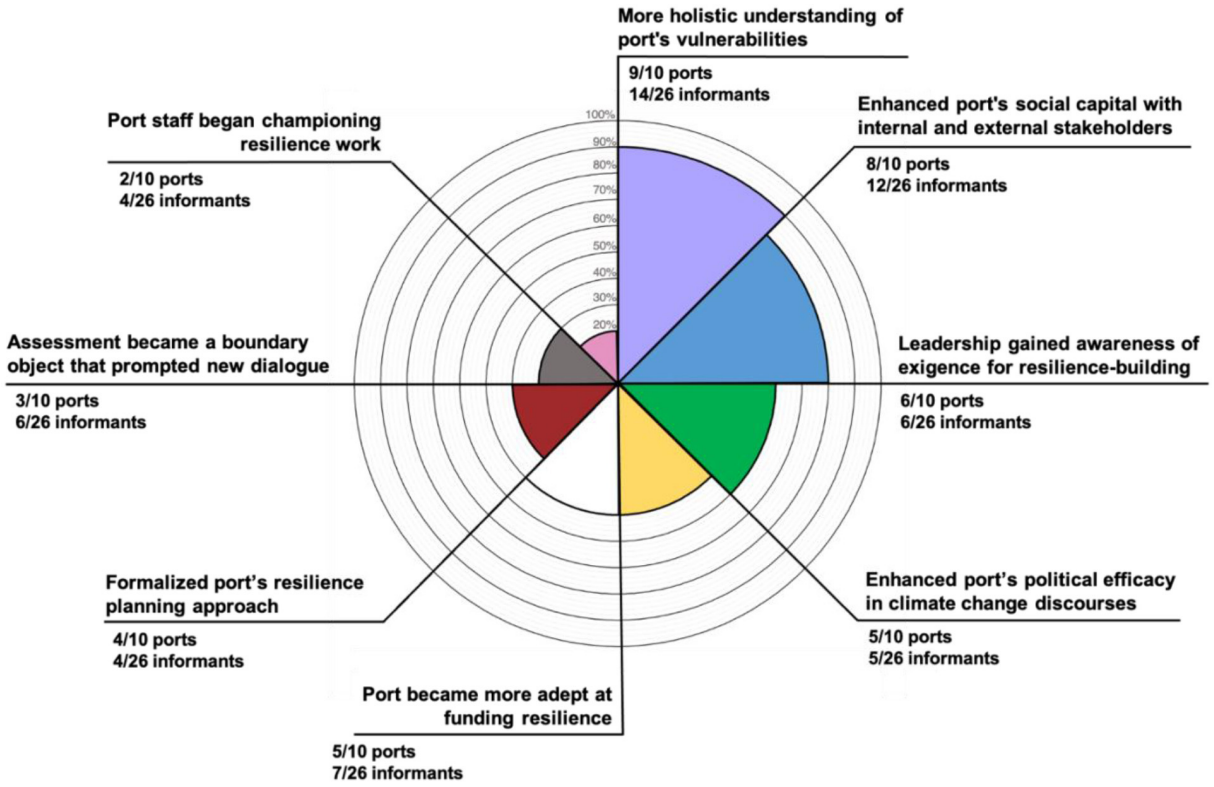


FIGURE 3
Eight benefits associated with resilience planning identified in 12 interviews with 26 seaport decision makers. Each colored pie is the percentage of seaports from which at least one informant mentioned that benefit.

as findings in this paper. To ensure reliability of the coding scheme (see Appendix E for further information), we held two exercises in which several third-party individuals independently coded selected passages of transcripts using our coding scheme. We then calculated intercoder agreement using the Krippendorf's Cu-alpha/cu-alpha coefficient, yielding a value of 0.796, suggesting very good agreement (Friese, 2019).

Results and discussion

This section presents the results from the data collection process organized by research question. Each subsection starts with an overview of the results, followed by analyses and interpretations, for which findings are compared back to theories and findings documented in the academic literature on seaport resilience, adaptive capacity, and so forth. To ensure participant anonymity, the following abbreviations are used: director/manager, DIR; environmental specialist, ES; engineer, ENG; or safety planner, SP. Our approached captured four main findings: (1) the enhanced quality of vulnerability information was most frequently emphasized as a benefit of RPIs, while (2) the most frequently cited challenge was the process of engaging stakeholders in the RPI; further, (3) survey results indicated a propensity of seaports to pursue resilience enhancements for their infrastructure (and, less often, various organizational changes) after completing an RPI; and (4) responses to interview and survey questions regarding institutional impacts of RPIs, together, demonstrated the realization of capacities proposed in the literature to bolster system resilience and adaptive capacity, such as enhanced social cohesion. We interpret such findings as evidence that RPIs lead seaports to enhanced resilience (technical and organizational).

RQ1—Key benefits/utilities of RPIs

Through analyses of the 12 interviews with 26 key informants, we coded 102 statements of benefits that fell into eight discrete benefit/utility categories. Figure 3 shows a radar plot the represents the frequency of interview responses that fell into the eight categories and Table 3 provides some examples of quotations from interviews (Figure 3; Table 2).

TABLE 2 Example quotations that were coded as one of eight resilience planning benefits.

Benefit of RPI	Example(s)
B1. More comprehensive and nuanced understanding the seaports' vulnerabilities (Mentioned by at least one informant from 9/10 seaports)	*"…we had never undertaken a study of that granularity, that got down to individual assets. We might have known anecdotally, 'that intersection floods' or 'that building needs to be built a little higher,' or something like that, but I would not say we had a comprehensive look at all those things together."* (SP, September 2020). "*[The sea level rise map] is some of the most valuable information, for me, because we do the maintenance on everything…If we start to see effects of inundation on something, we might bring it forward to engineering for a different design or some sort of capital project, moving forward to help address that."* (ENG, November 2020). "*The whole operation for unloading the cranes is to send a boom out over the ship…The concern was that the vertical clearance for that boom over that ship, was going to disappear because of sea level rise. Well, it didn't take us too long to show that, no, [that's not going to happen]…I couldn't put their mind at ease until I turned it into a formal study…"* (ES, December 2020).
B2. Enhanced social capital with internal and external stakeholders (Mentioned by at least one informant from 8/10 seaports)	*"The biggest takeaway for me in the whole process was involving all the players…If you keep it in-house, you sometimes get tunnel vision and you don't see the overall effects?."* (SP, November 2020). *"[The assessment process] made us more of an information network … [our economic development manager] is constantly sending emails out, or updates, from the weather service or whoever it is—constantly sending it out to all of our stakeholders."* (DIR, January 2021) *"Most of us were not really on the same page on how a port would approach [climate change issues]. I think the workshop and the internal stakeholder engagement in the development of the [assessment], really brought us together as a port team."* (ES, October 2020). *"[The assessment process] made us more of an information network … [our economic development manager] is constantly sending emails out, or updates, from the weather service or whoever it is—constantly sending it out to all of our stakeholders."* (DIR, January 2021).
B3. The intervention became a boundary object (Mentioned by at least one informant from 3/10 seaports)	*"I think our port's collaboration became better because the issue of climate change in general was highlighted, emphasized, and probably talked about within groups that otherwise maybe would not have talked about it."* (ES, October 2020).
B4. Leadership gained awareness of exigence for resilience (Mentioned by at least one informant from 6/10 seaports)	*"… in the past, there were a lot of people at the port that weren't aware or were dismissive of climate change and the hazards that it poses to us…after seeing the results of the study, I think it raises a couple eyebrows to see [our main piers] underwater."* (DIR, October 2020). *"I think going through this process and bringing it to the attention of the leadership of the port, brought us further into our master planning process, including resilience planning and sustainability into our long-term planning aspect."* (ES, September 2020).
B5. Improved political efficacy in climate change conversations (Mentioned by at least one informant from 5/10 seaports)	*"We deal with a number of federal and state agencies…These issues, topics, and risk assessments and stuff are things that other people are doing, so [the RPI] really gives us an ability to communicate with them… [and it also] helps us in understanding what they're talking about, or what they're looking at."* (ES, November 2020).
B6. Seaports became more adept at funding resilience projects (Mentioned by at least one informant from 5/10 seaports)	*"We've got four competing pillars—operations, IT, maintenance, and the civil side of the house—who are competing for a capital dollars. [The resilience plan] allows us to illustrate why this feature, why this project is important, and that helps sell the project. And when [our director of engineering] brings it up, or I bring it up, or whomever brings it up, they know that it is a valid part of a conversation."* (SP, September, 2020).
B7. Formalized resilience planning approaches (Mentioned by at least one informant from 4/10 seaports)	*"[The RPI] standardized how we approach projects from a resiliency standpoint—not just now, but also in the future … You can't get to that point without starting somewhere, right? It was kind of that "kindling for the fire," if you will."* (ENG, September 2020).
B8. Motivated staff to champion resilience projects (Mentioned by at least one informant from 2/10 seaports)	*"Three specific staffers [in our program management division] have really taken this role to help me out, to be my voice in the engineering team. Most of the engineers don't want to listen to [an environmental specialist]. So, I have three reps within our Program Management Division, who really sort of carry that torch on [our port's] climate programs."* (ES, October 2020).

Benefit 1: More comprehensive and nuanced understanding of the seaports' vulnerabilities

Key informants from nine of the 10 case studies described a more comprehensive and nuanced understanding of their seaports' vulnerabilities as a benefit of their RPIs (24 mentions voiced by 14 informants). In many instances, informants described their RPI as their seaports' first detailed investigation of their vulnerabilities. The impetuses to undertake these efforts were either a state mandate (as was the case for four case studies, though some started resilience planning voluntarily prior); to obtain federal mitigation funding (two case studies); growing recognition of the threats posed by climate change as evidenced by recent natural hazard events (one case study); or for some other reason (three case studies). Interestingly, some informants felt that, along with identifying risks to proactively mitigate, their RPI revealed what *not* to worry about. Several informants also valued the byproducts of their planning, such as inventories of their seaport's vulnerable assets or GIS-based inundation maps, as this information allowed them to better understand the geographic extent of climate risk and aided their roles in their respective departments.

The enhanced quality of vulnerability information was most frequently emphasized as a benefit, as one of the fundamental objectives of resilience planning is to elucidate this. It is also intuitive that informants would value a process that yields information about the localized risk to their seaports' future capital improvements, as this information enhances their organizations' capacities to satisfy their civic responsibilities of economic development and facilitating trade. Previous research on seaport decision makers' perceptions of climate change (Becker et al., 2012) and barriers to planning for it (Mclean and Becker, 2019) may further explain why this benefit was most frequently mentioned. Often, nuanced vulnerability information is lacking among seaports (Becker et al., 2012; Mclean and Becker, 2019), serving as a broader barrier to the process of building resilience and adapting (Moser et al., 2010). For example, in a 2012 study from Becker et al., more than half of seaport respondents felt that they were not sufficiently "informed" about climate change impacts to their facilities. Years later, in interviews with 30 seaport decision makers, Mclean and Becker (2019) documented a widespread lack of understanding of climate and natural hazard risks among a majority of their interviewed seaports. Our results suggests that RPIs amend a widely recognized barrier to climate action at seaports.

Benefits 2 and 3: Enhanced social capital with their internal and external stakeholders; the intervention became a boundary object that prompted new dialogue

Twelve informants, representing eight of the 10 participating seaports, found resilience planning to enhance their seaports' social capital with internal and external stakeholders (24 mentions; 12 informants). Social capital defines the "resources embedded in relationships among actors" (Häuberer, 2011, p. 50), and can be thought of as a function of the quality, quantity, and direction (i.e., horizontal or vertical) of relationships of trust, reciprocity, and exchange within a system (Adger, 2003; Häuberer, 2011; Djalante et al., 2012). Informants remarked how the resilience planning process enhanced social capital both during and after planning was complete. Many of the informants felt that engaging key stakeholders—especially during the preliminary planning phases of scoping and defining objectives—built social cohesion and facilitated mutual understandings amongst different departments and, in some instances, with the external community. One informant remarked how his seaport's inclusion of external stakeholders (city officials, NGOs, state government officials, etc.) provided a systems perspective of vulnerability otherwise unattainable through conventional planning approaches. In the opinion of another informant, his seaport became a centralized hazard information network for the surrounding community (DIR, January 2021). Interestingly, seaports' improved relationships with stakeholders were often byproducts of another interrelated benefit: the RPI served as a boundary object—a process, product, or other form that bridges communities, stakeholders, and disciplines and leads to links from knowledge to action (Star, 2010)—that stimulated dialogue amongst departments that often do not communicate with one another.

Our findings are consistent with previous research of seaport stakeholders' perceptions of collaboration in seaport resilience efforts. Becker (2017), for example, convened seaport stakeholders in workshops based on three boundary object scenarios, revealing the utility of boundary objects as planning tools that facilitate critical thinking amongst diverse stakeholder groups to create a shared mental model of risk. Similarly, in interviews with 25 stakeholders of the Port of Providence, Rhode Island, Becker and Kretsch (2019) provide empirical results capturing perceptions of the value of collaborative efforts as necessary to implementing resilience strategies.

Benefit 4: Leadership gained awareness of exigence for resilience

Another benefit that was voiced in six of the 10 focus groups was the impact that resilience planning had on seaports' leadership (12 mentions; six informants). Decision makers explained how, prior to their seaports' efforts, their leadership did not view resilience as a pressing matter that warranted capital expenditure, stymying long-term resilience-building efforts. When reports from the interventions were presented to lead decision makers, however, informants felt that leaders gained a heightened awareness of the exigence for resilience-building across the system, as suggested by Wilkinson (2012b).

The finding that RPIs may result in a more resilience-conscious and motivated leadership may correspond with

the aforementioned benefit of enhanced understanding of vulnerabilities, although this assertion warrants additional study. The information products that come out of resilience planning during the assessment phase, such as SLR inundation maps, may add tangibility to impending threats posed by climate change (Retchless, 2018; van Valkengoed and Steg, 2019) for leaders who are otherwise preoccupied with the short-term concerns of running a public enterprise. The leadership benefit is particularly significant given the key roles leaders play in the resilience-building process, such as incorporating resilience considerations into policies and budgets, using deadlines to instill a sense of urgency amongst their organizations, providing information on new ideas, problems, and solutions to resilience partners, and building stakeholder networks (Stiller and Meijerink, 2015). Moreover, institutional voids in leadership for resilience-building constitute a major resilience-building barrier (Moser et al., 2010) that has been documented in seaport organizations (Becker and Kretsch, 2019; Mclean and Becker, 2019). Our findings suggest that resilience planning efforts may help transcend the obstacles presented by rigid administration, and, in doing so, enhance seaport adaptive capacity.

Benefits 5 and 6: Enhanced political efficacy in climate change conversations; seaports become more adept at funding resilience projects

Five of the 10 seaports described their organizations' enhanced political efficacy in climate change conversations as a benefit of their RPIs (seven mentions; five respondents). In the opinion of several informants, resilience planning enhanced their organizations' abilities to engage in political arenas that previously challenged staff that were not accustomed to climate change jargon or concepts. Mentions of Benefit 5 coincided with mentions of another benefit: divisions of the seaport became more adept at funding resilience projects (11 mentions; five informants). Informants explained that the ability to sway decision-making in favor of resilience was enabled, at least in part, by the vulnerability assessment findings, which gave them data to better argue the value of public investments in resilience projects. In some cases, the ability to mobilize funds for resilience projects also improved. In the opinion of a director,

> "*Prior to [our resilience planning], we would have the tendency to Op-EX lots of stuff that would otherwise need to be able to be capitalized. As we've gone through these last few years, we've freed up a lot of additional funds by capitalizing things where otherwise we previously weren't doing it. That has brought in more funds that give us more ability to do some resilience-building projects.*" (DIR, October 2020).

Both benefits have important implications for the role of using a resilience planning process in facilitating adaptive capacity. The finding that several organizations' political efficacy in climate change discourses improved, suggests that, because of the RPIs, decision makers become better poised to advocate for their seaports' resilience needs—a capacity that has been integral to the transformation toward more adaptive social-ecological systems (Menzel and Buchecker, 2013). By working with different departments and incorporating climate change expertise (e.g., from consultants), decision makers may learn how to "talk the talk" of climate change. The improved abilities to mobilize and advocate financial resources after the RPI also have direct implications for seaport adaptive capacity, given the unique funding that climate change resilience projects require (Smit and Wandel, 2006; Moser et al., 2019). This, in turn, may point to the significance of the discursive processes among interests associated with system as a whole (Innes and Booher, 2010).

Benefits 7 and 8: Resilience planning became formalized; staff became motivated to champion resilience projects

Two additional benefits were mentioned in conjunction with one another. Four seaports valued how RPIs formalized seaports' strategic planning for climate change (eight mentions; four informants) and two felt that this motivated personnel from different divisions to champion resilience initiatives (four mentions; four informants). Informants explained that their seaports' climate change planning was largely an internal discussion with senior leadership or addressed by different departments in isolation, prior to their RPIs. Following an intervention, however, an engineer noted, *"The vulnerability assessment standardized how we approach projects from a resiliency standpoint… It was kind of that 'kindling for the fire' for our organization's resilience planning."* (ENG, September 2020). The formalization of climate change planning inspired staff of some seaports to carry out resilience projects in their respective departments. "*At first, our engineering director was like, 'We can't afford to go above and beyond building code. We're not going to add resilience.' But now, they are adding resilience into their projects and even applying for federal grants,*" an environmental specialist explained (ES, November 2020).

Again, the significance of these benefits is apparent when compared with findings of Mclean and Becker (2019). Over half of the seaport decision makers in their study acknowledged a governance disconnect—describing the lack of coordination across sectors, or across levels of an organization, or both—as a key barrier to their seaports' efforts to build climate resilience. The governance disconnect barrier has been found to result from the lack of a management plan for climate and extreme weather adaptation (Moser et al., 2010). Benefit 7 clearly demonstrates the ability of resilience planning to fulfill this role. Additionally, governance disconnect may arise from institutional crowdedness, resulting in a lack of clarity of

TABLE 3 Four main challenges mentioned in 12 interviews with 26 seaport decision makers.

Challenge of RPI	Example
C1. Engaging stakeholders (Mentioned by at least one informant from 7/10 seaports)	*"It was difficult to talk to people, to get them to speak back to you, and give you information. Many of the commercial stakeholders think that everything they do is proprietary information…"*
C2. Addressing hazards that lacked scientifically robust data (Mentioned by at least one informant from 3/10 seaports)	*"What was really challenging is the areas that don't have a lot of good data…you start talking about sea level rise–I'm either going to be at 19 feet elevation or I'm going to be four feet under. So, which do you start to try to plan for?".*
C3. Lack of an archetype RPI model to follow (Mentioned by at least one informant from 2/10 seaports)	*"[The assessment] was a challenge because we were kind of starting fresh, with a new thing…I needed something to go on, some sort of adaptation plan template…and it just simply didn't exist…"*
C4. Communicating vulnerability findings to stakeholders (Mentioned by at least one informant from 2/10 seaports)	*"…some port leaders have felt like, 'If we start showing these maps of sea level rise, is that going to deter investment into our waterfront?'. Are these investment groups going to say, 'Oh my gosh, [that port] is going to be flooded!'?".*

responsibilities for adaptation at local levels (Mukheibir et al., 2013; Ekstrom and Moser, 2014). Supported by Benefit 8, and consistent with resilience planning and adaptive management theory, it seemed that resilience planning helped formalize seaports' approaches to climate change. We posit that the multitude of seaport divisions may better understand their roles in their seaports' resilience-building efforts, leading them to actively champion the work that pertains to their respective departments (Schauppenlehner-Kloyber and Penker, 2016).

RQ1—Key challenges/limitations of resilience planning

Along with benefits, this study also explored challenges of resilience planning. In total, we coded 56 statements that fell into one of 21 discrete categories of challenges. Because of the comparatively large number of challenges, we included only those that were mentioned by at least two case studies in our analysis. The breadth of challenges reflects the highly contextual nature of resilience planning. Four challenges (Table 3) are considered in the subsequent discussion.

Challenge 1: Engaging stakeholders complicated the execution of various phases of the process

The most frequently mentioned challenge of RPIs involved engaging stakeholders (20 mentions; 10 informants). Our data reveal that stakeholder engagement was a challenge in all phases of the resilience planning process. For example, during the preliminary organization of the assessment, convening stakeholders was complicated by schedule conflicts or their views that the assessment was not worthy of their time. One safety planner remarked about the difficulty of conveying to stakeholders the value of participating in an exercise with no immediate or tangible benefits, as processes like disaster mitigation and prevention are "difficult to measure" (SP, November 2020). Additionally, RPIs necessitate discussion of vulnerabilities, often requiring participants to disclose sensitive information, which they may be reluctant to do.?? Scoping the assessment and defining objectives were also noted as bureaucratically cumbersome. For example, one informant mentioned the challenge of reaching consensus among his seaport's myriad stakeholder groups regarding the appropriate climate scenarios to plan for (ES, September 2020). Following the completion of their seaports' RPIs, several informants emphasized the challenge of communicating the vulnerability assessment findings to stakeholders and educating them about how to use the assessment (ES, September 2020). Two other focus groups' participants were challenged in their efforts to continue dialogue about the assessment after it was complete or raise awareness of the assessment to other departments that had not participated. In the opinion of informant,

> *"…even when talking to some of our capital project managers about how to incorporate some of the recommendations in this plan into their project planning, there's kind of a disconnect there. They weren't even necessarily aware that there were strategies that could specifically relate to their projects in this plan…It's hard to get this on their radar."* (ES, December 2020).

The challenge of coordinating a multitude of actors with individual interests in resilience affairs is documented in seaport (Becker, 2017) and in the collaborative planning and governance literature (Margerum, 2011). Sellberg et al. (2015) report the convening of a diverse stakeholder set to participate in an urban planning resilience assessment, as a key challenge with resilience planning. In interviews with Australian natural resource management practitioners who undertook resilience planning, Sellberg et al. (2018) identified the involvement of different organizational departments in the development of a resilience plan, as a primary challenge of resilience planning. Similarly, interviews with city officials leading their cities' resilience plans underscore the difficulty of reaching consensus on the starting point for resilience-building and the definition of

resilience to operationalize when multiple interests are engaged (Fastiggi et al., 2021). This challenge is even noticed as a barrier in the adaptation planning process in synthesis research investigating myriad adaptation contexts (Moser et al., 2010).

Challenge 2: Addressing vulnerabilities that lacked scientifically robust data

While the most commonly mentioned benefit was the enhanced vulnerability information, some informants acknowledged the limitations of the information their RPIs provided. Some seaports completed their RPIs over 5 years ago, when, as several informants mentioned, the science for certain climate hazards was less accurate and available as more recently. Informants from three focus groups felt that the lack of accurate, locally relevant climate hazard data (e.g., sea level rise projections) limited their seaports' abilities to identify and plan for those respective hazards (four mentions; four informants).

The finding that only three seaports mentioned this limitation is noteworthy. Though many seaports had completed their RPIs more recently, and thus had access to more accurate scientific information, this does not mean that uncertainties did not exist in their information products. For this reason, it was anticipated that this challenge would be more frequently mentioned. There are many propositions that could explain why more cases did not emphasize this challenge, though none can be proved empirically. For example, greater confidence in recent climate science (Reidmiller et al., 2018) may have provided those decision makers with more recently completed RPIs a greater sense of assurance in the vulnerability findings that came out of their assessment. Just as likely, due to the open-ended nature of the interview questions, other challenges may have been more palpable to the focus groups; hence, the absence of a mention of this challenge does not mean that it was not a challenge. Whatever the reason, this challenge suggests the administrative imperative of embedding flexibility in seaport policies and management to account for emerging information.

Challenge 3: The lack of an archetype RPI model to follow

Several informants noted how the RPI that their seaport undertook was different than conventional planning procedures, for example, because of the larger time horizons considered or the integration of numerous stakeholder groups. Informants from two case studies expressed the difficulty of organizing a planning process with which they had little experience and that had no model to reference, as a challenge (three mentions; three informants). In the opinion of one informant,

> "*Most challenging to start was that [the assessment] was something brand new…I needed something to go on, some sort of adaptation plan…and it just simply didn't exist…So, it was really a challenge because we were kind of starting fresh, with a new thing.*" (ES, October 2020).

Another informant from the same seaport explained that, unlike conventional risk assessment approaches, his seaport's RPI was necessarily improvised as it progressed. Unsurprisingly, when asked how they would execute their RPIs differently knowing what they do now, informants explained that they would seek advice from colleagues at other seaports that had already undertaken a similar effort. They had not anticipated the need to design the process to be inclusive of the multiple interests and authorities that were included as the process evolved.

Challenge 4: Communicating vulnerability findings to private stakeholders

An unanticipated challenge mentioned in two focus group interviews was communicating the vulnerability assessment results in a manner that would not harm the seaports' marketability to future lessees and investors (two mentions; two informants). Informants that mentioned this challenge felt that disclosing information about their seaports' vulnerabilities to external stakeholder groups may deter investment into their lands. For one informant's seaport,

> "*The larger challenge was figuring out how to do a plan without scaring the tenants…We actually stopped our planning process at one point and realized, 'That's going to be really scary to a tenant or even our own staff.' And so, we kind of stepped back and then we revamped our process to look at the [vulnerabilities of] systems.*" (ES, September 2020).

As discussed earlier, U.S. port authorities and agencies act as "public enterprises" that have civic responsibilities while also competing to secure market share, market their services, and facilitate economic development via private enterprise (Fawcett, 2006). Therefore, decision makers that wish to undertake a RPI or similar initiative may want to include a communication strategy for navigating the potential publicity issues of disclosing vulnerabilities. Unlike the three previous challenges, we find this challenge to be less generalizable, as the public-private duality that characterizes many seaports distinguishes them from other entities (e.g., natural resource management agencies).

RQ2—Resilience enhancement strategies that seaports implement after undertaking RPIs

The second objective of this research was to identify the types of resilience enhancement strategies that seaports implemented as a result of their RPIs. The research team considered this inquiry for two reasons: (1) documenting the resilience-building actions that seaports take after going through a RPI captures the tangible impacts of the resilience planning on the case studies (at least in some capacity); and (2) analyzing

informants' opinions of whether or not their seaport was likely to identify or implement a given strategy, allows us to further evaluate the utility (or lack thereof) of RPIs.

Implemented resilience enhancement strategies

We counted 155 discrete strategies from eight of the 10 case studies' resilience planning documents[1] (and several others during interviews) (Figure 4). Of these 155, we found that construction and design strategies were most frequently mentioned ($N_m = 60$) and implemented ($N_i = 25$) after RPI completion; however, no statistically significant difference in quantities of implemented strategies existed between the six typologies ($p = 0.689 > 0.05$, Fisher's exact test, two-sided). Strategies falling under the construction and design typology consisted of developing and implementing physical changes either on or off the seaport. The most frequently mentioned strategy of this type was reinforcing structures, such as terminal assets, with more durable materials ($N_m = 16$); however, this strategy was also most frequently marked as unsure, owing to one case study's non-response to this section of the survey. The most frequently implemented strategy of the construction and design typology was stormwater management infrastructure improvements ($N_i = 9$). Following construction and design strategies, we identified 31 total emergency preparation, response, and recovery strategies; 28 research strategies; 18 networks and new ways of thinking strategies; 10 long range planning strategies; and eight building codes and land use regulations strategies. In terms of total quantities implemented, research strategies were the next most implemented ($N_i = 12$) after construction and design, followed by networks and new ways of thinking strategies ($N_i = 11$), emergency preparation, response, and recovery ($N_i = 11$), long range planning ($N_i = 6$), and, finally, building codes and land use regulation ($N_i = 4$).

Overall, the survey findings suggest that the main dimension of resilience that seaports prioritized in their adoption of prescribed strategies was infrastructural (i.e., technical resilience), more so than strategies addressing governance, management and strategy, and operations and production (i.e., organizational resilience). One potential explanation of why construction and design strategies were most frequently mentioned and implemented, is that infrastructure improvements and modifications are going to be pursued regardless of changing hazard risk levels. Without functional infrastructure, the seaport's capacity to facilitate the transfer of cargo is compromised; thus, having resilient infrastructure is merely complementary to the seaport's mission. Nonetheless, the insignificant difference between implemented resilience enhancement typologies may suggest that resilience enhancement strategies are too case-specific for cross-seaport comparisons.

Influence of the RPI on strategy identification and/or implementation

Most respondents were unsure about whether their seaports might have identified or implemented specific strategies in the absence of their RPIs. We counted only the responses indicating that implementation of a given strategy was likely—suggesting that the RPI did not influence that area of the seaport's resilience portfolio—and not likely—suggesting that the RPI introduced the seaport to areas of resilience improvement. Overall, the informants found their RPIs to have the greatest influence on the implementation of monitoring systems that continually track environmental conditions (such as sea level height) or infrastructure damage, which fell under the research typology. By contrast, most respondents felt that participating in or establishing a climate change-related working group or *ad-hoc* committee was likely to be an implemented strategy in the absence of the intervention. The inability of most informants to indicate whether implementation was likely in the absence of the RPI, may indicate a weakness in the survey instrument to address the sought inquiry—the question may have been too speculative for informants.

RQ3—Perceived changes in seaports' capacities to manage climate change resilience

In the online pre-survey, we measured informants' perceptions of changes in their seaports' capacities to plan for and manage climate change, to further evaluate RPIs. Figure 5 presents the aggregated pre- and post-RPI strengths of the 10 institutional capacities. The primary takeaway from these survey results was that each capacity's strength increased after the intervention (however, we found that not all informants indicated a change after their RPI). On average, seaports' commitment to resilience-building endeavors was strongest before (3.7, i.e., moderate-to-strong) and after (4.4, strong-to-very-strong) the intervention. The other indicators' pre- and post-RPI strengths were generally similar; most increased from moderate to strong after the RPI. In terms of percent change in strength, the greatest increase (27.4%) was in resources sharing with external stakeholder groups, followed by internal

1 Resilience planning documents from two of the case studies mentioned no resilience enhancement strategies, as this was beyond the scope of their specific approaches. Therefore, these were left out of the count.

FIGURE 4
Heat map of mentioned resilience enhancement strategies that respondents indicated had been/will be implemented, may be implemented, and will not be implemented after completing a RPI. Strategy font size correlates with total number of mentions.

collaboration (26.4%), external collaboration (25.4%), internal resources sharing (23.9%), leadership presence (22.6%), data quality (20.8%), financial resource availability (19.7%), commitment (18.5%), data availability (15.8%), and staff availability (14.3%).

The coincidence that informants mentioned nearly all 10 adaptive capacity indicators as benefits in interviews is complementary to our survey findings. Together, the survey and interview data have important implications for the role of resilience planning in building adaptive capacity. In particular, we find Benefit 2—enhanced social capital—and the increased strength of internal and external collaboration and resource sharing, to be significant. The role of social capital in enhancing coping capacity and reducing vulnerability is well-recognized in resilience and collaborative planning literature (Innes and Booher, 2010 and others). Vertical and horizontal exchanges amongst agencies can build networks and help institutions avoid maladaptation (Adger, 2003; Innes and Booher, 2010; Margerum, 2011; Djalante et al., 2012; Bostick et al., 2017), but maintaining these at more complex scales requires a sponsoring agency such as a port authority to invest time and resources (Innes and Booher, 2010). Further, the "wicked problems" presented by the seaport examples require new avenues of knowledge production and decision-making that involve collaborations between actors from private and public sectors (Kates et al., 2001; Lynch et al., 2008), especially if one includes the owners and operators for the critical infrastructure systems that support seaport operations [Cybersecurity Infrastructure Security Agency (CISA), 2021].

Limitations of this research

The sampling approach introduces limitations that reflect the challenges of seaport research more broadly. The variability in positions and responsibilities across our 26 informants may impact their perceptions of the resilience planning process and introduces bias into the data. Informants also had varying degrees of participation in their seaports' RPIs, which limited our ability to

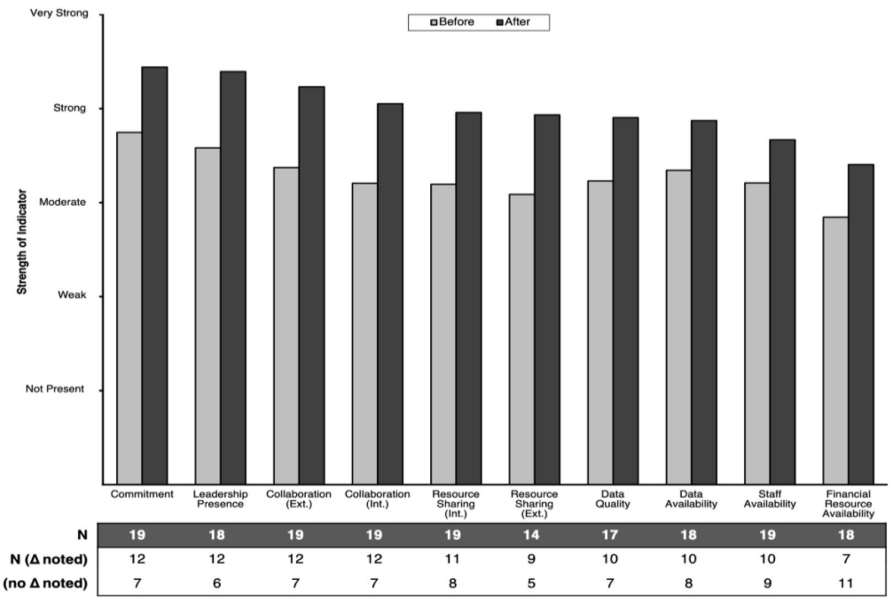


FIGURE 5
SEQ Figure/* ARABIC 5—Average strengths of key institutional capacities prior to (light gray) and after (dark gray) completion of RPIs.

collect their insights on them. Further, the perspectives captured for each seaport do not necessarily represent the organization as a whole. Given that interviewees are members of competitive public enterprises with the responsibility of good publicity, it is possible that interviewees may have provided limited or positive-skewing information as well. Lastly, the differences in each seaport's RPI limit our ability to synthesize the findings collected from our samples.

Our research design also limits the reliability of our conclusions regarding the impacts of resilience planning. Decisions to collaborate with external organizations or implement resilience-related capital improvements, are not made in a vacuum; hence, we cannot infer a direct causality between the implementation of a given strategy and the RPI, for example. At times, informants explained that the RPI coincided with other resilience initiatives going on at their seaport and acknowledged that their responses to the survey questions were speculative. Nevertheless, initial results point to the potential of understanding the challenges and benefits of resilience planning and assessment when conducted in a way that involves stakeholders in sharing information and risks, especially when these processes result in relationships or agreements on which future actions can be based. Additional research should investigate regional resilience planning initiatives, such as the CISA's regional resilience assessment and planning program cases, that involved multiple infrastructure providers and the private sector on which seaport operations depend, to further explore resilience planning for critical infrastructure.

Conclusions

Seaports, with their importance to regional and national transportation services, their complex ownership and governance context, and climate change challenges, present an important setting for evaluating largely normative resilience planning and adaptive management theories for managing complex social and ecological systems. This research constitutes a novel contribution to the literature on resilience planning and adaptive management of climate change risks by exploring how complex socio-technical systems like seaports operationalize resilience planning and assessment practice. Together, the survey and interview findings provide evidence that port owners and system operators found that the conduct of planning and assessments enhanced resilience by creating relationships on which future preparedness, recovery, and response depend. Findings further suggest that ports enhanced both their technical resilience (e.g., implemented infrastructure strategies revealed in the survey) and their organizational resilience (e.g., new processes and protocols to harmonize seaports' resilience affairs emerged) as a result of undertaking a resilience planning process. Further, although most of the selected seaport RPIs were undertaken by the port authorities and not the larger

set of stakeholders, and were initially focused on protecting business operations, the perceived benefits and institutional capacity changes reported in surveys and interviews supported adaptive management and resilience planning premises—e.g., that planning builds social capital that is essential to adapting to climate change and other threats across a complex system. Perceived stakeholder communication challenges suggest that organizers of future RPIs should strategize how to transcend anticipated stakeholder-related obstacles early in the process, which can be supported by further research.

Overall, our findings point to the added value of further investigating how planning and assessment activities might enhance resilience for seaports and other complex, socio-technological systems, For instance, future inquiries could probe the types of collaborative planning and information sharing processes that can build social capital and institutions that are essential to adapting to climate change and other threats across a complex system. As suggested by this initial study and emergent literature on the MTS, comparative research on the value of planning and assessment processes requires clarification of key resilience concepts (Cho and Park, 2017), variables, seaport types, contexts, operational dependencies, urban and diverse interests (Hein and Schubert, 2021) and the meaning of resilience in complex systems (Hosseini et al., 2016) affecting perceived benefits for planning and assessment tool users. Identifying stakeholders in the planning process will depend on characterizing how the seaport depends on infrastructure and operations conducted by others at multiple scales. As noted in recent maritime supply chain literature, seaports are not discrete—they are part of the coastal environment and urban economies and global supply chains, increasingly competing for economic resilience within the maritime transportation system and adapting to diverse risks. Therefore, future research on seaport resilience planning, assessment, and governance should be contextualized by multidisciplinary research that characterizes seaport infrastructure and system dependencies across the public and private sector and the application of resilience concepts across such complex systems.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by University of Rhode Island Institutional Review Board. The patients/participants provided their written informed consent to participate in this study.

Author contributions

AB conceived of the study, designed research approach, oversaw research as principal PI, and assisted with writing and editing. EK designed research approach, carried out interviews and survey, and wrote initial drafts. SP helped oversee research, provided feedback on methodological approach, and wrote and edited sections of manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frsus.2022.963555/full#supplementary-material

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